Inventors; and

Inventors/Applicants (for US only): MASON, Rodney; STEWART, P.C.; 28 Fernhill Drive, Blackpill, Swansea SA3 5BX (GB); MOOZYCKINE, Alexei, Uriah [GB/GR]; 82 Vivian Road, Sketty, Swansea SA2 OUL (GB); DINGLEY, John [GB/GR]; 105a Swansea Road, Llangyfelach, Swansea SA5 7HX (GB).

Agent: CAWDELL, Karen, Teresa; Urquhart-Dykes & Lord LLP, Three Trinity Court, 21-27 Newport Road, Cardiff CF24 OAA (GB).


Title: GAS CONTROL APPARATUS

Abstract: A method of removing nitrogen from a flow of gas (such as exhaled breath) which contains an anaesthetic agent in an anaesthesia breathing circuit, which method includes: a) cooling the gas in a first cooling means to a temperature substantially below the freezing point of carbon dioxide, so as to condense carbon dioxide and water vapour present in the gas; b) cooling the non-condensed gas from step (a) in a second cooling means to a temperature in a first temperature range which is substantially below the boiling point of an anaesthetic agent present in the gas but substantially above the boiling point of nitrogen, so as to provide a condensed material (which may be in liquid or solid form) comprising the anaesthetic agent; c) venting non-condensed gas from step (b); and d) permitting the condensed material from step (b) to increase to above a second temperature which is substantially above the boiling point of the anaesthetic agent so as to permit the anaesthetic agent to become gaseous.
TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— with international search report

— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
GAS CONTROL APPARATUS

The present invention is concerned with the removal of nitrogen from a flow of gas, such as exhaled breath.

The present invention is also concerned with a method and apparatus for recycling anaesthetic gases for use in breathing circuit apparatus.

Nitrous oxide and a number of other anaesthetic gases in common use (with the exception of sevoflurane) are damaging to the ozone layer and are to be banned by the year 2030 under the Kyoto Agreement.

In order to reduce the use of such ozone layer damaging anaesthetic gases, and also to lower the amount of anaesthetic gases utilised, specialised anaesthesia breathing circuits can be used. In use, a portion of exhaled gases are permitted to be re-inspired after waste carbon dioxide is removed, typically using a chemical carbon dioxide scrubbing agent.

Fully-closed anaesthetic breathing circuits can also be used during anaesthetic procedures. In such apparatus, the gases breathed by the patient are directed around a loop of tubing such that all exhaled gases/vapours are rebreathed after an initial treatment to remove, carbon dioxide, for example using soda lime granules.

The "fully-closed" nature of such a system means that fresh gas (such as oxygen or the anaesthetic gas) is added to the loop at a rate which equals the rate of uptake by the body of the patient (via the lungs). There is therefore no spillage of excess gas from the loop when it is functioning as a fully closed system.

Apparatus for recovering xenon or a mixture of krypton and xenon from air is disclosed in US-A-6164089.
However, the method and apparatus disclosed are for use in conditions of cryogenic separation plant and cannot be applied to medical, and in particular, anaesthetic purposes.

Apparatus for use in anaesthesia breathing circuits is disclosed in US-A-6134914. The apparatus disclosed is for the recovery of xenon gas, which may then be used in the same patient or alternatively in a different patient. The apparatus disclosed utilises filters and absorbers in order to remove carbon dioxide, water, hydrocarbons and particles. The apparatus disclosed is not a continuous process which is more desirable for the reason that under continuous process it is easier to keep the total volume of gas in the breathing circuit and lungs relatively constant, thereby reducing the total amount of anaesthetic gas used during an operation.

Closed-loop systems, however, have the disadvantage that nitrogen dissolved in the blood and tissue of the patient (in equilibrium with air) tends to build up in the anaesthesia circuit with time, as it emerges from the body into the lungs and subsequently into exhaled breath. This has the effect of diluting the concentrations of oxygen and anaesthetic gases in the circuit as the anaesthetic progresses.

A further disadvantage of US-A-6134914 is that it is difficult to remove the gas pathways for sterilisation, the pathways therefore have to be dismantled in order to sterilise the apparatus.

In order to alleviate some of the problems identified above, the patient may be required to breathe 100% oxygen for approximately 20 minutes from a close fitting mask before the anaesthesia commences. This has the advantage of removing most (but not all) of the nitrogen from the
body prior to use of the anaesthetic breathing circuit. This is however both inconvenient and uncomfortable for the patient. An alternative approach is to flush the anaesthetic breathing circuit with fresh gas periodically, whenever an unacceptable build up of nitrogen has occurred, thereby displacing the gases already inside the circuit together with nitrogen which has built up. However, this is wasteful of anaesthetic gases and volatile agents, which are also lost to the atmosphere.

It is therefore an aim of the present invention to alleviate at least some of the disadvantages highlighted above.

It is a further aim of the present invention to provide a method of removing nitrogen from a gas flow which permits greater economy in use of anaesthetic gases or the like, by eliminating the requirement to "flush" the closed circuit periodically.

It is yet a further aim of the present invention to provide apparatus for use in conjunction with an anaesthetic breathing circuit which is capable of being easily sterilised.

It is yet a further aim of the present invention to provide a method and apparatus for sustaining substantially continuous removal of nitrogen and/or recycling of anaesthetic gas.

Therefore, according to a first aspect of the present invention, there is provided a method of removing nitrogen from a flow of gas (such as exhaled breath) which contains an anaesthetic agent in an anaesthesia breathing circuit, which method includes:
a) cooling the gas in a first cooling means to a temperature substantially below the freezing point of carbon dioxide, so as to condense carbon dioxide and water vapour present in the gas;

b) cooling the non-condensed gas from step (a) in a second cooling means to a temperature in a first temperature range which is substantially below the boiling point of an anaesthetic agent present in the gas but substantially above the boiling point of nitrogen, so as to provide a condensed material (which may be in liquid or solid form) comprising the anaesthetic agent;

c) venting non-condensed gas from step (b); and

d) permitting the condensed material from step (b) to increase to above a second temperature which is substantially above the boiling point of the anaesthetic agent so as to permit said anaesthetic agent to become gaseous.

The anaesthetic agent may include nitrous oxide, xenon or the like.

It is particularly preferred that a substantial amount of water vapour is removed from the flow of gas prior to the gas entering the first condensing means.

A substantial amount of water vapour present in the flow of gas (typically about 85% of water present in the gas) is typically removed by permitting the gas to flow through a drying column which typically comprises small hollow stainless steel rings. Alternatively, the water vapour may be removed by use of a dehumidifier or water vapour absorber filled with a desiccating agent. It is, however, envisaged that the water vapour may be removed
by use of a drying column and a dehumidifier or water vapour absorber.

Advantageously, water vapour and carbon dioxide present in the flow of gas are condensed from the gas flow in step (a) typically as a solid. In addition, volatile anaesthetic vapours may also be condensed in step (a). Such volatile anaesthetic vapours may include, but are not limited to, Enflurane (CHFC1CF3H; Bpt +56.5°C), Halothane (CF3CBrClH; Bpt +50.2°C), Isoflurane (CF3CHClOCF3H; Bpt +48.5°C), Desflurane (Bpt +23.5°C), or Sevoflurane (Bpt +58.6°C).

The condensed material in step (a) is typically removed by allowing the condensate to heat up to room temperature at the end of the anaesthetic procedure and venting the resulting gas/vapour by flushing with air/oxygen.

The gaseous anaesthetic agent resulting from step (d) preferably remains in the breathing circuit for subsequent inhalation by the patient. Further preferably the gaseous anaesthetic agent resulting in step (d) should only be reused in the patient from which it was extracted and not stored in an additional vessel.

The non-condensed gas (in step (c)) typically includes nitrogen, oxygen and argon.

The method preferably includes a further step prior to step (a), whereby carbon dioxide present in the gas may be removed, using, for example, a carbon dioxide scrubbing material, such as soda lime, or the like. This is preferably achieved by directing a proportion of the gas to the nitrogen removing circuit from the anaesthetic "loop" at a point just beyond the carbon dioxide absorber of the anaesthesia circuit.
According to a first embodiment of the present invention, the first temperature range is substantially below the freezing point of the anaesthetic agent but substantially above the boiling point of nitrogen such that the condensed material in step (b) is in solid form. In this particular embodiment the temperature of the condensed material from step (b) (which typically comprises the anaesthetic agent) is increased to a second temperature substantially above the boiling point of the anaesthetic agent in the second cooling means. Advantageously, the second cooling means is capable of fluctuating between the first temperature range and the second temperature which is substantially above the boiling point of the anaesthetic agent.

Advantageously, the first temperature range is from about -91°C (when the anaesthetic agent is nitrous oxide) to about -205°C. Alternatively, the first temperature range may be from about -112°C (when the anaesthetic agent is xenon) to about -205°C. However, it should be noted that the first temperature is dependant on the anaesthetic agent used.

Advantageously, the method may include a further step whereby the temperature of the first cooling means is increased to a temperature substantially above 0°C when the temperature of the second cooling means is increased to the second temperature. This further step has the advantage that volatile anaesthetic agents and water vapour condensed in step (a) may be returned to the anaesthetic breathing circuit, preferably via a system of gas pump(s) and valves.

According to a second embodiment of the first aspect of the present invention, the first temperature range is substantially below the boiling point of the anaesthetic
agent and above the freezing point of the anaesthetic agent so that the condensed material is in liquid form.

In the second embodiment, the liquified material including the anaesthetic agent is permitted to exit the second vessel (typically under gravity), so as to permit the anaesthetic agent to become gaseous. The liquified material typically enters an expansion vessel (preferably arranged substantially adjacent to the second cooling means) where the liquified material is permitted to expand, preferably with the application of heat.

The second temperature above the boiling point of the anaesthetic agent in step (d) is preferably greater than -88°C (when the anaesthetic agent is nitrous oxide). Alternatively, the second temperature is preferably greater than -108°C (when the anaesthetic agent is xenon).

The non-condensed gas in step (c) is typically vented to the atmosphere.

According to a second aspect of the present invention, there is provided apparatus for removal of nitrogen from a flow of gas (such as exhaled breath) which includes:

- a gas flow circuit;
- first cooling means positioned in the gas flow circuit, the first cooling means being suitable for cooling to a temperature substantially below the freezing point of carbon dioxide so as to condense carbon dioxide, water vapour and volatile anaesthetic agents present in the gas;
- second cooling means positioned in the gas flow circuit, the second cooling means being arranged to be cooled to a first temperature which is substantially below the boiling point of the anaesthetic agent so as to condense anaesthetic agent gases from the flow of gas, to a solid
or liquid form.

Advantageously, the apparatus may be used in conjunction with a closed-loop breathing apparatus.

It is preferred that the apparatus includes drying means for removing a substantial amount of water vapour in the flow of gas, typically arranged prior to the first condensing means.

It is envisaged that the drying means for the second embodiment includes a drying column, typically arranged at a temperature in the range of about 0.5°C to about 5°C (further preferably about 1.0°C to about 3°C). In use, advantageously, water vapour in the gas flow is partially condensed to the liquid phase. The condensate is then removed from the drying column, preferably via a closable exit channel. The closable exit channel may be a solenoid on-off valve or the like.

Alternatively, the drying means may include a dehumidifier or water vapour absorber.

The apparatus typically includes a flowmeter, such as a digital flowmeter, so as to control the flow of gas through the apparatus.

Advantageously, the first cooling means and the second cooling means may be removed from the apparatus with minimal disruption thereby permitting cleaning of the apparatus without the apparatus being dismantled.

The flowmeter may be installed prior to or after the drying means. However, if the flowmeter is sensitive to high humidity, it is preferred that the flowmeter is installed after the drying means so as to maintain the flowmeter in good condition.
Advantageously, the first cooling means and/or the second cooling means are electrically powered refrigeration units.

The first cooling means and the second cooling means are preferably not liquid \(N_2\) cooled, as liquid \(N_2\) has the disadvantage that it requires periodical replenishment. It is therefore particularly preferred that the first cooling means and the second cooling means are refrigeration units cooled by closed circuit compulsorily circulating cooling agent(s), for example CFC’s.

The first cooling means and the second cooling means are preferably arranged in series. The apparatus is typically arranged such that the gas flows firstly through the first cooling means and subsequently through the second cooling means.

It is preferred that the first cooling means and the second cooling means have respective cooling chambers; the cooling chambers advantageously are arranged so as to permit removal from each respective cooling means, substantially without the apparatus being dismantled.

It is preferred that the parts of the apparatus which are in contact with the anaesthetic gas are made substantially of stainless steel. The use of stainless steel has the advantage that the gas pathways can be easily removed and cleaned (for example, by use of an autoclave unit).

Desirably, the apparatus includes an oxygen monitor and/or means for monitoring anaesthetic agent present in the flow of gas.

It is preferred that the apparatus, when in use, is
substantially at or about atmospheric pressure.

The first cooling means is preferably manufactured from metal, such as stainless steel. The first cooling means preferably comprises at least two cylinders (typically of stainless steel) which are separated by one or more O-rings (which may be rectangular in section), preferably manufactured from low temperature resistant silicon rubber or polytetrafluoroethylene (PTFE), such as the polymer sold by Du Pont under the trade mark TEFLON.

It is particularly preferred that the first cooling means is immediately preceded by a heating element which permits a high temperature gradient along the length of the first cooling means substantially without the risk of blocking the gas entrance into the first cooling means with ice, condensed volatile anaesthetics, etc.

The second cooling means typically comprises a hollow stainless steel cylinder substantially filled with copper rings or the like.

Advantageously, the first cooling means precools the flow of gas before it enters the second cooling means. This has the advantage of reducing the heat removal rate which needs to be applied to the gas by the second cooling means to attain the desired temperature.

According to a first embodiment of the second aspect of the present invention, the second cooling means is arranged to fluctuate between a temperature in a first temperature range which is substantially below the freezing point of the anaesthetic agent present in the gas, but substantially above the boiling point of nitrogen, and a second temperature which is substantially above the freezing point (preferably above the boiling point) of the anaesthetic agent. In this embodiment, the
anaesthetic agent solidifies in the second cooling means.

Advantageously, the first temperature range of the second cooling means is from about -91°C (when the anaesthetic agent is nitrous oxide) to about -205°C. Alternatively, the first temperature range of the second cooling means may be from about -112°C (when the anaesthetic agent is xenon) to about -205°C.

The second temperature is preferably greater than -88°C (when the anaesthetic agent is nitrous oxide). Alternatively, the second temperature is preferably greater than -108°C (when the anaesthetic agent is xenon).

According to a second embodiment of the second aspect of the present invention the second cooling means is arranged to attain a temperature which is substantially below the boiling point of the anaesthetic agent but above the freezing point of the anaesthetic agent, so as to condense the anaesthetic agent to a liquid.

In this embodiment of the present invention it is particularly preferred that the apparatus further includes an expansion chamber (typically in communication with the second cooling means). The expansion chamber is typically arranged such that liquid condensed in the second cooling means is permitted to flow into the expansion chamber (typically under gravity). The liquid is permitted to evaporate in the expansion chamber. The expansion chamber may include heating means so as to assist in the evaporation of the liquid. Alternatively the heat transfer from the adjacent parts of the apparatus exposed to ambient air provides enough heat for the liquid anaesthetic agent to become gaseous.
The second embodiment is particularly advantageous as the second cooling means does not have to attain as low a temperature as in the first embodiment, thereby reducing the energy required. Furthermore, the removal of nitrogen from the flow of gas is continuous, and also the recovery of gaseous anaesthetic agent and its supply to the anaesthesia gas circuit is substantially continuous.

It is preferred that the apparatus, when in use, is at atmospheric pressure.

The second cooling means typically comprises a hollow stainless steel cylinder substantially filled with copper rings or the like.

According to yet a further aspect of the present invention, there is provided apparatus for the continuous recovery of anaesthetic agent from a flow of gas, the apparatus includes:

- a gas flow circuit;
- first cooling means positioned in the gas flow circuit, the first cooling means being suitable to cool to a temperature substantially below the freezing point of carbon dioxide;
- second cooling means positioned in the gas flow circuit, the second cooling means being arranged to be cooled to a second temperature which is substantially below the boiling point of the anaesthetic agent and substantially above the freezing point of the anaesthetic agent so as to liquify the anaesthetic agent;
- an expansion chamber arranged to receive liquid anaesthetic agent.

It is particularly preferred that the apparatus for the continuous recovery of anaesthetic agent is substantially as described herein before with reference to the apparatus for removal of nitrogen from a gas flow.
The present invention will now be described, with reference to the accompanying figures which are given by way of example only, wherein:

FIGURE 1 represents a breathing circuit apparatus which includes nitrogen removal apparatus according to the present invention;

FIGURE 2 represents a cooling means for use in apparatus according to the present invention; and

FIGURE 3 represents apparatus according to an alternate embodiment of the present invention.

Referring to Figure 1, there is provided a breathing circuit apparatus generally indicated by numeral 1. Nitrous oxide is used as an example of the anaesthetic gas being recovered and returned to the anaesthetic circuit.

The apparatus 1 includes closed loop breathing circuit 1a and a nitrogen removal apparatus according to the present invention 1b. The breathing circuit includes an attached closed loop 2, an oxygen inlet port 3 controlled by valve 4 and a nitrous oxide inlet port 5 controlled by valve 6. The flow of gas around the apparatus is controlled by valves 7, 10, 11, mass flow controller 12, and pump 20.

In use, oxygen and nitrous oxide (or other anaesthetic gas) are introduced via inlets 3 and 5. The flow of gas circulates around circuit A. Gaseous CO₂ is removed from the circuit in CO₂ removal device 13 which contains soda lime. The respective concentrations of O₂ and nitrous oxide are measured using monitor 14. Mechanical ventilation of the lungs of the patient via circuit A is achieved by attachment of the bellows 22 to a suitable
mechanical ventilator. The circuit A contains passive one-way values (not shown) to ensure unidirectional flow of gas to and from the lungs and around the circuit.

When the level of nitrogen in anaesthetic circuit A, determined for example using mass spectrometer 19 by directing a gas sample via sample valve 21, reaches a predetermined level, valve 7 is switched to direct a predetermined volume/flow of gas around circuit B. Whilst valve 11 is closed, the flow of gas passes through first condenser 16, the temperature of which is set at about -85°C. Therefore, any water vapour and volatile anaesthetic agents (and also carbon dioxide if present) in the gas are condensed out.

The already cooled flow of gas subsequently passes to second condenser 17 which is cooled to a temperature of about -120°C. This temperature is below the freezing point of nitrous oxide but above the boiling point of oxygen and nitrogen, such that the nitrous oxide present in the flow of gas condenses out whilst nitrogen and oxygen present remains gaseous. The gaseous mixture of oxygen and nitrogen is directed via valve 10 to outlet 18 and vented to the atmosphere; valve 11 being closed during this time.

Valve 10 is then closed and valve 11 opened. The temperature of the second condenser 17 is then raised to about -80°C to enable the solid nitrous oxide to volatilise. The gaseous nitrous oxide is then circulated back to the anaesthetic breathing circuit via valve 11.

An analyser, for example a mass spectrometer 19 can be used to assess the composition of the gas mixture entering the nitrogen removal system 1b via sampling valve 8, and/or the purity of gas being vented to the atmosphere or sent back to the anaesthetic system 1a via
sampling valve 9, and/or the composition of the gas in
the anaesthetic circuit A via sampling valve 21.

Referring to Figure 2, there is provided a condensing
column generally indicated by the numeral 201 which may
be used as a second cooling means according to the second
embodiment of the present invention and as substantially
described with reference to Figure 3.

The condensing column 201 has a stainless steel
cylindrical body which is substantially filled with
hollow short cylinders of copper 202 (or other suitable
packing). A copper sleeve 203 is arranged around the
bottom of column 201 and has grooves therein to receive
copper cooling coil 204. A copper cartridge 206 is
provided for nichrome wire heating element 207.

A small stainless steel inverted cone 208 is attached to
the inlet gas pipe 209, the cone 208 having a foraminous
stainless steel panel 214. The inlet gas pipe 209 can be
positioned horizontally or at an angle to stop the
condensate from blocking the inlet. The cylinders 202 are
contained in column 201 by gas outlet funnel 210 and
liquid outlet funnel 211, each funnel having respective
foraminous panels 212 and 213.

The column 201 is separated into an upper part 201a and
lower part 201b which are separated by a Teflon (a
registered trade mark of Du Pont) or low temperature
resistant silicon rubber O-ring and held together by
bolted flange joint 215.

The flow of liquefied anaesthetic agent out of the column
is controlled by solenoid on-off valve 216.

In use, substantially dry gas containing anaesthetic
agent (for example Xe) enters column 201 via inlet 209.
The temperature of the column is maintained in the range -111°C to -109°C. The anaesthetic component of the gas (e.g. nitrous oxide or xenon) liquefies at this temperature and moves, under gravity, to the bottom of the column and exits via controlled solenoid valve 216. The gas flow, without anaesthetic component but containing N₂ gas, is directed towards gas outlet 217 and is vented to atmosphere.

The bottom part of the column 201b is inserted into the copper cartridge where the cooling coil 204 is positioned to provide good heat exchange contact. (An alternative design may include a hollow cylindrical copper cartridge made of two thin walled concentric copper tubes welded together, forming a jacket with a coolant passing in between, and the stainless steel column body is inserted into the inner tube).

After the anaesthetic agent has condensed on the bottom of the column, it is allowed out of the column 201 through the cryogenic solenoid operating valve 216.

Referring to Figure 3, there is provided a drying column 300, first freezing Unit 301, second cooling means 302 arranged in series in a gas flow circuit 303.

The gas mixture from the anaesthetic machine 304 (which typically contains anaesthetic agent such as Xe or N₂O, humidity ca 100%) at ambient temperature is fed by pump 305 at the desired volumetric rate, measured by digital flowmeter 306 through a drying column 300. The drying column 300 (working within the temperature range as described herein) removes about 85% of water vapour from the gas. The water vapour removed by drying column 300 is drained via solenoid on-off valve 308 arranged at the bottom of drying column 300.
After the flow of gas has passed through drying column 300 it is directed to freezing unit 301 which acts as a cooling means. The freezing unit 301 is arranged at a temperature in the range -101°C to -99°C (when the anaesthetic agent is xenon). A residual water vapour still present in the gas flow is therefore frozen out from the passing gas, together with volatile organics, N₂O and CO₂. The flow of gas enters the freezing unit 301 through heated vertical inlet 309 which is maintained at a temperature greater than about +1.5°C. Heat is applied to the stainless steel inlet pipe using a cylindrical copper cartridge with a nichrome wire heating element placed over the pipe. The upper part of the body of the freezing unit is separated from the bottom part by a few stainless steel rings interlaid with Teflon or silicon rubber O-rings, held together by bolt joints, in order to increase the temperature gradient along the freezing unit.

The flow of gas exits the freezing unit 301 via outlet pipe 310, and is directed towards cooling means 302 (the cooling means 302 being substantially as described herein before with reference to Figure 2). The gas enters cooling means 302 via stainless steel inlet 311.

Liquid anaesthetic agent (e.g. N₂O or xenon) exits cooling means 302 via solenoid on-off valve 216 which periodically opens for a short time. The liquid anaesthetic agent enters expansion chamber 312 which is positioned adjacent to column 302. The expansion chamber 312 permits the liquid anaesthetic agent to evaporate to gas. The expansion chamber 312 typically does not require additional heating means, as ambient temperature is sufficient to evaporate the liquid anaesthetic agent to gas. The expansion chamber also has the advantage of reducing pressure fluctuations in the system. The expansion chamber typically comprises a cylindrical
chamber (typically of stainless steel) with an inlet pipe 313 and an outlet pipe 314, both being arranged at the upper part of the chamber 312.

After the anaesthetic agent has been evaporated it is directed through 3-way valve 315 and either returned to anaesthetic machine 304 or directed to the anaesthetic agent collecting device 316 via gas analyser 317.
Claims

1. A method of removing nitrogen from a flow of gas (such as exhaled breath) which contains an anaesthetic agent in an anaesthesia breathing circuit, which method includes:

   a) cooling the gas in a first cooling means to a temperature substantially below the freezing point of carbon dioxide, so as to condense carbon dioxide and water vapour present in the gas;

   b) cooling the non-condensed gas from step (a) in a second cooling means to a temperature in a first temperature range which is substantially below the boiling point of an anaesthetic agent present in the gas but substantially above the boiling point of nitrogen, so as to provide a condensed material (which may be in liquid or solid form) comprising the anaesthetic agent;

   c) venting non-condensed gas from step (b); and

   d) permitting the condensed material from step (b) to increase to above a second temperature which is substantially above the boiling point of the anaesthetic agent so as to permit the anaesthetic agent to become gaseous.

2. A method according to Claim 1, wherein the anaesthetic agent includes nitrous oxide or xenon.

3. A method according to Claim 1 or 2, wherein a substantial amount of water vapour is removed from the flow of gas prior to the gas entering
the first condensing means.

4. A method according to Claim 3, wherein the substantial amount of water vapour is removed by permitting the gas to flow through a drying column which typically comprises small hollow stainless steel rings; and/or wherein the substantial amount of water vapour is removed by use of a dehumidifier or water vapour absorber filled with a desiccating agent.

5. A method according to any preceding claim, wherein the water vapour and carbon dioxide present in the flow of gas are condensed from the gas flow in step (a) typically as a solid.

6. A method according to any preceding claim, wherein volatile anaesthetic vapours are also condensed in step (a).

7. A method according to Claim 6, wherein the volatile anaesthetic vapours include Enflurane (CHFClCF₂H; Bpt + 56.5°C), Halothane (CF₃CBrClH; Bpt +50.2°C), Isoflurane (CF₃CHClOCF₂H; Bpt +48.5°C), Desflurane (Bpt +23.5°C), or Sevoflurane (Bpt +58.6°C).

8. A method according to any preceding claim, wherein the condensed material in step (a) is removed by allowing the condensate to heat up to room temperature at the end of the anaesthetic procedure and venting the resulting gas/vapour by flushing with air/oxygen.

9. A method according to any preceding claim, wherein gaseous anaesthetic agent resulting from step (d) remains in the breathing circuit for subsequent inhalation by the patient.
10. A method according to Claim 9, wherein the gaseous anaesthetic agent resulting in step (d) is reused in the patient from which it was extracted and not stored in an additional vessel.

11. A method according to any preceding claim wherein the non-condensed gas (in step (c)) typically includes nitrogen, oxygen and argon.

12. A method according to any preceding claim, which includes an initial step prior to step (a), whereby the initial step includes removing carbon dioxide present in the gas.

13. A method according to claim 12, wherein the carbon dioxide is removed using a carbon dioxide scrubbing material, such as a soda lime.

14. A method according to claim 12 or 13, wherein the initial step includes directing a proportion of the gas to the nitrogen removing circuit from an anaesthetic breathing circuit at a point just beyond the carbon dioxide absorber of the anaesthesia circuit.

15. A method according to any of claims 1 to 14, wherein the first temperature range is substantially below the freezing point of the anaesthetic agent but substantially above the boiling point of nitrogen such that the condensed material in step (b) is in solid form.

16. A method according to claim 15, wherein the temperature of the condensed material from step (b) (which typically comprises the anaesthetic agent) is increased to a second temperature substantially above the boiling point of the anaesthetic agent in the
second cooling means.

17. A method according to claim 15 or 16, wherein the second cooling means is capable of fluctuating between the first temperature range and the second temperature which is substantially above the boiling point of the anaesthetic agent.

18. A method according to any of claims 15 to 17, wherein the first temperature range is from about -91°C (when the anaesthetic agent is nitrous oxide) to about -205°C; or the first temperature range may be from about -112°C (when the anaesthetic agent is xenon) to about -205°C.

19. A method according to any of claims 15 to 18, which includes a further step whereby the temperature of the first cooling means is increased to a temperature substantially above 0°C when the temperature of the second cooling means is increased to the second temperature.

20. A method according to any of claims 1 to 14, wherein the first temperature range is substantially below the boiling point of the anaesthetic agent and above the freezing point of the anaesthetic agent so that the condensed material is in liquid form.

21. A method according to claim 20, wherein the liquefied material including the anaesthetic agent is permitted to exit the second vessel (typically under gravity), so as to permit the anaesthetic agent to become gaseous.

22. A method according to claims 20 or 21, wherein the signified material enters an expansion vessel (preferably arranged substantially adjacent to the
second cooling means) where the liquefied material is permitted to expand, preferably with the application of heat.

23. A method according to any of claims 20 to 22, wherein second temperature above the boiling point of the anaesthetic agent in step (d) is greater than -88°C (when the anaesthetic agent is nitrous oxide); or the second temperature is greater than -108°C (when the anaesthetic agent is xenon)

24. Apparatus for removal of nitrogen from a flow of gas (such as exhaled breath) which includes:

a gas flow circuit;

first cooling means positioned in the gas flow circuit, the first cooling means being suitable for cooling to a temperature substantially below the freezing point of carbon dioxide so as to condense carbon dioxide, water vapour and volatile anaesthetic vapours present in the gas;

second cooling means positioned in the gas flow circuit, the second cooling means being arranged to be cooled to a temperature which is substantially below the boiling point of the anaesthetic agent so as to condense anaesthetic agent gases from the flow of gas, to a solid or liquid form.

25. Apparatus according to claim 24 which includes drying means for removing a substantial amount of water vapour in the flow of gas, typically arranged prior to the first condensing means.

26. Apparatus according to claim 25, wherein the drying
means includes a drying column arranged at 0.5°C to 5.0°C; or the drying means may include a dehumidifier or water vapour absorber

27. Apparatus according to any of claims 24 to 26, which includes a flowmeter, such as a digital flowmeter, so as to control the flow of gas through the apparatus, prior to or after (which is preferred) drying means

28. Apparatus according to any of claims 24 to 27, wherein the first cooling means and/or the second cooling means are electrically powered refrigeration units

29. Apparatus according to any of claims 24 to 28, wherein the first cooling means and the second cooling means are preferably arranged in series.

30. Apparatus according to any of claims 24 to 29, wherein the first cooling means and the second cooling means have respective cooling chambers.

31. Apparatus according to any of claims 24 to 30, which includes an oxygen monitor and/or means for monitoring anaesthetic agent present in the flow of gas

32. Apparatus according to any of claims 24 to 31, which is substantially at or about atmospheric pressure.

33. Apparatus according to any of claims 24 to 32 wherein the first cooling means comprises at least two cylinders (typically of stainless steel) which are separated by one or more O-rings (which may be rectangular in section), preferably manufactured from low temperature resistant silicon rubber or polytetrafluoroethylene (PTFE).

34. Apparatus according to any of claims 24 to 33, wherein
the first cooling means is preceded by a heating element which permits a high temperature gradient along the length of the first cooling means substantially without the risk of blocking the gas entrance into the first cooling means.

35. Apparatus according to any of claims 24 to 34, which the second cooling means is arranged to fluctuate between a temperature in a first temperature range which is substantially below the freezing point of the anaesthetic agent present in the gas, but substantially above the boiling point of nitrogen, and a second temperature which is substantially above the freezing point (preferably above the boiling point) of the anaesthetic agent.

36. Apparatus according to claim 35, wherein the first temperature range of the second cooling means is from about -91°C (when the anaesthetic agent is nitrous oxide) to about -205°C; or first temperature range of the second cooling means may be from about -112°C (when the anaesthetic agent is xenon) to about -205°C.

37. Apparatus according to claim 35 or 36, wherein second temperature is preferably greater than -88°C (when the anaesthetic agent is nitrous oxide; or the second temperature is preferably greater than -108°C (when the anaesthetic agent is xenon).

38. Apparatus according to any of claims 24 to 33, wherein the second cooling means is arranged to attain a temperature which is substantially below the boiling point of the anaesthetic agent but above the freezing point of the anaesthetic agent, so as to condense the anaesthetic agent to a liquid.

39. Apparatus according to claim 38, which includes an
expansion chamber (typically in communication with the second cooling means)

40. Apparatus according to claim 39, wherein the expansion chamber is arranged such that liquid condensed in the second cooling means is permitted to flow into the expansion chamber (typically under gravity).

41. Apparatus according to claim 39 or 40, wherein the expansion chamber includes heating means so as to assist in the evaporation of the liquid.

42. Apparatus according to any of claims 24 to 41, which is substantially at atmospheric pressure.

43. Apparatus according to any of claims 24 to 42, wherein the second cooling means comprises a hollow stainless steel cylinder substantially filled with copper rings or the like.

44. Apparatus for the continuous recovery of anaesthetic agent from a flow of gas, the apparatus includes: a gas flow circuit; first cooling means positioned in the gas flow circuit, the first cooling means being suitable to cool to a temperature substantially below the freezing point of carbon dioxide; second cooling means positioned in the gas flow circuit, the second cooling means being arranged to be cooled to a second temperature which is substantially below the boiling point of the anaesthetic agent and substantially above the freezing point of the anaesthetic agent so as to liquify the anaesthetic agent; an expansion chamber arranged to receive liquid anaesthetic agent.
## INTERNATIONAL SEARCH REPORT

### A. CLASSIFICATION OF SUBJECT MATTER

| IPC | A61M16/10 | A61M16/00 |

According to International Patent Classification (IPC) or to both national classification and IPC

### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

| IPC | A61M |

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and where practical search terms used)

EPO-Internal

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>WO 02/26355 A (ATobe HITOSHI; FURUSE YOSHIO (JP); CHAEN SHIGEHIRO (JP); Hotta MAS) 4 April 2002 (2002-04-04)</td>
<td>24, 27, 29-32, 35-39, 42, 44</td>
</tr>
<tr>
<td>A</td>
<td>page 31, line 25 -page 32, line 11 page 30, line 13 - line 16</td>
<td>25, 26, 28</td>
</tr>
<tr>
<td>X</td>
<td>US 3 807 396 A (FISCHEL H) 30 April 1974 (1974-04-30) column 7, line 34 -column 10, line 4</td>
<td>24-26, 29, 30, 35-37, 39-41</td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of box C.

### Patent family members are listed in annex.

**Note:**
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation of other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

Date of the actual completion of the international search: 4 May 2004

Date of mailing of the international search report: 12/05/2004

Name and mailing address of the ISA
European Patent Office, P.B. 5818 Patentaana 2 NL - 2280 HV Rijswijk Tel. (+31-70) 940-2040, Tx. 31 651 epo nl, Fax (+31-70) 940-3016

Authorized officer

Kroeders, M

Form PCT/ISA/210 (second sheet) January 2004
<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
</table>
| A        | US 6 134 914 A (HAMM REINER ET AL)  
24 October 2000 (2000-10-24)  
column 2, line 59 -column 6, line 28 | 24-26,  
29-31,  
33,  
35-41, 44 |
| X,P      | US 2003/029449 A1 (BERRY JAMES M)  
13 February 2003 (2003-02-13) | 24,29,  
30,32,  
35-38, 42 |
| A        | page 1, paragraph 14 -page 2, paragraph 16; figure 1 | 27,31,  
39-41, 44 |
**Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. **X** Claims Nos.: 1-23
   
   because they relate to subject matter not required to be searched by this Authority, namely:
   
   Rule 39.1(iv) PCT - Method for treatment of the human or animal body by therapy

2. 
   
   because they relate to parts of the international Application that do not comply with the prescribed requirements to such an extent that no meaningful international Search can be carried out, specifically:

3. 
   
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

1. 
   
   As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. 
   
   As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. 
   
   As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. 
   
   No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

- The additional search fees were accompanied by the applicant's protest.
- No protest accompanied the payment of additional search fees.
<table>
<thead>
<tr>
<th>Patent document</th>
<th>Publication date</th>
<th>Patent family member(s)</th>
<th>Publication date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AU 9227101 A</td>
<td>08-04-2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CA 2423367 A1</td>
<td>04-04-2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CN 1462206 T</td>
<td>17-12-2003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EP 1322400 A2</td>
<td>02-07-2003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WO 0226535 A2</td>
<td>04-04-2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TW 553760 B</td>
<td>21-09-2003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 2003185735 A1</td>
<td>02-10-2003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FR 2718034 A1</td>
<td>06-10-1995</td>
</tr>
<tr>
<td>US 3807396 A</td>
<td>30-04-1974</td>
<td>BE 719965 A</td>
<td>26-02-1969</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CH 481655 A</td>
<td>30-11-1969</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CH 509555 A</td>
<td>30-06-1971</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 1708061 A1</td>
<td>03-06-1971</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FR 1559745 A</td>
<td>28-02-1969</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GB 1235541 A</td>
<td>16-06-1971</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GB 1235542 A</td>
<td>16-06-1971</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AT 202001 T</td>
<td>15-06-2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 59703812 D1</td>
<td>19-07-2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WO 9808583 A1</td>
<td>05-03-1998</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IN 187635 A1</td>
<td>01-06-2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 2001504386 T</td>
<td>03-04-2001</td>
</tr>
</tbody>
</table>