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TEMPERATURE AND PRESSURE EFFECTS ON SODASORB AND BARALYME

A Trident Scholar Project Report

by

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Annapolis, Maryland

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13 ABSTRACT

Baralyme and sodasorb used by the U.S. Navy to remove the carbon dioxide in closed and semiclosed respirators. In this experiment, the two absorbents were studied in their effects of changing the temperature and pressure of the breathing apparatus.

The inlet gas contained 2.5°/° surface equivalent carbon dioxide, and passed through the absorbent canister at a constant rate of about 40 liters/minute. The gas was humidified to 100°/o for all tests. The inlet gas temperatures ranged from -3 C to 31 C at 1 ATA. The pressures ranged from 2 ATA to 4 ATA at 30 C. The canister held 400 grams of absorbent for each test.

The efficiency of the absorbent decreased as temperature decreased. The results from pressure tests indicated decreasing efficiency with depth.

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ABSTRACT

The U. S. Navy uses Baralyme and Sodasorb in closed and semi-closed breathing apparatus. These apparati are exposed to various temperatures and pressures. Both Baralyme and Sodasorb remove the carbon dioxide by chemical reaction which could be effected by changes in temperature and pressure. The two absorbents were studied to observe the influence of changes in temperature and pressure on the efficiency of the reaction.

The standard used by the Experimental Diving Unit to indicate forthcoming break down of the absorbent is an exit concentration of 0.005 ATA, partial pressure of carbon dioxide. This standard was used in both the temperature and pressure tests. In addition, a 0.01 ATA standard was used for temperature tests for amplification of results.

The inlet gas contained 2.5% surface equivalent carbon dioxide, and passed through the absorbent canister at a constant rate of about 40 liters/minute. The gas was humidified to 100% for all tests. The inlet gas temperatures ranged from -3C to 31 C at 1 ATA. The pressures ranged from 2 ATA. to 4 ATA. at 30°C. The canister held 400 grams of absorbent for each test.

The efficiency of the absorbent decreased as temperature decreased. Below 5°C for Sodasorb the efficiency decreased rapidly. A similar drop occurred below 10°C for Baralyme. The results from the pressure tests indicated decreasing efficiency with depth.

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INTRODUCTION

The U. S. Navy uses the carbon dioxide absorbents, Sodasorb and Baralyme in closed and semi-closed breathing apparatus, habitats, and hyperbaric chambers. Within the scope of operations, the Navy exposes these absorbents to many different environments. It is known that temperature has an effect on carbon dioxide absorbent efficiency but the combined effect of pressure and temperature is unknown. Presently, the predicted life of a carbon dioxide absorbent canister is mostly based on experience. Dr. M. W. Goodman believes that the carbon dioxide absorption ability of a breathing apparatus is ".....the most significant factor obstructing any increasing efficient safe exploration of other apparatus components."[1]

Hypercapnia is the buildup of carbon dioxide in the body. An excess of carbon dioxide in the body causes several different effects, generally depending on the victim's physical condition. The effect of the carbon dioxide depends on it's partial pressure. Above 0.01 ATA. partial pressure the diver will suffer some sensory losses. Above 0.065 ATA. the diver will be dizzy, and above 0.1 ATA. he will probably loose consciousness.[2]

The partial pressure of the carbon dioxide is a function of its percent and the pressure of the environment. In hypercapnia all tissues of the body are affected, but the brain is the most susceptible. Confusion, loss of ability to think clearly, and drowsiness become more severe as the level of hypercapnia increases.[3]

CHEMICAL PROPERTIES

Baralyme and Sodasorb remove carbon dioxide from the breathing mixture by chemical reactions. The absorbents are porous granules, with particle sizes from 4 to 8 mesh. Both contain a color indicator which changes the absorbent color as carbon dioxide is absorbed. Sodasorb turns from white to blue, while Baralyme changes from pink to purple.

Sodasorb's active ingredients are 5% sodium hydroxide (NaOH) and/or potassium hydroxide (KOH), and 95% calium hydroxide ($Ca(OH)_2$). The absorbent used in this project, a product of Dewey and Almy Chemical Division of W. R. Grace & Co., had a "high moisture" content, 14 to 19%.

The reaction between Sodasorb and carbon dioxide follows:

1. $CO_2 + H_2O \rightarrow H_2CO_3$
2. $2H_2CO_3 + 2NaOH \rightarrow 2KOH \quad Na_2CO_3 + K_2CO_3 + 4H_2O$
3. $Na_2CO_3 + K_2CO_3 + 2Ca(OH)_2 \rightarrow 2CaCO_3 + 2NaOH + KOH$[4]

Baralyme contains 20% barium octahydrate ($Ba(OH)_2 \cdot 8H_2O$), 5% potassium hydroxide (KOH), and 75% calcium hydroxide ($Ca(OH)_2$). The $8H_2O$ is water of hydration which are the stable constituents of the absorbent and enter directly into the reaction during the absorption of carbon dioxide.[4]

The reaction of Baralyme and carbon dioxide follows:

1. $Ba(OH)_2 \cdot 8H_2O + CO_2 \rightarrow BaCO_3 + 9H_2O$
2. $9H_2O + 9CO_2 \rightarrow 9H_2CO_3$
3. $9H_2CO_3 + 9Ca(OH)_2 \rightarrow 9CaCO_3 + 18H_2O$
4. $2KOH + H_2CO_3 \rightarrow K_2CO_3 + 2H_2O$
5. $Ca(OH)_2 + K_2CO_3 \rightarrow CaCO_3 + 2\ KOH$[5]

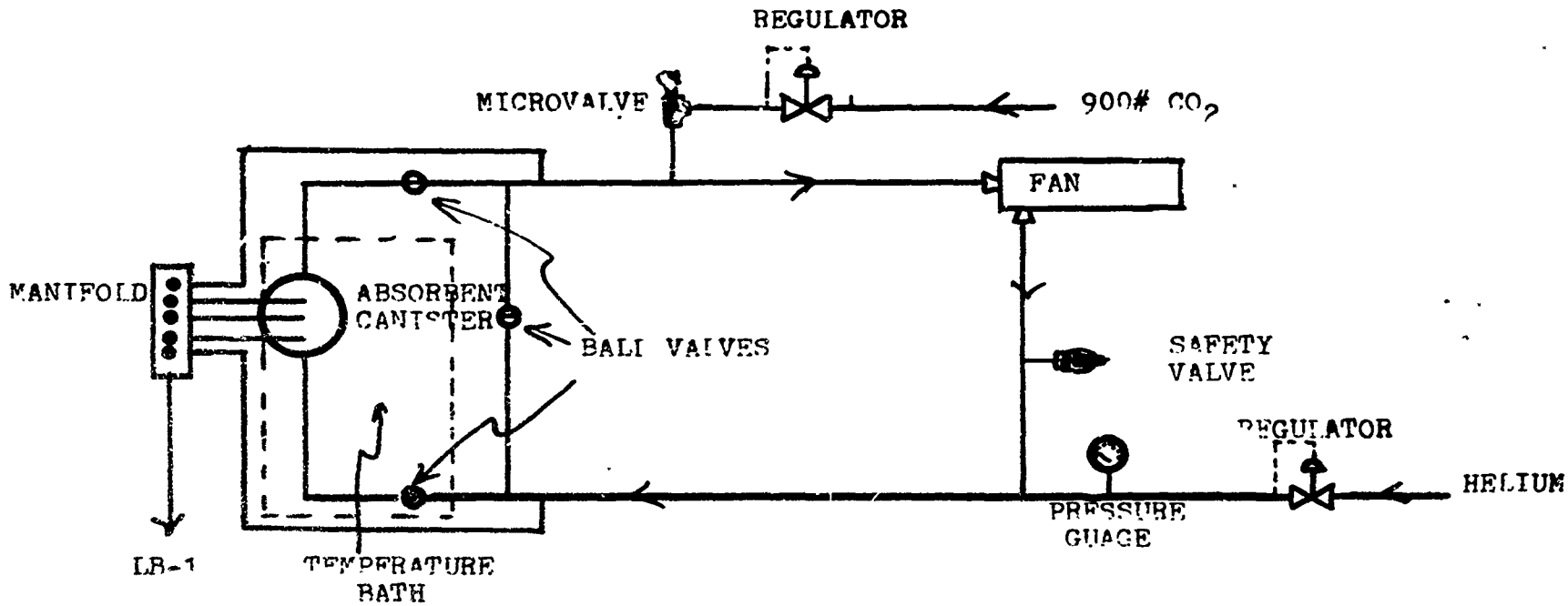
Sodasorb is affected more by shelf life due to its moisture content. Despite seals, shelf life is a considerable problem affecting the efficiency of Sodasorb.

APPARATUS AND PROCEDURE

Initially an apparatus which would incorporate both temperature and pressure tests was designed and constructed. The apparatus was a closed system capable of use at high pressure up to 1000 psia,) ½" stainless steel piping loop(Ref.Fig.7).

Helium was used to pressurize the system as that is the gas the Navy uses on its deep dives. Due to the cost of helium, a closed system was necessary. The absorbent was enclosed in a thick wall copper pipe 3" I.D. This metal was used due to its availability. Aluminum was not used for the canister housing as tests showed the absorbent reacted with aluminum and would cause pitting. The gas was circulated by a centrifugal fan enclosed in an aluminum cylinder. The system included a pressure gauge, safety valve, and two YSI 400 Series thermistors to record inlet and outlet temperatures at the canister. The system was hydrostatically tested to 1000 psia. The copper cylinder and a section of pipe were inserted into a water bath to maintain temperature.

A Beckman LB-1 Medical Gas Analyzer was used to monitor carbon dioxide concentrations. The LB-1 consists of two major units: a pickup and am amplifier. The pickup detects the carbon dioxide and generates an electrical signal proportional to the concentration of carbon dioxide. The signal is a function of the infrared absorption in the pickup. The amplifier translates the signal into a reading on a panel meter and into an output which was connected to an Esterline-Angus strip chart recorder.[6]



HIGH PRESSURE TEST LOOP
FIGURE 2

Meaningful results could not be obtained from this apparatus. The reaction of the carbon dioxide and the absorbent was exothermic. The outlet temperature quickly rose above 50°C upon input of carbon dioxide. The water bath maintained an inlet temperature of 30°C. Due to the closed loop the water produced by the reaction accomulated in the canister and the lower sections of pipe. This increased the line resistance to the fan reducing the flow rate. The water also reduced the efficiency of the chemical reaction by saturating the absorbent with water, reducing the surface area exposed to the gas. Due to the response time of the LB-1 (30 sec.) it was hard to control inlet CO_2 concentration, even with a bypass. At times during the tests, the inlet concentration was less than the outlet concentration.

Because of the complexity of the system and the inconclusive results, a simpler device was designed and built. It was decided it would be impractical to design and build a system for both tests, temperature and pressure. As a result, other combined effect of temperature and pressure could not be studied. Data was first taken from the temperature apparatus in the last week of March.

The temperature apparatus was an open system (Ref.Fig.8) Compressed air was in the inert gas and was used to push the carbon dioxide through the system. The absorbents were tested in a clear acrylic cylinder 10" in length, 2" in diameter. The canister held 400 grams of absorbent. After the absorbent was placed inside, the canister was tapped gently to insure packing. The level of absorbent for each test was kept constant. The cylinder was placed vertically to minimize channeling, with the inlet gas entering at the top.

TEMPERATURE TEST LOOP

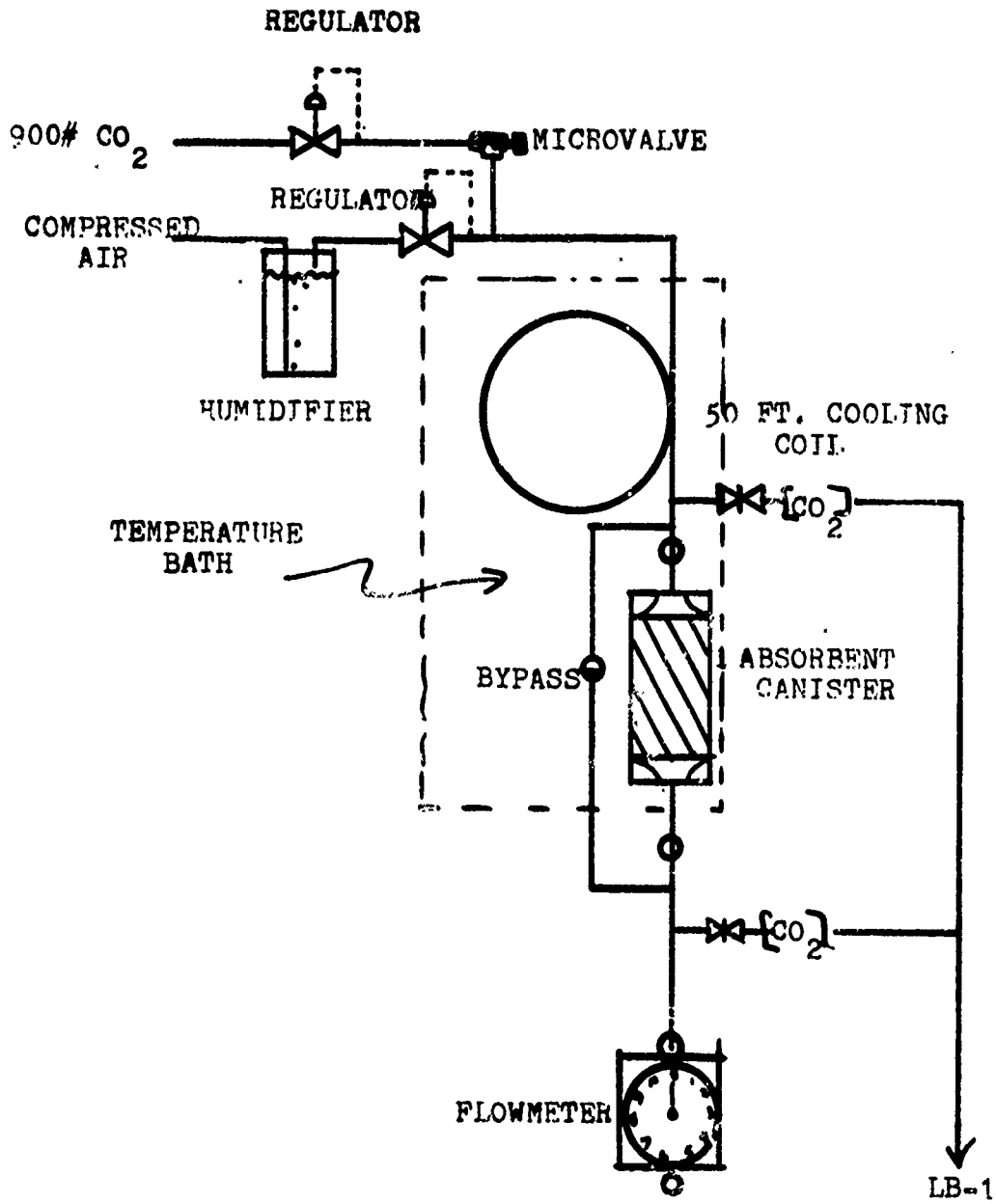


FIGURE 8

In this manner the produced moisture did not seriously hamper the absorbent. The large buildup of water which could restrict the flow or hinder the reaction was prevented by using an open system. As a result little water condensed in the canister. The flow of compressed air was controlled by a regulator. Air was used due to its availability and economy. The carbon dioxide was inputed through a regulator and a micro-valve in order to have a fine control of the carbon dioxide concentration. The compressed air was humidified prior to entering the cooling system.

The air was passed through 50 feet of $\frac{1}{4}$" copper tubing coiled in a temperature bath. The canister was also placed in this bath. Temperature was recorded by a YSI 400 series thermistor mounted at the inlet to the canister. Temperature was recorded on a strip chart recorder from the output of the thermistor and a resistance bridge. Flow was measured by a Parkinson-Conway flowmeter.

A valve was provided in the system which allowed the gas to bypass the canister until all initial conditions were met. For all tests the flow rate was maintained as close to 40 liters/minute as possible. The inlet concentration of carbon dioxide was 2.5 ± .2%. The temperature of the system was the ambient pressure. The LB-1 was recalibrated each day prior to testing. The bias setting change little over each day prior to testing the month of experimentation. Each run terminates at a value of 1% carbon dioxide in the outlet gas. A time for 0.5% carbon dioxide in the outlet gas was recorded along with the 1% time. Both values were used to

calculate efficiency. The 0.5% value was used as it is the standard used by the Experiment Diving Unit as an indication of impending breakthrough. The 1% value was used as above that value the diver will suffer some sensory losses.

The same basic system was used for the pressure tests. In this case, a pressure chamber replaced the temperature bath. The canister was again placed vertically. Helium was the inert gas for these tests. The gas was circulated by an A.C. centrifugal fan inputed from the chamber's atmosphere. The use of helium gas eliminated the fire hazard in the chamber. Input and output concentrations were tested by the LB-1.

Pressure tests were made at 2, 3, and 4 ATA. A limitation on depth was placed on the system by the LB-1. As the cutoff point was 0.005 ATA for this experiment at 4 ATA this represented .125% concentration of carbon dioxide. The LB-1 was calibrated with a full scale output corresponding to 1.25%. The LB-1 was recalibrated before and after each test. The temperature of the system was maintained at 30°C. The flow rate was kept at 40 liters/minute at depth. The inlet carbon dioxide partial pressure was maintained at 0.025 ATA. The flow rate of 40 liters/minute and 0.025 ATA partial pressure of carbon dioxide represents one liter of carbon dioxide per minute at the surface. This is the amount of carbon dioxide produced by a man swimming at about 0.7 knots.[7] (Ref.Fig.9)

PRESSURE TEST LOOP

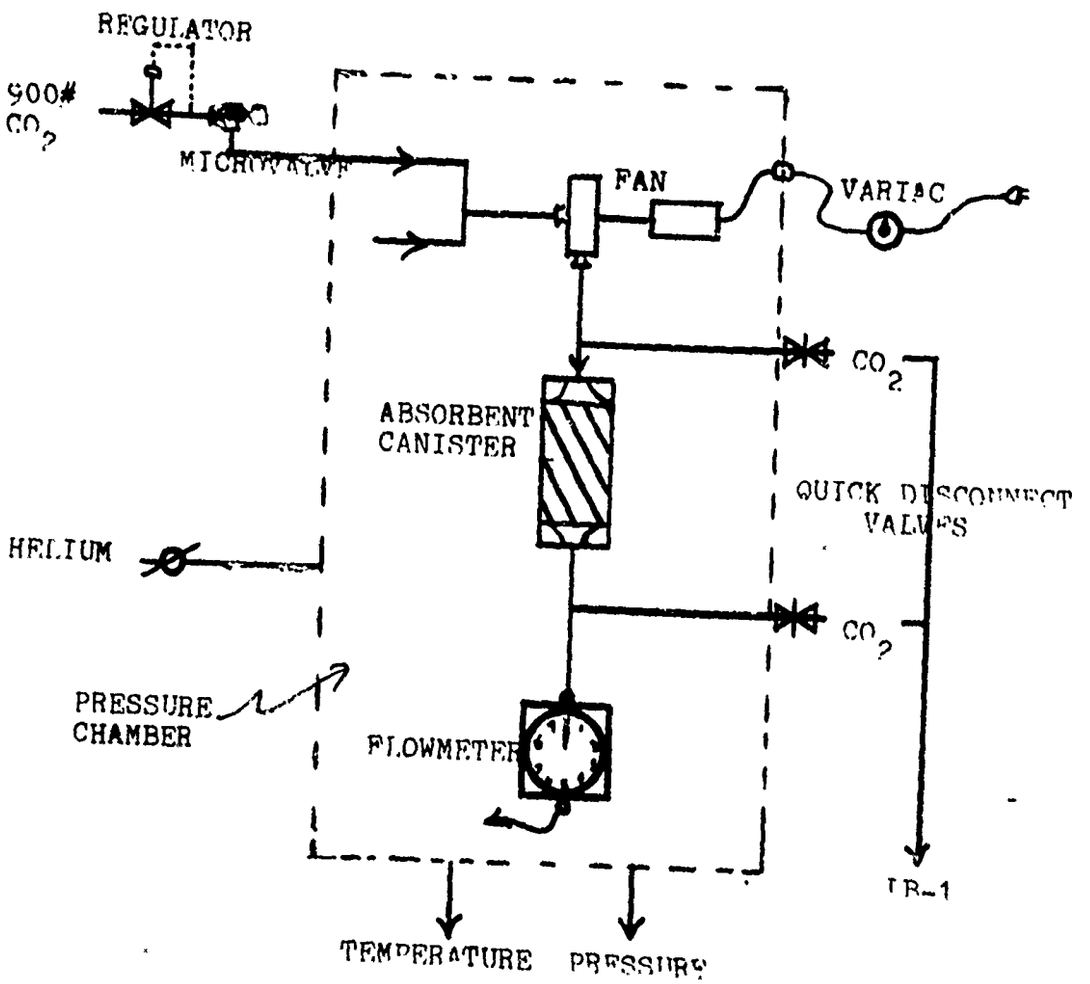


FIGURE 9

RESULTS

The efficiency of the carbon dioxide absorbent was found by calculating the amount of carbon dioxide absorbed in each run. This was done in the following manner:

LITERS OF CO_2 = FLOW RATE · TIME · % OF INLET IS CO_2 · PRESSURE

This value was corrected to account for the carbon dioxide that passed through the canister. A correction factor was arrived at by integrating the area under the curve on the strip chart recording. This factor was 3% reduction for the 0.005 ATA value for both Baralyme and Sodasorb. The correction factor for the 0.01 ATA cutoff point was 8% for Sodasorb and 9% for Baralyme.

The graphs plotting the efficiency in liters of carbon dioxide versus temperature and pressure for both absorbents are figures 1, 2, 3 and 4. Each point represents one data point. The efficiency for both absorbents is plotted in figure 4A.

During the data runs, the color indication show the working action of the absorbent. Near breakthrough (0.5% cutoff), the granules near the exit had just started their color change. By use of this color change, checks for channeling were made and there was no indication of channeling.

The pressure results are plotted in figures 5 and 6. This result represents only few data points.

LITERS OF CO_2 ABSORBED VERSUS TEMPERATURE

BARALYME: 0.005 ATA. CUTOFF

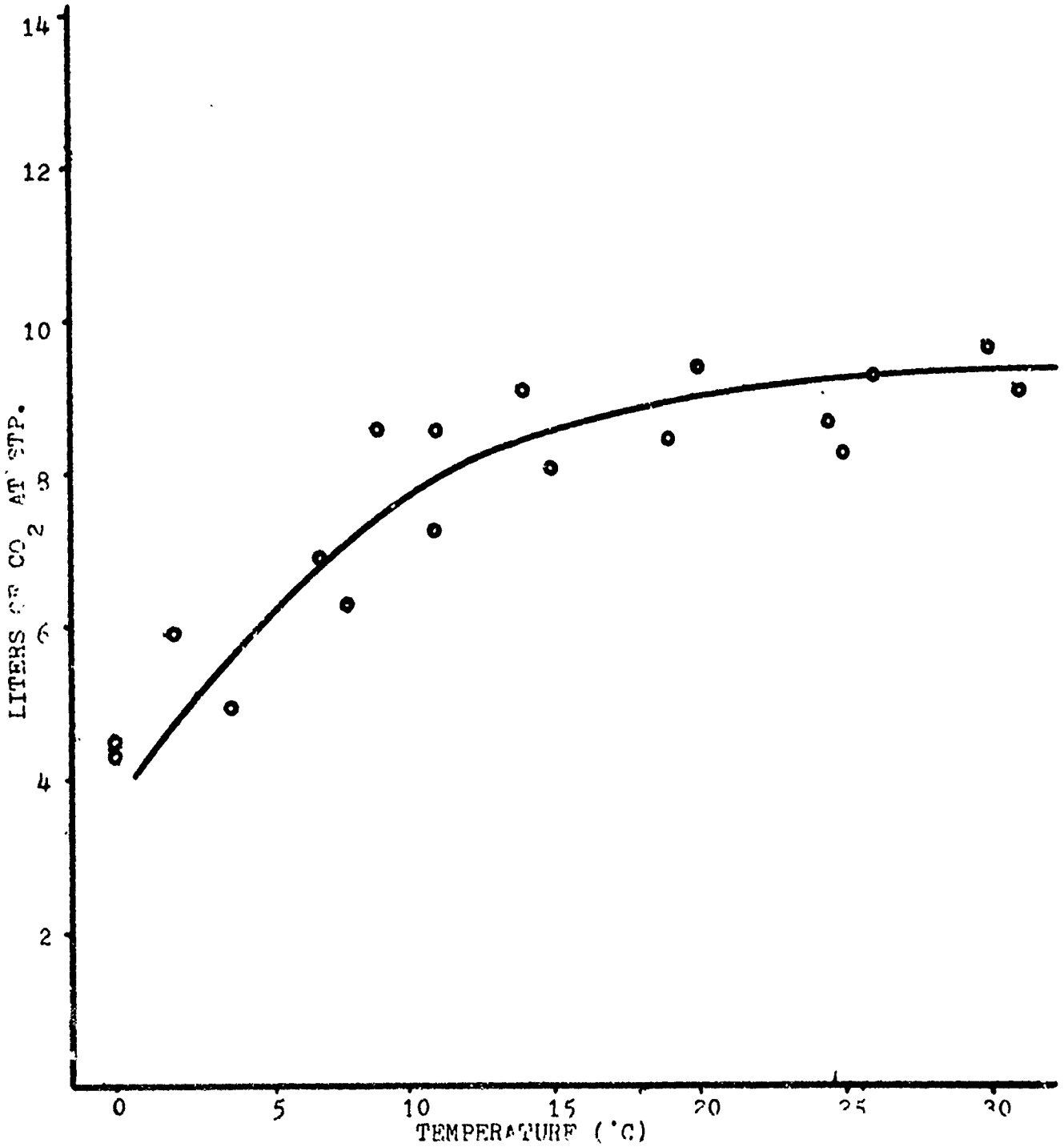
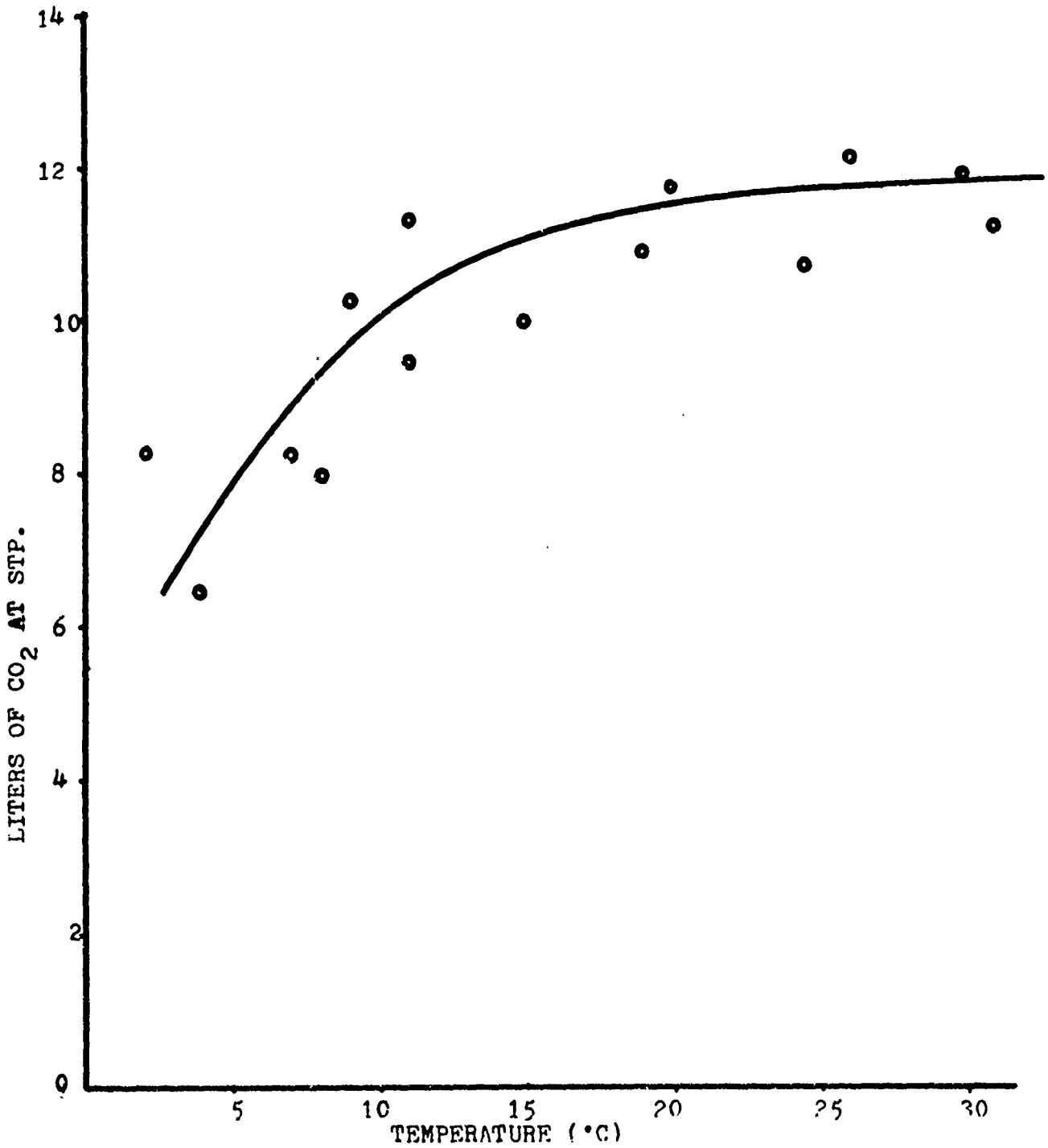


FIGURE 1

LITERS OF CO_2 ABSORBED VERSUS TEMPERATURE

BARALYME: 0.01 ATA. CUTOFF



EACH POINT REPRESENTS ONE DATA RUN

FIGURE 2

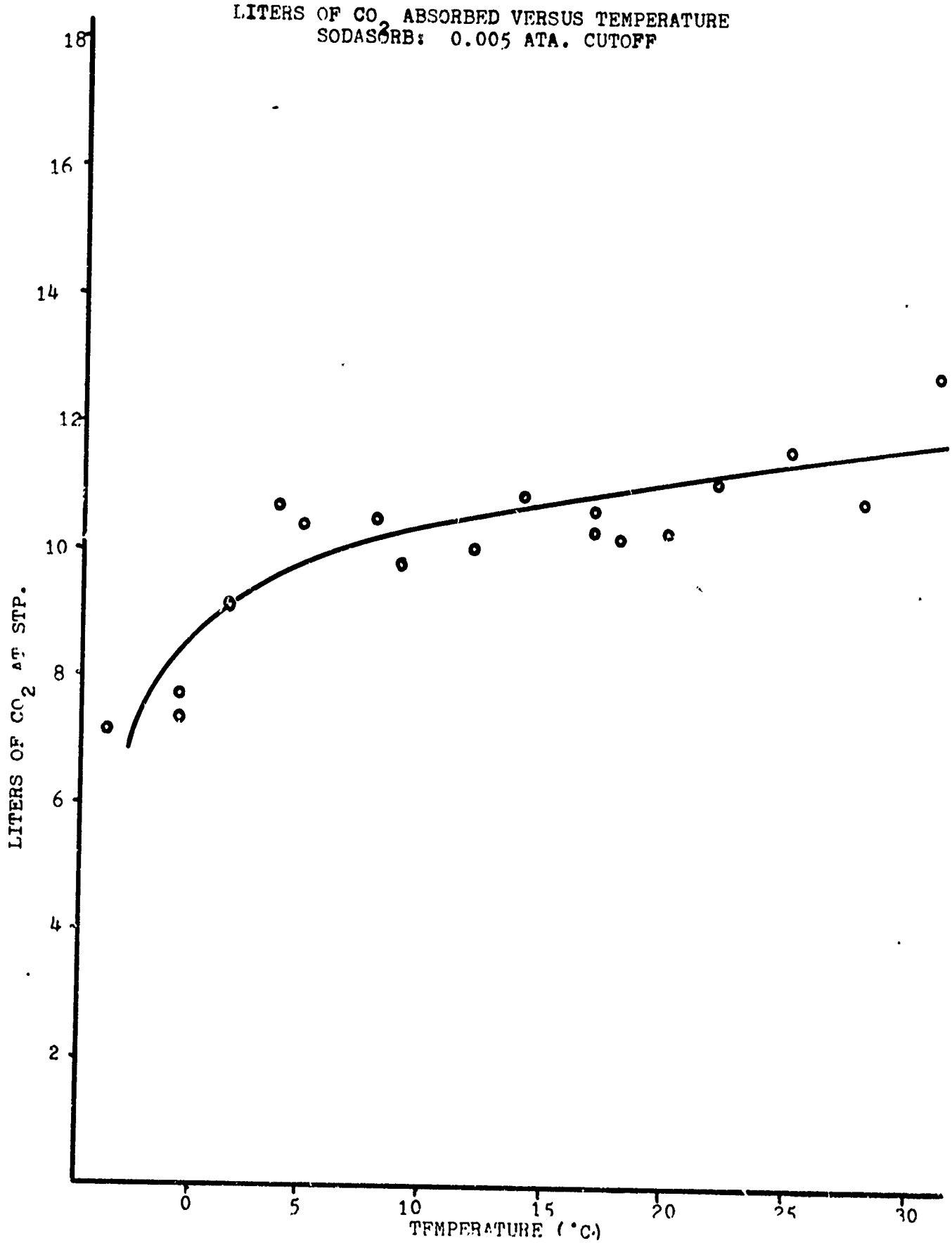

LITERS OF CO_2 ABSORBED VERSUS TEMPERATURE
SODASORB: 0.005 ATA. CUTOFF
LITERS OF CO_2 AT STP.
18
16
14
12
10
8
6
4
2
0
5
10
15
20
25
30
TEMPERATURE (°C)

Figure 3

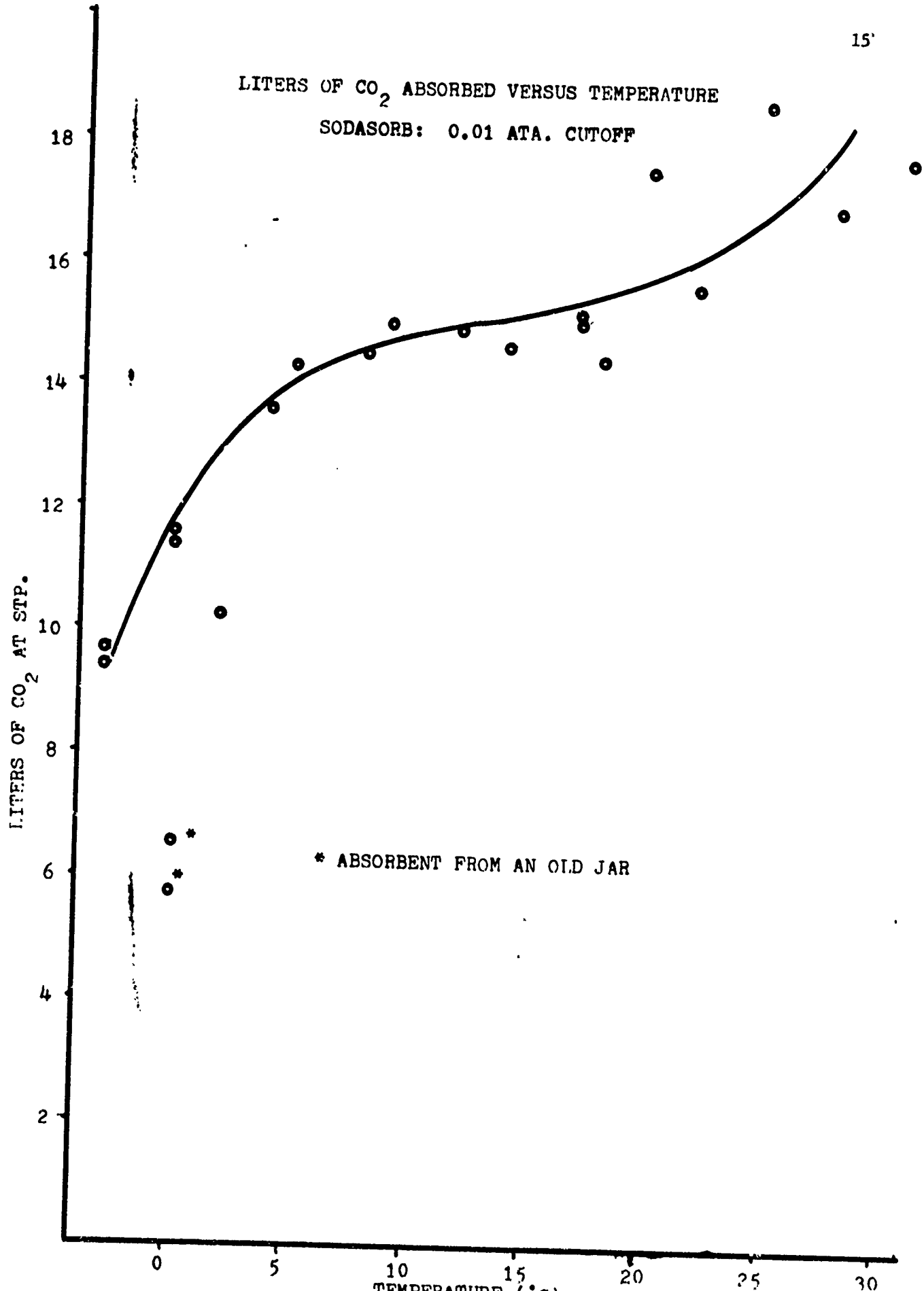

LITERS OF CO_2 ABSORBED VERSUS TEMPERATURE
SODASORB: 0.01 ATA. CUTOFF
LITERS OF CO_2 AT STP.
18
16
14
12
10
8
6
4
2
* ABSORBENT FROM AN OLD JAR
0
5
10
15
20
25
30
TEMPERATURE (°C)

FIGURE 4

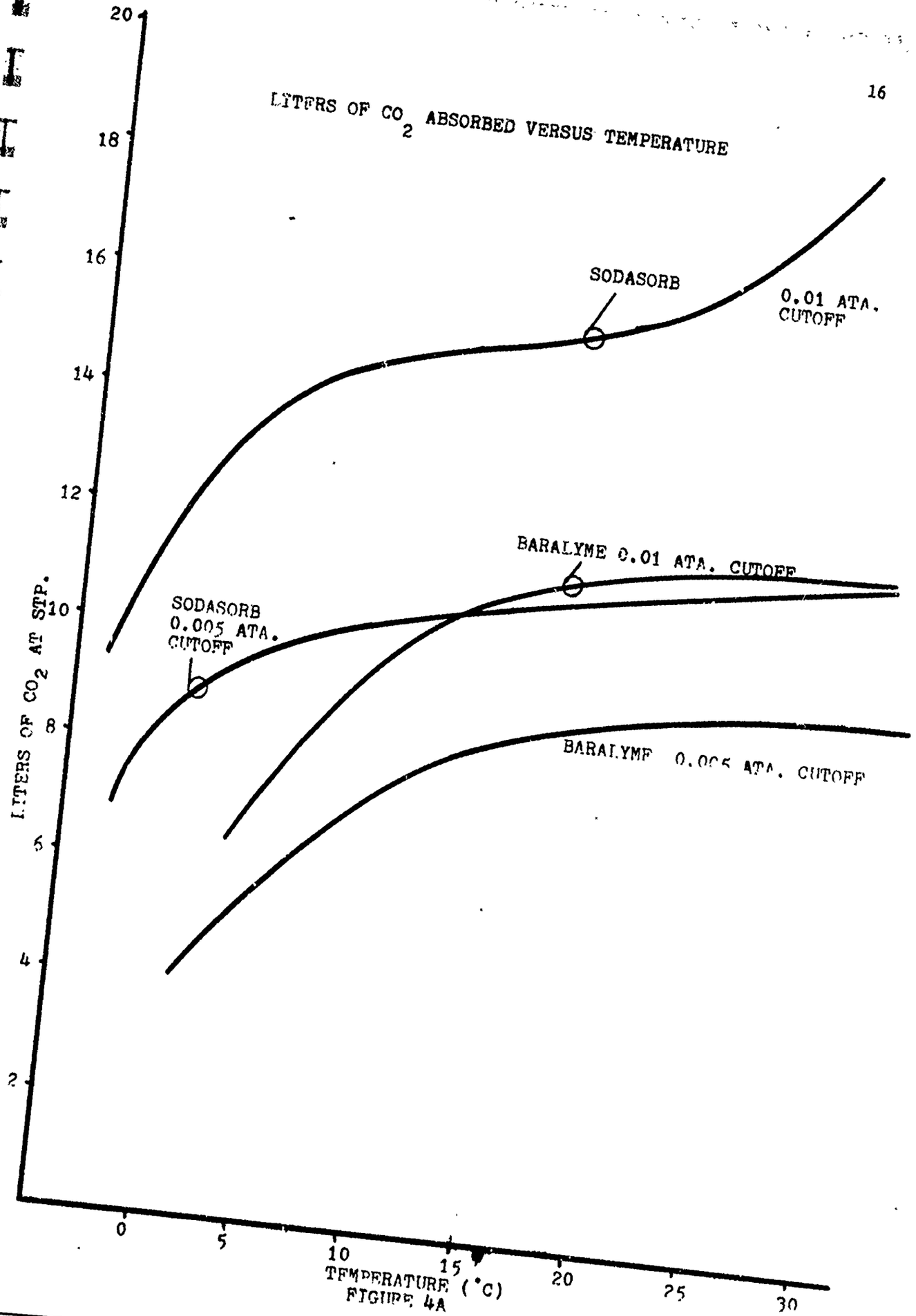
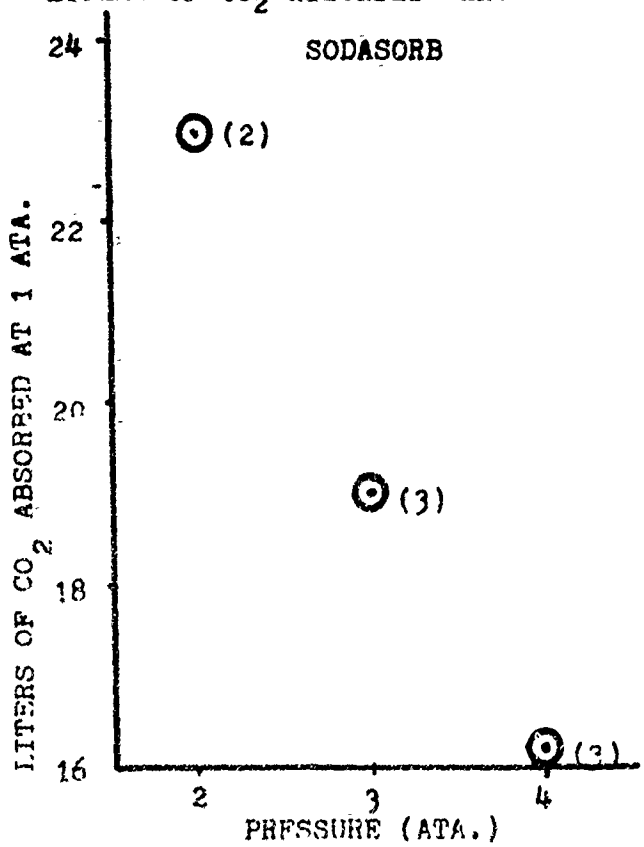

LITERS OF CO_2 ABSORBED VERSUS TEMPERATURE
SODASORB
0.01 ATA. CUTOFF
BARALYME 0.01 ATA. CUTOFF
SODASORB 0.005 ATA. CUTOFF
BARALYME 0.005 ATA. CUTOFF
LITERS OF CO_2 AT STP.
TEMPERATURE (°C)
20
18
16
14
12
10
8
6
4
2
0
5
10
15
20
25
30

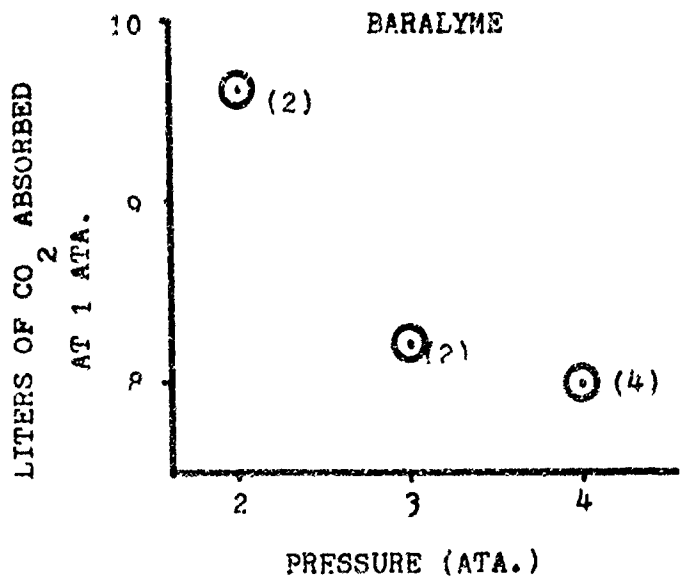
FIGURE 4A

LITERS OF CO_2 ABSORBED VERSUS PRESSURE



EACH POINT REPRESENTS THE AVERAGE OF THE NUMBER OF RUNS INDICATED BY THE NUMBER IN PARENTHESES

FIGURE 5



EACH POINT REPRESENTS THE AVERAGE OF THE NUMBER OF RUNS INDICATED BY THE NUMBER IN PARENTHESES

FIGURE 6

DISCUSSION

As a majority of the year was spent on the design, procurement of parts, and building of the unsuccessful high pressure system, there was insufficient time to collect enough data to establish statistical reliability.

Several factors control carbon dioxide absorbent efficiency and all of these were controlled to the maximum. One uncontrolled factor was the shelf life of the absorbents. Sodasorb showed this difference more radically than Baralyme. One can of older Sodasorb absorbent had little absorbent characteristics, breaking through after 6 minutes where the normal time was 10 minutes (Ref. Figure 4). Even within the same jar the absorbents displayed varying characteristics.

The efficiency of Sodasorb was 0.09 grams of carbon dioxide per gram of absorbent. This value compares with a study done in 1959 by Lt. HUSEBY. His value for an insulated canister at similar temperatures was 0.23 g/g. The theoretical efficiency of Sodasorb is 0.41 g/g[8]. In the same study by HUSEBY, the efficiency of Baralyme in an insulated canister was 0.14 g/g. In this experiment the efficiency of the Baralyme was 0.0475.g/g. The theoretical efficiency of Baralyme is 0.50 g/g[9]. The efficiency values for other studies were made with a lung simulation device. The efficiency for both absorbents is plotted in Figure 4A.

Another factor which effects efficiency was the design of the canister. The canister used in the tests was a simple cylinder, without baffles. The manufacturer of Baralyme recommends a canister with the diameter large in relation to its length. Due to time

considerations a larger more complex canister was not used.

Despite the lower efficiency values the trends of this experiment are still valid. One important trend can be noted from the plot of efficiency versus temperature. For Baralyme, for the 10°C to 25°C range, the volume of carbon dioxide absorbed changed little. (Ref.fig. 1,2). A similar result occurred in the 5°C to 20°C range for Sodasorb (Ref. fig 3,4). This trend points out the importance of insulating the breathing apparatus of the diver in order to maintain an inlet temperature above 10°C.

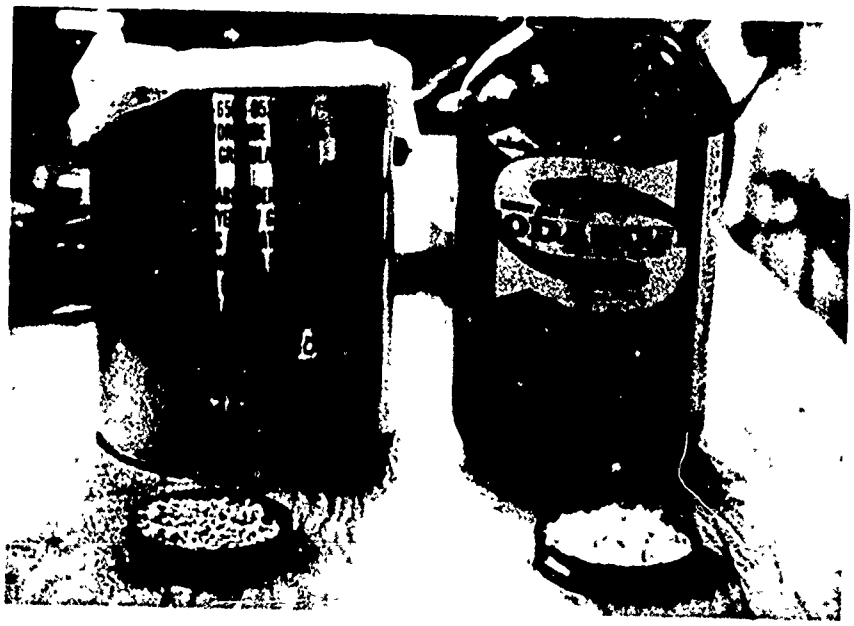
The results of the pressure tests indicate a trend toward a lower efficiency at lower depths (Ref.Fig 5,6). Time prevented this experiment from collecting sufficient data to reach reliable conclusions. Further analysis should be made as there was an effect due to pressure changes. Better equipment will be required to extend the depths to the depths the Navy uses today.

CONCLUSION

The efficiency of carbon dioxide absorbents decreases as the temperature of the inlet gas decreases. For the maximum efficiency the absorbent canister will have to be insulated from the environment. Heating by hot water or electric coils would not improve the efficiency substantially as above 10°C the efficiency increases little with temperature. The extra weight and volume of a heating package for the absorbent alone would be inefficient as well as impractical.

The efficiency of the absorbents decreased as the pressure increased. Due to the lack of consistent data only general trends could be arrived at. Before further studies can be made on the effects of pressure, a more accurate sensing device is required if the 0.005 ATA. partial pressure of carbon dioxide is to be used.

In this experiment Sodasorb was 20% more efficient than Baralyme above 15°C. At 5°C the efficiency of Sodasorb was 40% greater than Baralyme.



ABSORBENTS USED IN THE PROJECT

FIGURE 12

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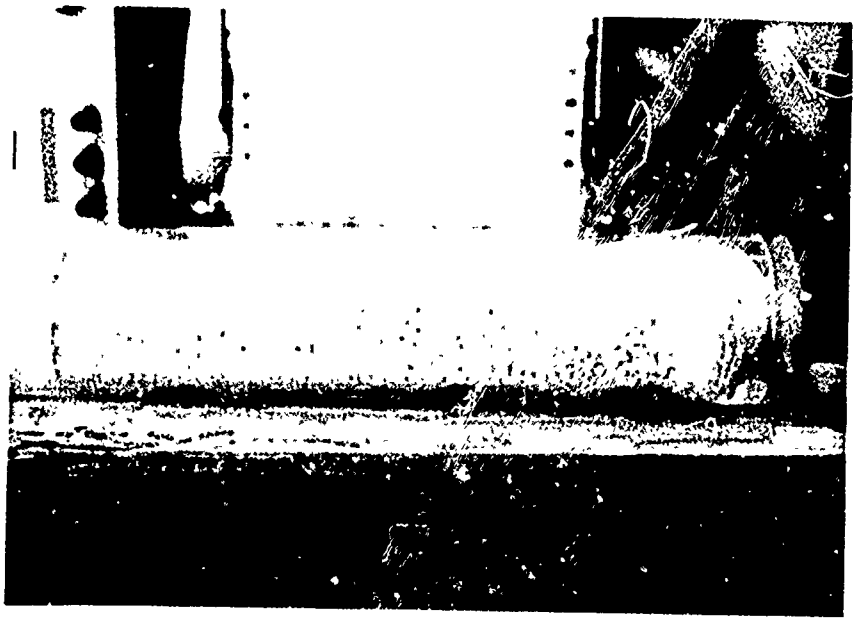
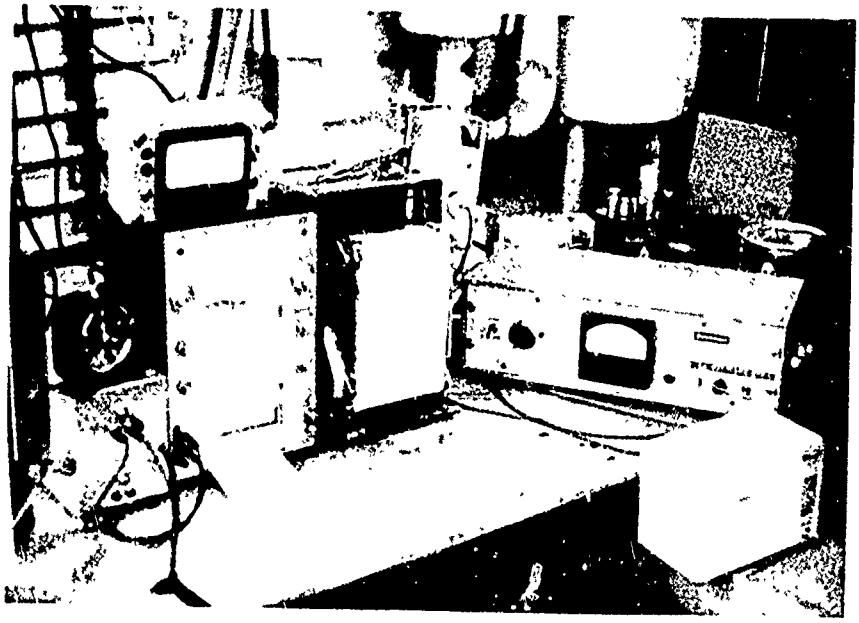


THE TESTING CANISTER

FIGURE 13



SENSING EQUIPMENT
TRUCK 14

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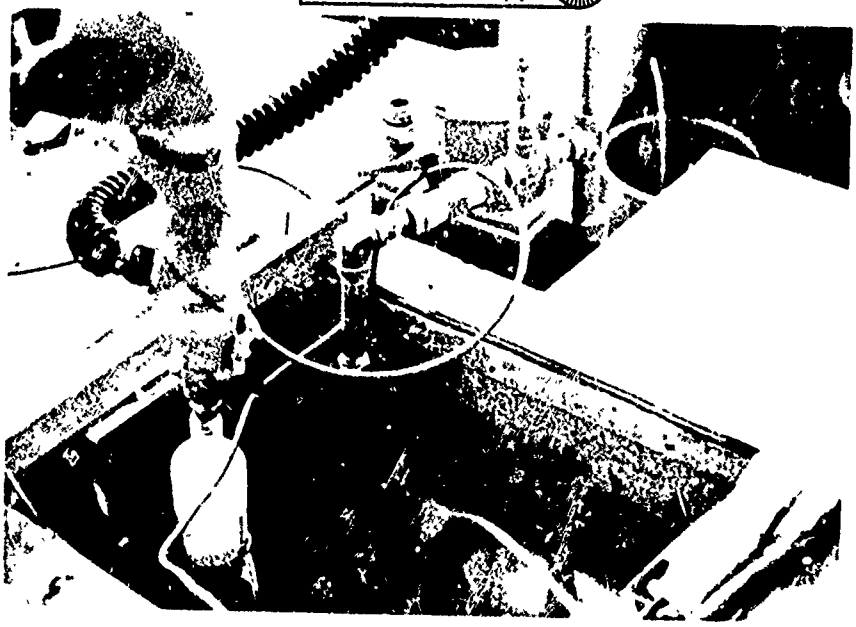

TEM GRAP

OUTPUT FROM LB-1 TO THE ESTERLINE-ANGUS RECORDER
HOUR FEEDS

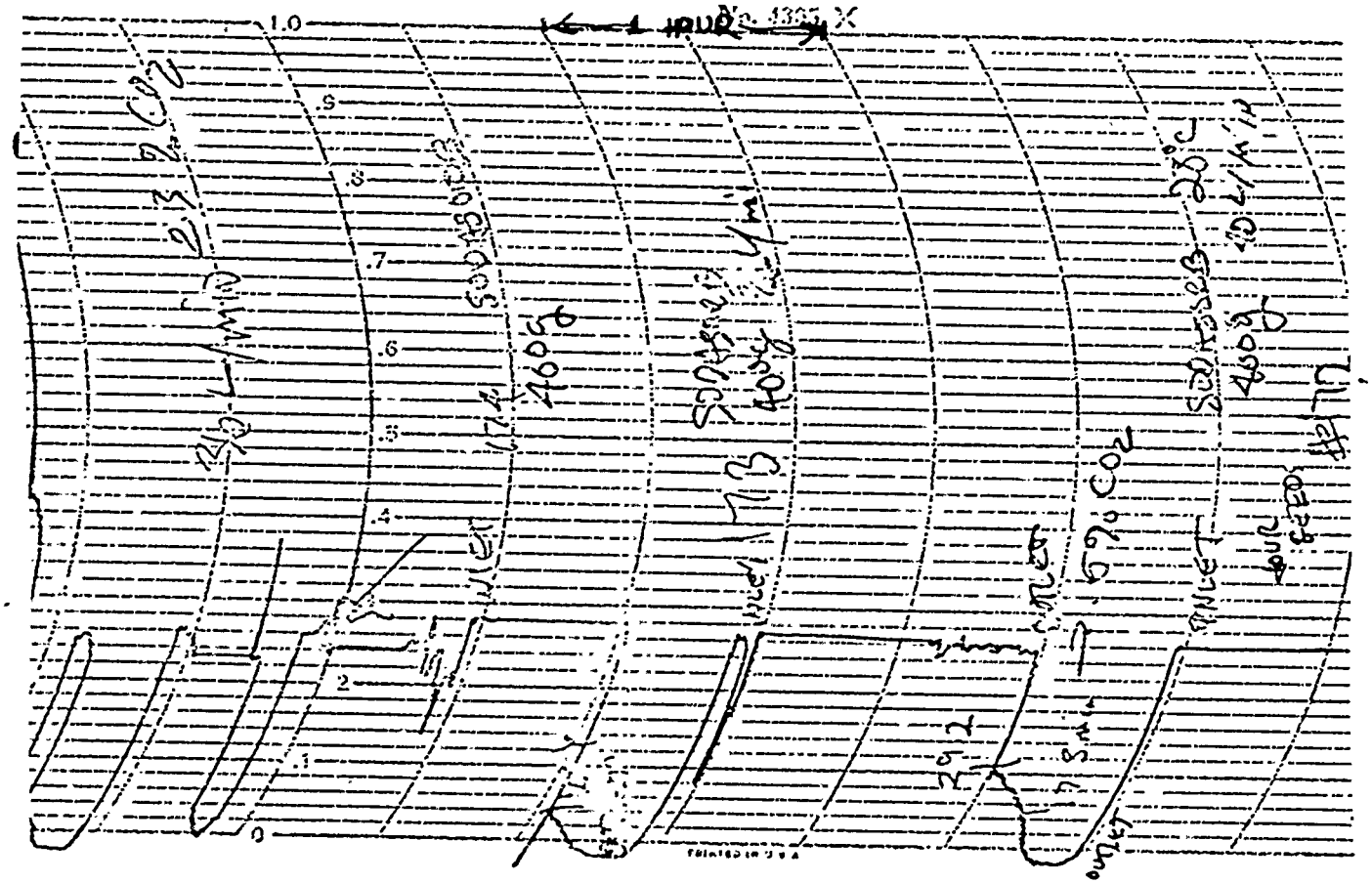

FIGURE 10

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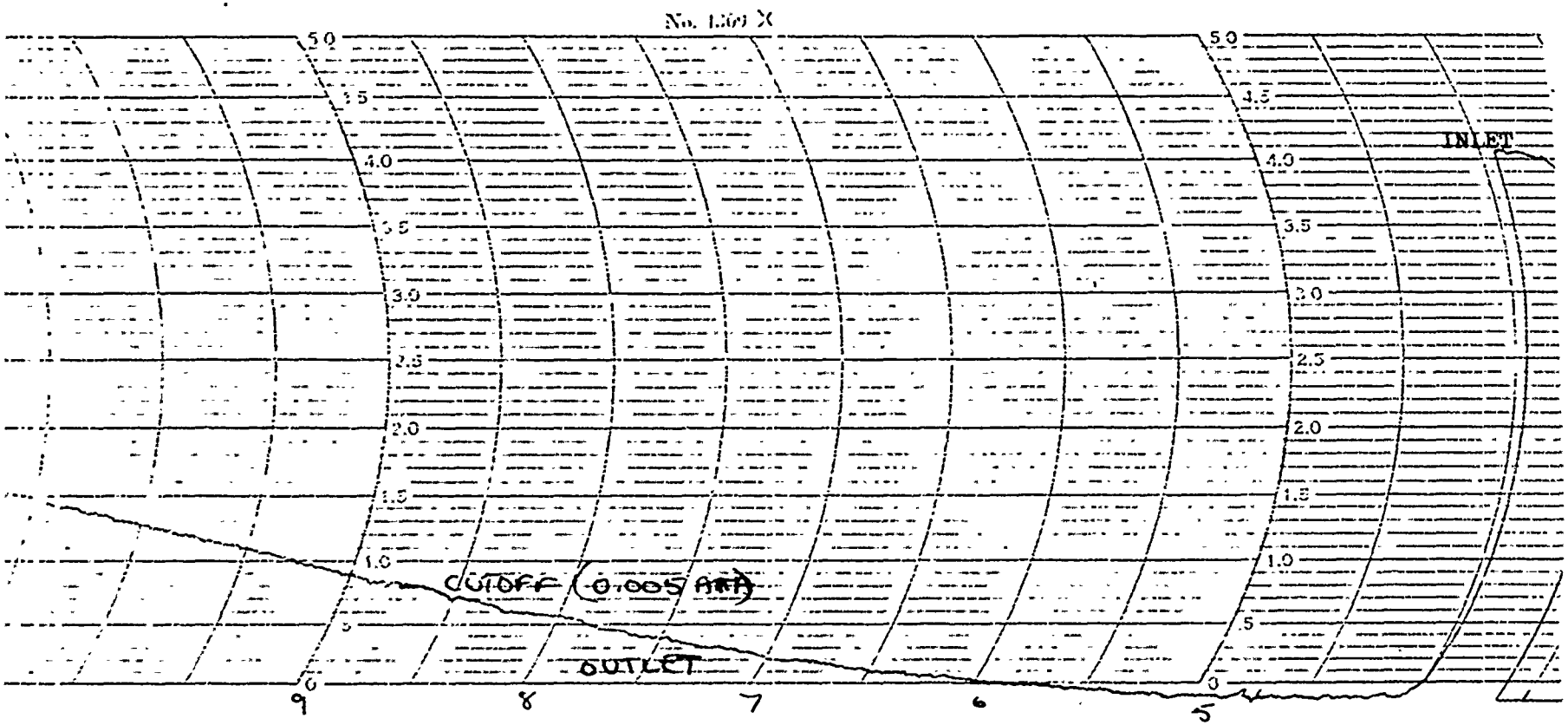

OUTPUT FROM LB-1 TO THE ESTERLINE-ANGUS RECORDER
MINUTE FEEDS

FIGURE 11

Reproduced from best available copy.

FOOTNOTES

[1]M. W. Goodman, "A Study of Carbon Dioxide Elimination from Scuba, with Standard and Modified Canisters of the U. S. Navy Closed-Circuit Oxygen Rig," Report presented to the U. S. Navy Experimental Diving Unit (Washington, D. C., 1964) p. 1.

[2]U. S. Diving Manual, Navy Department (Washington, D. C., 1970), pp. 66-67.

[3]Ibid.

[4]"CO_2 Absorbent Soda Lime U.S.P.," Leaflet of Dewey and Almy Chemical Division (Cambridge, Mass.)

[5]"Baralyme Granules: Carbon Dioxide Gas Absorbent," Leaflet of Chemetron Corporation (Chicago, Ill., 1966)

[6]Manual for the LB-1.

[7]U. S. Diving Manual, p. 59.

[8]W. E. McConnaughey, "Carbon Dioxide Absorption: A Study of Baralyme andSodalime in the Lithium Hydroxide Hopper," Report to the Naval Research Laboratory (Washington, D. C., 1952) Table II.

[9]Ibid.

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