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THE EFFECTS OF CHEMICAL HYDRATION LEVEL ON CARBON  
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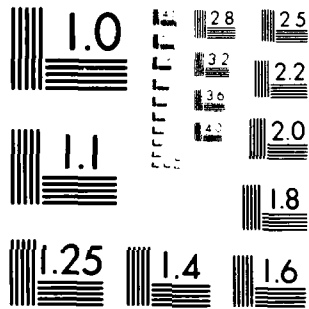
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# THE EFFECTS OF CHEMICAL HYDRATION LEVEL ON CARBON DIOXIDE ABSORPTION BY HIGH PERFORMANCE SODASORB

A. PURER  
G. A. DEASON  
M. L. NUCKOLS

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The investigation described in this report was performed during fiscal years 1981-82 as part of the Advanced Surface Supported Diving System (ASSDS) project sponsored by NAVSEA 05R2. This phase of the ASSDS project is intended to develop a design handbook for use in designing CO<sub>2</sub> scrubber systems for diving equipment.

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20. ABSTRACT (continued):

the general trend was for carbon dioxide absorption efficiency to increase with decreasing absorbent moisture content.

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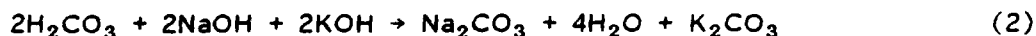
## INTRODUCTION

The design of high efficiency closed or semi-closed life support systems requires a knowledge of the characteristics of the carbon dioxide absorption materials used in such systems. Some of the parameters that affect the ability of the carbon dioxide scrubber to operate at peak efficiency are:

1. Absorbent mesh size
2. Water content of carbon dioxide containing gas
3. Temperature
4. Linear velocity of gas stream
5. Carbon dioxide concentration
6. Pressure
7. Hydration level of absorbent
8. Intermittent or continuous flow
9. Type of absorbent
10. Canister packing.

Previous reports<sup>1 2</sup> cover the effects of the first six parameters. This report cover the effects of water content of the absorbent materials on its carbon dioxide scrubbing capability. This study, along with previous studies, is intended to establish guidelines for carbon dioxide absorbent canister design.

The chemical absorption of carbon dioxide by Sodasorb may be represented by the following three quations:<sup>3</sup>



<sup>1</sup>Naval Coastal Systems Center Technical Memorandum NCSC TM 327-81, "Carbon Dioxide Absorption Characteristics of High Performance Sodasorb at 1 Atmosphere," by A. Purer, G. A. Deason, M. L. Nuckols, and J. F. Wattenbarger, October 1981.

<sup>2</sup>Naval Coastal Systems Center Technical Memorandum NCSC TM 349-82, "The Effects of Pressure and Particle Size on Carbon Dioxide Absorption of High Performance Sodasorb," by A. Purer, G. A. Deason, B. H. Hammonds, M. L. Nuckols, and J. F. Wattenbarger, June 1982.

<sup>3</sup>Adriani, J. and Rovenstine, E. A., "Experimental Studies on Carbon Dioxide Absorbers for Anesthesia," *Anesthesiology*, Vol. 2, No. 1, January 1941.

Water, Equation (1), must be present to initiate the reaction. Once the reaction is initiated, it will also produce water, Equation (2), which will be available for future reactions provided it is not absorbed by high temperature gas flowing through the system. This water will tend to form a thin film coating around the absorbent particle. The  $\text{CO}_2$  dissolves in the film of water coating the absorbent granules to form carbonic acid. The rate of  $\text{CO}_2$  removal from the gas stream is proportional to the rate of removal of dissolved  $\text{CO}_2$ , or  $\text{H}_2\text{CO}_3$ , from the water film. The removal of dissolved  $\text{CO}_2$  and  $\text{H}_2\text{CO}_3$  is controlled by the availability of the hydroxyl ions, Equation (2). The formation of water is instantaneous; therefore, available OH ions are quickly exhausted. Equation (3) is rate limited and may not be able to supply the required hydroxyl ions to keep the absorption of  $\text{CO}_2$  progressing at the desired rate.

The above observations suggest that the amount of moisture present in the Sodasorb could have a great effect on its overall efficiency. The following experiments using 0.6 to 20.1 percent absorbent moisture content were conducted to characterize this effect.

#### TEST METHODS

Four-to-eight mesh high performance Sodasorb, manufactured by W. R. Grace and Company, was used in this study. The reported specification of chemical composition for this material was 14 to 19 percent  $\text{H}_2\text{O}$ , 75 to 80 percent  $\text{Ca}(\text{OH})_2$ , and 4 to 6 percent activators consisting mostly of NaOH and KOH. The material also incorporates a pH-type indicator, ethyl violet, to provide a visual check on the absorbent status. Water was either added or removed from this commercial product to obtain variations in the material water content. The resulting materials used in this study had the following composition:

TABLE 1  
SODASORB TEST MATERIAL COMPOSITION

% $\text{H}_2\text{O}$	% $\text{Ca}(\text{OH})_2$	% Activator
20.1	76.3	3.6
14.1	82.0	3.9
7.0	88.8	4.2
3.8	91.8	4.4
0.6	94.9	4.5

Various moisture content Sodasorbs were prepared by taking small amounts of the original high performance Sodasorb and spreading it out in a large beaker which was then placed in an oven for 15 to 30 minutes. Oven temperatures varied from 80 to 130°C. The exact time and temperature

depended upon the moisture content desired. The material was allowed to cool in a desiccator before being placed in moisture-tight containers. Several days were allowed for moisture equilibration before moisture analysis with an Ohaus moisture determination balance. To obtain a moisture content above the 14.1 percent of the standard high performance Sodasorb, the uniform addition of water was required. This was achieved by spreading out a weighed amount of Sodasorb, one layer deep, and spraying a predetermined amount of water over the Sodasorb. The material was then gently mixed and placed in a sealed, moisture-tight container for several days before final moisture analysis.

The laboratory apparatus used in this study (Figure 1) is similar to that used in previous reports.<sup>1 2</sup> Helium containing 1 percent CO<sub>2</sub> was used as the major component in the steady flow gas stream. Because helium has a thermal conductivity 5.8 times that of air, it rapidly dissipates the heat of reaction and thus assures a more uniform temperature across the absorption cell.

Inlet gas flowed through a needle valve to a temperature equilibrating coil contained in a constant temperature bath. If a dry carrier gas was desired, the gas went directly to the CO<sub>2</sub> absorption cell assembly. To obtain a saturated carrier gas, the gas first passed through a bubble tower before entering the absorption cell assembly, which was made up of a temperature equilibrating coil and a cell containing the absorbent. The absorption cell had an internal diameter of 0.978 centimetre and a length of 12.50 centimetres. The maximum distance that a gas molecule could be from the constant temperature cell walls was 0.489 centimetre. This short distance assured rapid dissipation of the heat of reaction and a near isothermal condition throughout the cell. The gas stream passed from the absorption cell into a Beckman Model 865 infrared CO<sub>2</sub> analyzer. Total gas flow was recorded with a Precision Instrument wet test meter. Each run was terminated when the CO<sub>2</sub> level reached 0.5 percent by volume in the outlet gas.

### CALCULATIONS

Efficiency is expressed as the litres of 1 percent CO<sub>2</sub> in helium gas purified to 0.5 percent CO<sub>2</sub> per gram of absorbent. To obtain these values, the weight of the absorbent used in each run was divided by the absolute density<sup>1</sup> to obtain the true volume occupied by the Sodasorb. Subtracting this volume from the bulk volume of the Sodasorb yields the dead volume of the cell filled with Sodasorb, which is the volume available for gas flow. Dividing this dead volume by flow yields the average residence time an individual gas molecule would spend in the cell. Average linear velocity of a gas molecule through the cell is obtained by dividing cell length by residence time. Final efficiency is obtained by plotting linear velocity against the

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<sup>1</sup>ibid.

<sup>2</sup>ibid.

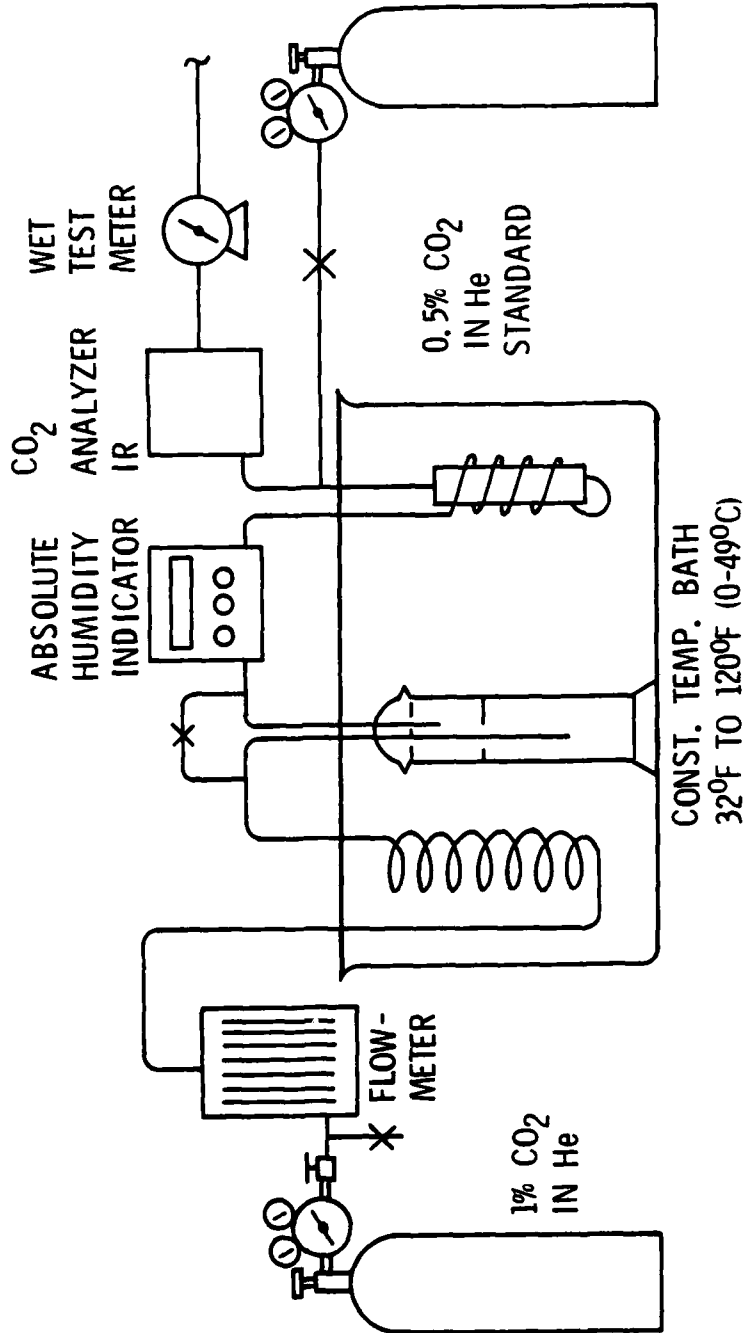


FIGURE 1. CO<sub>2</sub> ABSORBENT TEST APPARATUS

volume of CO<sub>2</sub> containing gas purified to the 0.5 percent level per gram of absorbent.

RESULTS

DRY CARRIER GAS

The effects of Sodasorb moisture content at 70°F (21°C) on CO<sub>2</sub> absorption varied with the moisture content of the carrier gas. With a dry carrier gas, the CO<sub>2</sub> absorption efficiency of the Sodasorb increased with increasing absorbent moisture content (Figure 2). Past studies<sup>1</sup> have shown that moisture content of the carrier gas stream has a pronounced effect on CO<sub>2</sub>

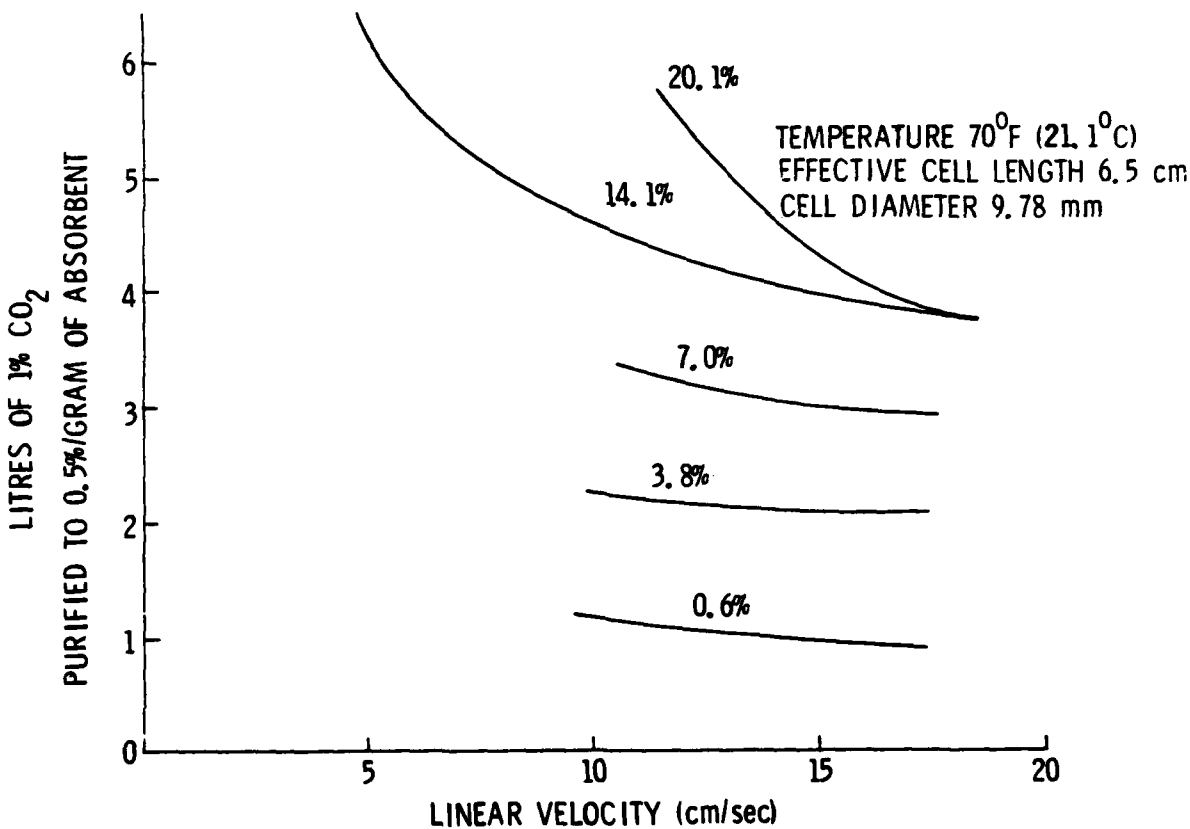


FIGURE 2. EFFECTS OF VARIOUS SODASORB MOISTURE CONTENTS ON CO<sub>2</sub> ABSORPTION FOR A DRY GAS STREAM

absorption, indicating that moisture from the carrier gas stream entered into the chemical reaction mechanism. This study indicates that this water content could be incorporated into the absorbent and, thus, tend to offset the lack of water in the carrier gas stream.

Figure 2 represents the total weight of the absorbent including the water content. The water enters into the mechanism of chemical reactions in a recycling manner; it is not chemically depleted and ties up no  $\text{CO}_2$ . Increasing the water content in a fixed weight of absorbent decreases the amount of  $\text{Ca}(\text{OH})_2$  and activators available for removing  $\text{CO}_2$ . This means that the 20.1 percent water absorbent has less active chemicals to absorb  $\text{CO}_2$  than the 0.6 percent water absorbent (Table 1). In an effort to get a better insight into the actual absorption capability of the various water content absorbents, the data were replotted (Figure 3) to represent the actual active chemicals (without water) available for  $\text{CO}_2$  absorption.

These curves further emphasize the effects of the water content of the absorbent for a dry carrier. The crossover of the 20.1 percent  $\text{H}_2\text{O}$  content absorbent with the 14.1 percent  $\text{H}_2\text{O}$  content absorbent is also eliminated within the range of linear velocities tested. This crossover was apparently caused by the reduction of absorbent material in the 20.1 percent  $\text{H}_2\text{O}$  content absorbent. With a dry carrier gas stream, the best efficiency is obtained with a high moisture content absorbent. Moisture contents above 22 percent, however, are not practical because the absorbent becomes a semi-solid and cannot be loaded properly into a canister.

#### WATER SATURATED CARRIER GAS

The evaluations of absorbent moisture content on  $\text{CO}_2$  absorption with a saturated carrier gas stream were found to be quite different than that obtained with a dry carrier gas stream. Increasing absorbent water content tended to decrease its efficiency. The general trend was for a decrease in  $\text{CO}_2$  absorption efficiency with an increase in absorbent moisture content. Figure 4 shows an abrupt change at the 14 to 16 centimetres per second linear velocity only for the 3.8 percent  $\text{H}_2\text{O}$  level. This abrupt deflection is more related to the selection, or definition, of breakthrough than it is to a sudden change in absorption efficiency. In this region, the cell's carbon dioxide effluent tended to approach the 0.5 percent breakthrough level very slowly; at times, its value would stay constant just slightly below the 0.5 percent breakthrough level for long periods of time. It was difficult to obtain reproducible data in this region.

As previously done for the dry carrier gas studies, these data are replotted in Figure 5 to show the actual absorption capability of the various water content absorbents based on the weight of the reactive portion of the absorbent.

The general trend for the effects of various absorbent water content for  $\text{CO}_2$  absorption for both a dry and saturated carrier gas streams at a fixed linear velocity (14 cm/sec) is displayed in Figure 6. This figure emphasizes

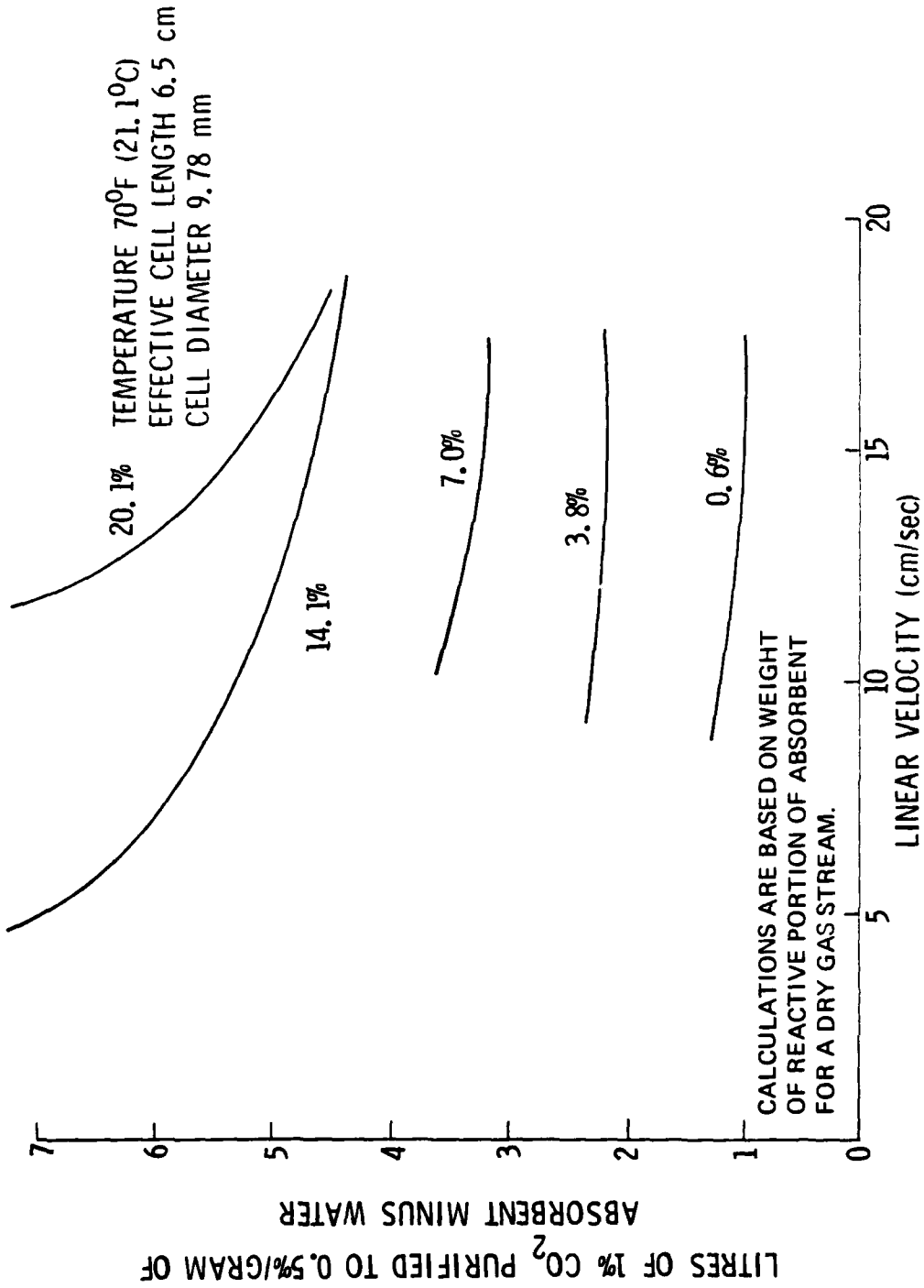


FIGURE 3. EFFECTS OF VARIOUS SODASORB MOISTURE CONTENTS ON CO<sub>2</sub> ABSORPTION

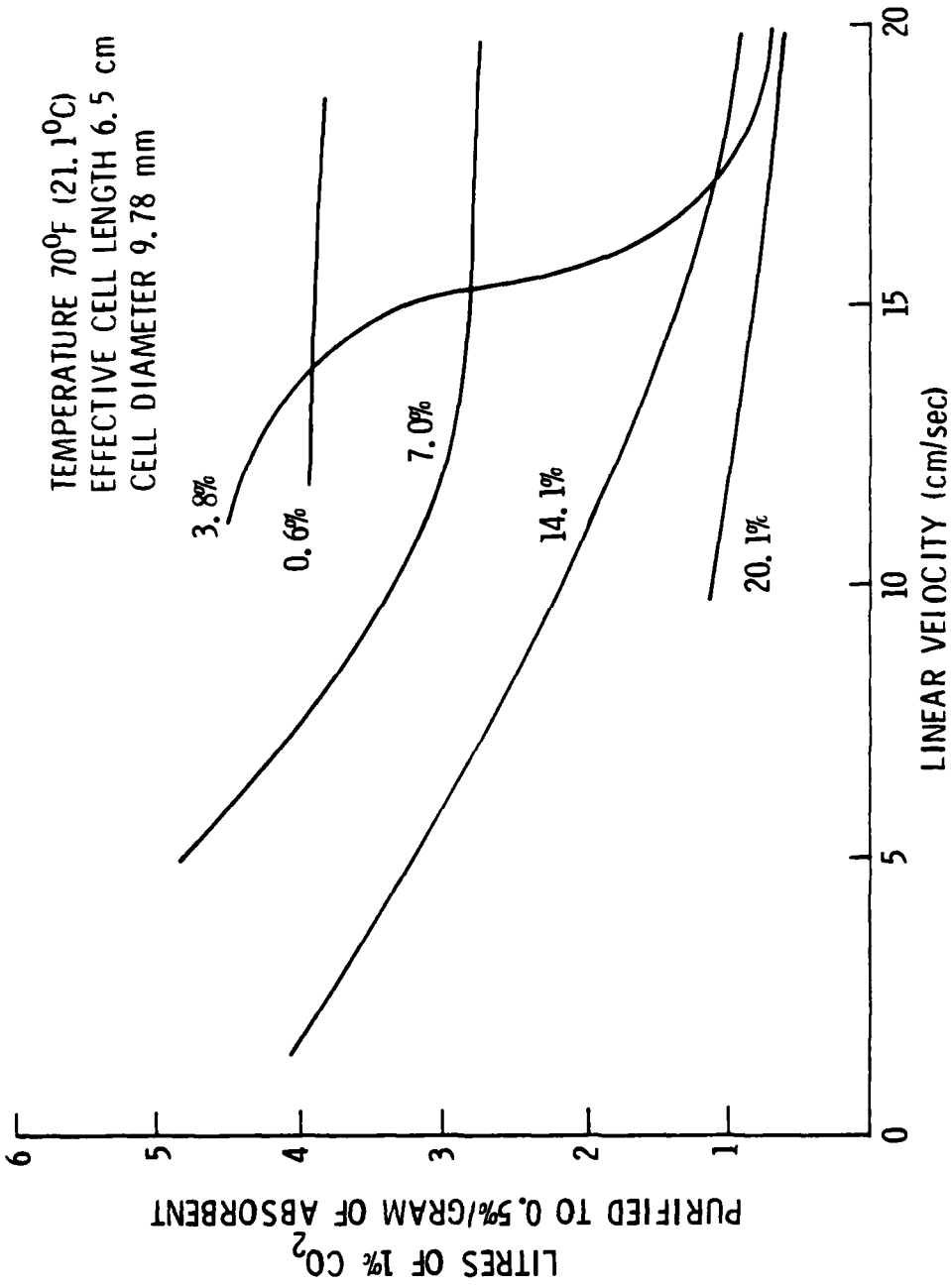


FIGURE 4. EFFECTS OF VARIOUS SODASORB MOISTURE CONTENTS ON CO<sub>2</sub> ABSORPTION FOR A SATURATED GAS STREAM

TEMPERATURE 70°F (21.1°C)  
EFFECTIVE CELL LENGTH 6.5 cm  
CELL DIAMETER 9.78 mm

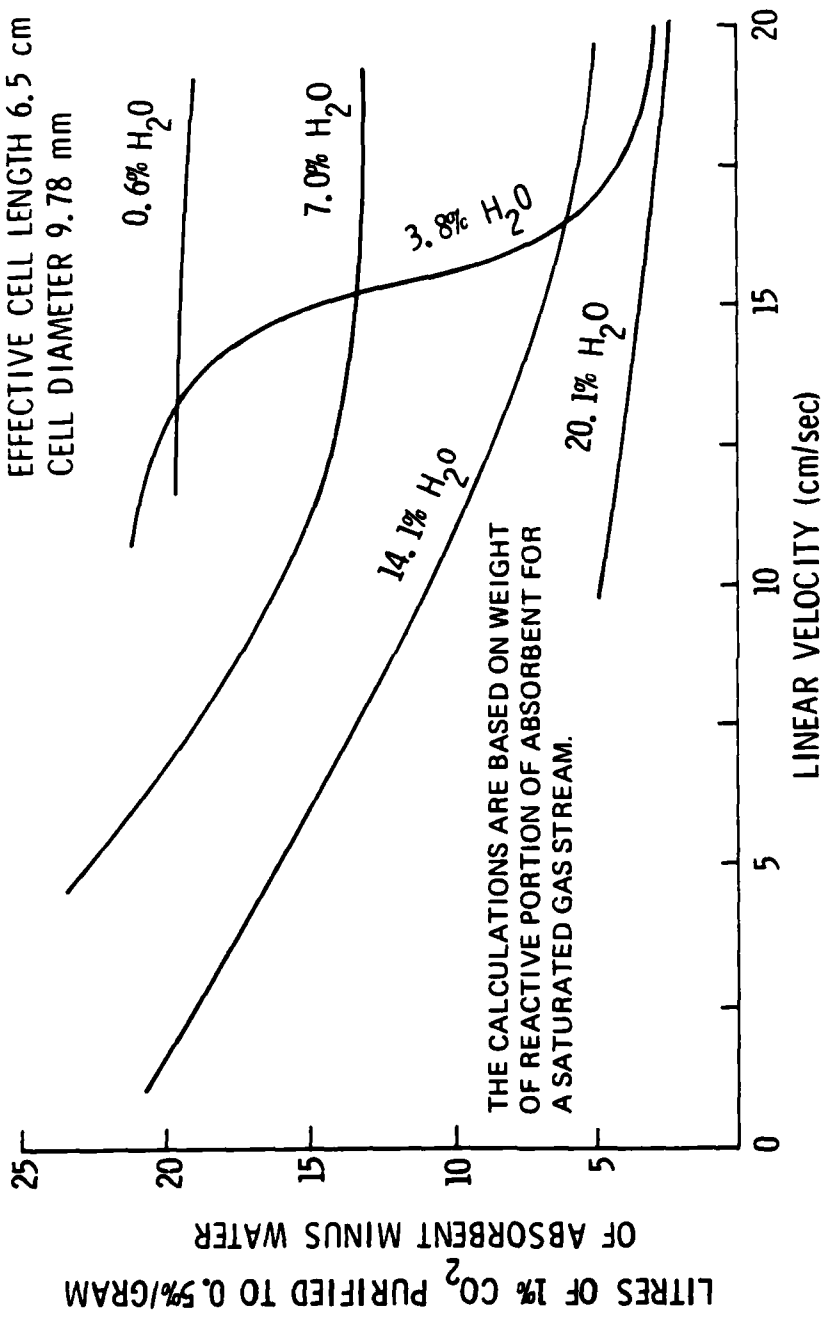


FIGURE 5. EFFECTS OF VARIOUS SODASORB MOISTURE CONTENTS ON CO<sub>2</sub> ABSORPTION

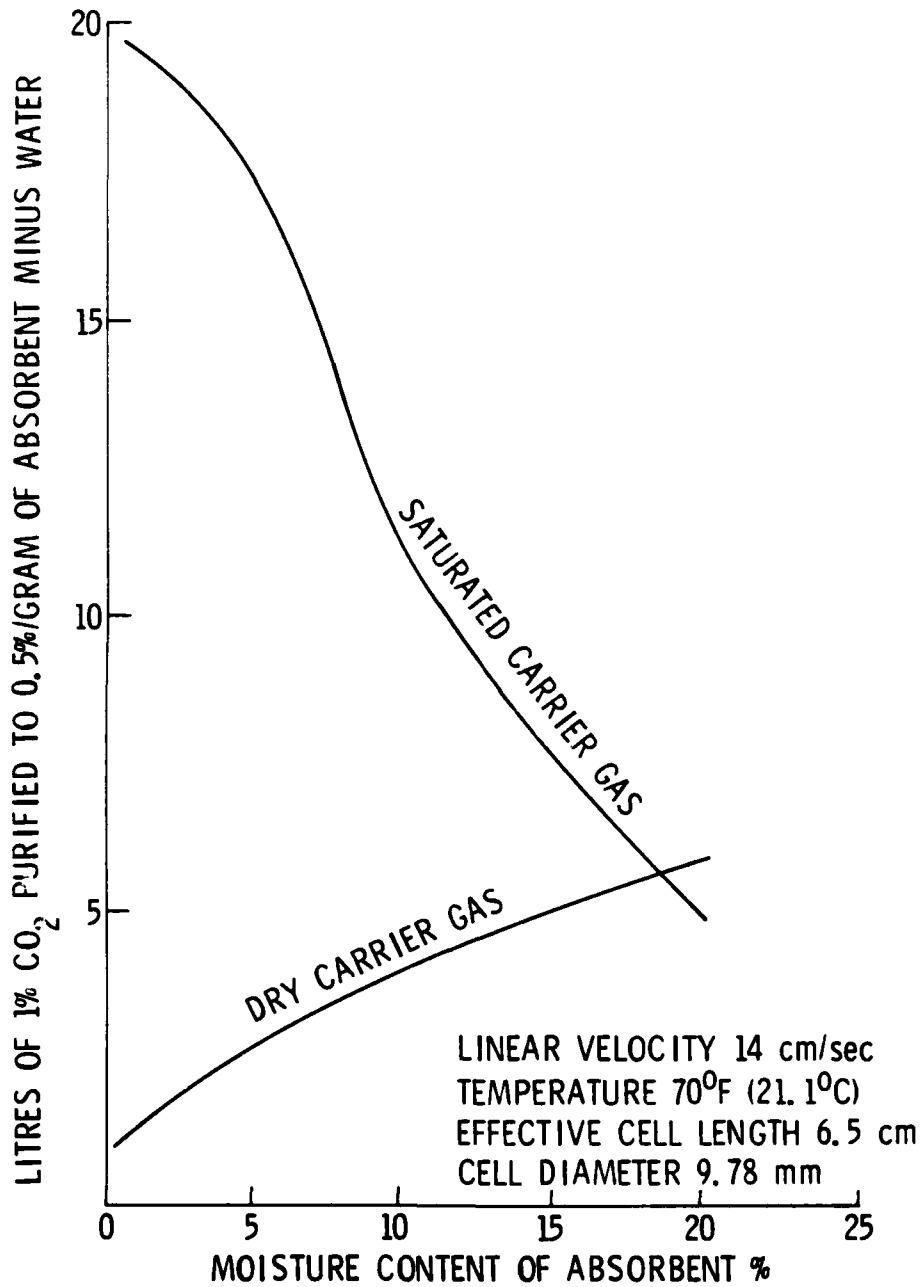


FIGURE 6. EFFECTS OF VARIOUS ABSORBENT WATER CONTENT ON CO<sub>2</sub> ABSORPTION FOR A DRY AND SATURATED GAS STREAM AT A FIXED LINEAR VELOCITY

the significance of absorbent hydration levels on absorption capability while showing the opposing influence of the hydration level with dry and saturated carrier gases.

#### CONCLUSION

It was learned from this study that with a dry carrier gas the higher the moisture content of absorbent, the greater the efficiency. It was also observed that with a saturated carrier gas the higher the moisture content of absorbent, the lower the efficiency. This trend is somewhat complicated by the observations at 3.8 percent water level due to the difficulty in obtaining reproducible data in this range.

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