



AEROSPACE INFORMATION REPORT

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SPACE TECHNOLOGY AVAILABLE FOR TRANSFER TO CIVIL
ENVIRONMENTAL PROTECTION AND POLLUTION CONTROL

PREFACE

This report was prepared to provide a summary of research, development and production of environmental control/life-support systems (EC/LSS) for manned spacecraft. The purpose of the summary is to relate this work to that being conducted in water, air and solid waste pollution control. Members of the preparing committee, life-support specialists and those familiar with civil pollution control, reviewed all of the literature for the past 15 years and determined that the references cited in this report were the most pertinent to pollution control. Tables are presented to indicate the type of data contained in each reference i. e. , descriptive, analytical, experimental and/or development data. In addition, discussions are presented on the past, present and future state-of-the art of each system to civil pollution control and environmental protection. This report is designed to be useful in familiarizing personnel in the pollution control fields with the wealth of related information available on the control of contaminants in air and water and the new methods for controlling and disposing of liquid and solid wastes.

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PREPARED BY

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SAE COMMITTEE SC-9, SPACECRAFT ENVIRONMENTAL CONTROL & LIFE SUPPORT SYSTEMS

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1. INTRODUCTION

Research and development of EC/LS systems for manned spacecraft began in the late 50's, after the U. S. S. R. and the U. S. A. demonstrated that rocket powered flight was sufficiently reliable to transport man in space. Agencies of the U. S. government initiated contract research and development on systems to support and maintain man in space flight circa 1958. Thousands of contracts were let in the subsequent years to provide reliable and efficient systems to provide the crew with the purest air and water possible and to store, recover or dispose of wastes in an aesthetic and sanitary manner. A great deal of this research is directly related to the problems of providing the occupants of "space ship earth" with pure water, pure air and suitable waste disposal or recycling techniques.

The systems that are specifically examined in this report, which may have direct benefit to the ecology of the earth, are:

A. AIR POLLUTION

- Carbon Dioxide Removal
- Oxygen Generation
- Trace Contaminant Control

B. WATER POLLUTION

- Water Recovery
- Waste Disposal
- Food Synthesis

In reference to these categories, the processes and techniques developed for manned space flight should have specific application to the following civil technologies in environmental control.

A. AIR POLLUTION

Carbon Dioxide Control

- Air Pollution Control
- Special Atmospheres for Food Storage and Shipments
- Medical Therapy
- Safety Equipment for Hazardous Atmospheres

Oxygen Generation

- Water Biooxidation
- Medical Therapy
- Chemical Processes
- Mining and Metallurgy Safety

Trace Contaminant Control

- Air Pollution Control
- Mining
- Chemical Processes
- Odor Control

B. WATER POLLUTION

Water Recovery

- Water Pollution Control
- Water Treatment and Purification
- Desalination

Waste Disposal

- Incineration
- Pyrolysis
- Waste Recycling
- Animal Waste Disposal

Food Synthesis

- Animal Feed
- Food Supplements



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2. CARBON DIOXIDE REMOVAL

- 2.1 Background Information: Carbon dioxide is removed from the atmosphere of a manned spacecraft to prevent its build up as a metabolic by-product to levels that would adversely affect the crew's performance (generally over 1.0% CO₂). It is desired to recover high purity (99%) carbon dioxide for oxygen regeneration. To accomplish this, the aerospace industry has sought to develop highly-efficient, low-weight processing systems with modest power requirements.

Although the atmospheric content of carbon dioxide may be increasing, it is not a significant atmospheric pollutant. This is true because the earth's atmosphere possesses a large, well-mixed storage capability--and because green plants, principally phytoplankton, photosynthetically remove carbon dioxide as one part of the earth's biological carbon cycle. This results in atmospheric carbon dioxide concentrations as low as 1/40 of those currently planned on manned spacecraft. Although the trend in spacecraft design is to lower carbon dioxide concentrations, the main thrust of aerospace interest has been in removal systems appropriate to the higher concentrations.

The greatest effort has thus been directed to various sorption systems in which removal capacity is directly proportional to adsorbent concentration.

Chemisorption, physical adsorption, and membrane separation processes are examples. All manned spacecraft up to and including the Apollo Command and the Lunar Excursion modules employed lithium hydroxide as a non-regenerable chemisorbent. Although this process requires only that a portion of the carbon dioxide laden atmosphere be passed through a bed of packed pellets, the process is not practically regenerable and hence is not useful for lengthy missions (i. e., in excess of 28 man days). Other chemisorbents, such as non-regenerable potassium superoxide (used by the U. S. S. R.) and various metal oxides (some regenerable) have been investigated, but they have not been developed past the early research stage.

For longer missions, the interest has been directed toward regenerable systems from which the carbon dioxide is recoverable. The most highly developed of these regenerable systems (the one employed on SKYLAB) uses artificial zeolites (molecular sieves) to physically adsorb carbon dioxide. These, too, are employed in the form of packed beds, and due to the looseness of the bond holding the carbon dioxide, they can be readily regenerated under the influence of vacuum, heat or both. They adsorb water preferentially to carbon dioxide so that, generally, regenerable pre-driers are employed to prevent water loss.

Several regenerable amine based granular materials have been developed which, although of lower carbon dioxide capacity, do not require pre-driers for efficient operation. Activated charcoal is still another sorbent that has been investigated, but results so far have proved disappointing due to low capacity and low regeneration times.

At lower acceptable spacecraft carbon dioxide partial pressures (~3 mm Hg) required for future missions, the zeolite systems are inefficient and thereby require a relatively high system equivalent weight. The electrochemical depolarized cell has received considerable attention recently and has reached an advanced state of development as the acceptable concentration of CO₂ has been reduced. This electrochemical process generates hydroxyl ions at the cathode which react with CO₂ to affect the removal process. Hydrogen is used to depolarize the cell, causing the CO₂ to be rejected at the anode. The electrochemical removal and recovery process also produces useful electrical power.

Other electrochemical processes have proved feasible. All use an electric field to affect the removal and recovery of the CO₂ through a chemical bath or matrix. A system using a bath of molten carbonates was successfully developed but it did not lend itself to low gravity applications. The carbonation cell has also been studied; it is similar in nature to the electrochemical depolarized cell.

2.1 (Continued)

Processes involving gaseous diffusion across semi-permeable membranes have also been developed. These have proved to be effective removal devices; but because the membranes are more permeable to water vapor than carbon dioxide, and they pass unacceptable amounts of oxygen and nitrogen, their use in oxygen regeneration systems has not proven practical.

Mechanical freeze-out, the process of lowering the process gas temperature until the carbon dioxide solidifies, has been considered for some years-but the complications involved have not made it attractive for space application.

2.2 Tabulation - Carbon Dioxide Removal:

<u>Techniques</u>	<u>Description or Analysis</u>	<u>Experimental Model/Data</u>	<u>Prototype System</u>	<u>Developed System*</u>
<u>Freezeout</u>	1, 22, 24, 30, 50 73, 90			
<u>Permeation (Membranes)</u>	14, 66, 73, 79, 83	26, 36, 66, 79, 83	79, 100	
<u>Absorption</u>	5, 60	37		
<u>Adsorption</u>				
Synthetic Zeolites	5, 8, 14, 22, 24 73, 76, 78, 90	7, 11, 12, 17, 18 20, 21, 24, 25, 26 67, 27, 54, 63, 70 72, 76, 78	10, 13, 17 28, 39, 53 55, 67, 72 95, 102	86, 93, 94, 99
Ion Exchange Resins	73, 84, 85	27, 37, 45, 51, 84	85, 77	77, 85, 92, 96
Activated Carbon		45, 59, 98		
Coprecipitated Gels		45		
<u>Chemisorption</u>				
Clathrates	71	71		
Limes, Soda	1	27, 42		
Baralyme	1	17, 42		
Hydroxides, Lithium	1, 3, 8, 14, 22	32, 56, 57		15, 95
Potassium		27, 29, 37, 46		
Oxides, Metallic	24	42, 61		
Silver	5, 8, 14	21, 34, 48		
Magnesium	23	52		
Ozonides		33		
Superoxides	1, 2, 22, 58 80	4, 9, 16, 19, 62 80	38, 41, 42	
Carbonates	5, 8	6, 27		
Phosphates		27, 37		
Amines	1, 5, 77, 78 82, 84, 85 87, 89	6, 27, 29, 37, 46 69, 82, 84, 85, 89 98	31, 69, 77	77, 85, 92, 96
Peroxides	74, 80	74, 80		

2.2 (Continued)

<u>Techniques</u>	<u>Description or Analysis</u>	<u>Experimental Model/Data</u>	<u>Prototype System</u>	<u>Developed System*</u>
<u>Electrochemical</u>				
Electrodialysis	22, 73	51	75, 88	
Carbonation	73	35, 40, 44, 49 68, 91	68	
Depolarization	73	64, 92, 101	95, 97	
Molten Carbonate	65, 90	65		
<u>Biochemical</u>				
	24	37, 47		

* Developed systems are those which are flight qualified and/or have been used successfully in manned chamber tests.

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2.3.2. Contacts in Government Agencies and Contractors:

NAME	COMPANY OR GOVERNMENT AGENCY	ADDRESS
H. F. Brose	Hamilton Standard Div. of United Aircraft Corporation	Windsor Locks Connecticut 06096
L. Clark	NASA Langley Research Center	Hampton, Va. 23365
T. Coull	The Garrett Corporation	2625 W. 190th Street Torrance, Ca
R. B. Martin	NASA Johnson Space Center	Houston, Tx. 77058
P. D. Quatromne	NASA Ames Research Center	Moffett Field, Ca. 94035
F. Tepper	Mine Safety Appliance Co.	201 N. Braddock Ave. Pittsburgh, Pa. 15208
W. J. Ward, III	Missile and Space Div. General Electric Company	Valley Forge, Pa.
R. A. Wynveen	Life Systems, Inc.	23715 Mercantile Rd. Cleveland, Oh. 44122
J. D. Zeff	Westgate Research Corp.	13478 Beach Ave. Marina del Rey, Ca. 90291

3. OXYGEN GENERATION SYSTEMS

Gaseous oxygen stored at high pressure has been used for many years in high altitude aircraft. The same approach was used in the Project Mercury spacecraft. However, the Gemini and Apollo spacecrafts were provided with oxygen stored at supercritical pressure to maximize storage density and thereby minimize the weight penalty of the storage containers. Chemical storage was considered for these spacecraft, but this technique appears best for applications that require a portable source of oxygen, (e. g. , advanced extravehicular protective system).

An average man engaged in sedentary activities consumes approximately 2 lb. of oxygen per day - which is relatively small weight penalty, even when the weight and volume of oxygen storage containers is considered. However, onboard generation of oxygen can be justified when the mission duration is longer than several months.

- 3.1 Regenerable Techniques: The basic regenerable oxygen recovery concepts evaluated for space applications are (1) the Sabatier process with methane or acetylene dump, (2) the Sabatier process with methane cracking, (3) the Bosch process, (4) the solid electrolyte process, and (5) the fused salt process. The recovery of oxygen from water is necessary for all concepts, because part of the inspired oxygen is used for metabolic water generation, and the oxygen recovered from expired carbon dioxide must therefore be supplemented.

3.1 (Continued)

The Sabatier-methane cracking processes generate water from concentrated carbon dioxide, and electrolysis units are required in addition to the carbon dioxide concentrator and the basic reduction unit. The Sabatier-methane (or acetylene) dump process, which reduces carbon dioxide to water and dumps hydrogen as methane (or acetylene) to space, consists of a carbon dioxide concentrator, the basic reduction unit, a water electrolysis unit, and stored expendable hydrogen.

The Bosch process generates water from the reduction of carbon dioxide with hydrogen. Oxygen is regenerated by electrolysis of the water formed in the reduction process.

The solid electrolyte process uses concentrated carbon dioxide, which is humidified so that electrolysis of the water-carbon dioxide mixture produces the full oxygen requirement. The solid electrolyte system consists of a carbon dioxide concentrator and the basic reduction unit; a separate water electrolysis unit is not required.

The fused salt process collects carbon dioxide directly from dried cabin air and electrolyzes it directly to oxygen. However, the quantity of oxygen recovered from the carbon dioxide is not quite sufficient for crew consumption, and a small water electrolysis unit must be added to meet the requirement. Thus, the fused salt system consists of the basic reduction unit and a water electrolysis unit. A separate carbon dioxide concentrator is not required.

- 3.2 Nonregenerable Techniques for Oxygen Supplies: Table I provides a comparison of chemical oxygen supply techniques evaluated for spacecraft use. Table II evaluates, in general terms, the application of space-oriented systems to a one-man, life support requirement.