SODASORB®
MANUAL OF CO_2 ABSORPTION

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MEDICAL APPLICATIONS

The Advent of Inhalation Anesthesia

Modern surgery would be impossible without the remarkable achievements in anesthesia, beginning in the mid-1800's. Our knowledge of scientific anesthesia will continue in the future with the exploration of new anesthetic agents, apparatus, and techniques of an ever- growing global scale. The result will be products which are safer, faster, and easier to use by health care professionals, while also fine tuned to improve overall patient safety and comfort.

In the beginning stages of anesthesia development, surgeons used physical methods to induce unconsciousness, such as blows to the head or neck and compression of the carotid arteries. In South America, narcotic analgesics of botanical origin, such as opium and cocaine, were used. The use of alcohol as an effective, but uncontrollable and unsafe, general anesthetic persisted into the 19th century. For the most part, surgery performed in this era required nothing more than physical restraint of the patient whose only antidote against pain was to "bite the bullet."

Modern attitudes toward anesthesia began to change in the middle of the 18th century, consistent with the new political and social ideas based on the concept of the *natural rights of the man*. This concept found many different expressions in politics, social thought, business, and science. Perhaps most familiar to students of history are the American and French revolutions, the Industrial Revolution, and the emergence of egalitarianism. New ideas abounded in science. Up until this time, pain and suffering were considered a necessary part of the daily life. Almost puritanical in nature, people viewed the endurance of pain as an opportunity to demonstrate the virtues of patience, devotion, and fortitude. This may explain why earlier discoveries of anesthetics or analgesics were ignored. The concept of the natural rights of man changed this, and, in so doing, contributed greatly to the advent of modern inhalation anesthesia.

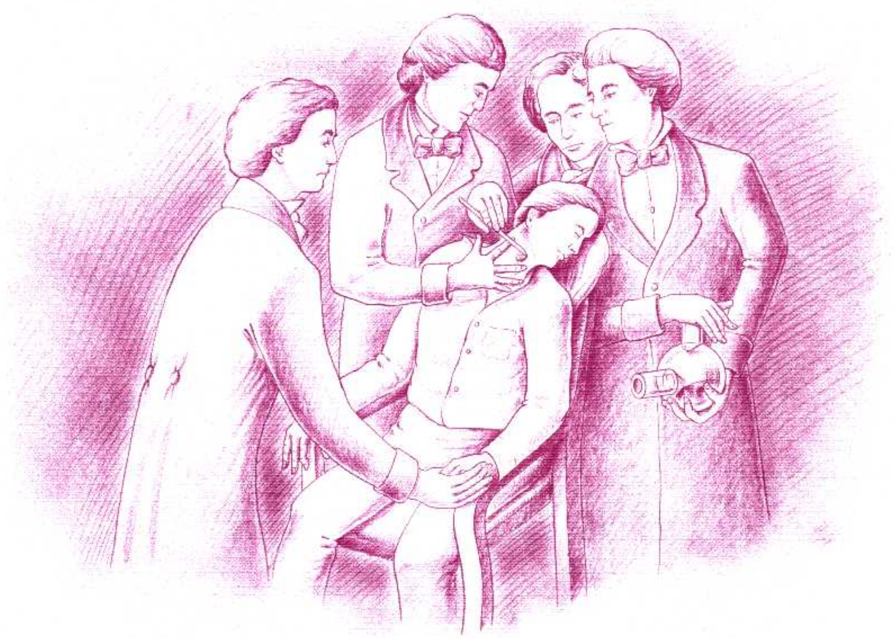
Inhalation anesthesia began at the turn of the 19th century in England when the anesthetic properties of diethyl ether and nitrous oxide were discovered. These agents were enjoyed for many years on both sides of the Atlantic for their euphoric and exhilarating effects as a popular social pastime, casually referred to by many as a *frolic*. Still, it was some time before these agents were put to use in anesthesia. Surgeons continued to operate on patients who were either drunk, tied down, or both.

Americans were the first to put diethyl ether and nitrous oxide to use in the clinic. In the earliest recorded cases, the idea of using diethyl ether as an anesthetic agent came from inferences drawn at a frolic. The first recorded diethyl ether case is credited to William E. Clarke of Rochester, Minnesota in January of 1842. In March of the same year, a physician named Crawford W. Long, in Athens, Georgia, became a local celebrity when he began producing complete anesthesia in his patients with diethyl ether.

Nitrous oxide was first put to clinical use in December of 1844, although it had been discovered in 1772 and identified as an anesthetic in 1798. Horace Wells, a Hartford dentist, used it first for a painless extraction. Like Clarke and Long before him, Wells got his idea at a frolic. He noticed that one of the participants had barked his shin without feeling pain and immediately saw the potential. Soon after, Wells arranged to have the gas administered to himself while another dentist removed a tooth. The success of this experiment led him to use nitrous oxide on dozens of his patients.

Wells then approached John C. Warren, Chief Surgeon of the Massachusetts General Hospital in Boston, and won permission to demonstrate this painless extraction to attending students. At the demonstration, Wells was assisted by his former pupil and partner, William T.G. Morton, a Boston dentist. Unfortunately, the nitrous oxide was discontinued too soon, the patient cried out, and the experiment was declared a failure. Nitrous oxide was, for the time being, rejected, even though the patient later admitted that the pain was less than expected.

Morton, inspired by this event, set about finding a stronger agent than nitrous oxide. He learned about diethyl ether from chemist Charles T. Jackson and soon began experiments on himself and animals. Morton, following in the steps of Wells, solicited permission of Dr. Warren for a new attempt at anesthesia at Massachusetts General Hospital. The demonstration took place in October of 1846 and was an impressive success. Warren, the Chief Surgeon, exclaimed, “Gentlemen, this is no humbug!” Another leading physician, Henry J. Bigelow, said “I have seen something today which will go around the world.”



William Morton published his paper on nitrous oxide in 1847, two years before Crawford Long published a paper on diethyl ether. The word “anesthesia” itself stems from Morton’s epoch-making demonstration. It was this historic event which prompted the poet Oliver Wendell Holmes to coin the word from the Greek word for insensibility.

By coincidence, chloroform was first used clinically in 1847, the same year as Morton’s pioneering paper. Chloroform was discovered in 1831m, when it was simultaneously discovered by Gutherie in the United States, Soubeiran in France, and von Liebig in Germany. Sir James Y. Simpson of Scotland used it first as an anesthetic. However, there was no general acceptance until 1853 when Queen Victoria permitted John Snow, often called the first anesthesiologist, to use chloroform anesthesia during the birth of their eighth child.

In the United States, however, nitrous oxide was still the preferred anesthetic. Gardner Colton promoted its use in 1863, but it was not until after about 1868 when cylinders of compressed nitrous oxide became readily available that its popularity and use increased.

Edmund Andrews of Chicago experimented with crude anesthesia machines for the administration of nitrous oxide with oxygen in 1868, but the technique was abandoned as too costly. Thereafter, nitrous oxide was again given without oxygen. The use of nitrous oxide as an induction agent for diethyl ether anesthesia was introduced in 1877 by Joseph Clover. A series of somewhat crude anesthesia machines were developed prior to World War I. In 1903, Charles Teter introduced the concept of vaporizing the ether by a stream of nitrous oxide and oxygen. The gas-air machines of Henry Boyle (1917) and Ralph Minnit (1934) followed.

At this time, it was recognized that soda lime could be used to remove carbon dioxide from exhaled gases in closed circuit anesthesia systems. Dennis Jackson’s laboratory work in 1915 with animals and, to a limited extent, with humans provided important information on carbon dioxide absorption in closed circuit nitrous oxide systems. Ralph Waters, taking a cue from Jackson, applied the principle of chemical absorption of carbon dioxide to clinical anesthesia in 1923.

During the 20th century, a number of inhalation anesthetics have been discovered, but only a few are sufficiently safe and predictable in their action. Table 1 on page M-4 lists the commonly employed agents, and their more important properties.

In spite of the rapidly growing use of regional anesthesia, many cases still require general anesthesia with endotracheal intubation. Modern anesthesia involves the use of inhalation anesthetics alone or in combination with a variety of intravenous agents. Semi-colored circuit breathing apparatus with Sodasorb carbon dioxide absorbent remains an efficient, cost-effective method of delivering inhalation anesthesia. It is the system of choice for the majority of anesthesiologists and nurse anesthetists worldwide.

Regardless of the choice of agents or techniques, modern anesthesia continues to require intimate knowledge of physiology and pharmacology in its attempts to control the patient’s vital cardiorespiratory functions.

Table 1. Physical Properties of Volatile Anesthetic Agents

	Nitrous oxide	**Halothane**	**Methoxyflurane**	**Enflurane**	**Isoflurane**	**Sevoflurane**	**Desflurane**
First used clinically	1844 Wells	1956 Johnstone	1960 Artusio & Van Poznak	1966 Virtue	1969 Stevens et al	1981 Holiday	1990 Jones et al
Chemical formula	N_2O	$CF_3CHBrCl$	$CH_3OCF_2CHCl_2$	$CHFCICF_2OCF_2H$	$CF_3CHClOCF_2H$	$(CF_3)_2CHOCFH_2$	$CF_3CFHOCF_2H$
Molecular weight (g/mol.)	44.02	197.4	165	184.5	184.5	200.053	168.036
Boiling point (°C)	-89.5	50.2	104.65	56.5	48.5	58.5	23.5
Specific gravity (g/ml)	-	1.86	1.4	1.52	1.50	1.520-1.525	1.465
Relative gas density (air = 1)	1.53	6.9	5.7	6.4	6.4	6.9	6.05
Vapor pressure at 20 °C	N-50	243	30	174.5	239.5	157 mmHg	669.2 mmHg
Flash point in air	-	-	-	>93°C	>93°C	Non-flamm.	>93°C
Flammability range (vol. % in air)	-	-	7.0%[1]	-	-	-	-
Flammability range (vol. % in O_2)	-	-	5.4%[1]	-	Non-flamm.[3]	>10% @ 90 Joules	17.0-20.8% non-flamm.[4]
Stabilizer	None	0.01% w/w thymol	0.01% butylated w/w hydroxyl-toluene	None	None	None	None
Stability with soda lime	Stable	Stable	Stable	Stable	Stable	Unstable	Stable
Min. alveolar conc. (MAC) % in O_2	101%	0.76%	0.16%	1.69%	1.13%	2.05%	6.0%
Gas concen. (vol./100 ml)	30-70 [2]	0.5-4	0.3-3	1.3-4.5	0.8-4.5	-	-
Blood concen. (mg/100ml)	20-30	-	3-18	-	-	-	-
Blood/gas partition coeff.	0.47	2.35	10.2	1.91	1.4	0.69	.42
Oil/gas partition coeff.	1.4	224	825	96	91	53	19

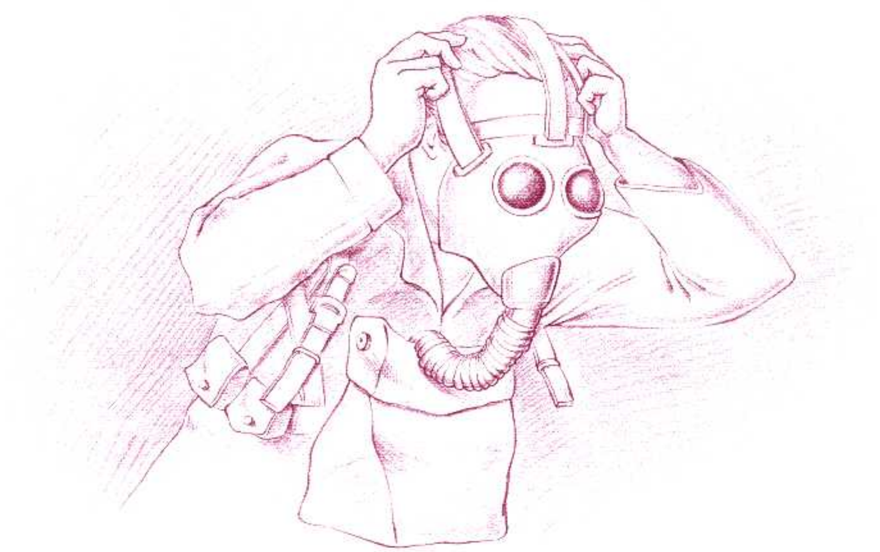
[1] Lower limit
[2] with other agent
[3] IEC601-2-13HA
[4] IEC 601-2-14HA

Sodasorb Carbon Dioxide Absorbent

Sodasorb absorbent is a pellet mixture of soda lime which removes carbon dioxide (CO_2) in anesthesia, metabolator, and other acid gas absorbent system.

The discovery of soda lime’s absorptive properties can be traced back more than 215 years. In 1777, a Swedish chemist named Scheele kept bees alive in a glass jar by absorbing their metabolically-produced carbon dioxide with lime water. Later in 1847, the same principle was duplicated in France when Regnault and Reiset kept dogs alive in a closed chamber by supplying oxygen while removing carbon dioxide with lime.

Although these first experiments with lime were successful, scientists did not develop an effective, long lasting carbon dioxide absorbent until World War I. Soda lime absorbent was originally developed by Professor Robert E. Wilson of Massachusetts Institute of Technology to meet the urgent need for an effective absorbent in military gas masks to absorb a soldier’s exhaled carbon dioxide.



After the war in 1919, the Dewey and Almy Chemical Co. was granted a license for and became the sole producer of Wilson Soda Lime. The additional trademark Sodasorb was granted to the product in 1929.

Throughout the years since its introduction, Sodasorb absorbent has established a tradition of quality and leadership unmatched in the industry. By carefully focusing on the customer’s needs, we have been able to constantly improve the product by anticipating future requirements.

Today, Sodasorb absorbent is used worldwide in a variety of industries, such as anesthesia, respiratory care, hyperbaric chambers, military and tourist submarines, underwater diving gear, fire safety apparatus, and mine rescue equipment. In each of these applications, the efficient removal of carbon dioxide is critical and Sodasorb CO_2 absorbent remains the time-tested brand of choice based on quality, effectiveness, and ease of use.

Physiological Factors in Carbon Dioxide Removal

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Life sustaining energy is derived from the oxidative metabolism of stored food at the cellular level. Carbon dioxide (CO_2) is an end product of this metabolism and is usually closely matched in its rate of formation at the cellular level to the rate of consumption of oxygen. It is stored in a labile pool as dissoslved gas, as bicarbonate ions, and as carbamino compounds in concentrations that depend on equilibrium between various chemical reactions and the cardiorespiratory status of the individual. Changes in the amount and distribution of carbon dioxide in transition from arterial to venous blood have many interrelated effects on physiological homeostasis in both awake and anesthetized people.

Human Production of Carbon Dioxide

Humans produce approximately 4 milliliters (ml) of carbon dioxide per minute per kilogram (kg) body weight at rest and slightly under anesthesia. This means that, for a 60 kg person with a resting cardiac output of approximately 5 liters per minute, 4 ml of carbon dioxide are added by the body tissues to each 100 ml of circulating blood per minute. Alteration in body temperature from its normal value of 37°C results in a change in CO_2 production rate (VCO_2) in the same direction of approximately 7-10% per degree Celsius (°C).

The total carbon dioxide content of arterial blood under normal conditions is 49 ml per 100 ml of blood. In transition from arterial to mixed venous blood, the additional 5 ml of CO_2 per 100 ml of blood is transported approximately 60% as bicarbonate ions, 30% as carbamino compounds, and 10% as dissolved carbon dioxide.

This quantity of carbon dioxide carried in the blood is much greater than would be expected from plasma solubility. In plasma at 37°C, the solubility coefficient for carbon dioxide is 0.067 ml of CO_2 dissolved per 100 ml of plasma per mmHg of PCO_2 (partial pressure of carbon dioxide, PCO_2, measured in millimeters of mercury, mmHg). For arterial blood with PCO_2 of 40 mmHg, approximately 2.7 ml CO_2 are dissolved per 100 ml of plasma. In venous blood for PCO_2 of 45, 3.0 ml of CO_2 per 100 ml of plasma are added. In plasma, some of the carbon dioxide reacts with water to form carbonic acid (H_2CO_3), which quickly ionizes to hydrogen ions (H^+) and bicarbonate ions ($HC0_3^-$).

$$CO_2+H_2O\leftrightarrow H_2CO_3\leftrightarrow H^++HC0_3^-$$

Approximately 90% of the carbon dioxide in the plasma enters the erythrocytes where a high concentration of the enzyme carbonic anhydrase greatly accelerates the rate of hydration of CO_2 to cabonic acid, which then dissociates rapidly to form bicarbonate. Bicarbonate then diffuses into the plasma until equilibrium is reached between the red cell and plasma. Chloride ions and water shift back into the red blood cells to maintain electrical and osmotic neutrality. This entry of CO_2 into erythrocytes explains the high CO_2 content of whole blood.

Carbon dioxide is also transported in combination with the terminal amino groups in blood proteins, especially hemoglobin. The reaction with hemoglobin is extremely rapid, is independent of the PCO_2, and is greater with deoxygenated hemoglobin. For arterial blood with a hematoctrit of 45% at PCO_2 = 40 mmHg and pH = 7.40:0.2 mM (millimoles) of CO_2 is carried as carbamino CO_2 in plasma and 0.8mM is carried in the red cells.

Carbon dioxide produced in the metabolizing cells diffuses down a concentration gradient from the high intracellular levels to the lower levels within the tissue capillaries. In the lungs, CO_2 diffuses from the blood into the alveoli. CO_2 is mechanically excreted from the body by the ventilation of these lung units. The ratio of the amount of carbon dioxide produced per minute divided by the alveolar minute ventilation determines the alveolar and, therefore, the arterial partial pressure of CO_2VCO_2 is proportional to the rate of oxygen consumption (VO_2) according to the equation:

$$VCO_2=R\chi VO_2$$

where R is the respiratory quotient. Under normal resting conditions, R is 0.8: that is, only 80% as much CO_2 is produced as oxygen is consumed. The value of R changes according to dietary intake.

Since the respiratory system is an open system which is adjusted to maintain a constant PCO_2, the ultimate distribution of carbon dioxide throughout the body is closely related to the ventilatory status of the individual.

Breathing Mechanisms

Breathing is regulated by neurons located in the brain stem within the lower pons and medulla. These neurons are excited by higher centers and circulating chemical factors. In particular, the rate and depth of ventilation are a function of the oxygen and carbon dioxide content of the blood. The cerebral chemosensitive area is stimulated by an increased Carbon dioxide tension and decreased pH. The control mechanism acts both directly on the respiratory center and reflexly through the chemoreceptor located in many parts of the body.

Alveolar ventilation, or effective ventilation, is that amount of the inspired gas that communicates with the alveoli and participates in gas exchange with pulmonary capillary blood. Alveolar ventilation is less than the total ventilation by an amount equal to the dead space or non gas-exchange ventilation. This dead space ventilation is composed of anatomic and physiologic components, as well as the non gas-exchanging dead space volume of the breathing circuit (e.g., endotracheal tube, Y-piece). For a fixed minute ventilation, any increase in the dead space ventilation will result in a decrease in alveolar ventilation and elevation of arterial PCO_2.

Hypercapnia During Anesthesia

Hypercapnia (increased arterial PCO_2) can be related to a number of factors during anesthesia. Anesthetic agents decrease the central respiratory drive to cause hypoventilation and CO_2 retention. Spontaneous respiration during anesthesia may also be diminished due to abnormal or suboptimal positioning on the operating room table, increased airway resistance, increased breathing apparatus resistance, decreased compliance of the lungs or chest wall, full or partial paralysis of the muscles of respiration, or decreased lung volumes from athelectasis or pulmonary edema.

Hypercapnia may also result from alterations in the ventilation-perfusion relationship of the lung, pulmonary embolism, or increased carbon dioxide production relative to its elimination at the lungs. Causes of the latter can be due to increased metabolic rates from shivering, increased levels of catecholamines from light anesthesia, hypertension, thyroid storm, malignant hyperthermia, or fever. Further mismatch of CO_2 production to elimination can be exacerbated by increased levels of inspired CO_2 as a result of exhaustion of the soda lime.

Regardless of the causes, the physiological effects of hypercapnia are complex and wide ranging. Increased arterial PCO_2 causes direct depression of myocardial contractility and vascular smooth muscle tone. Simultaneously, reflex stimulation of the sympathoadrenal system occurs, the net result of which may be increased cardiac output, decreased systemic vascular resistance, pulmonary vasoconstriction, and cardiac arrhythmia's. Hypercapnia also causes stimulation of the respiratory center and increase in ventilation. At arterial partial pressures of CO_2 higher than 100 mmHg, respiration is depressed. Extremely high levels of PCO_2 can also result in narcosis or anesthesia, with reversible suppression of brain electrical activity.

In addition to the direct respiratory effects exerted by hypercapnia, an increased concentration of CO_2 also shifts the oxyhemoglobin dissociation curve to the right, resulting in decreased affinity of hemoglobin for oxygen

Anesthesia Machines

The modern anesthesia machine is the result of a long series of developments, Modifications, and refinements. Current designs allow the administration of a choice of anesthetics, each of which can be accurately metered at any desired pressure or temperature. Metabolically-produced carbon dioxide can be removed from the breathing circuit absorption of the patient's exhaled carbon dioxide in a circle breathing system.

The circle breathing system of a modern anesthesia machine consists of seven major components arranged in a circular fashion. These include a fresh gas source, unidirectional inspiratory and expiratory breathing valves, reservoir bag, and a carbon dioxide absorbent to prevent CO_2 rebreathing. The basic system can be used in the closed, semi-closed, or semi-open modes depending on the rates of fresh gas inflow as described below.

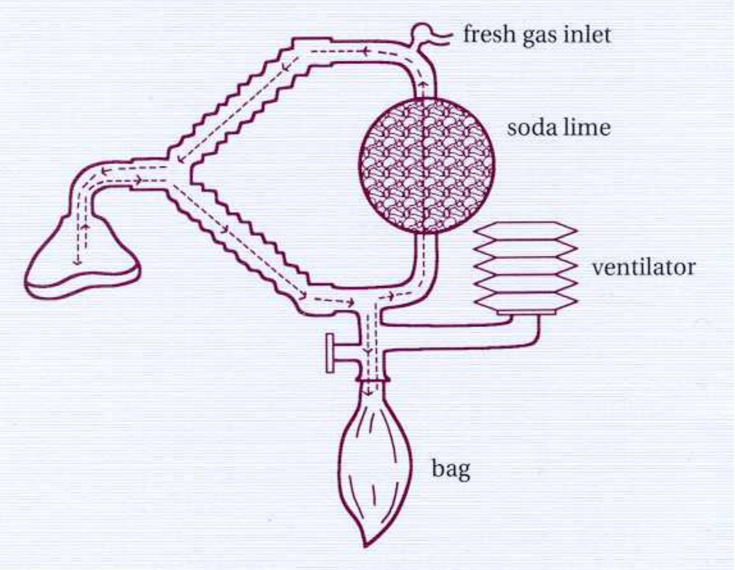

Figure 1. Circle Breathing System – A typical Circle-Type Closed system of anesthesia absorption is shown, with the direction of respiratory gas flow indicated. Fresh gas containing anesthetic vapor flows into the circuit at the fresh gas inlet. The circuit is connected to either a breathing bag or ventilator (with a selector switch). Overpressurization of the circuit is prevented by a pop-off valve. The soda lime absorbent removes carbon dioxide.

Closed Technique

In this technique, only those amounts of anesthetic gas or vapor required to produce anesthesia along with metabollically-required oxygen flow into the anesthesia circuit. Either a circle absorber or a to-and-fro absorber can be employed. Exhalation valves in the absorber circuit are closed. As the name of the technique implies, the anesthetic gases are retained within the circuit and there is little or no contamination of the atmosphere of the operating room. The closed technique has been particularly useful in the past to minimize explosion hazards when using flammable anesthetics. It is also the most economical way to administer inhalation anesthesia.

Semi-closed Technique

This technique also employs a carbon dioxide absorber. However, the total flow of the anesthetic gas(es) and oxygen exceeds the minimal anesthetic and metabolic requirements of the patient. Total flow of these gases into the circuit generally varies from 1 to 8 liters per minute. During induction of anesthesia, higher flows are usually employed, with lower flows for maintenance. The circle absorber or to-and from absorber can be selected. The semi-closed technique is most commonly used for adult anesthesia.

Semi-open Technique

The semi-open technique does not employ a carbon dioxide absorber. High flows of anesthetic gases and oxygen are utilized to rid the system of carbon dioxide. This technique is utilized with one of two different pieces of equipment. One of these, the Ayre's T Piece, is used to administer endotracheal anesthesia to children. The second method incorporates a non-breathing valve. This valve allows each breath of gaseous mixture to be a fresh one, exhaled gases being vented to the atmosphere.

Gas flow to the system must equal, or preferably slightly exceed, the patient's minute volume, since there is no rebreathing. A reservoir bag is positioned between the source of the gas and the valve, since the flow from the anesthesia apparatus is constant while the breathing of the patient is intermittent. This technique is one of the most costly because of the large volumes of anesthetic mixtures required.

Open Technique

The open technique, like the semi-open method, does not employ a carbon dioxide absorber. Carbon dioxide is eliminated by exhalation to the atmosphere. This technique employs the Yankauer or similar mask, and thus its use is often limited to inhalation anesthesia with one of the volatile liquids. Much larger amounts of anesthetic gases are employed with this method than with any other, because when the patient exhales, an amount of anesthetic equal to that utilized for anesthesia is exhaled into the atmosphere. It is the most wasteful technique and also the one which most contaminates the operating room. Open techniques of anesthesia are often used for pediatric procedures, due to inadequacy of available apparatus for infants and children.

The Absorber Canister

Efficient removal of carbon dioxide (CO_2) from an anesthesia breathing circuit depends on the optimization of the absorption canister/breathing system design, as well as on the chemical characteristics of the absorbent.

Assuming continuous use in a closed circuit apparatus for 8 hours, the canister should have absorption capacity for anticipated needs without requiring recharge, unless the canister or cartridge is intended for single patient use only. Average to maximal production of carbon dioxide in the adult under anesthesia is 12 to 18 liters an hour. For an 8-hour period, therefore, total absorptive capacity of the canister should be at least 100 liters (see “Rate of Carbon Dioxide Absorption”, Page XXX)

Absorber Unit Chambers

With minor differences, CO_2 absorbers usually consist of two transparent chambers, each with a capacity of approximately 1,000 to 1,500 cc (cubic centimeters). Each chamber, when properly packed, should contain from 950 to 1,300 grams of Sodasorb pellets and provide void space of approximately 500 to 750 cc. These figures apply to the traditional anesthesia absorber units and may not correlate to single-use disposable cartridges.

When an anesthesia CO_2 absorber is filled with Sodasorb absorbent containing an ethyl violet color indicator, a canister is used until the color change reaches the lower baffle of the upper chamber of the absorber unit. This signals that the absorptive capacity of this unit has been exhausted. The Sodasorb in the upper chamber is then discarded, the bottom charge is moved to the top chamber, and the bottom chamber repacked with fresh indicator Sodasorb. The original lower chamber will show by color change that it previously absorbed small quantities of CO_2 escaping from the upper chamber. However, the major part of its absorptive capacity is still intact, and it can now do the primary work of absorbing, while the new lower chamber can absorb the marginal escape. Although this design is very safe, it is still subject to operating room conditions such as moisture loss which may reduce its efficiency (see “Extended Use of Absorbents”, Page XXX and “Storage Within the Anesthesia Machine”, Page XXX.

Table 2. Twin Chamber Absorber Capacity

Absorbers (Model)	Lime Compartment (ml) Total Each Chamber	Void Space (ml) Total Each Chamber	Soda Lime (ml) Total Each Chamber
		Narkomed	
2,2A, 2B, 3, 4 (North American Dragër)	**3000, 1400**	**1410, 705**	**2700, 1350**
		Ohmeda	
20, 21, GMS (Ohmeda)	**3000, 1500**	**1410, 705**	**2700, 1350**

Air Space

The amount of air space in the canister is extremely important in the absorptive capacity of an absorbent. The intergranular air space varies with the size and surface of the pellets and moisture content in a given volume. The total air space ranges from 40-60%, depending on the absorbent used. As absorption proceeds, the pore space decreases.

Sodasorb pellets have uniform noodle shape which exposes an extraordinary area of absorbent surface in the canister. As a result, more surface is available for the absorption of CO_2 and the mass of pellets is highly permeable to gas flow.

Reserve Absorber Canister

A reserve absorber canister in series with the first has traditionally been used to provide a safety margin. As the void space of the first canister falls below the limit necessary for a particular tidal volume, the reserve canister will supply the requisite margin. Since continuous monitoring of inspired CO_2 during anesthesia is becoming standard, this excess absorptive capacity may not be necessary. Sufficient CO_2 absorptive capacity may be accomplished using disposable, single-use canisters.

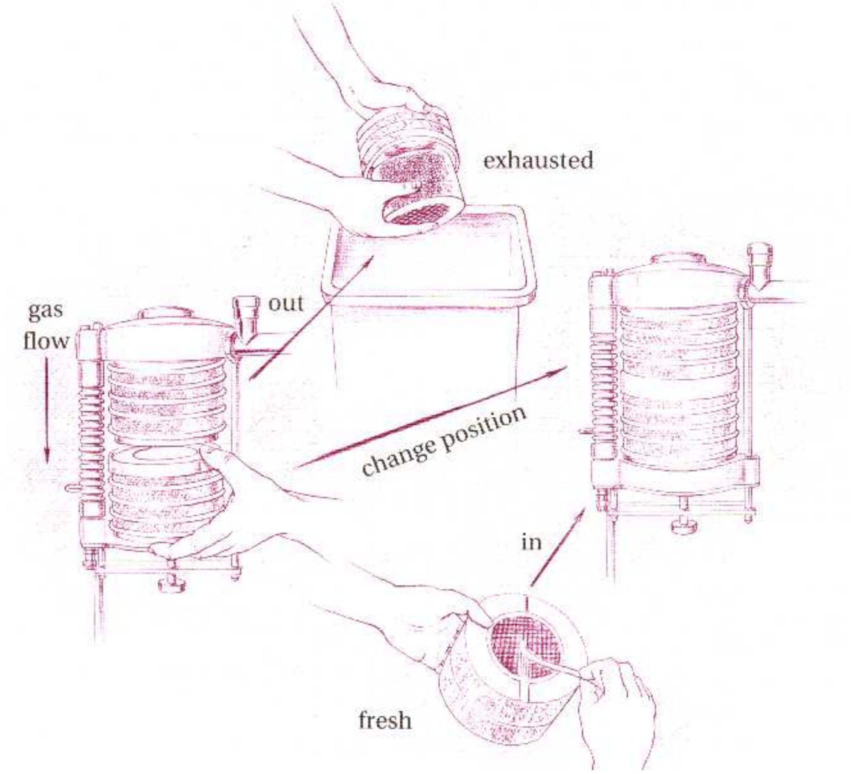

Figure 2. Switching Absorber Canister

Proper Filling of the Canister

Efficient removal of carbon dioxide is largely dependent upon the proper packing of Sodasorb in the absorbent canister. If the shape of the canister is complex, the uniform distribution of the airflow through the absorbent will be difficult. A small void space at the top of the soda lime compartment, to aid in initial distribution of the airflow is recommended.

Shake all canisters, including Pre-Pak cartridges, before use to insure that pellets are not clumped together, and an *even* distribution of pellets fills the canister. Channeling will most likely occur when the canister is hastily or unevenly packed.

To prevent the outlet end of the canister from becoming water-logged and to prevent the formation of caked Sodasorb, a space for condensate is usually located on the bottom of anesthesia machines between the canister and the rebreathing bag. Caked soda lime results in increased breathing resistance and decreased absorptive capacity.

The canister wall should be transparent, permitting visual inspection of the progressive exhaustion of the Indicator Sodasorb. Wall channeling is also readily apparent, permitting repacking of the canister before inefficient absorption occurs.

The Wall Effect

The deeper travel of the gas along the inside periphery of the canister is known as the *wall effect*. Pellets on the outer layer are in contact with the smooth wall, and the open space between these pellets and the wall is greater than elsewhere within the Sodasorb mass because no protuberances from other pellets are available to fill or partly fill the hollows. Hence, the flow resistance along the inside wall of the canister is less and the gas preferentially travels along this path. To avoid the wall effect, the canister should be well packed and routinely shaken prior to use to settle the Sodasorb into a consistent packing density within the cartridge or canister.

Sodasorb absorbent is not consumed in a simple, advancing frontal pattern throughout the canister. Studies by Conroy an Seevers have substantiated earlier work, mainly by Adriani, showing that the amount of carbon dioxide absorbed varies in different locations within the canister.

Channeling

Channeling is another pattern of non-homogeneous flow and occurs when the absorbent is incorrectly packed into the canister. In accordance with familiar hydraulic principles, the gas stream flows through pathways of least resistance, quickly forming channels, and bypassing the mass of the absorbent. The result is that a significant portion of exhaled gas may pass through the canister with much of its carbon dioxide unabsorbed. If channeling is suspected, the canister should be shaken to insure proper packing density, replaced, or refilled properly with fresh absorbent.

Absorptive Characteristics of Sodasorb Absorbent

Absorption efficiency is the effectiveness of the absorbent in completely removing carbon dioxide from gas stream. It can be very efficient and completely remove carbon dioxide for a short period of time. The amount of time which it takes for absorption to occur is called *time efficiency*. Both the absorption and time efficiencies of soda lime are high.

Rate of Carbon Dioxide Absorption

In a properly packed and well designed canister, approximately 100 grams of Sodasorb absorbent will absorb 15 liters of carbon dioxide (CO_2) before the concentration of CO_2 in the exit gas exceeds 1%, although clinical CO_2 breakthrough is 0.5%. This assumes that there is no significant amount of channeling through the soda lime. For 8-hour capacity, therefore, a canister should hold approximately 1 kilogram (2.2 pounds) of Sodasorb absorbent.

Efficiency of CO_2 absorption may be impaired with the use of high gas flows, if caking and/or decreased wetting of the Sodasorb absorbent occurs. When residence time (time of contact between CO_2 and absorbent) is less than 1 second, carbon dioxide absorption capacity is greatly reduced. Therefore, the void space (interstitial space) in a canister should equal or exceed the patient's tidal volume in order that exhaled gas has sufficient time in contact with the Sodasorb for maximum scrubbing efficiency. Tidal volume for adults is usually between 0.3 and 1.0 liter. The void space of fresh absorbent is approximately 50% of the gross volume. As the pores in the pellets of Sodasorb and then the intergranular space are filled with water,, progressively less void space is available to accommodate the patient's expired air. Hence, while approximately 500 cc of tidal volume can be accommodated in a 1000 cc canister of fresh Sodasorb absorbent, this capacity is reduced as the Sodasorb absorbent becomes converted to carbonate. Effective void space is reduced at the rate of about 60 cc an hour per 1000 cc of Sodasorb absorbent. The patient's tidal volume may eventually exceed the available void space.

Absorptive Capacity and Breakpoint

Clinical breakthrough or breakpoint is defined as the amount of time it takes for 0.5% carbon dioxide to leak through the Sodasorb absorbent, signaling the reduction in absorptive capacity of the absorbent. The efficiency of utilization is dependent on many factors including Sodasorb packing density, moisture content, porosity, patient minute volume, patient metabolic rate, and fresh gas flow rate.

Grace has a laboratory equipped with hospital operating room equipment, where we research the effects of operating room conditions and Sodasorb variables on absorptive efficiency and capacity. Whit this equipment, we can stimulate a complete range of airway operating conditions and assess the effects on soda lime efficiency and time to breakthrough or breakpoint.

Exothermic Heat Generation

The chemical reaction of carbon dioxide with a strong base such as Sodasorb is exothermic, the heat of neutralization amounting to 13,500 calories with the absorption of each gram molecular weight of carbon dioxide (44 grams or 22.4 liters). This heat is not evenly distributed throughout the canister because the reaction itself is zonal. For example, it was demonstrated by Adriani and Rovenstine that in the canister of a to-and-fro apparatus the temperature was in the range of 50° to 55°C at the center of the absorber canister, but 5°C lower towards the bag end of the canister and 5°C higher towards the face mask. The face mask temperature range was from 39° to 42°C.

Heat of reaction does not appear to affect absorptive efficiency, although rising temperature within the canister indicates that carbon dioxide absorption is proceeding. Some of the variables affecting heat generation are the patient's rate of carbon dioxide production, body size, metabolic rate, body temperature, and the ambient air temperature in the operating room.

A steep temperate gradient between the canister and the ambient air will result in rapid dissipation of the heat of the canister. *Therefore, do not rely on the temperature of the outside of a canister as an index of the amount of absorption taking place.* The temperate of the outside surface of the canister can be 20°C less than the temperature in the most reactive interior region.

The anesthetist should rely primarily on CO$_2$ monitors, time and volume calculations, and indicator color change for determining the usefulness of Sodasorb charge. Do not judge soda lime exhaustion solely by either color change or canister warmth.

Air Flow Resistance

As part of a standard operating procedure, breathing circuits should be checked before use to insure proper airflow characteristics.

For the patient under anesthesia, back pressure in the rebreathing apparatus can be dangerous. Resistance to airflow can be the result of faulty directional-valve action, length of tubes, or geometry of the fittings. These factors usually account for two-thirds of the total resistance. Sodasorb absorbent accounts for the remaining one-third. Numerous attempts to reduce resistance by means of variously-shaped canisters have been abandoned in favor of the simple cylinder having a length-to-diameter ratio of 1.5 to 1.

In modern equipment, resistance is also minimized by shortened breathing hoses, wide apertures, and minimum dead space in the mask and canister.

Flow resistance through the canister varies inversely with particle size. That is, the finer the pellets, the greater the surface area exposed to air friction, or put differently, the smaller the space between the pellets for air passage, the greater the resistance to flow. Large particles offer less resistance, but have the disadvantage of providing a smaller total surface area for reaction.

The specific resistance, K, of 4-8 mesh soda lime is of the order of 1 mm of water pressure per centimeter per liter per minute (mmH$_2$)•cm•L^{-1}•min). The pressure drop (P) across an absorber packed correctly, will depend upon the flow rate (V), length (L), specific resistance and effective cross sectional area (A) of the absorber. This relationship may be expressed by the equation:

$$P= \frac{KLV}{A}$$

For an absorber with a soda lime compartment of 2 liters, at a flow of 60 liters per minute, P is less than 1 centimeter (cm) of water pressure if the length of the combined chambers is less than 18 cm and the diameter greater than 12 cm, a ratio of 1.5 to 1. At a flow rate of 100 liters per minute, which is the maximum respiratory flow expected in anesthetized adults, the pressure across the Sodasorb compartment would not exceed 1.5 cm water pressure. These values do not take into consideration the resistance effect of breathing circuit, endotracheal tubes, directional valves, and fittings. In modern equipment, resistance offered by these components usually exceeds that of Sodasorb absorbent.

Absorbent Dusting

Dust may accumulate in a closed circuit breathing apparatus or the Sodasorb canister. Care must be taken to prevent dust induced laryngospasm, bronchospasm, or pneumonia.

Improper filling of loose absorbents or careless handling of prepackaged canisters can cause dusting. The chance of dusting is minimized with the Sodasorb Pre-Pak, a pre-filled cartridge.

High gas flows in the breathing circuit can also cause dust to accumulate at the bottom of the canister. This can be transmitted to the breathing circuit by over distention and rapid deflation of the breathing bag during preoperative leak testing of the circuit or from normal use. Slow deflation through the pop-off valve can minimize the risk of occurrence.

Soda Lime Reactivity

Bryant W. Stolp, M.D., Ph.D. and Richard E. Moon, M.D., Duke University Medical Center © 1992

Reactions with Common Anesthetic Agents

Most gaseous anesthetic agents will bind to CO_2 absorbents. Adsorption of halothane, enflurane, isoflurane, and sevoflurane to Sodasorb has been measured and reported. Theoretically, such adsorption could slow the rate of attainment of a desired inhaled concentration of anesthetic gas or produce a persistent level of gas in the anesthetic circuit after the vaporizer has been turned off. However, hydrated Sodasorb absorbs only small quantities of anesthetic agents, insufficient to result in a clinically significant effect. By comparison, dried soda lime can take up significant quantities of anesthetic gases. If the anesthetic circuit is designed such that the fresh gas inlet is upstream from the CO_2 absorbent, altering the anesthetic vaporizer setting may result in only a slow change in inspired concentration.

Soda lime degradation of halothane, enflurane, isoflurane, and desflurane occurs to a minor degree. Small quantities of chloride and fluoride have been detected in used absorbent which was used with enflurane or isoflurane anesthesia, presumably from chemical breakdown of the halogenated anesthetic agents.

Trace concentrations of difluorochlorobromoethane (CF_2CBrC1) have been detected in the expired gas of patients anesthetized with halothane (Sharpe, 1979). Its presence has been attributed to interaction of halothane with soda lime. Despite this evidence of chemical reactivity, Sodasorb does not break down either halothane nor isoflurane in significant quantities except at high temperatures (see Table 3).

A temperature as high as 81°C has been reported in a Sodasorb canister (Carden, 1944), although most studies have shown that the temperature inside canisters containing modern formulations of Sodasorb is circle systems rarely exceeds 40°C. Desflurane is reported to be the most stable anesthetic except it breaks down slightly more readily than isoflurane in dry soda lime.

Sevoflurane is the most unstable of the currently available fluorinated anesthetic agents in soda lime, with the compound

$$CF_2{=}C(CF_3)OCFH_2$$

as the breakdown product (Strum, 1987). Barium hydroxide lime is reported to degrade Sevolfurane up to four times faster than soda lime (Liu, 1991). However, the absorption and degradation of Sevoflurane by a carbon dioxide absorbent would probably not significantly affect the requirement for anesthetic delivery in clinical practice, even using low fresh gas flow during which the majority of the patient's inhaled gas first passes through the absorbent canister.

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Table 3. Rate of Breakdown (% per hour) of Fluorinated Anesthetics in Soda Lime

Temperature	Desflurane	Halothane	Isoflurane	Sevoflurane
22°C*	N/A	0.83±0.00	0.04±0.00	6.46±0.87
37°C*	N/A	0.52±0.00	0.06±0.00	31.04±0.48
40°C†	0.083±0.086	0.63±0.11	0.20±0.09	12.0±0.4
54°C*	N/A	2.21±0.00	0.30±0.00	57.36±2.05
60°C†	-0.094±0.071	1.56±0.07	0.15±0.06	56.4±4.3
80°C†	0.45±0.26	16.0±1.61	3.1±3.7	92.2±5.2

*From Strum (1987); †from Eger (1987).

Reactions with Halogenated Compounds

Sodasorb absorbent should not be used with trichlorethylene or chloroform

A possible reaction of strong bases with halogenated compounds has been known since the early 20th century (Kemp & Vellaccio, 1980). For example, the interaction of chloroform with a strong base can produce, via a carbanion intermediate, the highly reactive chemical dichlorocarbene ($CC1_2$). This molecule can react spontaneously with water to produce phosgene and formic acid, from which carbon monoxide can be produced.

An adverse interaction of trichlorethylene with sodalime was reported as early as 1945. In this reaction, both carbon monoxide and phosgene were produced when trichlorethylene interacted with Sodasorb absorbent inside an anesthetic circuit. The following reactions were hypothesized:

$$\underset{\text{Trichloroethylene}}{CC1_2{=}CHC1} \xrightarrow{[NaOH]} \underset{\text{Dichloroacetylene}}{CC1{=}CC1} + \underset{\text{Hydrogen Chloride}}{HC1}$$

$$CC1{=}CH1 \longrightarrow \underset{\text{Phosgene}}{COC1_2} + \underset{\text{Carbon Monoxide}}{CO}$$

These reactions are markedly accelerated at temperatures greater than 60°C. Trichloroethylene administration, due to its toxic properties, has been associated with cranial nerve palsies, adult respiratory distress syndrome, convulsions, postoperative confusion, and death (Carden, 1944; Hunter, 1944; McClelland; Firth, 1945; Atkinson;Anonymous, 1964).

Carbon Monoxide Production

Carbon monoxide (CO) may accumulate in closed circuit anesthesia systems (Middleton, 1965). Carbon monoxide concentration as high as 810 ppm was reported. In this case, researchers theorized that the source of this carbon monoxide was endogenous production by the patients from hemoglobin catabolism or due to release of carbon monoxide bound to hemoglobin from prior cigarette smoking.

Recently, carbon monoxide generation has been reported in anesthetic circuits which used enflurane, isoflurane, and halothane. Incidental observation of elevated arterial blood carboxhemoglobin (COHb) was observed in three hospitals (Moon, 1990; Centers for Disease Control, 1991; Moon, 1991). Carboxhemoglobin levels as high as 30% were reported. Most of the reported cases were associated with anesthesia machines which had not been used for one or two days or more prior to the observed COHb increase.

Analysis of Sodasorb absorbent associated with COHb elevation revealed evidence of formate, a probable precursor of carbon monoxide. The exact reaction mechanism has not yet been identified, however cases were associated with both barium hydroxide lime and soda lime, suggesting that the chemical reaction is related to alkalinity, rather than to a specific formulation. However, in the presence of soda lime, both isoflurane and enflurane could be broken down in trace quantities to fluoroform, the fluorinated analog of chloroform, and a fluorinated analog of trichlorethylene: $CFC1{=}CF_2$ (chlorotrifluorethylene). In theory, these compounds might decompose to carbon monoxide under alkaline conditions.

Because these observed cases of intraoperative carbon monoxide contamination have occurred after periods of disuse of the anesthesia machines, the chemicalreaction which produces carbon monoxide is probably a slow one. Therefore, to minimize the risk of significant exposure, flush the anesthesia circuit with fresh oxygen to eliminate any accumulated carbon monoxide prior to each use. Dispose of any absorbent which is left idle within an anesthesia absorber unit and replace it with a fresh charge.

Use with Flammable Anesthetic Agents

When a flammable anesthetic agent is used, take special precautions when emptying the canister. Substantial quantities of the anesthetic may be trapped between the Sodasorb granules and could present a serious fire hazard.

Discard this material in strict accordance with local fire prevention rules, e.g., remove any possible source of ignition and use a fire-safe container.

Sodasorb Carbon Dioxide Absorption Capacity

Absorbent Exhaustion Indicator

To signal the progressive exhaustion of Sodasorb absorbent, ethyl violet color dye (a sensitive acid-base indicator) is added during manufacture. Indicator Sodasorb changes from white to purple as absorption proceeds, full exhaustion being indicated by a deep purple color. Presence of the indicator does not affect absorption.

It should be noted that since the neutralization reaction is not uniform throughout the canister, color change is also not uniform. The zone of greatest reactivity in a circle apparatus canister is largely at the inlet end and in a parabolic central cone. The color of the exhausted absorbent showing through the transparent wall of the canister, or through the inspection window, requires experience for correct interpretation.

Intermittent use of the Sodasorb absorbent must be taken into account, since it may *revert* from purple back to white in a brief time. This means that when color shows vividly, the Sodasorb absorbent is consumed; when little or no color shows, there is at least some absorptive capacity, but the amount is indeterminate and may be very small. Color indication is an adjunct guide to be used in connection with CO_2 monitors, and time and volume calculations. If, prior to a procedure, there is any uncertainty about the Sodasorb CO_2 absorptive capacity in the existing charge, replace the existing material with fresh Sodasorb absorbent.

Ethyl violet is a particularly effective indicator for use with Sodasorb absorbent, its critical pH being 10.3. As the strong caustic sodium hydroxide (NaOH) is consumed and is replaced by the weak base calcium hydroxide, the color change parallels the falling pH in the canister. The color change is usually sharp enough to be conspicuous even under difficult lighting conditions.

Potential Deactivation of Ethyl Violet Indicator Dye

Ethyl violet may deactivate over time. Deactivation can also occur if the Sodasorb absorbent is exposed to intense ultraviolet light.

Severe moisture loss will also deplete the effectiveness of the ethyl violet indicator dye. A Sodasorb package which is left unwrapped, open, or even partially open will lose its moisture due to evaporation. This is equally true for Sodasorb left idle in the anesthesia machine absorber unit.

Color Reversion

Color reversion is the phrase used to describe the *reversion* of exhausted Sodasorb absorbent from purple to white when allowed to sit idle for a few hours or more. In the past, the term *regeneration* of soda lime has been incorrectly used to describe this process.

This color reversion is the result of subsurface calcium hydroxide regenerating active hydroxide at the surface of the granule. This alters the pH of the surface and, consequently, causes the indicator dye to revert back to white, even though the Sodasorb may be near exhaustion.

Soda lime does not regenerate. Instead, there has been a reversion of the indicator dye from purple to white. Although there may be some additional carbon dioxide uptake due to the migration of these hydroxides, the absorptive capacity of soda lime, previously saturated with CO_2, is minimal and should be relied upon, even if the color of the granules has reverted back to white.

It is important, therefore, for operating room personnel to determine how much absorptive capacity is left in Sodasorb absorbent immediately at the end of a surgical procedure. Visual inspection at the end of the procedure will yield an approximate estimate of the remaining absorptive capacity. If it is purple a quarter of the way down, the Sodasorb is exhausted by approximately 25%, half way down equals approximately 50%, and so on.

When starting a new procedure, if you are not sure how much absorptive capacity is left in the Sodasorb absorbent, it should be changed. In the future, a single-patient-use Sodasorb absorbent cartridge may solve this problem.

Extended Use of Absorbents

Two practical considerations are important for extended or multiple procedure use of CO2 absorbents. Extended oxygen flushing of the system or leaving the absorber open to the atmosphere for relatively long periods cause dehydration of the Sodasorb absorbent. This is undesirable because moisture content is a key component for carbon dioxide absorption. Decreased rates of absorption occur when the moisture content falls below the USP-NF minimum of 12%. Although flushing the system with oxygen between procedures is necessary to perform preoperative leak testing and remove residual anesthetic agents, its duration should be limited.

A second consideration is long-term oxidative stability of the indicating dye while in its colorless state. As long as Sodasorb absorbent is stored in its unopened packaging, the dye is stable because there is no flow or exchange of air. Once it is placed in the absorber, air flow ill be intermittent over several procedures. In addition, regular purging with fresh oxygen causes slow oxidation of the indicating dye while in its colorless state. In fresh absorbent, this slow oxidation will become significant over extended periods.

To be safe, Sodasorb absorbent which is used for several patients or remains unused in an anesthetic system should be changed regularly, even though there is still residual CO_2 absorptive capacity. Although regular flushing of the circle system with oxygen is required for preoperative leak testing and to purge any residual carbon monoxide buildup, the oxygen flush will dehydrate the Sodasorb and inhibit its ability to absorb carbon dioxide. Therefore, oxygen flush duration should not be overused.

OTHER APPLICATONS

Properties and Applications

Sodasorb absorbent is a proprietary mixture of hydrated lime ($Ca(OH)_2$) and a small quantity of sodium hydroxide (NaOH), with carefully controlled moisture content and porosity to maximize absorptive capacity.

Properties

Sodasorb absorbent is specially processed into porous, uniform pellets in order to expose the maximum absorbent surface area. The hardness of Sodasorb's pellets gives it high resistance to powdering and breakage.

As a result of its carefully designed physical composition, Sodasorb is an ideal absorbent for removal of carbon dioxide and other acidic contaminants from gas streams of air. In addition to the wide-ranging anesthesia applications previously discussed in this manual, here are a few other uses.

Applications

Medical Equipment
    Anesthetic rebreathing systems, metabolators, and oxygen therapy.
Underwater Breathing Systems
    Rebreathing systems for commercial and recreational diving and hyperbaric chambers.
Submarines
    Carbon dioxide removal for naval, research, civilian, and tourist submarines.
Safety Equipment
    Personal closed circuit rebreathers for mine, fire, and other safety rebreathing systems.
Industrial Uses
    Absorbs acid gases, aids purification, and functions as an aldol condensation catalyst.

HP Sodasorb Absorbent characteristics: Underwater Diving Experiment

Dewey and Almy Chemical Division, W. R. Grace & Co.-Conn. ©1979

Overview

High Performance (HP) Sodasorb Absorbent was developed primarily to remove carbon dioxide (CO_2) from underwater breathing systems and habitats for the United States Navy. This study examines some of the criteria that affect the ability of HP Sodasorb to remove CO_2, such as increased air flow through an absorbent bed, absorbent moisture content, particle size, and absorbent canister size. Absorbent reaction chemistry is reviewed with respect to pH of the moisture in the stream exiting the absorbent bed. Test data were also generated to show the maximum temperature reached in an absorbent bed using pure CO_2 versus 4.0% CO_2 in nitrogen and the flow resistance due to CO_2 absorbent. The methods used for determining these factors are described along with the results.

W. R. Grace & Co.-Conn. continually seeks to improve the quality of its Sodasorb CO_2 Absorbent. While originally developed for use in gas masks, Sodasorb moved on to gain wide-spread acceptance in the medical community, being used in surgical procedures requiring inhalation anesthesia. New uses for Sodasorb are continuously explored.

Today, Sodasorb is used to absorb carbon dioxide not only in the traditional medical industries, but also in tourist submarines, scuba apparatus, commercial diving, hyperbaric chambers, and even to absorb certain acid-gases, acting as an aldol condensation catalyst.

The underwater diving industry represents a key area for which the company has developed a technically improved product, High Performance Sodasorb.[1] In response to a series of customer questions within the diving industry, and in order to "fine-tune" our High Performance Sodasorb, a series of studies were undertaken. Today, these tests continue to yield improved absorbent capacity and more effective packaging/delivery systems.

In terms of High Performance Sodasorb, these studies were designed to address the following issues:

- The effect of differing flow rates on HP Sodasorb efficiency and the back pressure generated by the absorbent.
- The effect of HP Sodasorb moisture content on efficiency at a constant flow rate.
- The effect of absorbent particle size on pressure drop and efficiency through a fixed bed configuration.
- The effect of canister size on efficiency.
- The maximum temperature reached in the absorbent bed during a reaction.
- The pH of water in the gas stream exiting the absorbent bed.

The set-up for determining time efficiency, air flow resistance, and reacted gas temperature utilized a modified Navy Mark VI canister. Holding approximately 600 grams of absorbent, a gas stream consisting of 4.0% CO_2 in nitrogen was routed through a humidifier device to moisturize the gas to 100% relative humidity. This gas stream was then passed through the absorbent canister which was submerged in a constant temperature water bath (20°C). A manometer measured the differential pressure across the canister (back pressure), and a telethermometer electrode inserted into the top of the canister monitored the gas temperature exiting the absorbent bed. Gas exiting the canister was analyzed by an infrared detector, which was calibrated before and after each test with pure nitrogen (baseline) and 0.5% CO_2 in nitrogen (end point). Absorption data was recorded on a strip chart device. For checking flow rate accuracy, a gas totalizer recorded the amount of gases passing through the system.

Efficiency Test Protocol

Analysis of the test results consisted of determining time (in hours) from the start of gas flow to the point where carbon dioxide concentration in the exit stream reached 0.5%. This span was recorded as the absorbent time efficiency rating. While this level of carbon dioxide indicates impending breakthrough, practical experience shows that a diver begins to experience sensory losses above 1% carbon dioxide concentration.[2]

All efficiency tests, unless otherwise specified, were run under the following conditions: bath temperature 20°C, inlet gas at 100% relative humidity, and flow rate of 10.41 liter per minute (22 cu.ft./hr.). This flow rate was chosen since it approximated the generation rate of CO_2 by an average adult male at a normal breathing rate.[3,4] All time efficiency results were normalized to a 1,000 gram dry sample size. Back pressure was measured by observing the difference, in inches of water, between canister inlet and outlet gas pressures.

Experiment Description

Employing this test apparatus at varying flow rates, analysis revealed that HP Sodasorb efficiency decreases when flow rate is increased. This may be explained by a reduction in contact time between the absorbent and gas. At 22 cubic feet per hour, the high performance product showed a minimum efficiency of five hours to CO_2 breakthrough and a lesser time efficiency at flow rates above this level. Conversely, absorber unit back-pressure increased with higher flow rates. Some of the change was also due to apparatus design and particle flow resistance.

Table 1. Time Efficiency/Back Pressure Results Under Various Flow Rates

Efficiency (hours)	Flow Rates Avg. (cu.ft./hr.)	Back Pressure (inches of water)
5.0	22.0	0.4
3.0	25.0	0.6
1.4	26.5	1.0

Several HP Sodasorb lots were moistened to obtain samples containing between 6%-19% water. We found that efficiency was relatively constant within this range. This correlated well to medical experience where the desired moisture level is 12%-19%. If the moisture content is too low, the reaction with carbon dioxide will not be initiated. Conversely, if the moisture content is too high, the absorption sites become saturated with water which hinders the reaction.

Although with our experimental design, efficiency was constant for absorbent moisture content between 6%-10%, certain applications may require a higher or lower moisture content. For example, our work with the U.S. Navy indicated that a moisture range of 18.5%-21.5% was required for optimal absorbent efficiency with their Mark XI system due to the flow rate and the design of the absorber unit.

Granule size of the absorbent has a marked effect on the rate of carbon dioxide absorption due to the surface area. Our data shows that increased efficiency is experienced when particle size is progressively reduced. An absorbent of finer mesh, as noted, exposes greater active surface area, resulting in more efficient absorption rates. Back pressure was found to be relatively constant for granules ranging from 6-16 mesh; less than 16 mesh, there was a significant pressure increase.

Table 2. Back Pressure per Particle Mesh Size

Particle Mesh Size	Back Pressure (inches of water)
6	.2
8	.3
10	.4
12	.4
16	.4

There have been numerous attempts to reduce flow resistance by perfecting absorbent canisters and breathing systems. A reduction of flow resistance through technical improvements of canister design could allow the use of absorbent granules finer than 16 mesh.

To further demonstrate how canister design affects efficiency, the absorbent canister was increased in length from 1 to 2 feet. Based on 1,000 grams of HP Sodasorb removing 4.0% CO_2 from a gas flow, efficiency times of 4.9 hours per 1,000 grams were obtained from the one foot canister and 7.5 hours per 1,000 grams from the 2 foot canister. Doubling length per diameter ratio increased the time efficiency by 53% per 1,000 grams of absorbent. This suggests that canister designs should maintain a length per diameter ratio as high as possible to obtain maximum efficiency.

In all tests, the temperature of the reacted gases leaving the absorbent canister was monitored. There were no appreciable temperature differences observed. With the absorbent canister submerged in a constant temperature water bath (20°C), and the gas stream humidified to 100% relative humidity, the highest exit gas temperature monitored was 37°C. This correlates well with previous work where temperature conditions within face masks have been measured.[5] It should be noted that in certain diving environments, an increase in heat from the breathing apparatus may have a debilitating effect on the diver's ability to function normally underwater. Therefore, temperature should be monitored.

The reaction of Sodasorb with CO_2 generates heat and causes the exit gas temperature to rise as described above. Obviously, the absorbent bed temperature also rises. In addition, the exit gas contains moisture which has passed over the caustic absorbent. We decided to measure the absorbent bed temperature and the pH of the water contained in the exit stream, the latter prompted by concern in the diving industry that exit moisture may contain caustic which could burn the user.

A temperature probe was placed in one side of the U-tube and a cotton wad inserted in the center of the tube at the bottom. The half of the U-tube containing the probe was then filled with absorbent. Pure CO_2 was passed through the U-tube, and reaction temperatures were monitored from the absorbent bed. Once the HP Sodasorb was exhausted, the cotton was removed and the water pressed from it for pH determination. The condensate from the empty side of the U-tube was also tested with calibrated pH paper. The pH of the water and the condensate from the empty side of the U-tube were neutral, indicating no caustic was being carried over. Although the exit stream gas was neutral, care must be taken to ensure that the absorbent itself does not come in direct contact with the user, as it will cause skin irritation.

The observed bed temperature was dependent upon where the temperature probe was placed. Temperature results averaged 95°C pure CO_2, with a maximum temperature of 101°C. Prior work had shown that, in the canister of a to-and-fro apparatus, the temperature of the absorbent bed ranged from 50° to 55°C when subjected to a gas stream that contained CO_2 levels similar to human respiratory production.

Summary

Sodasorb absorbent has been used for over sixty years as a carbon dioxide absorbent for inhalation anesthesia. The introduction of High Performance Sodasorb several years ago was the first major attempt at designing a product specifically for use outside the conventional medical area. Continued experiments with this absorbent, coupled with a better understanding of its end uses, have shown that significant improvements in performance are achievable. Future work in the areas of absorbent and system design should further improve absorption efficiency.

Various experiments have demonstrated that higher efficiency involves several factors: absorbent selection, mesh distribution, moisture content, canister design and configuration, gas flow, and velocity. For undersea application, absorption improvement involves several evaluations. And, based on operating conditions, a concept suitable for one system may not be applicable with another set of conditions.

While maximizing efficiency is, to some extent, a trial and error procedure, the results of our experiments suggest the following approaches towards maximizing absorbent efficiency:

- Utilization of smaller particle size absorbent.
- Reduction of air flow velocity through the canister.
- Maintenance of a high length to width ratio canister design.
- Proper moisture level selection for the absorbent. Moisture should be in the range of 12%-16%, if high velocity air flow is not a problem.

As a final note, we should also mention the effect of bed temperature on efficiency. While not included in this series of experiments, a previous study has shown that efficiency decreases as the temperature drops.[7] In those instances where the canister will be subjected to low or below freezing conditions, the unit should be insulated or protected with a heat exchanger device. While the significantly higher porosity of HP Sodasorb offsets the low temperature effect to some extent, efficiency at temperatures below freezing does suffer. Basically, what occurs is that the free moisture freezes and inhibits the reaction process.

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PRODUCT INFORMATION

Chemical and Physical Processes in Carbon Dioxide Absorption

Some of the information presented in this section is also contained in the previous Medical and Other Applications sections. For your convenience and due to the technical subject matter, some of the information is repeated.

Chemical Process of Sodasorb CO_2 Absorption

Sodasorb absorbent is a proprietary mixture of calcium hydroxide, sodium hydroxide and water.

Hydroxides are used in acid gas absorption because they are efficient, stable, and can be easily handled. They are derived from alkalies and alkaline earth metals and are the most efficient absorbers of carbon dioxide available.

The absorption of carbon dioxide (CO_2), or of any acid gas, by Sodasorb absorbent is a chemical process, not a physical one. The reaction is quite different from absorption by activated carbon, for example, which involves physical entrapment of gases.

In Sodasorb absorption, the CO_2 first reacts with water to form carbonic acid, subsequently reacting with the hydroxide to form soluble salts of sodium carbonate. The soluble salts then react with the calcium hydroxide to form insoluble calcium carbonate. By-products include both heat and water.

Neutralization of CO_2 by Sodasorb may be expressed by the following equations:

(i) $CO_2 + H_2O \longleftrightarrow H_2CO_3$

(ii) $2H_2CO_3 + 2NaOH \longrightarrow Na_2CO_3 + 4H_2O + \text{Heat}$

(iii) $2Ca(OH)_2 + Na_2CO_3 \longrightarrow 2CaCO_3 + 2NaOH + \text{Heat}$

In (reaction I) the CO_2 dissolves at a rate governed by a number of physical chemical factors. The rate is not proportional to the partial pressure of the CO_2 which is in contact with the film of moisture coating the Sodasorb pellets, but is greater because some of the CO_2 combines chemically with the water to form carbonic acid. The rate is directly proportional to the rate of removal of H_2CO_3 from solution by reaction with active hydroxide (reaction ii). Thus, the rapidity of removal of combined CO_2 is directly related to the availability of active hydroxide. Since the reaction between H^+ and OH^- is instantaneous, forming water, reaction (ii) is extremely rapid and active hydroxides are quickly exhausted. Hence, equation (iii) must supply additional active hydroxide to keep the absorption of CO_2 progressing. The last reaction is, therefore, rate limiting.

Most carbon dioxide absorbents contain dissociated sodium hydroxide (NaOH) and/or potassium hydroxide (KOH) which can damage tissue. Care should be taken to avoid direct physical contact or inhalation during use.

To assure adequate absorption of CO_2 under normal use conditions, including both sufficient total capacity and rapidity of reaction, a prime requirement is smoothness and evenness of the reaction. Our studies have shown that optimum absorption occurs when moisture content is between 12 and 19%. Below this range, absorptivity is slowed, and above 20% the rate is also slowed, but to a lesser degree. Moisture content can vary significantly; flushing with dry gas will dehydrate soda lime, while high CO_2 concentrations entering the absorber generate large quantities of water (reaction ii).

The relationship between caustic content and CO_2 absorbent activity is not clearly defined. Activity increases as caustic content rises to 3%, beyond which the rate of absorptivity continues to increase, but more slowly.

Rate of CO_2 Absorption in Sodasorb Absorbent

In a properly packed and well designed canister, approximately 100 grams of Sodasorb will absorb 15 liters of carbon dioxide before the exit gas exceeds 1% carbon dioxide (CO_2). This assumes no significant amount of channeling through the absorbent. Hence, for an eight hour capacity, a canister should hold approximately 1 kilogram of Sodasorb absorbent.

High gas flows may impair the efficiency of CO_2 absorption, if caking or decreased wetting of the Sodasorb absorbent occur.

When residence time (time of contact between CO_2 and absorbent) is less than 1 second, CO_2 absorption capacity is greatly reduced.

Exothermic Heat Generation

The chemical reaction of carbon dioxide with a strong base such as Sodasorb is exothermic, the heat of neutralization approximating 13,500 calories with the absorption of each gram molecular weight of carbon dioxide (44 grams or 22.4 liters). This heat is not evenly distributed throughout the canister because the reaction itself is zonal.

Heat or reaction does not appear to affect absorptive efficiency. Rising temperature indicts that carbon dioxide absorption is proceeding, but there is little direct correlation between the heat generated and the amount of absorptive activity. Warmth of the canister, therefore, should not be relied on as an index of the amount of absorption taking place.

A steep temperature gradient between the canister and the ambient air may result in proportionately rapid dissipation of the canister's heat of reaction. Ordinarily, the canister will remain warm to the touch long after the Sodasorb absorbent has been exhausted. This is especially the case when the canister is made of glass or plastic. A warm canister is not, in itself, a reliable sign of reactive capacity.

A cool canister usually indicates the absence of chemical activity and inadequate absorption. The user should rely primarily on a CO_2 monitor and time and volume calculations for determining the usefulness of the Sodasorb charge.

Physical Process of CO_2 Absorption

Granular Efficiency - The availability of active hydroxide for CO_2 absorption is limited by the amount of calcium hydroxide ($Ca(OH_2)$ close to the absorbent surface which can regenerate active hydroxide from sodium carbonate (Na_2CO_3) (reaction iii on page P-2). Hence, the larger the surface area or the more porous the granular solid, the larger the capacity of the system to absorb carbon dioxide. This was empirically developed in the Grace laboratories and verified independently by other scientists.

Sodasorb pellets have highly porous surfaces, which expose a greater area of absorbent surface. As a result, more surface is available for the absorption of CO_2 and the mass of pellets is highly permeable to gas flow.

Sodasorb absorbent is produced to provide pellets having maximum surface area, hardness, and toughness for resistance to abrasion, uniformity in mesh size, and consistency in quality.

Air Flow Resistance - All absorber systems should be checked before use to insure proper air flow characteristics. Flow resistance varies inversely with particle size. That is, the finer the pellets, the greater the surface area exposed to air flow. When the space between the pellets is small, there is more resistance to flow. Large particles offer less resistance, but have the disadvantage of providing a smaller total area for reaction.

There is a wide range of user conditions and no single pellet size could be expected to meet all requirements. The most commonly used size today is 4-8 mesh material, which is used predominantly in medical equipment. However, Sodasorb absorbent can be manufactured into relatively large pellets or as a fine powder.

The user must choose a specific granular size, based on their requirements for absorbing specific carbon dioxide concentrations with varying air flow velocities and flow patterns. There are also special absorber or scrubber apparatus requirements.

Proper Filling of the Absorber Unit - Efficient removal of carbon dioxide is largely dependent upon the proper packing of Sodasorb in the absorber canister. If the shape of the canister is complex, the uniform distribution of the airflow through the absorbent will be difficult. A small space at the top of the Sodasorb compartment, to aid in initial distribution of the airflow, is recommended.

Shake all canisters prior to use to insure that pellets are not clumped together and that an even distribution of pellets fills the canister. Channeling will most likely occur when the canister is hastily or unevenly packed.

When using Indicator Sodasorb, the canister wall should be transparent, permitting visual inspection of the progressive exhaustion of the absorbent. Wall channeling is also readily apparent, permitting repacking of the canister before inefficient absorption occurs.

Sodasorb Carbon Dioxide Absorption Capacity

Absorbent Exhaustion Indicator

To signal the progressive exhaustion of Sodasorb absorbent, ethyl violet color indicator dye, a sensitive acid-base indicator, is added during manufacture. The Indicator Sodasorb changes from white to purple as absorption proceeds, full exhaustion being indicated by a deep purple color. Presence of the indicator does not affect absorption.

It should be noted that, since the neutralization reaction is not uniform throughout the canister, color change is also not uniform. The zone of greatest reactivity in a circle apparatus canister is largely at the inlet end and in a parabolic central cone. The color showing through the transparent wall of the canister, or through the inspection window, requires experience for correct interpretation.

Intermittent use of Sodasorb absorbent should be allowed for, because the reversion action of Sodasorb will in a brief time cause the purple to revert to white. This means that when color shows vividly the Sodasorb is consumed; when little or not color shows, there is at least some absorptive capacity, but the amount is indeterminate and may in fact be very small. Color indication is an adjunct guide to be used in connection with CO_2 monitors and time and volume calculations.

Ethyl violet indicator dye is a particularly effective indicator for use with Sodasorb absorbent, its critical pH being 10.3. As the strong caustic sodium hydroxide (NaOH) is consumed and is replaced by the weak base calcium hydroxide, the color change reflects the falling pH in the canister. The color change is usually sharp enough to be conspicuous even under low lighting conditions.

Color Reversion

Color reversion is the phrase used to describe the change in color of exhausted Sodasorb absorbent from purple to white when allowed to sit idle for a few hours or more. In the past, the term regeneration of soda lime has been incorrectly used to describe this process.

This color reversion is the result of subsurface calcium hydroxide regenerating active hydroxide at the surface of the pellet. This alters the pH of the surface and, consequently, causes the indicator dye to revert back to white, even though the Sodasorb absorbent may be near exhaustion.

Soda lime does not regenerate. Instead, there has been a reversion of the indicator dye from purple to white. Although there may be some additional carbon dioxide uptake due to the migration of these hydroxides, the absorptive capacity of soda lime, previously saturated with CO_2, is minimal and should not be relied upon, even if the color of the pellets has reverted to white.

It is important, therefore, for the user to determine how much absorptive capacity is left in Sodasorb absorbent immediately at the end of its use. If Indicator Sodasorb absorbent is used, visual inspection will help determine the remaining absorptive capacity. If you are not sure how much absorptive capacity is left in the Sodasorb absorbent, it should be changed. Carbon dioxide monitors and time and volume calculations should also be used to determine remaining CO_2 absorbent capacity.

Commercial Specifications

Sodasorb absorbent is produced for a variety of applications, including medical, underwater diving, and industrial uses. The most common grade is 4-8 mesh, Indicator, High Moisture Sodasorb, although the user can choose from a range of physical specifications.

Appearance

A slight discoloration (off-white, gray or tan) may occur due to the natural variability of the raw materials. Nonetheless, all product meets or exceeds soda lime specifications as set forth in the United States Pharmacopoeia-National Formulary (U.S.P.-N.F.).

Pellet Size

Mesh size describes a particular pellet size. Mesh refers to the number of openings per linear inch in a sieve through which the pellet particles are measured.

The relationship between mesh size (also referred to as screen size) and pellet size is inverse; the higher the mesh size, the smaller the pellet size, and vice versa. Sodasorb pellets are supplied in various sizes. However, for most uses, the standard pellet size is defined as 4-8 mesh. The United States Pharmacopoeia-National Formulary (see page 66) prescribes the standard mesh size to be 4-8 and, consequently, this is the grade most widely used.

Smaller pellets can be supplied for special needs, primarily for industrial or experimental laboratory environments. Smaller pellets are used when the flow resistance is either not important or can be overcome by a strong air flow. Sodasorb fines (i.e., almost a salt-like pellet) have been used to absorb carbon dioxide and neutralize acid based vapors.

Industrial Sodasorb Absorbent

All grades of Sodasorb absorbent, regardless of pellet size or moisture content, are available either with or without the ethyl violet color indicator dye. The ethyl violet dye changes the Sodasorb absorbent color from white or near-white to a distinct and deep purple as its carbon dioxide absorptive capacity is exhausted.

Ethyl violet indicator color dye is acid based, and remains colorless in unused Sodasorb absorbent, which is still strongly alkaline. As the indicator dye is exposed to carbon dioxide (or other acid gases), it becomes less alkaline, triggering a color change from white to distinct purple. Color change has been the primary indicator of Sodasorb exhaustion for most of this century, however, color change should only be used as an adjunct guide to more accurate CO_2 monitors and time and volume calculations.

Moisture Grades

There are two types of moisture grades available for Sodasorb absorbent: High (12-19% water content) and Low (less than 7% water content). Other moisture grades may be available upon request.

High moisture content is the standard as prescribed in the United States Pharmacopoeia-National Formulary and is how most Sodasorb absorbent is supplied. High moisture Sodasorb absorbent is recommended for most medical applications, because it is at equilibrium with gases having a relative humidity of 85% at normal temperatures, the physiological standard.

Low moisture Sodasorb absorbent is most often used in veterinary applications involving large animals whose exhaled breath contains a much higher moisture content than humans.

Non-Indicating Sodasorb Absorbent

Non-indicating Sodasorb absorbent refers to that material that has no ethyl violet color indicator dye, and obviously will not change color as carbon dioxide absorption capacity is depleted. This non-indicating material is recommended only for applications where visual cues to material exhaustion are not important or necessary.

Packaging

Sodasorb absorbent is available in a variety of air tight containers designed for speed, safety, and convenience.

Medical Applications - Specific packages have been designed for medical applications, including:

Pre-Pak -

A pre-filled, disposable plastic cartridge designed for easy insertion into Ohmeda, Dräeger, and other machines currently available in the United States. Packaged in a shrink-wrapped film, the Pre-Pak package requires no pouring and minimal cleaning of the absorber unit canisters.

Canister Pak –

This foil-lined bag contains sufficient material to fill the popular 1,350 gram canister. The bag is completely air-tight and easy to pour. The empty bag is readily disposable.

Pail –

This durable, all-plastic 5-gallon 37 lb. pail is equipped with a handy, plastic, pull-out spout to facilitate easy pouring.

Government Packaging - The U.S. Government has established National Stock Numbers and requirements based on Sodasorb standards:

Pre-Pak	NSN# 6505-01-362-8311
Canister Pak	NSN# 6505-00-687-3562
Pail, 5 gallon	NSN# 6505-00-687-3564
High Performance (HP)	NSN# 6810-01-113-0110

Underwater Applications Packaging - High Performance (HP) Sodasorb is specifically formulated for CO_2 absorption in underwater habitats, closed circuit scuba apparatus, manned submersibles, tourist submarines, and hyperbaric chambers.

HP Sodasorb is available to the underwater diving industries in the following packages:

Package	Net Weight	Gross Weight
Pail, 5 gallon	37 lbs/16.8 kg	40 lbs/18 kg
Canister Pak (1640 cc)	2.8 lbs/1.3 kg	36 lbs/16.4 kg

Industrial Packaging - For industrial applications, Sodasorb absorbent is available in a variety of packages. Standard packages range from 1 kilogram, foil-lined, paper bags (CanisterPak) to 30 gallon fibre drums holding 210 lbs of material. If you require non-standard containers, contact
W. R. Grace to arrange for special packaging.

Table 1. Sodasorb Packaging*

Container	Moisture Grade	Container Volume	Net Weight Each	Packages (Per Carton)	Gross Weight (Per Container)
Medical Sodasorb Absorbent					
4-8 USP Mesh					
Pre-Pak	High	1360cc	2/5 lbs/1.1 kg	12	35 lbs/15.9 kg
Canister Pak	High	1640cc	2.8 lbs/1.3 kg	12	36 lbs/16.4 kg
	Low	1640cc	2.3 lbs/1.0 kg	12	32 lbs/14.5 kg
Canister Pak (Kilo Pak)	High	1000cc	2.2 lbs/1.0 kg	12	29 lbs/13.2 kg
Pail	High	5 gal	37 lbs/16.8 kg	1	40 lbs/18 kg
	Low	5 gal	31 lbs/14.1 kg	1	36 lbs/16 kg
Fibre Drum	High	30 gal	210 lbs/95 kg	1	220 lbs/100 kg
	Low	30 gal	175 lbs/80 kg	1	190 lbs/86 kg
6-12 USP Mesh					
Pail	High	5 gal	37 lbs/16.8 kg	1	40 lbs/18.2 kg
	Low	5 gal	31 lbs/14.1 kg	1	35 lbs/15.9 kg
Fibre Drum	High	30 gal	210 lbs/95 kg	1	220 lbs/100 kg
	Low	30 gal	175 lbs/80 kg	1	190 lbs/86 kg
High Performance (HP Sodasorb Absorbent					
4-8 USP Mesh					
Pail	High	5 gal	37 lbs/16.8 kg	1	40 lbs/18 kg
Canister Pak	High	1640 cc	2.8 lbs/1.3 kg	12	36 lbs/16.4 kg

Note - Call for non-standard packaging
*All weights expressed as average container weights

Specifications and Test for Sodasorb Absorbent

United States Pharmacopeia-National Formulary (U.S.P.-N.F.) specifications establish the standard for composition and performance of medical soda lime.

To insure that each batch of Sodasorb absorbent meets or exceeds these specifications, the Grace quality assurance laboratory prescribes a variety of tests. The critical physical properties to be tested are those of moisture content, particle size distribution, and hardness.

Chemical tests include the carbon dioxide absorbency test prescribed by the U.S.P.-N.F. and a laboratory method for measuring efficiency devised by Grace. In addition, to verify the efficiency of packaging techniques, random samples of packaged Sodasorb absorbent are routinely tested prior to commercial distribution.

Moisture Content

High Moisture Grade - The moisture content of the standard Sodasorb absorbent is manufactured between 12-19%. This is determined by intermittent testing during the manufacturing process in which a 20 gram sample is placed in a drying oven, then weighed. The water loss is calculated as a percentage of the original weight.

Low Moisture Grade - Low moisture Sodasorb absorbent can be manufactured between 0-7% moisture content and is tested the same way as the high moisture grade.

Testing for Granular Size Distribution

Grace's manufacturing standards for 4-8 mesh Sodasorb, standard grade material, permit a maximum of 7% oversize particles (those retained by a #4 screen) and 7% undersize (those passed by a #8 screen). The proportion retained by a #6 and #8 screen must, in each instance, be less than 65 percent.

The test is made by agitating a 200 gram sample for five minutes in a Ro-Tap™ machine at the standard 1750 rpm, using #4, #6, and #8 screens and a fines pan. To meet Grace's standard for mesh size distribution, Sodasorb absorbent must be of optimum composition as regards resistance to airflow, and of optimum particle size to provide surface area available for CO_2 absorption. These standards, along with that for hardness, assure that any abrasion due to handling and shipping will not substantially alter the flow and absorption characteristics of the product.

Testing for Hardness

The hardness of Sodasorb absorbent is a major consideration, even though hardness has only an indirect relationship to absorptive efficiency. If the Sodasorb absorbent is too soft or friable, it physically breaks down during transportation producing an excess of undersize particles and dust. Minimum desirable hardness has been determined by the Grace quality control lab to be no less than 80 on a scale of 100.

Grace testing involves using only material retained on the #6 and #8 screens, thus rejecting both oversize and undersize particles. A 50 gram sample is placed in a steel cylinder having a close-fitting piston and subjected to hydraulic pressure at 45 lbs. gauge pressure for one minute. The contents of the cylinder are then placed on a #10 screen in a Ro-Tap machine and agitated. The material retained by this screen must weigh over 40 grams, which should be over 80% of the weight of the original sample.

The pressure test now used was developed in the Sodasorb quality control lab to replace a much slower abrasion test method, still commonly used elsewhere.

Abrasion Test

A 50 gram sample of Sodasorb particles retained on #6 and #8 screens, together with 15 ball bearings of 5/16 inch diameter for grinding balls, is agitated in a steel pan, in a Ro-Tap testing machine, for 30 minutes. The ground material is then placed on a #8 screen and agitated in the Ro-Tap. Retention of not less than 80% of the original sample weight is required for acceptability. The abrasion test and the newer Sodasorb pressure test for hardness show excellent correlation in parallel testing.

Chemical Test

To prove compliance with U.S.P.-N.F. requirements, a sample weighing 10 grams is placed in a U-tube, together with calcium chloride ($CaCl_2$) for trapping the moisture produced by the neutralization reaction. After the U-tube is weighed, CO_2 is run through for 20 minutes from the Sodasorb side, and the tube allowed to cool. Weighed again, the increase must be at least 19%, representing the minimum permissible quantity of CO_2 which any soda lime labeled U.S.P.-N.F. must absorb. Actual figures for Sodasorb absorbent are appreciably higher.

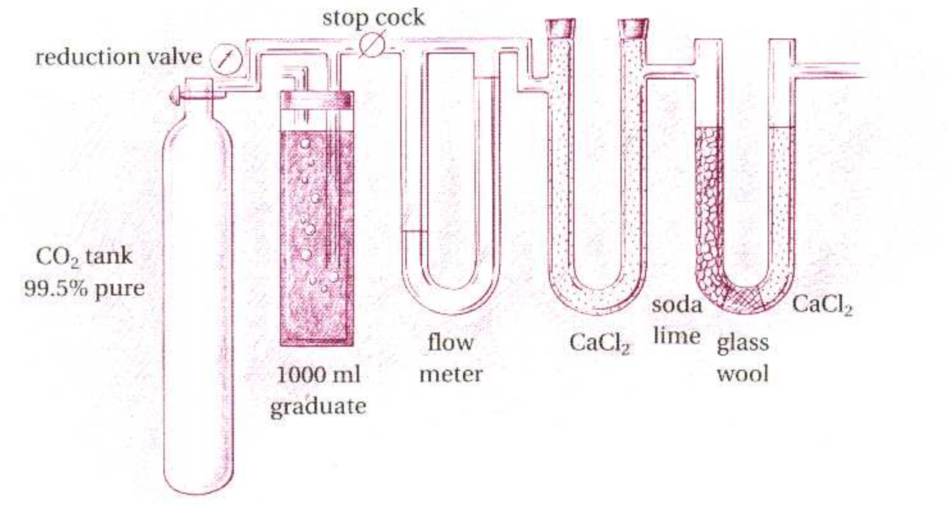

Figure 1. U.S.P.-N.F. Test Apparatus - U.S.P. Test Protocol. To prove compliance with U.S.P. requirements a sample weighing 10 g is placed in a U-tube, together with $CaCl_2$ for trapping the moisture produced by the neutralization reaction. After the U-tube is weighted, CO_2 is run through for 20 minutes, from the Sodasorb side, and the tube allowed to cool. Weighed again, the increase must be at least 19 percent, representing the minimum permissible of CO_2 which any sodalime labeled U.S.P. must absorb. Actual figures for Sodasorb are appreciably higher.

Efficiency Test

While the U.S.P.-N.F. test for CO_2 absorption measures Sodasorb absorbent's ability to absorb pure carbon dioxide over a short period of time, Grace's efficiency test is used to more accurately measure differences in effective absorptive capacity per unit of weight.

The test apparatus consists of a temperature controlled cavity which is uniformly packed with a weighed, uniform particle size sample of Sodasorb absorbent. A constant flow of 4% carbon dioxide is passed through the cavity. The effluent gas is monitored using a recording infrared analyzer. When the effluent CO_2 reaches 0.5%, the test is ended and the time per unit weight of Sodasorb absorbent is recorded.

U.S. Pharmacopeia XXII - National Formulary XVII Requirements

Carbon Dioxide Absorbents

The efficient absorption of carbon dioxide is of critical importance in operating apparatus used for administering anesthetic gases and oxygen, and for determining the metabolic rate through measurement of the respiratory exchange. For this reason, U.S. Pharmacopeia-National Formulary standards are provided in this section for soda lime carbon dioxide absorbent.

Soda Lime

Soda lime is a mixture of calcium hydroxide and sodium or potassium hydroxide, or both. It may contain an indicator that is inert toward anesthetic gases such as ether, cyclopropane, and nitrous oxide, and that changes color when the soda lime no longer can absorb carbon dioxide.

Identification - A. Place a pellet of it on a piece of moistened red litmus paper: the paper turns blue immediately. B. A solution of soda lime in acetic acid responds to tests for Calcium. It also imparts a yellow color to a non-luminous flame which, when viewed through cobalt glass, may show a violet color.

Size of Granules - Screen 100 gm of soda lime for 5 minutes as directed under *Powder Fineness - Method for Determining Uniformity of Fineness* using a mechanical shaker. It passes completely through a No. 2 standard-mesh sieve, and not more than 2.0% passes through a No. 40 standard-mesh sieve. Not more than 7.0% is retained on the coarse-mesh sieve, and not more than 15.0% passes through the fine-mesh sieve designated on the label.

Loss on Drying - Weigh accurately, in a tarred weighing bottle, about 10 gm, and dry at 105°C for 2 hours: it loses not less than 12.0% and not more than 19.0% of its weight.

Moisture Absorption - Place about 10 gm in a tared, 50 ml weighing bottle having a diameter of 50 mm and a height of 30 mm, and weigh. Then place the bottle, with cover removed, for 24 hours in a closed container in which the atmosphere is maintained at 85% relative humidity by being in equilibrium with sulfuric acid having a specific gravity of 1.16. Weigh again: the increase in the weight is not more than 7.5%.

Hardness - Screen 200 gm on a mechanical sieve shaker having a frequency of oscillation of 285±3 cycles per minute, for 3 minutes, to remove pellets both coarser and finer than the labeled particle size. Weigh 50 gm of the pellets retained on the screen, and place them in a hardness pan of the following description: the hardness pan has a diameter of 200 mm and a concave brass bottom, and the bottom of t he pan is 7.9 mm thick at the circumference and 3.2 mm thick at the center and has an inside spherical radius of curvature of 109 cm. Add 15 steel balls of 7.9 mm diameter, and shake on a mechanical sieve shaker for 30 minutes. Remove the steel balls, brush the contents of the hardness pan onto a sieve of the fine-mesh size designated on the label, shake for 3 minutes on the mechanical sieve shaker, and weigh: the percentage of soda lime retained on the screen is not less than 75.0, and represents the hardness.

Carbon Dioxide Absorbency - Fill the lower transverse section of a U-shaped drying tube of about 15 mm internal diameter and 15 cm height with loosely packed glass wool. Place in one arm of the tube about 5 gm of anhydrous calcium chloride, and accurately weigh the tube and the contents. Into the other arm of the tube place 9.5 gm to 10.5 gm of soda lime, and again weigh accurately. Insert stoppers in the open arms of the U-tube, and connect the side tube of the arm filled with soda lime to a calcium chloride drying tube, which in turn is connected to a suitable source of supply of carbon dioxide. Pass the carbon dioxide through the U-tube at a rate of 75 ml per minute for 20 minutes, accurately timed. Disconnect the U-tube, cool to room temperate, remove the stoppers, and weigh: the increase in weight is not less than 19.0% of the weight of soda lime used for the test.

Packaging and Storage - Preserve in tight containers. Do not expose packaging to harsh environmental conditions.

Labeling - If an indicator has been added, the name and color change of such indicator are stated on the container label. The container label indicates also the mesh size in terms of standard-mesh sieve sizes.

SAFETY, HANDLING AND STORAGE

Safety and Handling Considerations

Sodasorb carbon dioxide (CO_2) absorbent is a pellet mixture of hydrated lime ($Ca(OH)_2$) and a small quantity of sodium hydroxide.

Read the Material Safety Data Sheet (MSDS) for Sodasorb absorbent before handling or using the product (see pages S-4). The following comments are provided to offer a perspective on safety and handling concerns, but should not be used as a substitute for the detailed information on the MSDS.

Shipping Regulations

Sodasorb absorbent is non hazardous as defined in the Hazardous Materials Transportation Act and U.S. Department of Transportation regulations contained in 49 CFR. It can be safely transported by land, sea, or air, and does not require any special shipping warning.

First Aid Treatment

Inhalation - Dust can cause irritation to the respiratory system. Remove affected person to fresh air. Get medical attention after first aid if irritation continues.

Skin Contact - Direct contact can cause skin irritation. Thoroughly wash the affected area with large amounts of water. Get medical attention after first aid if irritation continues.

Eye Contact - Severe irritation upon contact. Flush eyes immediately with water for a minimum of 15 minutes. Get medical attention after first aid if irritation continues.

Ingestion - Harmful if swallowed. Ingestion of soda lime can cause burns of the mucous membranes of the mouth, throat, esophagus, and stomach. *Do not induce vomiting.* Administer large quantities of water or milk. Get medical attention after first aid if irritation continues.

Filling the Canister

Pre-filled Packages - Sodasorb absorbent is supplied in factory pre-filled, plastic disposable cartridges for easy insertion in popular anesthesia machines. Pre-Pak cartridges provide a safe and convenient package for anesthesia machine absorber units.

Bulk Packaging - All personnel handling Sodasorb absorbent should be advised that it is caustic. Protective clothing including gloves, goggles, and masks should be used when handling loose Sodasorb absorbent.

In order to fill a canister properly with loose Sodasorb absorbent, pour the material into the canister while it is slowly rotated, stopping occasionally to tap the canister to compact the pellets and distribute evenly. This technique assures absorptive efficiency by providing uniformity of the pellet mass, thus minimizing channeling. Always fill the canister according to manufacturer's recommendation.

Absorber Unit Instructions - Sodasorb absorbent is available for use in a variety of industrial absorber units. Fill the canister as directed by the equipment manufacturer using the Sodasorb bulk packaging guidelines described above.

Emptying the Canister

All personnel handling fresh Sodasorb absorbent should be advised that it is caustic, while used absorbent may have been saturated with bio-hazardous materials. Protective clothing including gloves, goggles, and masks should be used.

Replacement of Sodasorb Absorbent

Sodasorb absorbent should be replaced in accordance with the procedures established by the user. Since the color change from white to purple of Indicator Sodasorb is a signal of absorptive capacity exhaustion, the product can be carefully monitored when in use and changed after prescribed time intervals.

To avoid any under-capacity for absorption, use only fresh Sodasorb absorbent for each charge. Non-Indicating Sodasorb absorbent should always be discarded after every use.

Use with Flammable Anesthetic Agents

When a flammable anesthetic agent is used, take special precautions when emptying the canister. Substantial quantities of the anesthetic may be trapped between the Sodasorb pellets and present a serious fire hazard.

Discard this material in strict accordance with local fire prevention rules, e.g., remove any possible source of ignition and use a fire-safe container.

Storage

Storage in Warehouse – Store Sodasorb absorbent in a clean, dry environment. Avoid contact with other chemicals, acid, or water.

Sealed packages of Sodasorb absorbent are well protected against loss of moisture and have a shelf life of two years from the date of manufacture. An expiration date is marked on all packages. Once opened, packages are vulnerable to moisture loss, unless they are promptly and carefully resealed.

The moisture in Sodasorb, as well as other absorbents, will expand when frozen and result in some granule fragmentation and excessive dust. Packages which have been subjected to repeated freeze/thaw cycles should be examined closely for dust and discarded if questionable.

Indicator Sodasorb should not be stored under intense light, especially ultra-violet light, since this may degrade the ethyl violate indicator dye in Sodasorb absorbent.

Storage within the Anesthesia Machine – Carbon monoxide (CO) has been found to build up in unused anesthesia units.

If Sodasorb absorbent is left in the machine, the absorber unit should be sealed and airtight. Change Sodasorb absorbent which has been in an idle absorber unit for more than 48 hours.

Flush the anesthesia system with oxygen prior to use.

Avoid storage under intense lights. Indicator Sodasorb absorbent containing ethyl violet indicator is light sensitive and may be subject to photodeactivation. It has been demonstrated that prolonged exposure of the granules to high intensity lights will hasten the failure of the ethyl violet indicator in Sodasorb absorbent.

We recommend discarding any absorbent tinged with color. To avoid any under capacity for absorption, use only fresh Sodasorb absorbent for each charge.

Disposal

Disposal of used Sodasorb absorbent must be determined by the end user in compliance with federal, state, and local regulations. Specific disposal methods vary with the chemical (e.g., anesthetic agents, acid-based vapors, etc.) or biological agents used with the absorbent by the end user.

Unused Sodasorb absorbent is not a federally regulated hazardous waste under Resource Conservation and Recovery Act (RCRA) regulations. Consult state and local regulations prior to disposal of unused Sodasorb absorbent.

Consult safety information on the Sodasorb Material Safety Data Sheet.

INSERT MSDS

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