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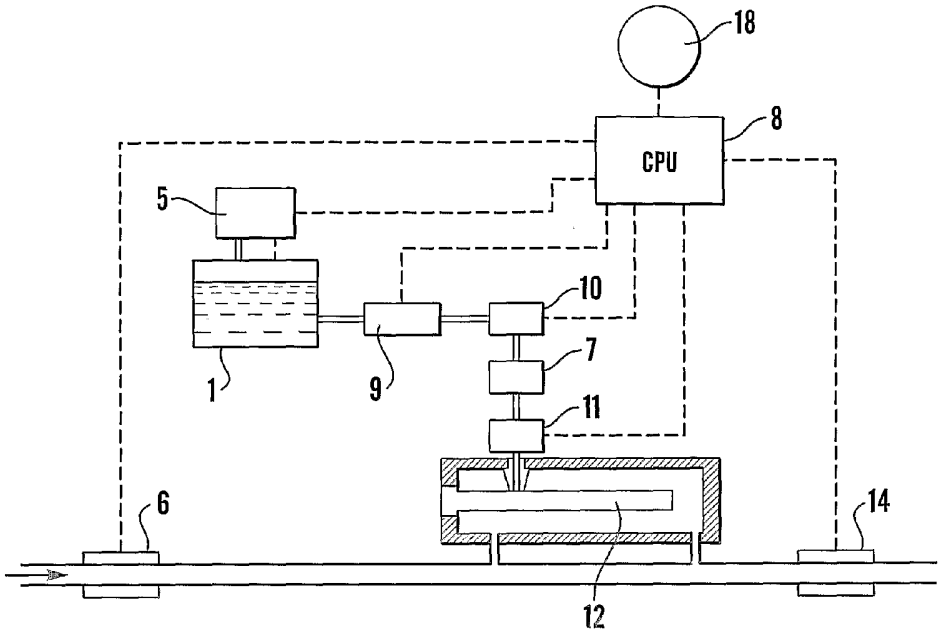

(57) Abstract: An anaesthetic vaporizer comprises a reservoir (1) for containing liquid anaesthetic agent, pressurizing means (5) for pressurizing the liquid anaesthetic agent in the reservoir, a vaporizing device (12) and a conduit for a carrier gas supply, the vaporizer being arranged such that in use liquid anaesthetic agent contained in the reservoir is pressurized by the pressurizing means and conveyed in liquid form by that pressurization to the vaporizing device where it is vaporized for delivery to a patient with the carrier gas, wherein both the pressurization and the conveyance of the liquid anaesthetic agent to the vaporizing device are controlled independently of the carrier gas supply.

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Improved Anaesthetic Vaporizer

The present invention relates to an apparatus for vaporizing a liquid and, more particularly, to a vaporizer that receives carrier gas, vaporizes a liquid anaesthetic agent and combines it with the carrier gas to produce a stream of carrier gas containing a known concentration of anaesthetic agent for introduction into a patient.

UK Patent No. 1 224 478, describes an anaesthetic vaporizer of the by-pass type in which a carrier gas, comprising a mixture of gases such as oxygen, air and nitrous oxide, is initially divided on entry to the vaporizer between a first stream which is directed towards the sump or vaporizing chamber of the vaporizer to entrain vapour from a volatile liquid anaesthetic contained therein; and a second by-pass stream, the first and second streams subsequently recombining prior to leaving the vaporizer for delivery to a patient. This known vaporizer has been used successfully over a number of years for delivery of anaesthetic agents such as halothane, trichlorethlene and ether derivatives including enflurane, fluoroxene, methoxyflurane and isoflurane. All the aforementioned anaesthetic agents have a boiling point at atmospheric pressure well above 40°C, but vaporization is achieved at ambient temperatures, typically using wicking materials to achieve a large vaporization surface.

However, a class of anaesthetic agents has been developed, including 2-(difluoromethoxy)-1,1,1,2-tetrafluorethane ("Desflurane") which has a boiling point at atmospheric pressure of approximately 22°C. This physical characteristic of Desflurane renders by-pass type anaesthetic vaporizers unsuitable for delivering this agent to a patient. By-pass type vaporizers are unsuitable for use with Desflurane because its boiling point is approximately in the middle of a conventional vaporizer's operating ambient temperature range of between 15°C and 35°C. When the ambient temperature and hence the vaporizer temperature is above 25°C, heat is transferred to the anaesthetic agent

and causes vapour to boil off at a rate limited by the heat lost by the latent heat of vaporization (equal to the heat transferred to it), and not by the vaporizer settings.

US patent US 5,146,915 discloses an alternative to a conventional by-pass type vaporizer for the new class of agent in which the liquid in a reservoir is deliberately heated in order to provide both a continuous source of anaesthetic vapour to blend with the carrier gas and the pressure to drive the vapour through a passive flow control device. A gas pressure regulator is placed between the pressurized reservoir and the flow control device to limit the pressure drop across it so that the gas flow is independent of the pressure in the reservoir. Although apparently simple in concept, vaporizers incorporating this principle are typically about twice the size and weight of conventional vaporizers. They also use significant amounts of electrical power to the extent that they present a problem in providing the backup power usually considered desirable with critical medical equipment.

European patent application EP 0911053 and United States Patent US 5,509,405 each disclose a vaporizer in which liquid anaesthetic agent is pumped to a vaporizing chamber where it is introduced into a carrier gas stream for delivery to a patient. A drawback of these vaporizers however is that the use of a dispensing pump to deliver the correct amount of liquid to be introduced into the carrier gas stream has associated accuracy and reliability problems. In particular, a peristaltic pump (as used in the vaporizer disclosed in US 5,509,405) generally does not provide the accuracy and reliability required for the delivery of controlled doses of anaesthetic to a patient.

European patent EP 0449 545B1 discloses a vaporizer which avoids the above problems by delivering liquid anaesthetic agent into a gas carrier stream by pressurization of the liquid agent. However, the pressurization of the liquid agent is by means of a pressure differential

purposely created in the carrier gas bypass passage. This pressure is limited by the characteristics of the gas supply system and cannot be sufficient to prevent the liquid anaesthetic agent boiling at the higher ambient temperatures.

European patent application EP 0983773 A2 discloses a vaporizer in which pressurized liquid anaesthetic agent is introduced into a carrier gas supply by controlling the flow rate of the carrier gas. Consequently the introduction of the liquid anaesthetic agent is not controlled independently of the carrier gas supply.

The present invention seeks to provide an improved anaesthetic vaporizer which controls, in a reliable and safe manner, the delivery of an independently pressurized liquid anaesthetic agent to a vaporizing chamber within, or connected directly to, the carrier gas flow path within the vaporizer.

Accordingly, a first aspect of the invention provides an anaesthetic vaporizer, comprising a reservoir for containing liquid anaesthetic agent, pressurizing means for pressurizing the liquid anaesthetic agent in the reservoir, a vaporizing device and a conduit for a carrier gas supply, the vaporizer being arranged such that in use liquid anaesthetic agent contained in the reservoir is pressurized by the pressurizing means and conveyed in liquid form by that pressurization to the vaporizing device where it is vaporized for delivery to a patient with the carrier gas, wherein both the pressurization and the conveyance of the liquid anaesthetic agent to the vaporizing device are controlled independently of the carrier gas supply.

Preferably the vaporizing device comprises a part of, or is in communication with, the conduit for the carrier gas supply.

The vaporizer according to the invention has several advantages. Firstly, because the anaesthetic agent is conveyed in liquid form to the carrier gas the invention avoids the need to heat a large mass of liquid agent in order to vaporize it. Because the liquid anaesthetic agent is pressurized the invention also avoids the need to cool it. The power consumption required by the vaporizer is thereby significantly reduced. This enables the use of a low voltage electrical power supply that has the benefit of safety due to the avoidance of high voltages and the possibility of a battery-powered backup in the event of a power failure. Secondly, because the liquid agent is conveyed by means of pressurization of the liquid rather than by the use of a metering pump, it avoids the poor accuracy and reliability problems often associated with liquid metering pumps, particularly when low volumes of liquid are involved. Thirdly, and most importantly, because the pressurization of the liquid agent and the conveyance of the liquid agent to the vaporizing device are controlled independently of the carrier gas supply, the vaporizer provides better control and safety than hitherto. In particular, the invention enables the possibility of accurate measurement and control of the supply of liquid agent to the vaporizer, and hence to the carrier gas, independently of the flow of the carrier gas. This, preferably coupled with independent measurement of the gas flow, provides for greater accuracy and a means of checking, preferably in real-time, that the vaporizer is in fact functioning as intended.

The vaporizer preferably includes a liquid flow sensor (for example a mass flow sensor) arranged to measure the rate at which the liquid agent is conveyed to the vaporizing device.

Preferably the vaporizer includes means for measuring the concentration of vaporized agent in the carrier gas. Such means preferably comprise first and second gas flow sensors. The first gas flow sensor preferably measures the rate of flow of the carrier gas prior to

introduction of the agent therein. The second gas flow sensor preferably measures the rate of flow of the carrier gas containing vaporized agent.

Accordingly, therefore, a second aspect of the invention provides an anaesthetic vaporizer comprising a reservoir for containing liquid anaesthetic agent, pressurizing means for pressurizing the liquid anaesthetic agent in the reservoir, a vaporizing device, a conduit for a carrier gas supply, a liquid flow sensor, a liquid flow control device and first and second gas flow sensors, the vaporizer being arranged such that in use liquid anaesthetic agent contained in the reservoir is pressurized by the pressurizing means and conveyed in liquid form by that pressurization to the vaporizing device where it is vaporized for delivery to a patient with the carrier gas, wherein the liquid flow sensor measures the rate at which the liquid agent is conveyed to the vaporizing device, the first gas flow sensor measures the rate of flow of carrier gas, the second gas flow sensor measures the rate of flow of carrier gas containing vaporized agent, and the rate of flow of the liquid agent conveyed to the vaporizing device is controlled by the liquid flow control device.

As already stated, the vaporizer according to the first and/or the second aspect of the invention includes a system for pressurizing the liquid anaesthetic agent in the reservoir. This may be achieved, in a first embodiment of the invention, by heating the liquid in the reservoir such that the vapour pressure of the liquid pressurizes the liquid. In practice this normally requires the use of temperatures of the order of 30° C or more, which means that such an arrangement suffers from some of the limitations of some of the prior art using vapour flow control systems.

A second embodiment of the invention uses independent pressurization means. For example, a gas compressor may pressurize the liquid agent by applying gas pressure to the surface of the liquid,

either directly, or indirectly, e.g. by such means as a diaphragm, or bellows, interface. If a pressure above approximately 1.0 bar is used then the liquid agent will not boil with the vaporizer operating at any normal ambient temperature; even without cooling the liquid. This means that the pressure can be maintained completely independently of ambient temperature.

A preferred method is to use gas pressure to pressurize the liquid to a minimum pressure that is required to adequately control the liquid flow but to use a flow control system that will not be affected if the vapour pressure rises to pressures above the gas pressure due to high ambient temperatures. This has the advantage that a smaller, lower powered compressor can be used.

Whichever of these systems is used there are practical problems that arise and which require further inventive steps to resolve. These problems arise largely due to the vaporization and gas solubility characteristics of liquids, which are described in standard physics texts.

As a liquid is heated its vapour pressure increases until, at its boiling point, the vapour pressure equals atmospheric pressure and vapour is released from within the liquid. Common observation confirms that boiling is a chaotic process, with bubbles appearing at random throughout the liquid, this resulting from an interrelation of the facts that liquids can become superheated and need to be 'seeded' to start the formation of a boiling bubble and that once a bubble starts growing, due to the latent heat of vaporization, large amounts of heat are absorbed from the volume around the bubble. This creates an inherently unstable process. If this process occurs within the confines of a delivery tube this results in a flow in which relatively large vapour bubbles develop which break up the liquid flow in an irregular pattern. If such a process develops, it is no longer possible to deliver a constant

flow of liquid into the vaporizing device and hence the output of the vaporizer becomes irregular when measured over short time periods.

Regarding gas solubility, Henry's Law teaches that a gas dissolves in a liquid in direct proportion to its partial pressure. It is also common for the solubility constant to be temperature dependent, with more gas dissolving as the temperature decreases. The converse of this is that once gas is dissolved, if the pressure is subsequently decreased, gas may be released from solution. However, because there is no absorption of latent heat in this case it is found that this process is a much more benign, continuous process.

These facts have several practical implications for a vaporizer dispensing liquid agent.

The first of these is that both of the characteristics described above can result in a flow pattern where the gas or vapour accumulate into bubbles which completely fill the passage and break the liquid up into separated slugs. (This will subsequently be referred to as "slug flow".) This presents a problem when controlling or measuring a liquid flow because the measurement and control characteristics of devices change substantially according to whether liquid or gas is passing.

Secondly, it has been explained that if gas pressurization is used to pressurize the reservoir this ensures that vaporization does not occur. However, if direct pressurization is used this results in some of the gas dissolving into the liquid and hence any subsequent reduction of pressure may cause some of this gas to be released. This could be avoided by the use of indirect pressurization, such as could be achieved by the use of a diaphragm or a bellows interface between the gas and the liquid but such a system is mechanically more complex and is less space efficient than direct pressurization.

A pressure drop inevitably occurs across the device controlling the flow of liquid anaesthetic agent, and to avoid the release of dissolved gas (the gas having been dissolved due to the direct gas pressurization) and the consequent generation of slug flow, a means must be provided to prevent this gas from being released. A convenient method to do this is, prior to reducing its pressure, to reduce the temperature of the liquid to a level where the increased solubility offsets the decrease of solubility due to Henry's Law. This has been found to give the predicted result although it has to be recognised that within the core of an electrically operated control valve the temperatures may be higher than the external body temperature and that the reduced temperature must be effective at the hottest point in the liquid flow path.

Further points that have to be addressed with such a system are the practical problems of manufacturing and the use of a control device to control extremely small flows. The requirement is to dispense flows over the range of approximately 8000 to 5 micro litres/min. This requires a control device (valve) with a turndown ratio of greater than 1000:1. To achieve resolvable control over this flow range it is necessary that the orifice size of the control device is closely matched to the maximum flow requirement when operating with its maximum pressure drop. It is found in practice that a device with an orifice size of 0.3 mm will pass a flow of 8000 micro litres with a pressure drop of the order of 0.1 bar. With a pressurization pressure in excess of 1.0 bar then if the device were to supply liquid directly to the vaporizing device then an orifice size of the order of 0.1 mm would be required. This is on the extreme of the range of the technology available and such an orifice would be extremely susceptible to blockage by micro contaminates in the liquid.

The preferred solution to this conflict of requirements is to use a specially devised pressure-difference control device that maintains a substantially constant pressure difference, e.g. of the order of 0.1 bar ,

across the control device irrespective of the supply pressure of the liquid flow being controlled. A preferred embodiment of this pressure-difference control device is shown in Fig 3, and is described in detail below. With liquid flow, in contrast with gas flow, the absence of compressibility effects mean that the metering characteristic of a flow control device is independent of the supply pressure and dependent only on the pressure difference across it. The use of this device, therefore, allows the use of a more practically sized flow-control device. The pressure-difference control device also substantially maintains the set pressure difference across the flow-control device irrespective of the downstream pressure; typically this will be the pressure of the carrier gas. This is important because, in practice, it can vary by an amount in excess of 0.1 bar, typically as an anaesthetic ventilator cycles between inspiration and expiration, and this would be sufficient to affect the liquid flow in an uncompensated system.

Accordingly, a third aspect of the invention provides an anaesthetic vaporizer comprising a reservoir for containing liquid anaesthetic agent, a vaporizing device, a conduit for a carrier gas supply, and a liquid flow control device, the vaporizer being arranged such that in use liquid anaesthetic agent contained in the reservoir is conveyed in liquid form to the vaporizing device where it is vaporized for delivery to a patient with the carrier gas, wherein the liquid flow control device is adapted to control the rate of flow of the liquid agent conveyed to the vaporizing device and to maintain a substantially constant pressure difference across itself.

If vapour pressurization is employed to pressurize the liquid chamber there is no subsequent problem with gas being released from solution but this is replaced by the problem of boiling occurring during any pressure drop, such as must take place in any flow control device, unless there is also a reduction in the liquid temperature at that point. Also, unless the temperature of the relatively large mass of liquid in the

reservoir is fairly accurately controlled, probably necessitating cooling as well as heating, then the supply pressure to the control device will vary. As in the previously described arrangement, the use of a pressure-difference control device will solve both of these problems.

For both of the systems described, therefore, it is seen that the use of a pressure-difference control device and an appropriate amount of local cooling of the liquid being dispensed is an innovative solution to prevent the formation of slug flow, whether this be due to gas release or vapour formation.

This solution also opens the way to use a system that requires neither the higher temperatures necessary to drive a solely vapour-pressure energised system nor the higher pressures necessary to prevent local boiling. All that is required is for a gas-pressurization system that maintains a minimum overall supply pressure sufficient to allow accurate flow control to be achieved. Independently from this the vapour pressure is allowed to attain its own level according to the reservoir temperature with no need to specifically control this temperature. This results in a smaller, lower-power gas compressor requirement and avoids the higher electrical-power loads necessary to control the bulk temperature of the liquid in the supply reservoir. Typically, the gas-pressurization pressure need be no more than about 0.3 bar but the system can still operate accurately if the liquid bulk temperature rises to 35° C with its corresponding vapour pressure of the order of 1 bar.

Whichever system is used, once the liquid has exited the pressure-difference control device the pressure will be substantially that of the carrier-gas pressure (typically, less than 0.1 bar). At these pressures any dissolved air will be released, unless the temperature is very low, and the liquid will start boiling at a rate determined by the heat flow into the liquid passage. In practice, it is found that by careful

design of the flow passages the release of gas is sufficiently ordered that it presents no problem in achieving a regular delivery to the vaporizing device but that if boiling occurs the process is generally spasmodic and, although the average anaesthetic-agent delivery is accurate, excessive fluctuations are observed at the outlet of the vaporizer. However, if the temperature of the liquid at the outlet of the pressure-difference control device is maintained at below its atmospheric-pressure boiling point of about 22° C, then boiling is avoided. All the flow-control devices can be arranged so that they are thermally linked so that it is possible to use a single cooling source to maintain the flow-control assembly at below the agent's boiling point. This then also satisfies the previously described requirements. Insulation can be used to minimise the power required to maintain these cooled conditions, the only necessary power loss being that transported by the cooled liquid flowing to the vaporizing device. Typically less than 5 Watts is required.

Preferably the vaporizing device comprises a part of, or is in communication with, the conduit for the carrier gas supply.

The vaporizer according to the present invention is not just an open-loop calibrated dispenser. It dispenses under closed-loop control using real-time feedback of liquid delivery flows. It preferably also confirms correct dispensation with real-time measured vapour concentration by the second gas sensor. It is a system which firstly independently measures, and controls by direct feedback, correct delivery of liquid agent, as necessary, according to the carrier gas volume flow, or any other requirement determined by the control algorithm, based on safety, accuracy or alternative control strategies, and secondly confirms the subsequent vapour concentration within the carrier gas after the liquid has vaporized, features not found in prior vaporizers.

Existing electronic vaporizers rely on measurement of differential pressure to determine the carrier gas flow but as the carrier-gas composition changes so does the differential pressure at constant flow, therefore, at best, flows are approximated. The same is true of the vaporizers in the above-mentioned patent publications in which a pressure drop in the carrier-gas flow path is used as the reference to determine the flow of the anaesthetic agent into the carrier-gas stream. In the present system the carrier-gas composition preferably is monitored directly. Preferably the gas-flow sensors also detect additional characteristics of the carrier gas so that they can determine when N_2O (and/or other gases) is/are present in the carrier-gas flow. These gas flow sensors preferably also use the same additional information to determine the composition of the carrier gas, and this information preferably is fed back to a processor, which adjusts the liquid agent flow rate and preferably maintains a constant agent vapour volume/volume concentration throughout the specified carrier gas composition ranges.

Other preferred and optional features of the invention are described below and in the subsidiary claims.

The present invention will now be described in further detail by way of the following non-limiting example as illustrated in the accompanying drawings, of which:

Figure 1 represents a schematic diagram of a vaporizer according to one embodiment of the present invention;

Figure 2 shows a functional block diagram of the vaporizer shown in Figure 1; and

Figure 3 shows a preferred form of pressure-difference control device used in vaporizers according to embodiments of the invention.

In Figures 1 and 2 a multi-agent vaporizer for the delivery of any chosen volatile liquid anaesthetic agent is illustrated.

The vaporizer may allow the operator to deliver a range of anaesthetic agents. The agent reservoir 1 may be built into a removable cartridge allowing the delivery of the anaesthetic agents Desflurane, Sevoflurane, Isoflurane, and Enflurane, for example. The different agents can be recognised by the use of a different indexing system on each agent-specific cartridge. The software-controlled system then automatically recognises the agent to be delivered, the fresh-gas flow and the concentration to set. The delivery system then delivers the correct liquid-agent flow through to the carrier gas.

The vaporizer reservoir is filled, at normal room temperature, with liquid agent through a proprietary filler system. The filling system operates whether the reservoir is pressurized or not. When a liquid level sensor 3 indicates the level as full, the filling bottle is removed and the filler is sealed. If unpressurized, the reservoir is then pressurized, by pressurizing means 5, such as a gas compressor (that pumps air or another gas into the reservoir 1), to the predetermined operating pressure. A pressure is selected that is above the minimum pressure at which the flow-control system will operate in a manner that gives stable flow control independent of any changes of pressure of the carrier gas. The pressure generated in the reservoir by the compressor will typically be 0.2 bar, or more, but vapour pressure of the liquid agent at the maximum specified ambient operating temperature may typically raise this up to 1.0 bar.

Fresh gas inlet and outlet flows are measured with flow-measuring sensors 6 and 14 and the flow rate is registered in the control processor 8. With no anaesthetic agent being delivered the inlet and outlet flow sensors will provide similar flow readings to each other irrespective of the fresh gas composition, and only by the addition of the

agent will there be a difference between the inlet and outlet flow sensor readings. From this difference the concentration of anaesthetic agent can be determined and checked with that set on a concentration selection dial 18 (or other anaesthetic concentration control) by the operator of the vaporizer. The sensors preferably also detect the presence of N_2O in the carrier gas, and calculate the concentrations of N_2O and O_2.

The flow of liquid anaesthetic agent from the pressurized reservoir chamber is measured with a micro-flow sensor 9. The preferred form of this sensor incorporates a low-power heating device which may cause a small local rise of temperature of the liquid flowing through it. If the reservoir has been pressurized by means of vapour pressure then local boiling could occur at the sensing element and so with this arrangement the liquid may need to be cooled by the amount necessary to counteract the heating effect before it enters the sensing element. The central processor checks the actual flow of anaesthetic agent against that expected for the set concentration and the carrier gas flow. The proportional flow-control valve 10 is then controlled via a closed loop with the sensor, to deliver the required amount of agent. Extremely low flows, below that which can be continuously controlled by the flow-control valve, can be achieved through pulsed operation, and specifically pulse-width modulation, of the control valve. Measured flows of liquid are integrated over time to confirm correct delivery.

Whichever pressurization strategy is employed, as has been explained it is desirable to cool the liquid before its pressure is reduced in passing through the control valve (or in some cases before it passes through the flow-sensing element). This cooling may be conveniently achieved by the use of a thermoelectric solid-state cooling device, operating on the reversed thermocouple principle. Such devices are extremely compact and pump heat from a 'cool' surface to a 'hot' surface. They are widely available commercially as standard

components. For the requirements of the vaporizer described in this patent the 'cool' surface of such a heat pump can be connected to a thermally-connected assembly containing the liquid flow sensor 9, the proportional flow control valve 10, the pressure-difference control device 7 and the shut-off valve 11. This assembly can, in turn, be thermally insulated from the rest of the vaporizer. The 'hot' surface of the heat pump can be connected to the main body of the vaporizer at a point where any heat flow can be readily conducted away so as to result in a minimum temperature rise at the 'hot' surface. A second cooling device could be installed in parallel to ensure that cooling can be maintained even if one of the two devices fails.

After the flow control valve 10, the liquid agent then flows through the pressure-difference control device 7, across which a substantially constant pressure difference is maintained irrespective of the flow or supply pressure of the liquid agent being delivered. On exiting the pressure-difference control device 7 the liquid agent is delivered, via a safety shut-off valve 11, into a heated vaporizing device 12.

It has been explained how the liquid in the liquid supply passage will be kept below its boiling point to prevent irregular vapour-bubble formation but that there may well be slug flow due the steady release of dissolved air which collects into air bubbles regularly spaced in the flow. If the liquid supply passage is of a constant, small diameter, typically of the order of 1.0 mm, and with no discontinuities, or pockets where air can collect, then the flow to the vaporizer has been found to be sufficiently regular to provide a substantially constant vaporization rate.

In order to provide extra safety in case the flow-control valve fails to reduce the liquid flow when required, a normally-closed, electrically-operated shut-off valve 11 is placed in the passage to the vaporizing device. With the design used here for illustration, care is taken in the

selection and positioning of this valve to ensure that it does not present any air collection points that might cause air to collect and build up into larger and more randomly released bubbles. It is also arranged that any temperature rise that may occur as the liquid passes through this valve does not raise the liquid to its boiling point so as to form the more irregular vapour bubbles.

In the illustrative design described here only on reaching the vaporizing device is the liquid agent vaporized. As explained earlier, the vaporization process can be very unstable because of the large heat flows as vaporization bubbles are formed. It has been found by the present inventors that in the configurations that have been tested the best results are achieved by introducing the liquid as a continuous stream, or with regularly dispersed bubbles, and to drop this flow onto a solid, good-heat-conducting surface connected directly to a heater element. This arrangement maximises the flow of heat back into the surface following any local drop of temperature due to the formation of a vaporization bubble on the surface. If a local cool spot does temporarily occur any liquid that does not vaporize just flows on to another part of the surface and is evaporated there.

It has also been found by the present inventors that a smoother vaporization rate is achieved if at least part of the vaporizing surface is inclined to the horizontal, e.g. by 45° or more, and in such a manner that any liquid that meets a temporary cool spot quickly flows on to another part of the vaporizing surface. The bulk temperature of the vaporizing device is maintained at a predetermined temperature by means of control loop with a temperature sensor and a heating element. As the liquid flow into the device increases it spreads over a larger area and more is evaporated. The latent heat of vaporization takes heat from the surface, reducing the temperature and hence causing the control system to deliver more power to the heater. As the vaporization increases there is an inevitable increase in the thermal gradient between

the heating element and the vaporization surface and so it may be beneficial to increase the required operating temperature as the liquid flow increases.

The vaporizing device may be either in a side passage but connected to the carrier-gas flow conduit or may be situated within this conduit. If in a side passage the vapour will flow into the carrier gas conduit at the rate at which it is generated and the temperature of the carrier gas will be largely unchanged. If the carrier gas flows through the vaporizing device the heat within the carrier gas can be used to vaporize some of the liquid, which may economise on heater power consumption but will result in a corresponding cooling of the carrier gas. If the vaporizing device is insulated, heat flow back into the body of the vaporizer can be minimised which has the advantage of both reducing the electrical power requirement of the vaporizing device and of minimising the cooling power required to maintain the outlet flow from the pressure-difference control device below its boiling point. It is found that a heater of no greater than 15 Watts is adequate to both maintain the vaporizing surface temperature and to give sufficient margin to provide a thermal time-constant more than adequate to respond to the most rapid changes in liquid flow. Typically, the vaporizing surface temperature will be maintained at between 25° C and 35° C. If the temperature is too low a larger surface area for vaporization is required and if it is too large more heat will be lost to the body of the vaporizer and the vaporization process will become more violent and hence potentially less regular.

As illustrated in Figure 2, the vaporizing device 12 is in communication with the conduit for the carrier gas supply. The anaesthetic agent that is transformed into the vapour phase in the vaporizing device passes at substantially constant pressure through a port connected directly to the carrier-gas supply conduit. Alternatively,

the vaporizing device could be located in (or comprise part of) the carrier gas supply conduit.

The vaporized agent may then pass through a mixing device 13 ensuring a complete mixing of the fresh gas and vapour. The mixture subsequently passes through a second flow-measuring device 14 which independently monitors the increased output flow due to addition of vapour and provides for additional confirmation of correct vaporizer performance.

The control system is a software-controlled device using a safety-critical high-level language. The software also monitors the controlled hardware and all of the feedback signals. In the event of a device failure the system closes off the delivery of all anaesthetic agent, failing into a safe mode and generating a visual and audible alarm.

The use of electronics for the independent control of the liquid-anaesthetic-agent flow also means that the set concentration on the vaporizer can be overridden by other inputs making the vaporizer suitable for incorporation into an external control loop as, for example, may be used in a system that monitors and automatically controls the depth of patient anaesthesia.

The use of a liquid anaesthetic agent flow sensor has the additional benefit that the signal output from the sensor can be integrated to measure the amount of agent dispensed in a given period. The display of this quantity is useful to users, not least for keeping records of costs when using very expensive agents.

The vaporizer is powered by mains electrical supply transformed down to a low voltage, thereby increasing safety. A low voltage supply (for example 12V) is possible because the vaporizer avoids the need to heat or cool a large mass of anaesthetic agent; instead, only the

required small mass of agent required to be mixed with the carrier gas is heated or cooled at any time. The use of a low voltage supply also means that a battery back-up 16 may be present in case of mains supply failure.

A preferred form of pressure-difference control device used in vaporizers according to embodiments of the invention is shown in Figure 3. The device 7 comprises a diaphragm 21, a low force bias spring 22, a needle valve 23, a control seat 24, and a diaphragm support 25. The functional components are retained in a suitable housing.

Pressure from the anaesthetic agent reservoir is applied directly to the bottom of the diaphragm 21 and with the control valve 10 closed no pressure is applied to the upper surface of the diaphragm. The bias spring force is significantly lower than that provided by the pressure on the underside of the diaphragm 21 and the needle valve 23 will remain tightly closed.

As the control valve 10 opens, fluid from the anaesthetic agent reservoir is allowed to flow through the control valve onto the upper side of the diaphragm 21. Pressure will rise on the upper side of the diaphragm 21 until the pressure coupled with the addition of the spring force 22 balances the force due to the reservoir pressure on the lower side of the diaphragm, and the diaphragm with its needle valve 23 will move downward and open the needle valve allowing the fluid to flow.

As the control valve 10 opens further, the pressure on the upper surface of the diaphragm 21 will increase, however as the force increases the diaphragm will move downward to increase the opening of the needle valve 23 further, maintaining a constant pressure differential across the valve assembly (i.e. the pressure-difference flow control device) for the range of specified flows. Conversely, as flow from the control valve 10 reduces, the pressure on the upper side of the

diaphragm 21 will decrease, the diaphragm will move upward and close the needle valve 23, thus maintaining the same pressure differential.

CLAIMS

1. An anaesthetic vaporizer, comprising a reservoir for containing liquid anaesthetic agent, pressurizing means for pressurizing the liquid anaesthetic agent in the reservoir, a vaporizing device and a conduit for a carrier gas supply, the vaporizer being arranged such that in use liquid anaesthetic agent contained in the reservoir is pressurized by the pressurizing means and conveyed in liquid form by that pressurization to the vaporizing device where it is vaporized for delivery to a patient with the carrier gas, wherein both the pressurization and the conveyance of the liquid anaesthetic agent to the vaporizing device are controlled independently of the carrier gas supply.

2. A vaporizer according to claim 1, further comprising a liquid flow sensor arranged to measure the rate at which the liquid agent is conveyed to the vaporizing device.

3. A vaporizer according to claim 2, in which the liquid flow sensor is a mass flow sensor.

4. A vaporizer according to any preceding claim, further comprising means for measuring the concentration of vaporized agent in the carrier gas.

5. A vaporizer according to claim 4, in which said means comprise first and second gas flow sensors.

6. A vaporizer according to claim 5, in which the first gas flow sensor measures the rate of flow of the carrier gas prior to introduction of the agent therein.

7. A vaporizer according to claim 5 or claim 6, in which the second gas flow sensor measures the rate of flow of the carrier gas containing vaporized agent.

8. A vaporizer according to claim 2 or any claim dependent thereon, in which the rate at which the liquid agent is conveyed to the vaporizing device is controlled, at least in part, by means of the measurement made by the liquid flow sensor.

9. A vaporizer according to claim 5 or any claim dependent thereon, in which the first and/or second gas flow sensor(s) determine the composition of the carrier gas.

10. A vaporizer according to claim 5 or any claim dependent thereon, in which a check is carried out of whether the liquid agent is being conveyed to the vaporizing device at the correct rate, by means of the measurements made by the first and/or second gas flow sensors.

11. A vaporizer according to claim 9, in which a check is carried out of whether the liquid agent is being conveyed to the vaporizing device at the correct rate, from the determination of the composition of the carrier gas by means of the first and/or second gas flow sensor(s).

12. A vaporizer according to claim 9 or claim 11, in which the first and/or second gas flow sensor(s) determine the concentration of N_2O and/or O_2 in the carrier gas.

13. A vaporizer according to any preceding claim, further comprising a liquid flow control device adapted to control the rate of flow of the liquid agent conveyed to the vaporizing device.

14. An anaesthetic vaporizer comprising a reservoir for containing liquid anaesthetic agent, pressurizing means for pressurizing the liquid anaesthetic agent in the reservoir, a vaporizing device, a conduit for a carrier gas supply, a liquid flow sensor, a liquid flow control device and first and second gas flow sensors, the vaporizer being arranged such that in use liquid anaesthetic agent contained in the reservoir is pressurized by the pressurizing means and conveyed in liquid form by that pressurization to the vaporizing device where it is vaporized for delivery to a patient with the carrier gas, wherein the liquid flow sensor measures the rate at which the liquid agent is conveyed to the vaporizing device, the first gas flow sensor measures the rate of flow of carrier gas, the second gas flow sensor measures the rate of flow of carrier gas containing vaporized agent, and the rate of flow of the liquid agent conveyed to the vaporizing device is controlled by the liquid flow control device.

15. A vaporizer according to claim 13 or claim 14, in which the liquid flow control device is adapted to maintain a substantially constant pressure difference across itself.

16. An anaesthetic vaporizer comprising a reservoir for containing liquid anaesthetic agent, a vaporizing device, a conduit for a carrier gas supply, and a liquid flow control device, the vaporizer being arranged such that in use liquid anaesthetic agent contained in the reservoir is conveyed in liquid form to the vaporizing device where it is vaporized for delivery to a patient with the carrier gas, wherein the liquid flow control device is adapted to control the rate of flow of the liquid agent conveyed to the vaporizing device and to maintain a substantially constant pressure difference across itself.

17. A vaporizer according to any preceding claim, in which the vaporizing device comprises a part of, or is in communication with, the conduit for the carrier gas supply.

18. A vaporizer according to any preceding claim, in which the pressurizing means comprises a compressor that pressurizes the reservoir by gas pressure.

19. A vaporizer according to claim 15, in which the gas pumped by the compressor is air.

20. A vaporizer according to any preceding claim, in which vapour pressure of the liquid agent provides pressurization of the liquid agent by which the liquid agent is conveyed to the vaporizing device.

21. A vaporizer according to any preceding claim, in which gas pressure directly or indirectly provides pressurization of the liquid agent by which the liquid agent is conveyed to the vaporizing device.

22. A vaporizer according to any preceding claim, further comprising cooling means by which the liquid agent conveyed to the vaporizing device is cooled.

23. A vaporizer according to any preceding claim, in which the vaporizing device includes a vaporizing surface.

24. A vaporizer according to claim 23, in which, at least in use, the vaporizing surface is inclined with respect to the horizontal.

25. A vaporizer substantially as herein before described and/or as illustrated, with reference to the accompanying figures 1, 2, or 3.

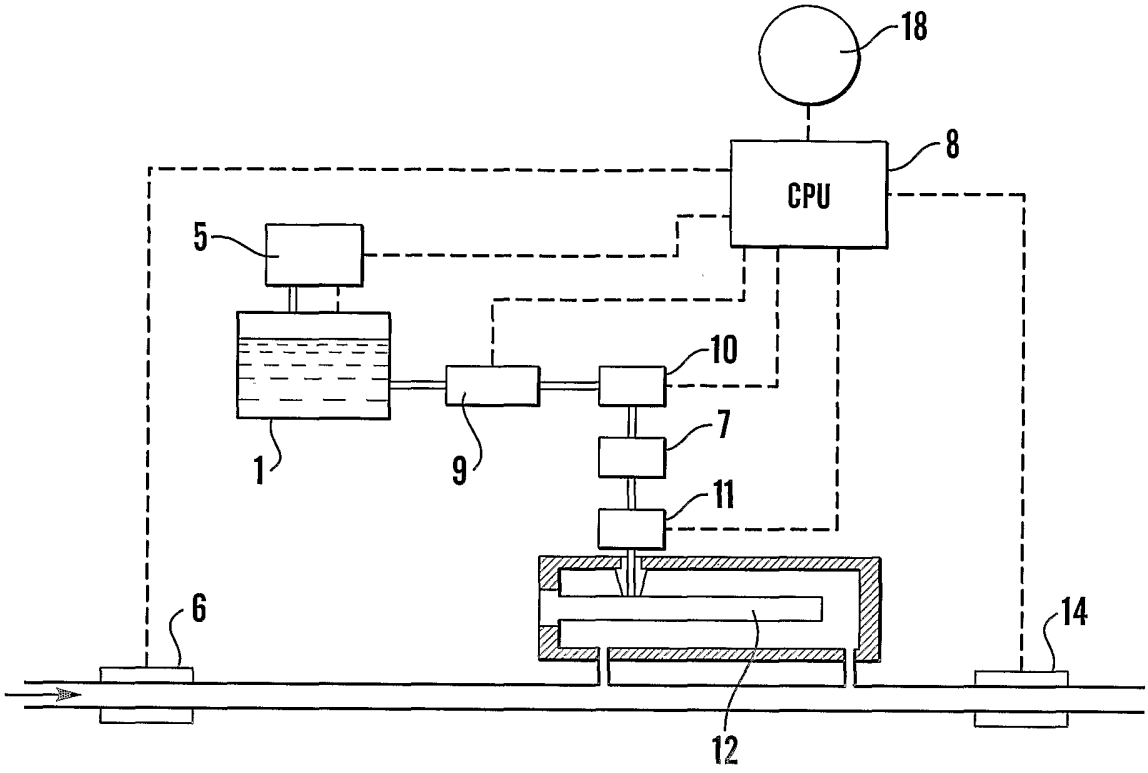

18
CPU
8
5
10
7
1
9
11
6
14
12

Fig. 1

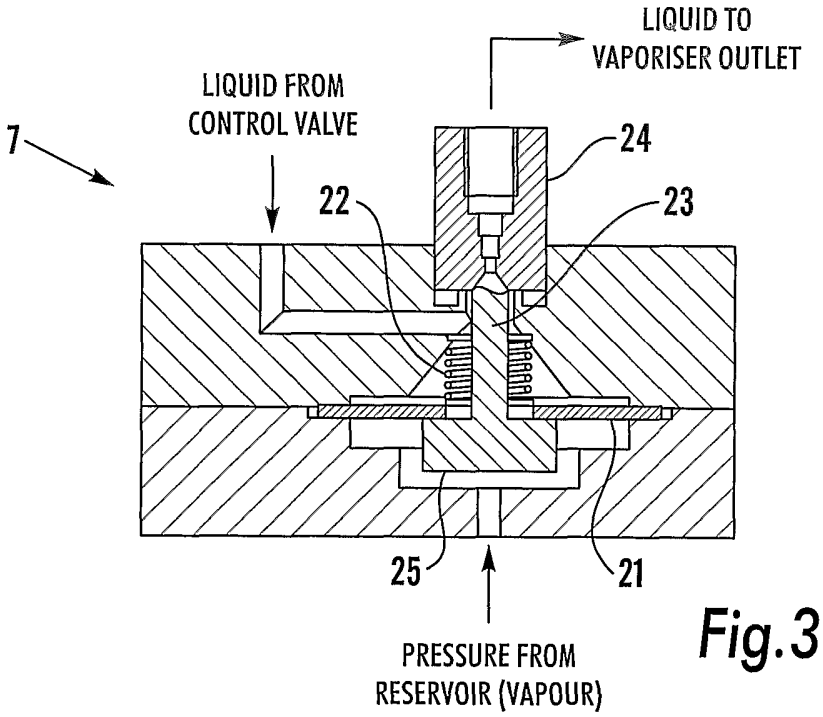

LIQUID TO
VAPORISER OUTLET
LIQUID FROM
CONTROL VALVE
7
24
22
23
25
21
PRESSURE FROM
RESERVOIR (VAPOUR)

Fig. 3

Fig.2

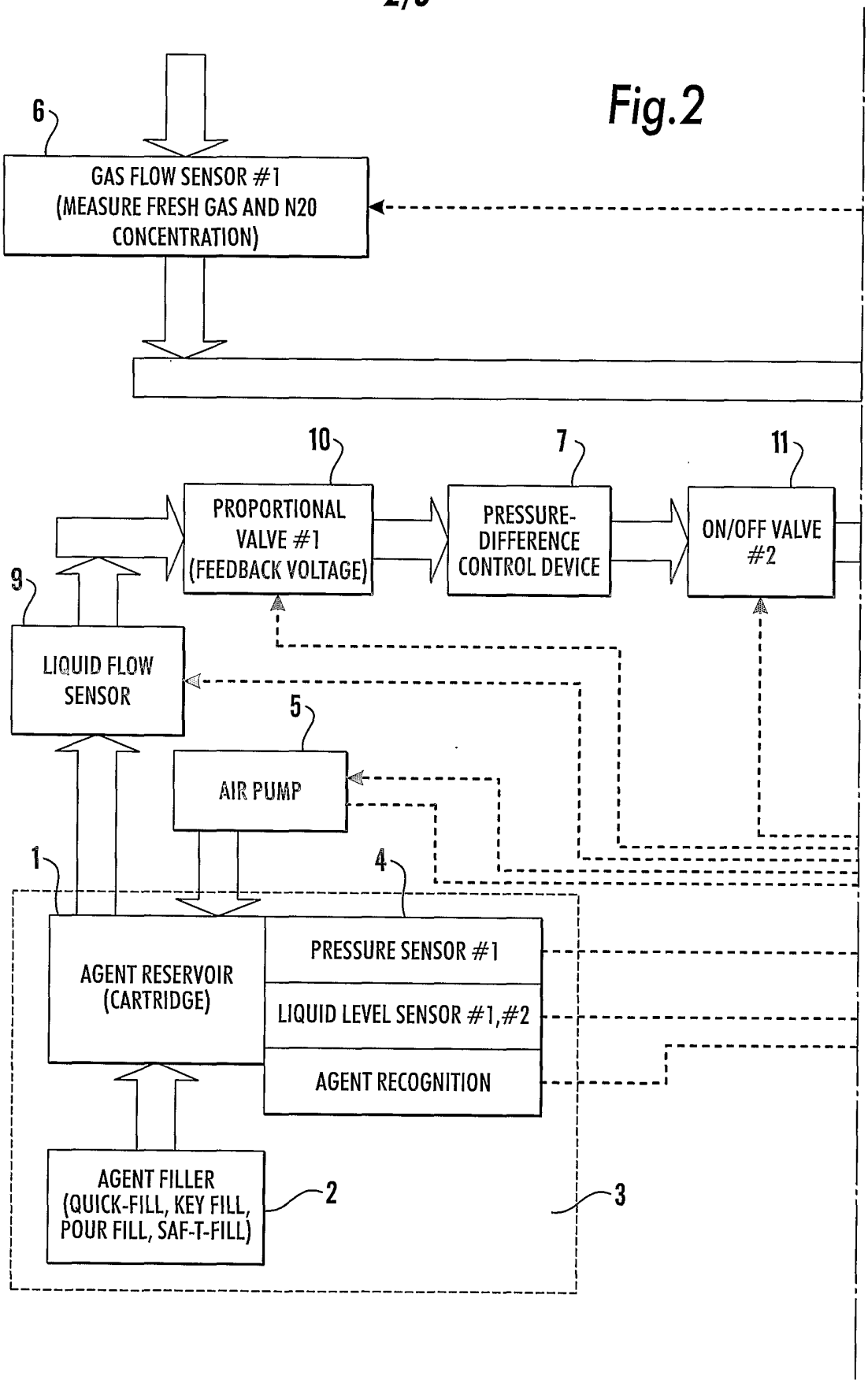
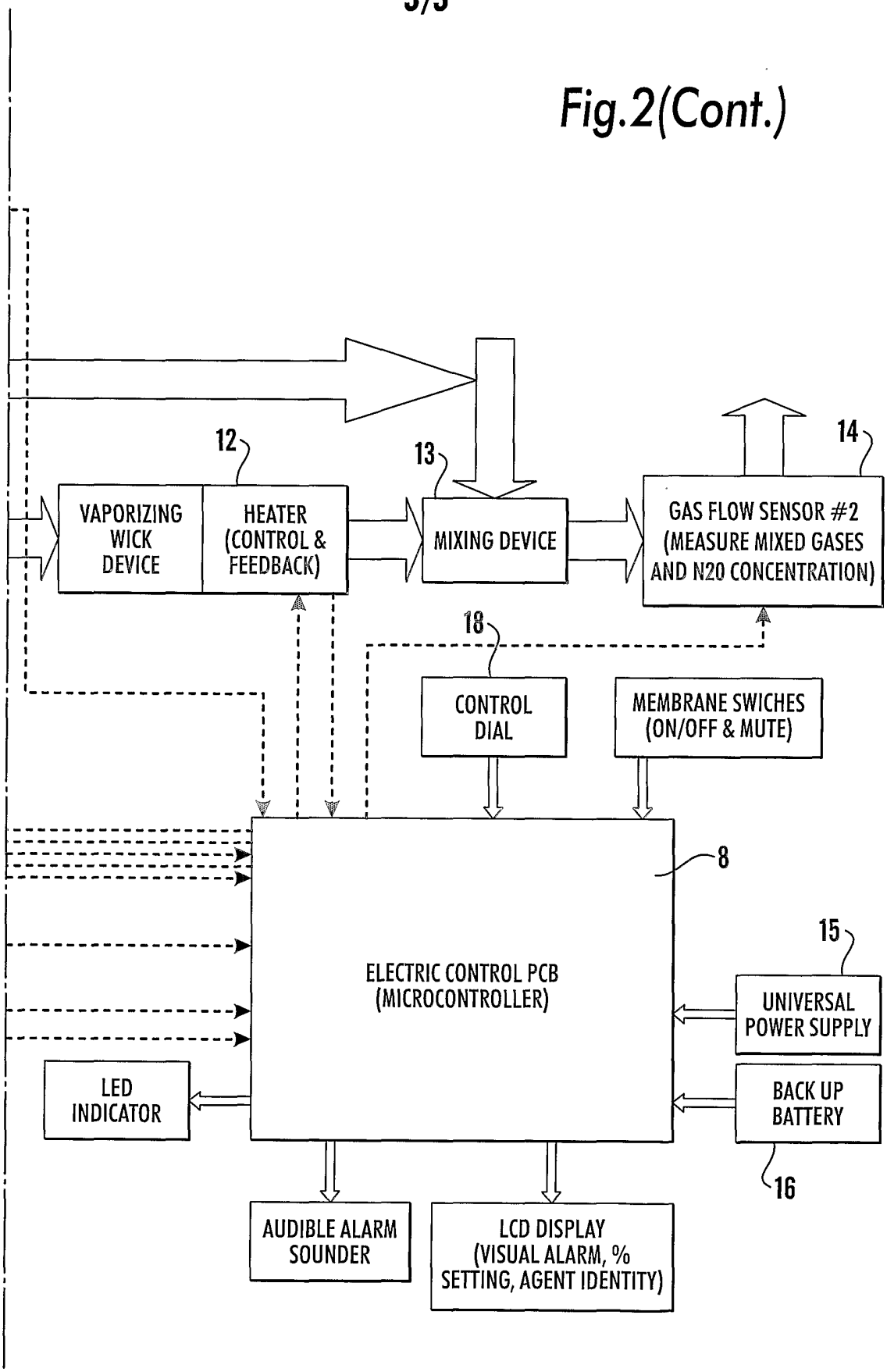

6
GAS FLOW SENSOR #1
(MEASURE FRESH GAS AND N20
CONCENTRATION)
10
PROPORTIONAL
VALVE #1
(FEEDBACK VOLTAGE)
7
PRESSURE-
DIFFERENCE
CONTROL DEVICE
11
ON/OFF VALVE
#2
9
LIQUID FLOW
SENSOR
5
AIR PUMP
1
4
AGENT RESERVOIR
(CARTRIDGE)
PRESSURE SENSOR #1
LIQUID LEVEL SENSOR #1,#2
AGENT RECOGNITION
AGENT FILLER
(QUICK-FILL, KEY FILL,
POUR FILL, SAF-T-FILL)
2
3

Fig.2(Cont.)


12
13
14
VAPORIZING WICK DEVICE
HEATER (CONTROL & FEEDBACK)
MIXING DEVICE
GAS FLOW SENSOR #2 (MEASURE MIXED GASES AND N20 CONCENTRATION)
18
CONTROL DIAL
MEMBRANE SWICHES (ON/OFF & MUTE)
8
ELECTRIC CONTROL PCB (MICROCONTROLLER)
15
UNIVERSAL POWER SUPPLY
LED INDICATOR
BACK UP BATTERY
16
AUDIBLE ALARM SOUNDER
LCD DISPLAY (VISUAL ALARM, % SETTING, AGENT IDENTITY)