

PERFORMANCE OF ABSORBENTS: CONTINUOUS FLOW

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PREVIOUS studies indicated that the initial activity of carbon dioxide absorbents was high, and that while a large surface was available for absorption, only a small part of this area was active.¹ While these conditions may prevail initially, we are interested in the pattern of the fall in activity of the absorbent during its useful life.

Of particular interest is the effective absorption capacity for carbon dioxide of a given quantity of absorbent. While the theoretical absorption capacity can be calculated from the chemical composition, this capacity is seldom approached in practice. This study was undertaken to determine the effective absorption capacity of the carbon dioxide absorbents and to determine the effect of flow rate on this capacity.

METHOD

A continuous flow of carbon dioxide, 5.0 per cent in oxygen, humidified to 100 per cent relative humidity, was passed through various absorbents. The concentrations of carbon dioxide at the inlet and outlet were monitored continuously by rapid infrared carbon dioxide analyzers. Flow rates were maintained by monitoring with a rotameter. Carbon dioxide concentrations were recorded on a direct writing oscillograph. Absorbents were packed to a constant bulk density. Moisture content of the absorbent was determined to permit calculation of the active ingredients and the theoretical capacity of the absorbent.

RESULTS

The basic data for the several rates of flow through the 8 × 13 Waters to-and-fro absorber are typical "break point" curves (figs. 1, 2, and 3). For rapid flows, the "break point" appeared earlier. The shape of the curves changes with flow rate and a difference between the soda limes and Baralyme is apparent. To achieve a common denominator along the

time axis, the curves were replotted on the basis of total carbon dioxide absorbed per unit weight of absorbent. To achieve a common denominator in the vertical axis, the overall mass transfer coefficient was calculated¹ from the equation:

$$K'_o a = \frac{\dot{V} \ln (p_I/p_E)}{A L p_B}$$

where

- K'_o is the overall mass transfer coefficient,
- a is the surface area per unit volume,
- \dot{V} is the flow rate through the bed,
- p_I is the inlet partial pressure of CO₂,
- p_E is the partial pressure at the end of the bed,
- A is cross section,
- L is the length of the bed, and
- p_B is the absolute pressure of gas passing through the bed.

This calculation essentially eliminated the influence of flow rate and absorbent volume on the initial activity of the absorbent and subsequent activity for most of the absorbent life. To more readily compare the initial activities, the reciprocal of the overall mass transfer coefficient which is called the overall resistance to mass transfer ($R_{OG} = 1/K'_o a$) was used. The initial activities of the absorbents

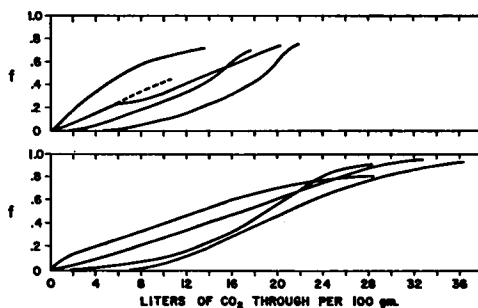


FIG. 1. Break point curves for Dewey and Almy Sodasorb. Upper set of curves—1957 lime, lower set—1958. Ordinate is fraction (f) of inlet carbon dioxide concentration appearing at exit. Flow rates 60, 40, 20, and 10 liters per minute from left to right.

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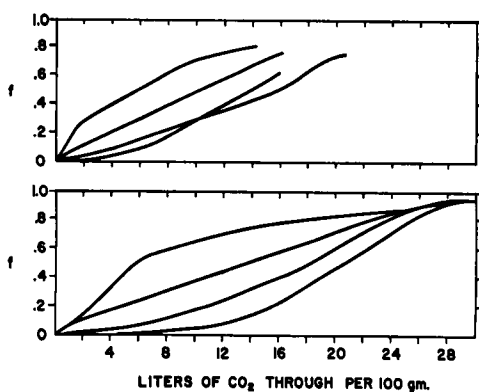


FIG. 2. Break point curves for Mallinckrodt Indicating Soda Lime. Upper set of curves—1957 lime, lower set—1958. Flow rates the same as figure 1.

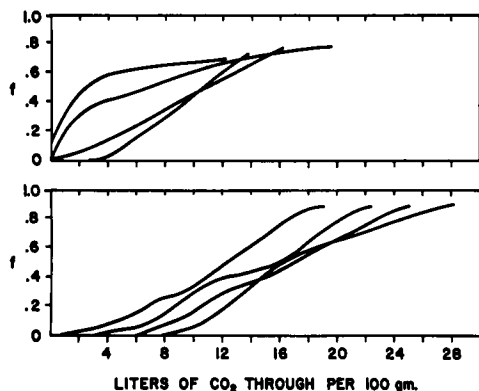


FIG. 3. Break point curves for Edison Baralyme. Upper set of curves—Baralyme pellets, lower set—Baralyme granules. Flow rates the same as figure 1.

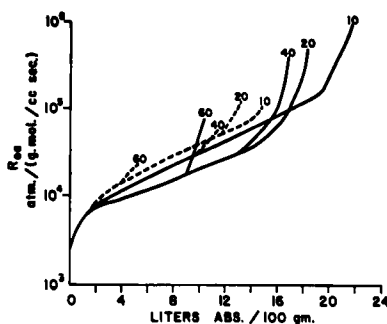


FIG. 4. Increase in resistance to absorption of carbon dioxide by Sodasorb during exhaustion. Dotted curves for 1957 lime, solid curves, 1958 lime. Overall mass transfer coefficient rises gradually along same path for all flow rates until point of terminal failure. Figures at the end of curves denote flow rates in liters per minute.

obtained by extrapolation to the start of absorption show Baralyme pellets to have an initial activity of 17×10^{-5} ; Soda Sorb and Indicating Soda Lime 39.5×10^{-5} ; and Baralyme granules, 78×10^{-5} g.mol./sec./cc.atm. The point of terminal failure of absorption was obtained from a plot of the logarithm of R_{00} versus total carbon dioxide absorbed per 100 grams of absorbent (figs. 4, 5, and 6).

These points of terminal failure could be correlated by the formula:

$$Q_F = Q_M(1 - k\bar{V})$$

where

Q_F was the total quantity of carbon dioxide absorbed to the point of terminal failure,

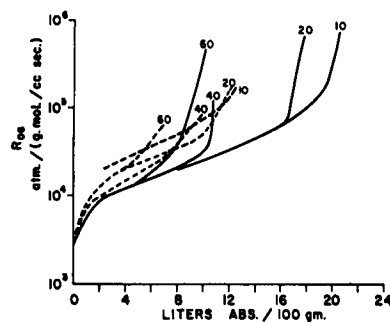


FIG. 5. Increase in resistance to absorption of carbon dioxide by Mallinckrodt Indicating Soda Lime during exhaustion. Dotted curves for 1957 lime, solid curves, 1958 lime. Figures at the end of curves denote flow rates in liters per minute.

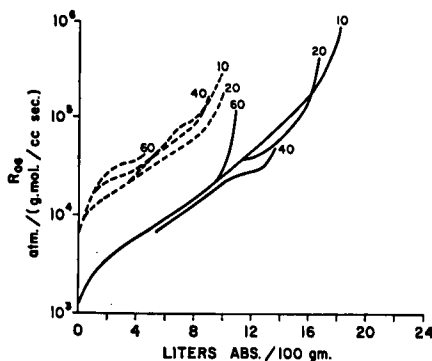


FIG. 6. Increase in resistance to absorption of carbon dioxide by Baralyme during exhaustion. Dotted curves for pellets, solid curves for granules. Figures at the end of curves denote flow rates in liters per minute.

TABLE 1
THEORETICAL AND MAXIMUM EFFECTIVE ABSORPTION CAPACITIES OF CARBON DIOXIDE ABSORBENTS

		Q_T (l./100 g.)	Q_M (l./100 g.)	k 1/l./minute	$Q_M/Q_T \times 100$ (per cent)
Mallinckrodt Indicating Soda Lime	1957	25.6	13.7	.012	54
	1958	25.6	20.6	.011	80
Soda Sorb	1957	24.4	16.2	.014	66
	1958	24.0	21.3	.010	89
Baralyme	Pellets	25.6	9.8	.004	38
	Granules	24.3	18.1	.008	74

Q_T = Theoretical capacity calculated from composition.

Q_M = Maximum effective absorption capacity.

The magnitude of k represents the decrease in maximum effective capacity produced by flow. $100 Q_M/Q_T$ is the maximum chemical efficiency in per cent.

Q_M was the maximum effective absorption capacity,

k was a constant for each absorbent, and
 \dot{V} was flow rate.

In table 1, the values obtained for the values k and Q_M for the various absorbents are listed.

DISCUSSION

Exhaustion of an absorber should be visualized in terms of the absorption wave.² This name has been given the orderly progression of the zone of most active absorption along the length of the absorption bed. The heat wave that runs down an absorber accompanies the absorption wave and the indicator change follows this wave. Carbon dioxide concentrations change markedly across the wave. The steepness of the change in carbon dioxide concentration will be a measure of the quality of the lime as Cara² suggested. It will also be a function of the linear flow rate through the absorbent with the wave spread out by high velocities of gas flow.

The volume of lime encompassed by the absorption wave at the various flow rates can be calculated (fig. 7). These values were obtained from the number of liters of carbon dioxide absorbed before appreciable carbon dioxide appeared in the exit gas to mark the appearance of the absorption wave. The change in shape, porosity, and composition in Baralyme reduced the volume of the absorption wave markedly. The absorption zone was decreased in volume from 260 cc. at 10 liters

per minute flow to 90 cc. at the same flow by changing from pellets to various types of granules. Soda limes at the same flow rate showed volumes of 150 to 220 cc. for the absorption zone. Improvements in maximum effective capacity through changes in composition had no effect on the volume of the absorption wave in the soda limes.

The terminal failure of the absorbent occurs when the absorption wave leaves the end of the canister. The carbon dioxide concentration in exit gas at this time is appreciable.

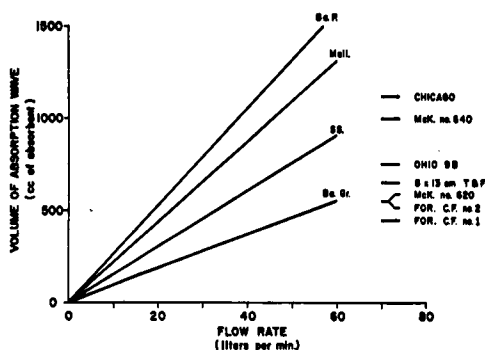


FIG. 7. Effect of flow rate on the volume of the absorption wave. Flow rates of 20 liters per minute during quiet breathing produce absorption waves exceeding the volume of smaller canisters. Volume of several absorbents in common use are indicated by horizontal bars at right. These include Chicago, McKesson No. 640, Ohio 9B, Foregger 8 x 13 cm. to-and-fro canister, McKesson No. 620, and Foregger circle filters no. 1 and 2. Absorbents were Baralyme pellets (Ba.P.), Indicating Soda Lime (Mall.), Soda Sorb (SS.), and Baralyme granules (Ba.Gr.).

Only the residual activity of the absorbent holds back carbon dioxide. The product kV in the equation for the quantity of carbon dioxide absorbed to the point of terminal failure represents the remaining available absorption capacity of absorbent behind the absorption wave.

The effective absorption capacities, Q_M , are considerably smaller than the theoretical capacities of the absorbent. Several factors could reduce the capacity of the absorbent below the theoretical: (1) Channeling or poor distribution of air flow could bypass active lime. (2) Drying by the airstream and heat of reaction could reduce activity. (A stream of gas humidified to 100 per cent relative humidity and then heated 50 degrees by the heat of absorption has a low relative humidity.) (3) Active absorbent may be so deep in the granule that the activity of the granule is essentially zero.

Some channeling occurs in the canisters employed but this is not a major reason for the reduction in capacity since a number of various sized and shaped canisters showed little variation in their Q_M . Breaking the pellets shows the indicator did not change at the very center of the granules even at the inlet. Moisture analysis of lime along the length of the canister shows the moisture to be low but fairly uniform throughout the length of the canister.

From the appearance of the exhausted granules and the uniform water content, the limitation in absorption capacity of a granule is believed related to diffusion. The outside of the granule and the surface of the pores near the outside are exhausted first. Thereafter, absorption of carbon dioxide must occur deeper in the pore system. The diffusion rate of carbon dioxide down the pores becomes a limiting factor and absorption slows. At apparent exhaustion, the pores in the center of the granule still have adequate moisture and activity but it requires too long a time for carbon dioxide to diffuse in. Resting allows hydroxide ions to diffuse throughout the granule and increase its overall activity. However, the unused lime is still buried in the center of the granule and when the small amount of hydroxide ion that migrated during the rest period is used up, the activity drops again.

In several cases the absorbent that had been carried to terminal failure in a continuous flow run was rested overnight and run again. The initial activity of this used absorbent was as high as fresh absorbent. However, terminal failure occurred after less than a liter more carbon dioxide had been absorbed per 100 grams. Thus, regeneration was successful in extending the capacity of the absorbent but not markedly.

From these data, terminal failure can be expected in an absorber after 15 to 20 liters of carbon dioxide have been absorbed by each 100 grams of absorbent. The average adult patient produces about this amount of carbon dioxide per hour. Thus, somewhat less than an hour could be expected from each 100 grams of absorbent charged. However, other factors relating to the breathing pattern may affect the absorption capacity in the absorber applied to the patient undergoing surgery.

SUMMARY

The total quantity of carbon dioxide absorbed per 100 grams of absorbent to the point where the absorption was extremely inefficient was determined in standard canisters for various rates of flow. The differences between these quantities for the several flow rates were directly related to changes in flow rate. By extrapolation, the quantity absorbed for zero flow rate where the absorption would be most complete was obtained. This quantity which is the maximum effective capacity of the absorbent was about 80 per cent of the theoretical capacity. The maximum effective absorption capacity of 100 grams of absorbent equalled the volume of carbon dioxide excreted by the average adult patient in one hour.

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