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**A5T** TDP
**B1R** RAJB

(56) Documents Cited:
**FR 002524809 A** **SU 000614990 A**
**US 4350662 A** **US 4029483 A**

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UK CL (Edition X ) **A5T, B1R**
INT CL$^7$ **A62B, B63C**
Other: **EPODOC, WPI**

(54) Abstract Title**: Cardon dioxide gas scrubber**

(57) The invention provides a carbon dioxide gas scrubber 19 of the type in which exhaled gas is passed through a body of re-agent material 39 for removal of at least a proportion of the carbon dioxide content from the exhaled gas prior to or following the introduction of a determined quantity of oxygen or a mixture of oxygen and other gases to the re-circulating gas and presentation of the gas for re-breathing. The gas scrubber 19 is characterised by having a means for transferring heat (not shown) from the re-conditioned gas after it has passed through the re-agent material 39 to the exhaled gas prior to it passing through the said re-agent material. Preferably a heat exchanger (not shown) is provided for performing this function.

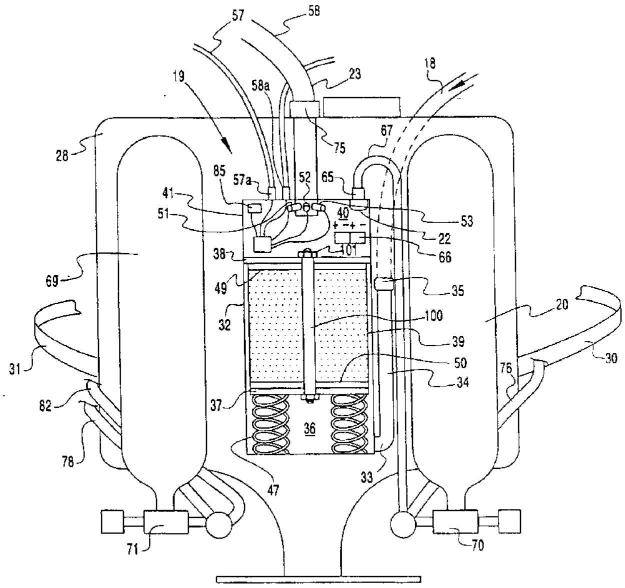


FIG 2

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 1995

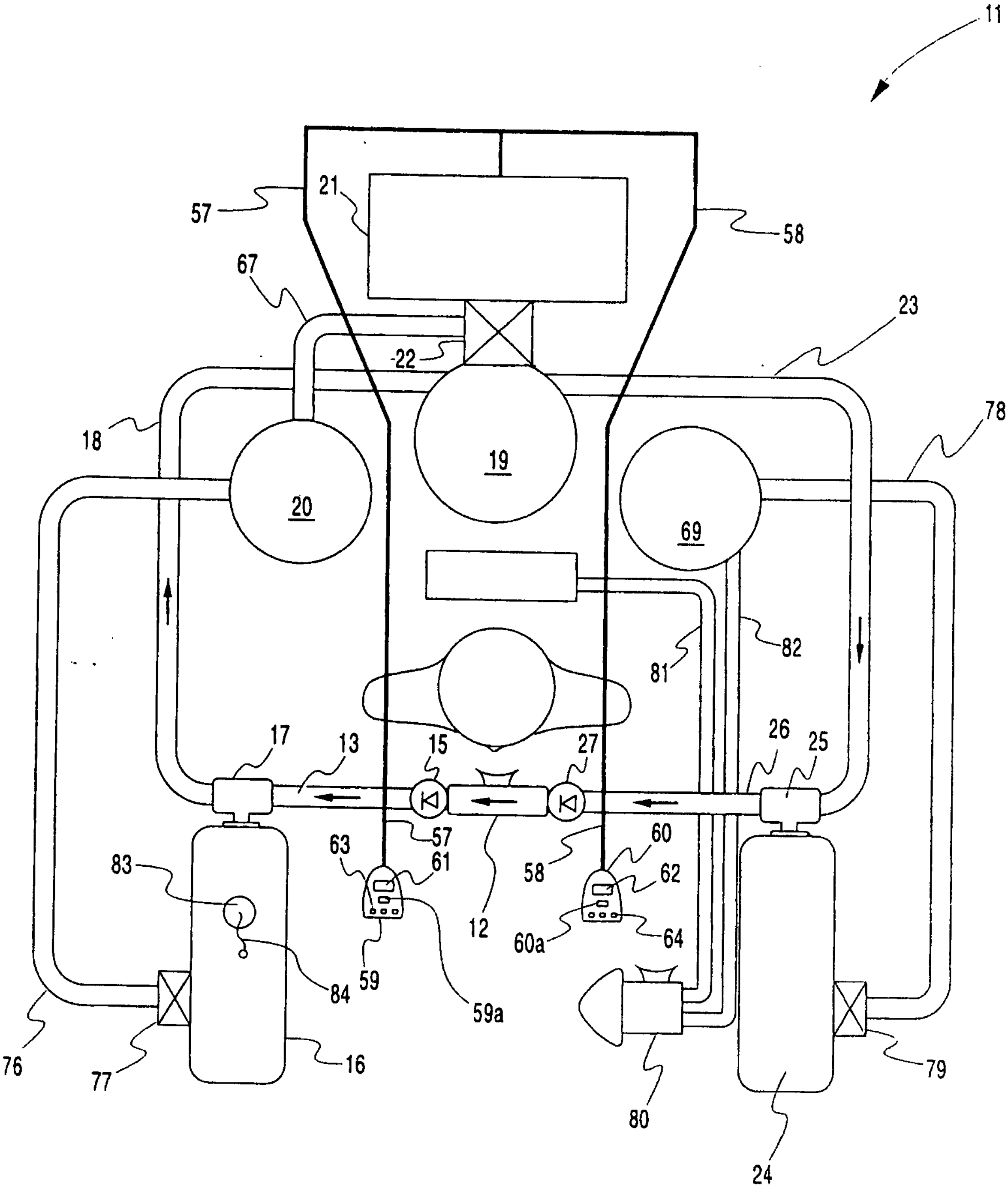
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FIG 1

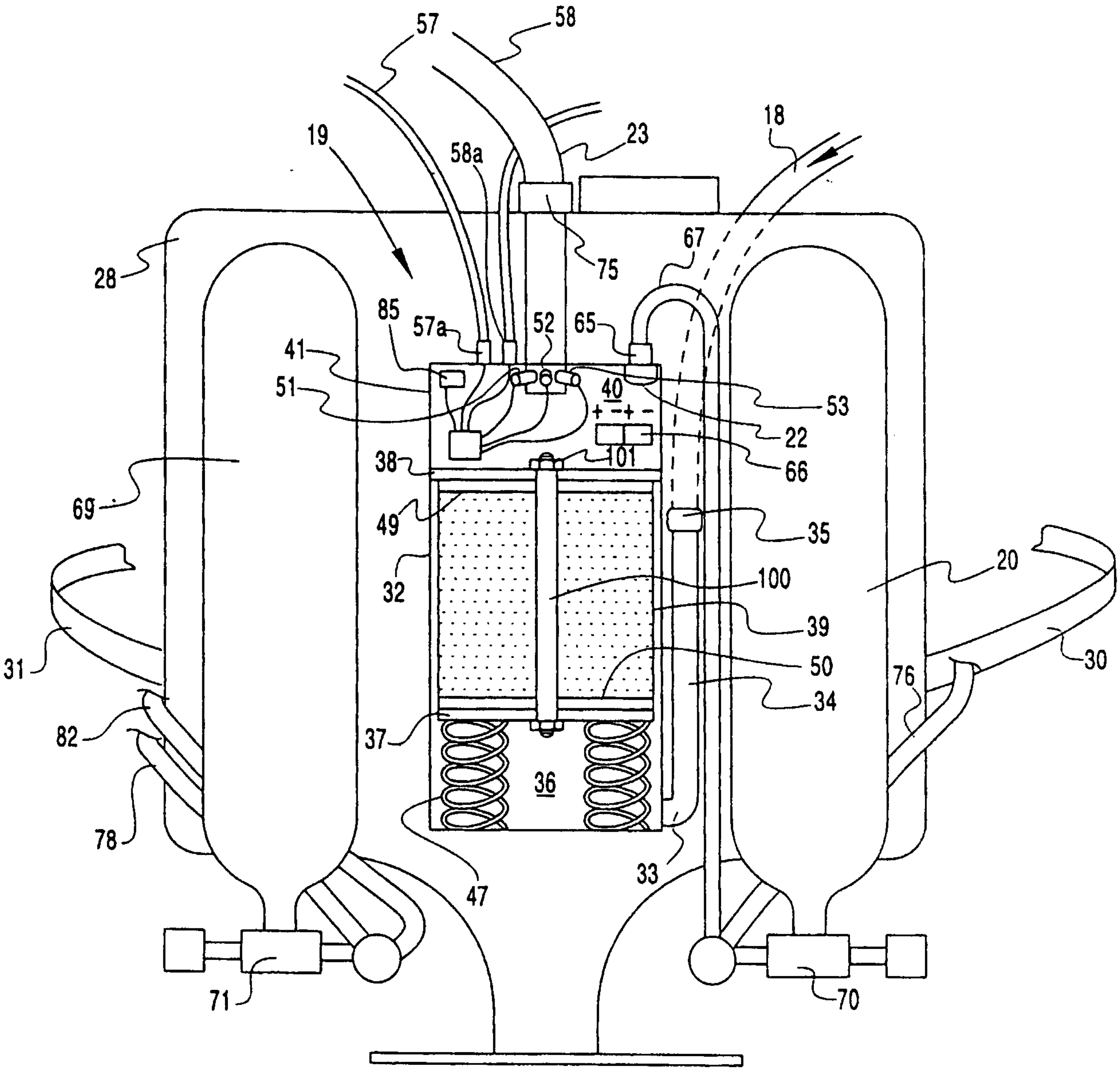
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FIG 2

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# CARBON DIOXIDE GAS SCRUBBER

The present invention relates to carbon dioxide gas scrubbers and in particular concerns a carbon dioxide scrubber for breathing apparatus such as may be used for underwater diving or in other hostile environments in which a user may need a supply of breathable gas. Such uses include fire fighting where the atmosphere may be heavily polluted with combustion products and noxious gases, other industrial environments where the atmosphere may be polluted or otherwise unbreathable, or at high altitude where the atmosphere itself is too thin or effectively non-existent. The term re-circulating gas self-contained breathing apparatus used herein refers to both closed circuit and semi-closed circuit re-breathers and any other type of re-breathing apparatus in which at least a portion of the exhaled gas is recirculated.

Although applicable to a wide range of other uses the present invention will be described hereinafter with particular reference to its application to underwater breathing apparatus for diving applications. It will be understood, however, that this description is provided without prejudice to the generality of the invention or its range of applications.

It is well known to provide divers with self-contained underwater breathing apparatus in order to prolong the time for which they can remain below the surface of the water. The most widely used self-contained breathing apparatus comprises a rigid container within which is housed a supply of compressed air which is allowed out of the container via a high pressure or first stage regulator and directed through a flexible hose to a mouthpiece containing a demand valve including a second stage regulator which acts automatically to open and close as the diver inhales and exhales. Such systems are known as open-circuit breathing apparatus because exhaled gas is allowed to pass directly out into the marine environment so that a stream of bubbles is emitted upon each exhalation. If the compressed gas breathed from the gas container is air a large proportion of the exhaled gas will constitute nitrogen which is present in air in an approximate ratio of 4:1 with oxygen as is well known. In other words 80% of the air which is breathed by the diver, and therefore 80% of the content of the compressed air container, or air bottle, comprises little more than a vehicle for the oxygen some of which is converted to carbon dioxide during its residence in the lung. Thus 80% of the breathed gas is not really needed by the body except to dilute the oxygen. It is not possible to breathe pure oxygen below 10 m since at higher pressures oxygen is toxic.

Proposals have in the past been made for so-called closed circuit or "re-breather" apparatus in which the carbon dioxide content of exhaled air is removed from the exhaled air outside the body, fresh oxygen is introduced to replace that consumed, and the thus-reconditioned air returns to the diver for re-breathing. In this way it is necessary for the rebreather to have only sufficient nitrogen within the breathing circuit to allow circulation, for example, only two or three lungfuls of nitrogen sufficient to circulate around the closed circuit. Such a system is described, for example, in US Patent 4 964 404 to William C Stone and in US Patent 3 556 098 to

John W Kanwisher and Walter A Starck II. These Patentees were not the first to devise closed circuit re-breather apparatus, however, it being known that so-called "frogmen" used re-breather apparatus during World War 2 in order to avoid the tell-tale bubbles rising to the surface upon exhalation in an open-circuit system such as the traditional compressed air bottle arrangement described above. US Patent 4 964 404 describes an improved such mixed gas breathing apparatus in which a container for exhaled gas (the so-called counterlung) is formed in two parts, a first part communicating with a hose leading from a mouthpiece to a carbon dioxide removal filter, and a second part in the line between the carbon dioxide removal filter and the mouthpiece. The carbon dioxide removal filter in the system described in US 3 556 098 includes a chamber housing oxygen partial pressure sensors used to detect the oxygen content in the exhaled gas and to reinstate the oxygen balance by introducing oxygen through a valve controlled indirectly by the sensors.

In self-contained underwater breathing apparatus the carbon dioxide removal filter comprises a filter bed of re-agent material housed within a container within the recirculating circuit to safely remove exhaled carbon dioxide. In normal operation the re-agent material prevents the exhaled carbon dioxide passing through the filter and back to the user's lungs. However when the re-agent material becomes exhausted so-called "breakthrough" occurs and carbon dioxide passes through the filter and if the user continues to breathe through the breathing apparatus the carbon dioxide concentration will increase until it reaches toxic levels. European patent application

EP-A-1,316,331 discloses one way of monitoring the remaining absorption capacity of the reagent material by monitoring the temperature of the material at various locations in the material in the gas flow direction.

Although the apparatus disclosed in EP-A-1,316,331 is effective for determining the remaining absorption capacity it does not provide a solution to another problem encountered with breathing apparatus of the aforementioned type, namely the degradation of expected scrubber life with depth. It is well know that the maximum expected duration, or life, of a carbon dioxide gas scrubber is determined by dive depth. In one particular example a carbon dioxide gas scrubber which has a life of 180 minutes at a depth of 20 meters in water temperatures of 4 degrees C has been shown to have a reduced life expectancy of 80 minutes when operated at a depth of 100 meters. This degradation in performance is found in all self-contained re-breathing devices in use today. There is a requirement therefore for an improved carbon dioxide gas scrubber for self-contained breathing apparatus which has improved performance characteristics at depth, particularly in terms of expected life, desirably comparable to expected life at moderate depths.

According to an aspect of the invention there is provided a carbon dioxide gas scrubber of the type in which exhaled gas is passed through a body of re-agent material for removal of at least a proportion of the carbon dioxide content from the exhaled gas prior to or following the introduction of a determined quantity of oxygen or a mixture of oxygen and other gases to the re-circulating gas and presentation of the gas for re-breathing; characterised in that the said device comprises a means for heating the exhaled gas prior to it passing through the said re-agent material.

According to an aspect of the invention there is provided a carbon dioxide gas scrubber of the type in which exhaled gas is passed through a body of re-agent material for removal of at least a proportion of the carbon dioxide content from the exhaled gas prior to or following the introduction of a determined quantity of oxygen or a mixture of oxygen and other gases to the re-circulating gas and presentation of the gas for re-breathing; characterised in that the said device comprises a means for transferring heat from the re-conditioned gas after it has passed through the re-agent material to the exhaled gas prior to it passing through the said re-agent material.

The carbon dioxide scrubber according to the present invention pre-heats the incoming gas using heat from the outgoing re-conditioned gas so that the re-agent material is not continually cooled to the extent it would otherwise be if heating of the incoming gas did not occur. The effect of this pre-heating is significant and can noticeably improve the absorption capacity of the re-agent material, particularly at diving depths of 20 metres or more and significantly at diving depths of 100 meters or so leading to improved scrubber duration times during deep dives. Test have shown that the temperature of the re-agent material can be a significant factor in terms of the maximum duration, or expected life, of the scrubber and can be even more significant than the work rate of the diver. In known breathing apparatus cooling of the reagent material increases with depth not only because the ambient water temperature reduces with depth but mainly because the increase in pressure results in a greater number of gas molecules in the breathing circuit per unit volume which increases the cooling of the re-agent material by the exhaled gas. Indeed at a depth of 100 metres there are eleven times the number of gas molecules per unit volume than at atmospheric pressure on the surface. Pre-heating the incoming gas increases the life of the scrubber in cold water environments. The efficiency of a carbon dioxide gas scrubber is measured in terms of the percentage of Calcium Hydroxide that converts to Calcium Carbonate. The inventor has found that known types of $CO_2$ scrubber are only about 50% efficient in cold water compared with 80% efficiency or more for a scrubber of the present invention.

Heating the incoming gas using heat from the outgoing gas is particularly efficient. In known breathing apparatus as the reconditioned gas exits the gas scrubber it flows through a hose to a counter-lung type breathing bag and then through another hose before being breathed in by the diver through an attached mouthpiece. The gas in the scrubber is hot, typically about 35 degrees C and it is essential to cool it before it is breathed in. The gas is heated again when it is in the diver's lungs but it has been found that on entering the scrubber the exhaled gas is only a few degrees C above ambient temperature. On the one hand therefore it is essential to cool the outgoing gas and on the other, and as the inventor has found, it is desirable to pre-heat the incoming exhaled gas. This can be readily achieved in the present invention by the transfer of heat from the hot outgoing reconditioned gas to the cooler incoming gas. This is particularly advantageous because the heat generated by the exothermic reaction is recycled to heat the incoming gas. The efficiency of the gas scrubber can therefore be improved without requiring an independent power source for heating the incoming gas.

In a preferred embodiment of the invention the means for transferring heat comprises a heat exchanger. This provides a particularly efficient means for recovering heat from the outgoing gas to the incoming gas that is both simple and compact and therefore suitable for use in a carbon dioxide scrubber, particularly in a breathing apparatus of the aforementioned type.

Preferably, the heat exchanger is located adjacent to the re-agent material. This readily provides for a simple and efficient scrubber since connecting ducts, hoses or other pipe-work can be minimised.

In one embodiment the heat exchanger may comprise a cross-flow heat exchanger, alternatively a contra-flow heat exchanger may be used. Heat transfer is more efficiently achieved with contra-flow or cross-flow types of heat exchanger and both types provide for different scrubber configurations.

In preferred embodiments, the reagent material is housed within a canister and the heat exchanger is integral with or located adjacent to the canister for receiving both the exhaled gas and the reconditioned gas. This readily provides for an integrated scrubber design wherein the heat exchanger is part of or integrated with the canister which contains, inter alia, a removable cartridge of re-agent material.

According to another aspect of the present invention there is provided a method of heating the incoming gas entering a carbon dioxide gas scrubber device of the type in which exhaled gas is passed through a body of re-agent material for removal of at least a proportion of the carbon dioxide content from the exhaled gas prior to or following the introduction of a determined quantity of oxygen or a mixture of oxygen and other gases to the re-circulating gas and presentation of the gas for re-breathing; the said method comprising the steps of: directing both the exhaled incoming gas entering the device and the outgoing re-condition gas exiting the device through a heat transfer means to transfer heat from the outgoing reconditioned gas to the incoming exhaled gas.

An embodiment of the present invention will now be more particularly described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram illustrating a circuit for a self-contained re-breather formed as a first embodiment of the present invention;

Figure 2 is a schematic view from the rear of an embodiment of the invention illustrating the arrangement of the component parts.

Referring first to Figure 1, self-contained re-breather apparatus generally indicated with the reference numeral 11 comprises a closed circuit leading from a mouthpiece 12 along an air hose 13 within which is a unidirectional valve indicated schematically

15 and connected to an exhaled-gas counterlung 16 by a T-coupling 17.

From the T-coupling 17 of the exhaled gas counterlung 16, which in use contains oxygen-depleted exhaled gas, extends a connector hose 18 leading to a gas reconditioning unit 19 which will be described in more detail in relation to Figures 2 et seq. In the gas reconditioning unit 19 carbon dioxide in the exhaled gas is removed and oxygen from a reservoir 20 is introduced (under the control of a control system) via a solenoid valve 22. The reconditioned gas is drawn from the unit 19 via an air hose 23 and delivered to a second counterlung 24 in the form of a flexible sac joined to the hose 23 by another T-coupling 25 which, like the T-coupling 17 is swivelable to allow free movement of the air hose during use and for ease of assembly. From the T-coupling 25 a breathing hose 26 leads to the mouthpiece 12 via a further unidirectional valve 27 shown schematically in Figure 1. A reservoir 69 of diluent gas is directly connected to a control valve 79 on the counterlung 24.

Referring to Figure 2, the exhaled air treatment apparatus generally indicated 19 comprises an upright cylindrical container 32 having an inner cartridge 39, which will be described in more detail below, a lower inlet port 33 with a rigid inlet duct 34 extending parallel to the axis of the container 32 and having a releasable coupling 35 for connection to the air hose 18 leading from the T-coupling 17. Within the container 32, as illustrated in the schematic sectional view of Figure 2, there is a lower chamber 36 into which the port 33 opens and which houses the inner cartridge 39.

At each end of the cartridge 39 there is a "spider" 37, 38 which supports respective non-woven gas-permeable, water impermeable filters 49, 50. The cartridge 39 contains a granular material, such as soda lime, which absorbs carbon dioxide. The composition of Sofnolime (TM), a commercially available soda lime, comprises:

| | |
|---|---|
| Ca $(OH)_2$ | 70-80% |
| Na (OH) | 4-5% |
| $H_2O$ | 17% |

The lower chamber 36 houses a heat exchanger (not shown) which is connected to the inlet duct 34 at the port 33 so that the exhaled gas entering the chamber 36 first pass through the heat exchanger where the gas is pre-heated before passing through the reagent material in the inner cartridge 39. The heat exchanger is further connected to the upper chamber 40 of the canister 32 for receiving the re-conditioned gas after it has passed through the re-agent material. The exhaled gases are pre-heated in the heat exchanger by heat transfer from the re-conditioned gases, which are typically at about 35 degrees C. The exact construction of the heat exchanger is not shown in the drawing of Figure 2 but it will be readily apparent to the skilled person in the art that this may be constructed in such a way that the reconditioned gas, or a part thereof, may be diverted through the heat exchanger before exiting the reconditioning unit,or gas scrubber, 19 through the connector 75 to the hose 23 leading back to the oxygen enriching counter-lung 24.

In another embodiment (not shown) the inlet duct 34 is repositioned such that it is connected to an additional port in the cover 41. The incoming gas flows through this port into a heat exchanger duct, for example a copper pipe, which extends through the upper chamber 40 towards the cartridge of re-agent material. The heat exchanger duct is continuous with or connects to a tube of a generally heat non-conductive material, for example a non-conductive plastic, which passes through the re-agent material and into the chamber 36.

Heat from the outgoing reconditioned gas in the upper chamber 40 is transferred to the incoming gas through the copper tube. The incoming gas retains this heat as it passes through the duct or pipe, in the re-agent material and exits into the lower chamber 36. It is important that the duct passing through the re-agent material insulates the incoming air from the heat contained within the re-agent material in order to minimise heat losses. For example, if the copper heat exchanger duct continued through the re-agent material there would be heating of the incoming gases but cooling of the re-agent material which of course would give no overall improvement in efficiency, in fact losses would occur and there would be a slight detrimental effect on efficiency.

In a further embodiment the down tube 34 on the outside of the canister is insulated and heat from the reconditioned gases in the upper chamber 40 is transferred to the incoming gas in the downtube via heat pipes. Heat pipes are a particularly efficient means of transferring heat and embodiments having distilled water as the heat transfer medium are particularly suitable for use in an embodiment of this type since they fail safe, that is to say if they were to split open in use they would not release anything other than water into the breathing circuit.

Although the embodiment shown in the accompanying drawings refer to a breathing apparatus in which carbon dioxide is removed from the gas prior to injection of a determined quantity of oxygen, embodiments are envisaged in which carbon dioxide is removed from the gas following injection of oxygen or a mixture of oxygen and other gas(es). In other embodiments, the breathing apparatus can be a so-called "semi-closed circuit" rebreather apparatus where the injected gas is one that is suitable for direct breathing at a determined depth. For example, for a 20m dive an appropriate gas is 50% oxygen, 50% nitrogen, for a 40m dive depth an appropriate gas is 28% oxygen, 62% nitrogen. For depths greater than 40m a mixture of oxygen, nitrogen and helium is appropriate. In a semi-closed rebreather apparatus the different gasses are mixed directly with oxygen prior to diving, independently of the rebreather apparatus, so that separate reservoirs 20 and 69 are not required.

Although aspects of the invention have been described with reference to the embodiments shown in the accompanying drawings it is to be understood that the invention is not limited to those precise embodiments and various changes and modifications may be effected without exercise of further inventive skill and effort, for example the heat exchanger may be located elsewhere on or in the reconditioning unit 19 or elsewhere on the breathing apparatus.

## CLAIMS

1. A carbon dioxide gas scrubber of the type in which exhaled gas is passed through a body of re-agent material for removal of at least a proportion of the carbon dioxide content from the exhaled gas prior to or following the introduction of a determined quantity of oxygen or a mixture of oxygen and other gases to the re-circulating gas and presentation of the gas for re-breathing; characterised in that the said device comprises a means for heating the exhaled gas prior to it passing through the said re-agent material.

2. A gas scrubber device as claimed in Claim 1, wherein the said means for heating comprises a means for transferring heat from the re-conditioned gas after it has passed through the re-agent material to the exhaled gas prior to it passing through the said re-agent material.

3. A gas scrubber device as claimed in Claim 1 or Claim 2 wherein the means for transferring heat comprises a heat exchanger.

4. A gas scrubber device as claimed in Claim 3 wherein the said heat exchanger is located adjacent to the re-agent material.

5. A gas scrubber device as claimed in Claim 4 wherein the heat exchanger comprises a cross-flow or contra-flow heat exchanger.

6. A gas scrubber device as claimed in any of Claims 3 to 5 wherein the reagent material is housed within a canister and the said heat exchanger is integral with or located adjacent to the said canister for receiving both the exhaled gas and the reconditioned gas.

7. A gas scrubber device as claimed in any preceding claim wherein the means for transferring heat comprises at least one duct of thermally conductive material which extends through an outlet gas chamber which, in use, receives the reconditioned gas and wherein the said duct is connected to or is continuous with a second duct of a thermally insulating material which extends through the said re-agent material.

8. A gas scrubber device as claimed in any preceding claim wherein the said means for transferring heat comprises at least one heat pipe.

9. A method of heating the incoming gas entering a carbon dioxide gas scrubber device of the type in which exhaled gas is passed through a body of re-agent material for removal of at least a proportion of the carbon dioxide content from the exhaled gas prior to or following the introduction of a determined quantity of oxygen or a mixture of oxygen and other gases to the re-circulating gas and presentation of the gas for re-breathing; the said method comprising the steps of: directing both the exhaled incoming gas entering the device and the outgoing re-condition gas exiting the device through a heat transfer means to transfer heat from the outgoing reconditioned gas to

the incoming exhaled gas.

10. A self-contained breathing apparatus comprising a carbon dioxide scrubber as claimed in any preceding claim.

11. A carbon dioxide gas scrubber device substantially as hereinbefore described with reference to the accompanying drawings.

12. A method substantially as hereinbefore described with reference to the accompanying drawings.

The Patent Office

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**Application No:** GB0513746.8

**Claims searched:** 1-12

**Examiner:** Dr Matthew Parker

**Date of search:** 6 October 2005

## Patents Act 1977: Search Report under Section 17

**Documents considered to be relevant:**

| Category | Relevant to claims | Identity of document and passage or figure of particular relevance |
|---|---|---|
| X | 1,3,4,6,8 | US4029483 A (LONG), see page 3 lines 44-47 |
| X | 1,3,4,6,8 | SU614990 A (ALEKSEEV), see abstract |
| X | 1,3,4,6,8 | US4350662 A (DOWGUL), see claim 1 |
| A | 1 | FR2524809 A (LEMASSON), see abstract |

Categories:

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|---|---|---|---|
| X | Document indicating lack of novelty or inventive step | A | Document indicating technological background and/or state of the art. |
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| & | Member of the same patent family | E | Patent document published on or after, but with priority date earlier than, the filing date of this application. |

**Field of Search:**

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC$^{X}$ :

A5T; B1R

Worldwide search of patent documents classified in the following areas of the IPC$^{07}$

A62B; B63C

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI