THE ACTIVITY AND SURFACE AREA OF FRESH SODA LIME

E. S. Brown, M.D.

Recent advances in absorption theory have eliminated the need for tedious empiric methods in the design of absorption equipment. It would seem timely to apply this modern approach to the problem of carbon dioxide absorption in anesthesia. In the development of the to-and-fro absorber, Waters achieved an efficient design established by extensive clinical trials (1). More than a decade later, the performance of Water's absorber was tested in the laboratory and found superior to other possible shapes and sizes (2). In recent years, a different system, the circle, has become commonplace in various designs which depart radically from that of the cylindrical to-and-fro. It would appear worth while to base absorber design upon a consideration of the properties of the absorbing material on the one hand and the requirements derived from the patient's breathing on the other.

To obtain data for application of this absorption theory to design of absorbers for anesthesia, a number of studies have been undertaken in our laboratories. This report presents data pertinent to the initial activity of high-moisture soda lime.

Theory

In the absorption of a gas by a liquid there is a transfer of material from the gas phase to the liquid phase where reaction takes place. The transfer is accomplished by diffusion gradients. For absorption of carbon dioxide by lime slurry containing sodium hydroxide, the diagram of gradients in figure 1 has been postulated by Weber and Nilsson (3). Probably the same diagram applies to the surface of soda lime since moisture is vital to adequate activity (4, 5, 6), and the transfer can be considered to be from gas to a thin layer of solution overlying the surface of the lime.

Two gradients are present, one in the gas phase and the other in the liquid phase. Both can be considered together to give an over-all gradient and activity expressed as an over-all mass transfer coefficient. As for other diffusion coefficients, the over-all mass transfer coefficient is dimensionally cm.^{2} per second. The units used are gram moles per second per atmosphere per square centimeter.

To obtain the over-all mass transfer coefficient we need to know the gradient or the difference of the partial pressures in the gas and in

Accepted for publication August 31, 1957. The author is in the Department of Anesthesiology, Roswell Park Memorial Institute, Buffalo 3, New York.

the bulk of the liquid. As indicated in figure 1, the partial pressure in the bulk of the liquid can be ignored. The partial pressure of carbon dioxide in gas flowing through a bed of absorbent having a uniform transfer coefficient throughout should decrease logarithmically along the length of the bed. This is expressed in the equation:

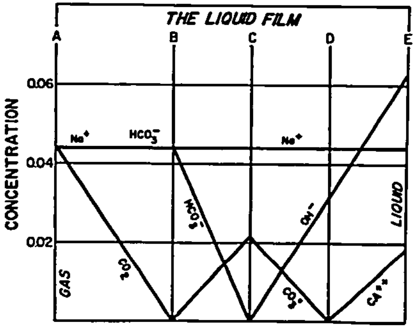

FIG. 1. Four major parts of the liquid film of absorption of carbon dioxide by milk of lime containing sodium hydroxide (3). (Reprinted by permission from Ind. Eng. Chem. 18: 1070, 1926.) A—gas-liquid interface; A–B—carbon dioxide diffusion inward and reaction with water; B–C—HCO_3^- diffusion inward and reaction with water; C—neutralization reaction $H^+ + OH^- \rightarrow H_2O$); C–D—$CO_3^=$ diffusion inward, OH^- diffusion outward; D—reaction of Ca^{++} and $CO_3^=$ with precipitation; D–E—OH^- and Ca^{++} diffusion outward, and E—Bulk of the liquid.

$$\ln\left(\frac{p_E}{p_I}\right) = -K_g a \frac{AL}{\dot{V}} p_B$$

where:

p_I is the inlet partial pressure of CO_2,
p_E is the partial pressure at the end of the bed,
K_g is the over-all mass transfer coefficient,
a is the surface area per unit volume,
A is cross section and
L the length of the bed,
$\dot{V}$ the flow rate through the bed, and
p_B the absolute pressure of gas passing through the bed.

One quantity that is not known is a, the surface area per unit volume. A number of factors can decrease the effective surface area particularly when liquid flows through the bed to act as the absorbent. Here parts of the bed can be completely filled with fluid, while other parts can be dry. With soda lime, channeling can be expected to reduce the effective area. The usual practice is to incorporate this unknown area to volume ratio in the transfer coefficient and report a bulk mass transfer coefficient, K_ga, gram moles per cubic centimeter per atmosphere per second.

METHOD

Data from a previous report (7) were combined with recent results to calculate bulk mass transfer coefficients. A constant flow of carbon dioxide 5 per cent in oxygen, humidified to 100 per cent relative humidity, was passed through to-and-fro canisters at several flow rates. Carbon dioxide concentrations at the inlet and outlet of the canister were measured by means of an infrared carbon dioxide analyzer and recorded. A rotameter was employed to monitor flow rate. Initial values for the outlet concentration were obtained by extrapolation on the record to zero time to allow for washout of the absorbent bed.

TABLE 1

INITIAL OVER-ALL MASS TRANSFER COEFFICIENTS AT VARIOUS FLOW RATES

	Canister Sizes (grams)	Flow (liters/minute)						
		18	30	40	66	93	117	135
Exit CO_2 (per cent)	450				0.06	0.145	0.31	0.51
	350			0.03	0.155	0.43	0.92	1.30
	180			0.23	0.80	1.23		
	Infant	0.25	0.865	1.39				
$K_ga \times 10^{-5}$ (g. mol./cc./sec./atm.)	450				35.0	39.5	39.0	36.9
	350			34.5	38.7	38.5	33.5	30.8
	180			32.2	31.6	34.1		
	Infant	34.0	31.3	30.9				

No essential difference between brands of soda lime. K_ga about 39.0×10^{-5} gram mole per hour per cubic centimeter per atmosphere.

RESULTS

The initial value of the bulk mass transfer coefficient was relatively unchanged by gas flow rate or bed volume in to-and-fro canisters (table 1). The best K_ga value from these studies (7) and recent unpublished data was 39.5×10^{-5} gram mole cm.^{3} per atmosphere per second.

Values of K_g for absorption of carbon dioxide by caustic solutions (8, 9) indicate a maximum value of from 3.5 to 4.0×10^{-6} gram mole per cm.^{2} per atmosphere per second. The value of a would therefore be not less than 100 cm.^{2}/cc. for 4 to 8 mesh soda lime. The surface area of 4 to 8 mesh particles without pores should be 5 to 6 cm.^{2}/cc. (10). Thus the pore surfaces are active in the absorption. From catalyst theory developed by Wheeler (11) the percentage of the total surface that is being actively used can be calculated. Essentially a comparison of the rate constant determined experimentally and the maximum theoretical rate of diffusion into the pores, K_D, gives a factor, 6.5, which (from Wheeler's figure 5) indicates that about 16 per cent of the surface is being used. Therefore, the total surface area should be about 600 cm.^{2}/cc.

These studies were repeated using 8 to 16 mesh soda lime. This absorbent had a moisture content of 14.9 per cent dry basis and a pore volume of 11.1 cc. per 100 grams with a potential pore volume of 26 cc. per 100 grams. The bulk mass transfer coefficient $K_g a$ was 78×10^{-6} gram moles per second per cubic centimeter per atmosphere. The apparent surface area is at least 200 cm.^{2}/cc. Application of Wheeler's formulas yields a factor of 3.2 which indicates that about 30 per cent of the total area is active. The total area would be about 670 cm.^{2}/cc. This is an excellent check of the specific surface.

Discussion

These estimates of total surface area per cubic centimeter of absorbent assume proper packing of absorbent and the absence of channeling in the to-and-fro canister. If channeling is present, the active surface area as calculated is too small. Moreover, the factor employed in finding total area will also be too small and the active area would be a smaller fraction of total area. Thus, an appreciable amount of channeling in to-and-fro absorbers would require an upward revision of these estimates of total surface area.

The results obtained in this study necessitate a change in visualizing the processes involved in absorption of carbon dioxide by soda lime. Besides the gradients present across the surface films, an additional gradient is present from the pore mouths into the granule. During exhaustion this gradient must extend deeper into the granule. This brings more surface into activity. Thus, as the activity of the surface decreases near the pore mouth, carbon dioxide molecules can diffuse deeper into the granule and active surface area increases.

The activity of the granule is not increased by this additional surface area. The amount of carbon dioxide diffusing into the granule depends on the area of the pore mouths opening on the external surface of the granule and is inversely related to the average distance carbon dioxide diffuses into the pore. When the diffusion path lengthens, as it must to increase the active surface, the amount of carbon dioxide transferred into the pores decreases. Only an increase in the carbon dioxide concentration in gas surrounding the granule will push more carbon dioxide into the granule. This has no effect on the apparent activity of the granule, which would be expressed as gram moles per second per atmosphere per granule.

Another factor must also be considered. With pores partially filled with water, this water must be evaporated by the heat of reaction before more surface is exposed. This immediately raises the question as to what exhausts soda lime, using up of reactants or drying out the particle.

SUMMARY

The over-all bulk mass transfer coefficient of fresh 4 to 8 mesh high-moisture soda lime in to-and-fro canisters was 39.5×10^{-6} gram moles per second per cm.^{2} per atmosphere. Calculations indicate that the active surface area is not less than 100 cm.^{2}/cc. and is about 16 per cent of the total surface area. Total surface area is estimated at 600 cm.^{2}/cc.

This study was supported in part by funds provided under Contract DA 49-007-MD-507 with the Division of Research and Development, Office of the Surgeon General, Department of the Army. The soda lime used in this study was supplied by Mallinckrodt Chemical Works, St. Louis, Missouri.

REFERENCES

1. Waters, R. M.: Clinical Scope and Utility of Carbon Dioxide Filtration in Inhalation Anesthesia, Anesth. & Anal. 3: 20 (Feb.) 1924.
2. Adriani, J., and Rovenstine, E. A.: Experimental Studies on Carbon Dioxide Absorbers for Anesthesia, ANESTHESIOLOGY 2: 1 (Jan.) 1941.
3. Weber, H. C., and Nilsson, K. T.: Absorption of Gases in Milk of Lime, Ind. Eng. Chem. 18: 1070 (Oct.) 1926.
4. Wilson, R. E.: Soda Lime as Absorbent for Industrial Purposes, Ind. Eng. Chem. 12: 1000 (Oct.) 1920.
5. Adriani, J.: Effect of Varying Moisture Content of Soda Lime upon Efficiency of Carbon Dioxide Absorption, ANESTHESIOLOGY 6: 163 (March) 1945.
6. Letts, H. R. J.: Preparation and Properties of Granular Carbon Dioxide Absorbents, Part I; Soda Lime Granules, Porton Technical Paper No. 101 (May) 1949.
7. Brown, E. S.: Certain Physical Properties and Reaction Kinetics of Carbon Dioxide Absorbents, USAF School of Aviation Medicine, Unnumbered Report, May, 1954.
8. Jenny, F. J.: Thesis in Chemical Engineering, "Gas Absorption Followed by Chemical Reaction in Liquid Phase," Massachusetts Institute of Technology, 1936.
9. Tepe, J. B., and Dodge, B. F.: Absorption of Carbon Dioxide by Sodium Hydroxide Solutions in Packed Column, Trans. Am. Inst. Chem. Engrs. 39: 255 (May) 1943.
10. Perry, J. H.: Chemical Engineers Handbook, ed. 3, sec. 12, New York, McGraw Hill Book Company, Inc., 1950.
11. Wheeler, A.: Reaction Rates and Selectivity in Catalyst Pores in "Catalysis" (P. H. Emmett, Editor), New York, Reinhold Publishing Corp., 1955, pp. 105–164.