# PERFORMANCE OF ABSORBENTS: EFFECT OF MOISTURE

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Despite a number of studies of the importance of moisture in the absorption of carbon dioxide by soda lime, no decision has been reached regarding the optimum moisture content. Wilson [1] indicated that moisture was necessary in the reaction. Adriani and Rovenstine [2] found "low moisture" soda lime to be as efficient as "high moisture" soda lime in to-and-fro absorbers. Adriani reported [3] that in the circle system, absorption efficiency improved as the water content of the absorbent increased but, at 22 per cent moisture, the charge became water logged. Mousel, Weiss, and Gilliom [4] reported that clinically "low moisture" soda lime was less efficient and thought that regeneration was a result of rehydration from condensation of moisture on the lime. Letts [5] has re-examined production methods of soda lime manufacture and has indicated that the optimum moisture content was about 18 per cent (wet basis).

Of the two commercial sources of soda limes in this country, one is shipped at about 19 per cent moisture and the other at 15 per cent. Some moisture loss occurs during shipment and storage. The aim of this investigation was to determine whether the differences between the efficiencies of these two products can be accounted for by the differences in moisture content. In addition, we wished to examine the effect on activity of water logging the lime, thus filling up the pores and reducing the active surface. This condition has been observed in the larger absorbers after use.

## Methods

The commercial absorbents were dried to various moisture contents by heating in a convection ventilated oven at 140 C. for varying periods of time. They were hydrated by flowing oxygen humidified to 100 per cent relative humidity at 5 to 10 C. above room temperature through a loose bed of absorbent. During both the drying and the hydrating procedures, the absorbent was mixed thoroughly at frequent intervals.

Moisture content was determined by drying samples in the oven at 140 C. to constant weight. All data in this study are reported in terms of dry weight of lime in order to provide some uniform means of comparison.

Carbon dioxide absorbing capacity was determined by two methods.

*Continuous Flow Studies.* Absorption efficiency was studied by flowing 5 per cent carbon dioxide in oxygen through the absorbent contained in the $8 \times 13$ centimeter to-and-fro canister. Exit carbon dioxide concentration was monitored by an infrared gas analyzer. A gas flow rate of 20 liters per minute was used throughout these studies. Calibration and recording methods have been described previously.[6]

*Intermittent Flow Studies.* Performance in closed circle absorption systems was investigated at low and high moisture contents. An $8 \times 13$ centimeter to-and-fro canister in a Morris circle arrangement was contrasted with the upper half of a Roswell Park Absorber, the lower half containing completely exhausted lime. Standard test conditions were employed: 500 ml. tidal volume, 150 ml. dead space, 15 respirations per minute, and 300 ml. per minute carbon dioxide production rate.

## Results

The continuous flow studies showed definite deterioration in efficiency with low moisture content soda lime. The absorption wave appeared sooner in the exit carbon dioxide concentration as moisture content was decreased. The resistance to mass transfer ($R_{OG}$) of carbon dioxide was calculated and plotted against

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carbon dioxide absorbed per 100 grams of dry lime to show terminal failure (fig. 1). Terminal failure appeared to start at a resistance of about $7 \times 10^4$ atm./g.mol./cc./sec. which corresponds to an absorption rate of 3 per cent of the initial activity. The plot of carbon dioxide absorbed to this end point against per cent moisture showed a linear increase to a maximum at about 22.5 per cent (fig. 2). Above this maximum, the capacity of Soda Sorb decreased slightly and linearly up to 32.5 per cent moisture. Indicating Soda Lime exhibited a rounded peak in absorption capacity and the quantity of carbon dioxide absorbed decreased precipitously above the maximum. Some activity was exhibited by completely dry lime. Moisture content of the exhausted lime tended toward 5 per cent with an increase for completely dry lime and a decrease for lime initially of higher moisture content.

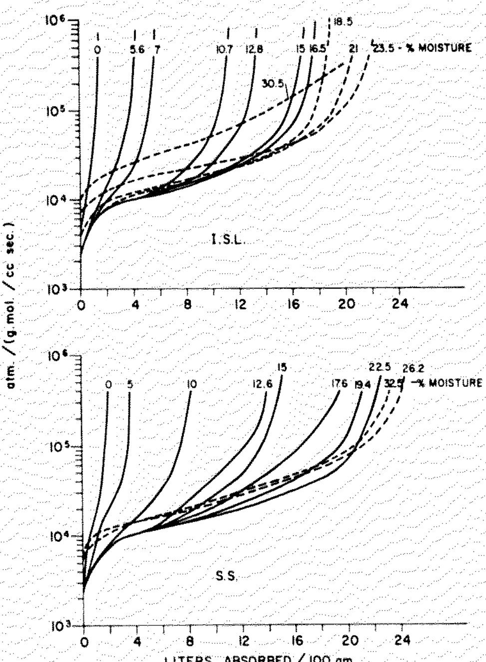


Fig. 1. Effect of initial moisture content on the exhaustion rate of soda limes with continuous gas flows of 5 per cent carbon dioxide in oxygen. Upper figure (I.S.L.), Indicating Soda Lime; lower figure (S.S.), Soda Sorb. Dotted curves are hydrated lime; solid curves are partially-dried limes. Numbers at upper end of each curve indicate per cent moisture (dry basis).

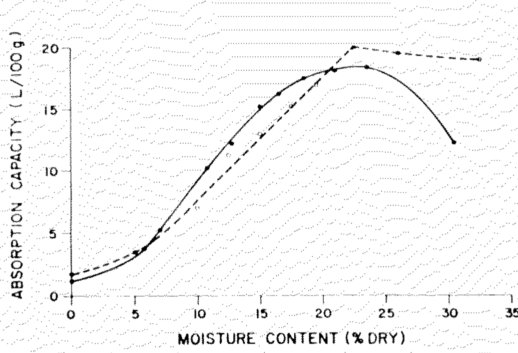


Fig. 2. Effect of initial moisture content on absorption efficiency with continuous gas flow. Solid curve, Indicating Soda Lime; dashed curve, Soda Sorb.

Lime which had been hydrated in excess of the above maximum had a lowered initial activity (fig. 1). However, the rate of exhaustion was the same or slower than the original product. Thus, hydration of Indicating Soda Lime improved its life for moisture contents up to 23.5 per cent.

In the closed circle absorbers, the absorption capacities were compared at an endpoint of 1 per cent inspired carbon dioxide. In the larger absorber, Soda Sorb at its original moisture content had an absorption capacity of 23 liters of carbon dioxide per 100 grams of dry lime compared to 19 liters for Indicating Soda Lime. In the smaller absorber, Soda Sorb had a capacity of 17 to 19 liters compared to 14.5 liters for Indicating Soda Lime. These were the largest capacities the limes exhibited. No change in absorption capacity was found for Indicating Soda Lime over the moisture content range from 10 to 25 per cent (fig. 3). Soda Sorb showed the same type of broad maximum but over a range of 12 to 32 per cent moisture. Superimposed on this broad maximum, a small peak appeared at a moisture content of 23 per cent. This peak is at the original moisture content of some batches of lime.

Baralyme had a broad but well-defined peak at about 23 per cent moisture with a maximum absorption capacity of 18 liters of carbon dioxide per 100 grams. The absorption capacity was not sustained as well at lower moisture contents as was the capacity of soda lime. This effect could be a result of melting of barium

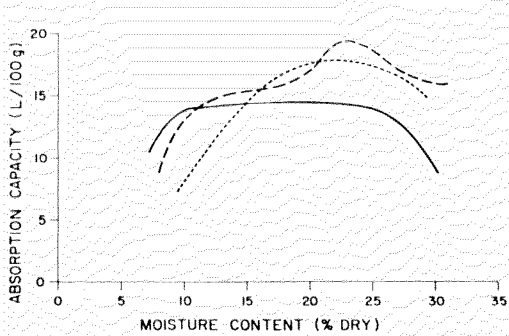


FIG. 3. Effect of initial moisture content on absorption efficiency in a closed circle system. Solid curve, Indicating Soda Lime; dashed curve, Soda Sorb; dotted curve, Baralyme granules.

hydroxide octahydrate (M.P. 78 C.) and occlusion of pores during the preparatory drying.

## DISCUSSION

Some alteration of the characteristics of the limes can be expected from the drying and hydrating procedures. Letts [5] found slight differences in absorbent life depending on whether the lime was dried to 28 per cent moisture wet weight, granulated, and further dehydrated, or dried to 3 per cent moisture, granulated, and then rehydrated. The latter process gave the longest life to the "break point." On this basis, the hydrated material should be slightly better than the dehydrated. However, no sharp break in the transition from hydrated to dehydrated lime was observed in our study.

The continuous flow data show a maximum in absorption capacity at a moisture content of about 22 per cent which agrees with the results of Letts.[5] Below this maximum, the rate of exhaustion was increased. The resistance to carbon dioxide absorption ($R_{OG}$) increased with the quantity of carbon dioxide absorbed, but the rate of increase in resistance was inversely proportional to the moisture content. Previous studies [6] indicate that the rate of absorption resistance ($R_{OG}$) increase is not related to the velocity of gas flow through the absorbent. Finally, all the limes were found to approach a moisture content of about 5 per cent. These data indicate that a drying process not related to gas velocity governs the rate of exhaustion.

Within the granules, approximately 13,500 calories are liberated for each mole of carbon dioxide absorbed. This energy raises the temperature in the reaction zone. Part can be removed by heating the gas passing around the granule. Part can be transmitted to the wall of the canister and radiated from this surface. These are slow processes and remote from the source of energy liberation. Most of the energy probably is employed in evaporating water in the granule. The large surface area facilitates this evaporation. The heat of reaction can provide enough energy to vaporize 25 grams of water for each mole of carbon dioxide absorbed. The water vapor diffuses out of the granule as the carbon dioxide diffuses in. The gas stream then carries it on through the absorbent. The activity of the granule decreases as the moisture content is reduced by evaporation, probably because the surface film of moisture is removed. At about 5 per cent moisture content, little activity remains and absorption essentially stops.

The initial activity of the absorbent was not affected by drying. Even the completely dry lime apparently picks up a surface layer of moisture on exposure to air. Capillary action provides a surface film of moisture when any moisture is present in the pores. This surface film provides enough moisture to support the high initial activity. As the surface film is evaporated by the heat of reaction, the activity decreases rapidly.

Above the optimum moisture content, the activity during the early part of exhaustion was reduced. About 80 per cent of the pore volume of the granules should be occupied by water at a moisture content of 22 per cent. Previous calculations [7] indicated that only the outer sixth of the surface area was used initially in absorption. When moisture filled the pores to a point where less than a sixth of the surface area was exposed, the activity was reduced as predicted. However, even when the pores were completely filled and water covered the surface of the granule, the absorption on the surface provided heat to evaporate the excess water. Although the initial activity was reduced, the activity decreased less rapidly than at lower moisture contents. Consequently, the water-logged lime lasted almost as long as that with optimum moisture content but its activity was lower throughout its useful life.

In the continuous flow experiments, the moisture is carried away continuously down the canister and has little chance to condense in the absorbent. Most condensed in the tubing beyond the canister. In the circle absorber system, moisture is conserved by the intermittent flow. The pause allows time for some heat radiation and for condensation of water in and beyond the absorption wave. This condensed water sustains the activity of lime in the absorption wave and improves the moisture content of lime further downstream.

A two-chambered reversible absorber was charged with "high moisture" lime in the active chamber and "low moisture" lime was used in the reserve chamber and for subsequent recharging. Efficiencies of 27.2, 21.1, 21.4, 20.0, 20.0, and 18.3 liters of carbon dioxide absorbed per 100 grams were obtained for successive charges. However, low moisture lime could not be used as the initial charge in the active chamber of a two-chambered absorber. Efficiencies of 4 liters of carbon dioxide per 100 grams of low moisture lime were obtained both in the $8 \times 13$ centimeter canister and in the two-chamber absorber. Not enough moisture was mobilized to rehydrate lime further downstream.

In these studies, Indicating Soda Lime consistently had a smaller absorption capacity than Soda Sorb or Baralyme. Moisture content was not the reason since in the circle system, the absorption capacity of Indicating Soda Lime was essentially unchanged over a moisture range of 10 to 25 per cent. Soda Sorb showed a small peak at 22.5 per cent moisture corresponding to the peak found in the continuous flow studies. Either the formulation or the processing must be implicated in the difference between these products.

From these results, our conclusions are the same as those of Adriani[4] in regard to the tolerable moisture content of soda lime in circle absorbers. The optimum moisture content of soda lime is somewhere between 10 and 22 per cent (wet basis). Baralyme, which contains at present about 5 per cent moisture as water of crystallization, must have water added to reach the range of moisture content providing efficient absorption.

The specification of moisture content should have as an upper limit the pore volume of the absorbent or about 25 per cent (dry basis). The lower limit should be based on a minimum of 12 per cent (dry basis) at the time of use. How to insure this minimum moisture content by specification is a problem. The container may be stored for an indefinite time before use. Some methods of packaging may retain moisture better than others. Probably each type of container should have its shelf life determined. Each package could then be stamped with an expiration date. Barring damage in storage, the absorbent would be expected to have a moisture content of more than 12 per cent up until the expiration date.

## Summary

A direct relationship between moisture content and absorption capacity for carbon dioxide was found in continuous flow experiments. Progressive dehydration by heat liberated in the reaction of carbon dioxide with the soda lime was implicated in the early exhaustion of the granules in continuous flow experiments. Absorption capacities were identical over a wide range of moisture contents in the closed circle absorber. In the closed circle system, the intermittent flow allowed condensation of the moisture in the absorbent so moisture was conserved. Drowning the absorbent by increasing the moisture content to a point where all the pores were filled reduced its activity but did not reduce the absorption capacity remarkably either in the continuous flow studies or in the closed circle system. When moisture content exceeded the pore volume, the activity and capacity were both reduced. Differences in the moisture content of the two brands of soda lime tested were not the cause of the slight differences found in their absorption capacities.

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**HEREDITARY DISEASES** The anesthetic problems posed by patients with familial dysautonomia have recently been reviewed by Kritchman, Schwartz and Papper. An increased anesthetic risk also exists in patients with the hepatic type of porphyria. This disease may be undiscovered until the patient exhibits untoward reactions to intravenous barbiturate anesthesia. Acute episodes of porphyria with paralysis and occasionally death have been precipitated with this agent. An increased anesthetic risk may also exist in patients with sicklemia, the carrier or heterozygous state of the gene for sickle cell anemia. Approximately 7 per cent of American Negroes have asymptomatic sicklemia. In such patients, partial anoxia induces changes in the erythrocytes which predispose to thrombosis and infarction. Thus, accidental hypoxia during anesthesia is particularly hazardous in this group. Further, patients with gout are likely to have acute exacerbations following any operative procedure, and it has also been suggested that patients with gargoylism react poorly to anesthesia. Anesthesia and chemotherapy in patients with hereditary diseases should be approached with caution. An unusual reaction, or idiosyncrasy, to an anesthetic or other drug may be an expression of a genetically determined inherent difference—perhaps some alteration of biochemical function such as specific enzyme deficiencies. (*Editorial: Anesthetic Dangers in Hereditary Diseases, J. A. M. A. 170: 564 (May 30) 1959.*)

**TONSILLECTOMY** Four case reports are presented of death during anesthesia for tonsillectomy or following tonsillectomy. In two of the four cases, anesthesia clearly was the major responsible factor. The causes of these deaths are discussed candidly, and the ethical basis of tonsillectomy is considered. " . . . the operation of T's and A's has such slender foundations and nebulous indications as to be quite unjustifiable when there is any chance of . . . fatal accident. . . ." (*Smith, M. E. N.: Death from Tonsillectomy, Lancet 1: 671 (March 28) 1959.*)