

REVIEW

The CO₂ Absorber Based on LiOH

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Carbon dioxide absorbers have been used in anesthesiology for many years. However, this process is not limited to this field of medicine. Removing carbon dioxide from human environment is used in other areas as well: mining industry, submarines, scuba diving, space travel and many others. The rationale to remove carbon dioxide from confined spaces is that cannot be eliminated otherwise. Anesthesia practitioners are well aware of this component of the circle system, the carbon dioxide absorber. In daily practice the clinician is less concerned with what kind of substance fills the dedicated canister, as this is usually in the care of the maintenance personnel. The appearance of Sevoflurane and Desflurane, with their own chemical characteristics, prompted the clinician to dedicate new attention to these absorbents. The classical substances used for this purpose are different combinations of limes. The practical concern of the anesthesiologist is to notice when the absorbent is consumed and call for its replacement. Still, many other aspects remain: compound A formation with Sevoflurane, carbon monoxide formation with Desflurane and dry absorbent for instance. The latest member of these products in the medical field is the LiOH carbon dioxide absorbent. Although used for many years in the space exploration, its way into the operating room is a rather recent achievement. Special-chemical properties and high absorptive capacity make this new type of absorbent an attractive option for modern anesthesia practice. The article below invites the reader through a short journey on the history of the CO₂ absorbents and anesthesia circuits, Lithium as a chemical element and, finally, to this new type of absorbent.

Keywords: carbon dioxide absorbent, anesthesia circle system, lithium, traditional and proprietary absorbents, absorptive capacity, Apollo 13 story, recycling

Received: 25 December 2014 / Accepted: 15 January 2015

Short history of the carbon dioxide absorbents in anesthesia

The history of carbon dioxide removal from the gases returning to the patient goes back many years. As early as 1850 John Snow (1813-1858) recognized that ether and chloroform were exhaled unchanged with the expired air (1). He built a “to-and fro” rebreathing system in which the carbon dioxide was absorbed by an aqueous solution of caustic potash.

Alfred Coleman (1828-1902) was the first to use a to-and-fro system with carbon dioxide absorption in clinical practice. It was absorbed by a slaked lime. The idea was similar to Snow's, reusing the anesthetic gases (at that time mostly nitrous oxide) while preventing carbon dioxide from returning to the patient.

Other researchers like Carl Sauer (1835-1892) (2), Franz Kuhn (1866-1929) (3), were also involved in the development of different rebreathing techniques with carbon dioxide absorption.

The first report of prolonged anesthesia in animals by means of a closed circle system with volatile anesthetics, nitrous oxide and oxygen was done by Dennis E. Jackson (1879-1980) in 1915 (4).

A German chemist, Herman D. Wieland (1877-1928) and a German gynecologist Carl J. Gauss (1875-1957) in cooperation with the German engineer Bernhard Dräger (1870-1957) built the first anesthetic apparatus equipped

with an anesthetic circle rebreathing system. It was operational and put in clinical practice in 1924 (5,6).

Modern carbon dioxide absorbents use similar chemical reactions. Several formulations are available today, the most common being the soda lime and calcium hydroxide lime. The absorption process follows several steps:

1. $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$
2. $\text{H}_2\text{CO}_3 + 2\text{NaOH} \rightarrow \text{Na}_2\text{CO}_3 + 2\text{H}_2\text{O} + \text{Heat}$
3. $\text{H}_2\text{CO}_3 + 2\text{KOH} \rightarrow \text{K}_2\text{CO}_3 + 2\text{H}_2\text{O}$
4. $\text{Na}_2\text{CO}_3 + \text{Ca}(\text{OH})_2 \rightarrow 2\text{NaOH} + \text{CaCO}_3$
(or K_2CO_3) (or 2KOH)

A novel carbon dioxide absorbent was created in 1999. Calcium hydroxide lime (Amsorb) is composed of calcium hydroxide (70%) and several other components to improve hardness. Water is 14.5%. With removal of strong alkali calcium hydroxide lime has potential benefits, including decreased formation of compound A with sevoflurane, minimal formation of carbon monoxide when exposed to desflurane or isoflurane, and minimal destruction of inhaled agents (7). Detailed description of the various combinations and producers of CO₂ absorbents can be found in any anesthesia textbook.

Lithium

Its name derived from the Greek word “lithos” (stone). It was discovered in 1800 by the Brazilian chemist Bonifacio de Andrada e Silva in a mine on the Swedish island of Utö, probably from here derived its name. Extensive data

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on lithium can be found elsewhere. In this article we only remind some of its main uses: air industry lubricants (in fact its first use), medicine (as a mood stabilizing drug), nuclear technology, ceramic and glass industry, electronics (in high quality batteries), pyrotechnics, air purification in spacecraft and submarines and others.

Its use in anesthesia as carbon dioxide absorbent seems to be documented for the first time in 2010 (8-10). The relative novelty of this type of absorbent as well as the long time familiarity and market availability of previous absorbents make this new type of absorbent still difficult to implement in practice.

Traditional vs. premium CO₂ absorbents (11)

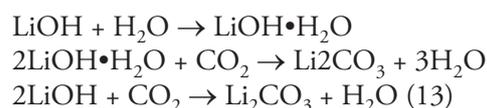
All carbon dioxide absorbents use a catalyst, Ca(OH)₂ and water which react with carbon dioxide to form CaCO₃, water and heat. During this cyclical process, Ca(OH)₂ is continually re-moistened during the exothermic reaction of CO₂ absorption until it becomes fully exhausted and converted to CaCO₃. While all absorbents undergo the same basic process to capture carbon dioxide, there lie important safety differences between traditional and premium absorbents which stem primarily from the catalyst used in the formulation.

Traditional carbon dioxide absorbents use Na or K catalysts to facilitate carbon dioxide absorption reaction. Under desiccated conditions NaOH and KOH catalyst preferentially bind and process inhaled anesthetic agents into toxic compounds. Additional to this potential for generation of harmful substances NaOH and KOH used in traditional carbon dioxide absorbents remain in the exhausted material regenerate after use, causing the reversion of the pH based dyes that are used to indicate exhaustion. Indicator dye color reversion renders this safety mechanism unpredictable and increases the probability of inadvertent re-use of exhausted absorbent.

Premium carbon dioxide absorbents do not use NaOH or KOH. They incorporate proprietary formulations containing catalysts that do not react with common inhaled anesthetic agents, even under desiccated conditions. The absence of NaOH and KOH catalysts also eliminates the potential for the regeneration of the indicator dye, thus providing the benefit of a permanent color change. To date, carbon dioxide absorbents that confer these enhanced safety characteristics also carried a premium price, limiting their adoption. It must be specified that the irreversibility of the indicator dye once its color has changed is characteristic of one of the two LiOH carbon dioxide absorbents existing on the market today, Litholyme (Allied Healthcare Products Inc.). The other product, Spiralth (Micropore, Inc) does not use any dye; the exhaustion of the absorbent is noticed by the elevation of the FiCO₂. Every hospital should have its own limits, but usually when the FiCO₂ reaches 0.5% (or 760 mm Hg x 0.05 = 38 mm Hg) the absorbent must be replaced.

Despite the additional expense of the premium carbon dioxide absorbents, the Anesthesia Patient Safety Foundation (APSF) considers them the best practice in the market due to their increased safety, especially in low-flow systems where gases are subject to longer exposure to the carbon dioxide absorbent (12).

The simplified chemical reaction (without the heat produced at different steps) in these proprietary absorbents is described here:



No strong alkalis appear in these reactions. In fact several papers demonstrated that this characteristic practically eliminates the production of compound A (14,15).

Other works also concentrate on the, production of carbon monoxide of different carbon dioxide absorbents. They show the minimal, if at all, production of carbon monoxide with Amsorb and LiOH ones, in the desiccated state (16,17).

The carbon dioxide absorbent capacity has been also evaluated. Traditional formulations absorb carbon dioxide usually in the range of 26 L / 100 g absorbent (soda lime). Other compositions range around 10.2 L / 100 g absorbent (calcium hydroxide lime). However, in the traditional pellet form, due to channeling, the absorptive capacity can decrease (18). The absorptive capacity of the LiOH absorbents can range from similar to Sodalime, to more than Amsorb and even to 5 times more (19).

This high absorption capacity has led many years ago the space exploration to adopt the LiOH carbon dioxide absorbers as the preferred solution that fit the crew production of this metabolic gas (20). A simple calculation demonstrates the high absorptive capacity of the LiOH.

The theoretical binding capacity of LiOH is 0.92 kg CO₂/kg LiOH. This value has been calculated in chemistry and is called stoichiometric limit of the reaction (21). In anesthesia the absorptive capacity is expressed in liters of CO₂, not kg. The equivalent between kilograms and liters for carbon dioxide is approximately 0.5 m³/1 kg (22). The carbon dioxide production of a 70 kg human in resting state is theoretically 282 L/day (3.5 ml oxygen/kg/min x 24 h = 352800 L/day. Respiratory quotient = 0.8). This brings us to the conclusion that, stated in another way, 2 kg of LiOH can remove one person's daily carbon dioxide from the cabin environment.

In fact the LiOH carbon dioxide absorbers became more known to the general public due to the Apollo 13 accident. It was exactly this high absorption capacity that saved the life of the entire crew (23).

It is probably too early at this stage to evaluate the impact of this new carbon dioxide absorbent in the daily practice. As any new product it must get to be known and

understood. Price issues must be overcome as well. A comprehensive perception balancing comfort, safety, financial issues and environment concerns will give the answer.

A possible boost to the implementation of this type of absorbent might be the renewed interest for the low flow anesthesia technique. It is this type of general anesthesia that consumes the most the carbon dioxide absorbent together with all the other abovementioned problems. The LiOH carbon dioxide absorbers may be the answer to all these problems.

Two major actors on the stage

At present there are only two producers of this type of absorbents. The chemical process is roughly similar, but there are differences too. They will be reminded here briefly.

Litholyme is produced as pellets, the way all the anesthesiologists are used today with, both as filling bags and pre-filled canisters. This conditioning brings with it the usual concerns related to channeling during use and dusting. Its big advantage, however, is the non-reversible color change once the active substance is consumed. Thus, the so called "Monday morning syndrome" seems to be eliminated.

Spiralith has a novel way of appearance: the active substance is disposed on a polymer matrix base and rolled as a fixed spiral in a cylinder, thus maintaining its tridimensional shape and, consequently, its absorptive properties all during the lifetime of the absorber. It has no dye, thus requiring the anesthesiologist to follow the FiCO_2 on the monitor. Its main disadvantage is that exactly this conditioning requires sometimes special housings, depending on the type of the anesthesia machine used. However, the big advantage, and seemingly total novelty, is that once the absorbent is consumed, it can be returned to the producer for recycling.

Conclusion

The LiOH carbon dioxide absorbent is a new type of component in the breathing circuit. Its chemical properties make it a very attractive option for the future of volatile anesthesia. As any new appearance in medicine it must pass a certain learning curve on behalf of the clinician. Once the experience with this new product will grow its penetration into clinical practice will extend. But at this stage it is too early to predict where and when it will happen.

Disclosure

Nothing to declare.

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