ADVANCED REGENERATIVE ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS: AIR AND WATER REGENERATION

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ABSTRACT

Extended manned space missions will require regenerative life support techniques. Past U.S. manned missions used nonregenerative expendables, except for a molecular sieve-based carbon dioxide removal system aboard Skylab. The resupply penalties associated with expendables becomes prohibitive as crew size and mission duration increase. The U.S. Space Station, scheduled to be operational in the 1990's, is based on a crew of four to sixteen and a resupply period of 90 days or greater. It will be the first major spacecraft to employ regenerable techniques for life support. The paper uses the requirements for the Space Station to address these techniques.

INTRODUCTION

The need and requirements for a low earth orbit Space Station have been studied and defined. It will provide for the U.S. and other free world countries a comprehensive capability to exploit and explore the space environment. It will support and be part of a wide range of missions with objectives in science, applications, commercial activities and technology development. The Space Station will evolve by time-phased modular increments delivered and supplied by the Space Shuttle /1,2/. It will be capable of operating continuously manned and, under special circumstances, unmanned. A minimum useful lifetime of ten years is sought, but life cycle costs decrease continuously as the operating life increases beyond this minimum level.

SPACE STATION SYSTEMS

The Space Station has been divided into 13 systems /1/. The current paper addresses just one of these: the Environmental Control/Life Support System (ECLSS).

Environmental Control/Life Support System

The ECLSS can be divided into six functional categories:

- Air Revitalization System
- Atmospheric Pressure and Composition Control System
- Cabin Temperature and Humidity Control System
- Water Reclamation System
- Personal Hygiene System
- Waste Management System

Each of these, in turn, are further subdivided, e.g., the Air Revitalization System into carbon dioxide (CO_2) concentration, CO_2 reduction, oxygen (O_2) generation, trace contaminant control and atmosphere quality monitor. The first three functional categories makeup the Atmosphere Management Group. The last three makeup the Water and Waste Management Group. A third group could be considered those functional elements needed to provide a safe haven capability.

ECLSS Functions. Table 1 summarizes the ECLSS functions. The functions include, for example, providing O_2 for metabolic consumption, Space Station leakage and airlock use. It is maintained or controlled by monitoring the partial pressure of O_2 (pO_2) in the atmosphere.

ECLSS Performance Requirements. Table 2 summarizes the ECLSS performance requirements /3/ being used on the Space Station studies. These requirements are close to those used for previous studies /4-7/. These requirements are further supplemented by such needs as sufficient O_2 and nitrogen (N_2) storage aboard the Space Station for one total emergency repressurization; atmospheric leakage to be less than 0.5 lb/day

TABLE 1 ECLSS Functions

Functions[a]	Applications	Maintain Or Control
• Provide O_2	— For Metabolic, Leakage, Airlock Use	pO_2
• Provide H_2O	— For Drinking, Cooking, Bathing, Dishes, Laundry	--
• Remove CO_2	— From Metabolic	pCO_2
• Remove H_2O	— From Respiration, Perspiration, Use of Handwash, Shower, and Washer/Dryer	pH_2O (RH)
• Remove Trace Contam.	— From Crew, Equipment, Outgassing	Trace Contam.
• Provide N_2	— For Leakage, Airlock Use, Purging, Pressure Reference	O_2/N_2 Ratio
• Provide Environment	— Temperature, Pressure, Relative Humidity	T, P
• Provide Facilities	— Handwash, Shower, Dishwasher, Clothes Washer/Dryer, Toilet, Trash Compactor, Air Ventilation/Filtration	--
• Provide Bacterial Control	— Of Air, Water, Waste Solids/Liquids	Bacteria

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a. Provisions for food assumed part of Space Station Habitability and Crew Support System.

TABLE 2 ECLSS Performance Requirements

PARAMETER	UNITS	OPERATIONAL	90-DAY DEGRADED(1)	21-DAY EMERGENCY
CO_2 Partial Pressure	mmHg	3.0 Max.	7.6 Max.	12 Max.
Temperature	deg. F	65 - 75	60 - 85	60 - 90
Dew Point(2)	deg. F	40 - 60	35 - 70	35 - 70
Ventilation	ft/min	15 - 40	10 - 100	5 - 200
Potable Water	lb/man-day	6.8 - 8.1	6.8 min	6.8 min
Hygiene Water	lb/man-day	12 min	6 min	3 min
Wash Water	lb/man-day	28 min	14 min	0
O_2 Partial Pressure(3)	psia	2.7 - 3.2	2.4 - 3.8	2.3 - 3.9
Total Pressure	psia	14.7	10 - 14.7	10 - 14.7
Trace Contaminants	—	24 hr. Ind. Standard	8 hr. Ind. Standard	8 hr. Ind. Standard
Microbial Count	per ft^3	100	—	—
Maximum Crew Member	Per Space Station	8	8	12
Maximum Crew Member	Per Habitat Module	4	8	8

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1. Degraded levels meet "Fail Operational" reliability criteria
2. In no case shall relative humidities exceed the range of 25 - 75%
3. In no case shall the O_2 partial pressure be below 2.3 psia, or the O_2 concentration exceed 26.9%

per module and 5 lb/day for the entire Space Station; exposure of ECLSS equipment to cabin pressure of 0 to 10 psia must not create hazard of cause damage; etc.

ECLSS Average Design Loads. The ECLSS average design loads are given in Table 3 /8/. Although similar to those used for previous studies, values often differ significantly in areas of importance to ECLSS designers.

ECLSS CLOSURE OPTIONS

Current state-of-the-art ECLSS is based on an expendable or "open loop" system approach. Various options exist for the space ECLSS designer to reduce the resupply requirements and costs associated with expendables. Options range from an enhanced open loop in which only regenerable CO_2 removal is used to a completely closed ECLSS where food is regenerated aboard the space vehicle.

TABLE 3 ECLSS Design Average Loads

	Space Station Values /8/	SOC Value /9/
Metabolic O_2	1.84 lb/man day	1.84 lb/man day
Leakage Air	TBD	5.00 lb/day total SOC
EVA O_2	1.32 lb/8 hr EVA	1.22 lb/8 hr EVA
EVA CO_2	1.67 lb/8 hr EVA	1.48 lb/8 hr EVA
Metabolic CO_2	2.20 lb/man day	2.20 lb/man day
Drinking Water	2.86 lb/man day	4.09 lb/man day
Food Preparation Water	3.90 lb/man day	1.58 lb/man day
Metabolic Water Production	0.78 lb/man day	0.70 lb/man day
Clothing Wash Water	27.50 lb/man day	27.50 lb/man day
Hand Wash Water	7.00 lb/man day	4.00 lb/man day
Shower Water	5.00 lb/man day	8.00 lb/man day
EVA Water	9.68 lb/8 hr EVA*	9.68 lb/8 hr EVA
Perspiration and Respiration Water	4.02 lb/man day	4.02 lb/man day
Urinal Flush Water	1.09 lb/man day*(a)	1.09 lb/man day
Urine Water	3.31 lb/man day*(a)	3.31 lb/man day
Food Solids	1.36 lb/man day	1.60 lb/man day
Food Water	1.10 lb/man day	1.00 lb/man day
Food Packaging	1.00 lb/man day*	1.00 lb/man day
Urine Solids	0.13 lb/man day	0.13 lb/man day
Fecal Solids	0.07 lb/man day	0.07 lb/man day
Sweat Solids	0.04 lb/man day	0.04 lb/man day
EVA Wastewater	2.00 lb/8 hr EVA	2.00 lb/8 hr EVA
Charcoal Required	0.13 lb/man day*	0.13 lb/man day
Metabolic Sensible Heat	7,010 BTU/man day	7,000 BTU/man day
Hygiene Latent Water	0.94 lb/man day	0.94 lb/man day
Food Preparation Latent Water	0.06 lb/man day*	0.06 lb/man day
Experiments Latent Water	1.00 lb/day	1.00 lb/day
Laundry Latent Water	0.13 lb/man day	0.13 lb/man day
Waste Wash Water Solids	0.44%	0.44%
Expended Water Solids(b)	0.13%	0.13%
Air Lock Gas Loss	2.40 lb/EVA	2.40 lb/use
Trash	1.80 lb/man day*	1.80 lb/man day
Trash Volume	0.10 ft 3/man day*	0.10 ft 3/man day

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*Not cited in reference but taken from the Space Operations Center Study /9/.

(a) Cited reference identified urine, at 4.4 lb/man day, approximately combined total of urinal flush water and urine water.

(b) Assumed shower and hand wash.

Alternatives

Cost-effective continuous operation of the Space Station requires use of some level of regenerative techniques. Table 4 presents a range of closure operations. Major ones include: a) Regenerable CO_2 removal; b) Regeneration of O_2; c) Reclamation of water and d) Regeneration of food. All of these are candidates for a 1990's in-orbit Space Station. Technology for closure of the food cycle, however, while currently under development, may not reach the maturity level needed to be a viable candidate when the initiation of the detailed Space Station design must start (projected 1987). Regeneration of N_2 is not under development, *but* a subsystem for on-board generation of N_2 from potential propellents (e.g., hydrazine, N_2H_4) is being developed.

Open Loop Costs

The launch weight of a Space Station decreases as the CO_2 removal, water and O_2 loops are closed. This is illustrated in Figure 1. The level of launch weight savings, however, can vary depending upon many factors. This is illustrated in Figure 2 which shows the impact on launch weight for the initial launch (with 120 days of on-board storage) and for resupply every 90 days as function of crew size. The results are presented for three different levels of water allotment:

- A minimum level defined as only the water required for drinking, food preparation, hand washing and urinal flushing
- An acceptable level defined as the minimum level plus adding the water for a full body shower
- A full service level defined as the acceptable level plus adding the water for clothes washing and dish washing

The water requirements are based on the quantity of water per person day for the water uses cited in Table 5. Note, the water requirements from Table 3 have been included. There are, however, many less visible, but yet expensive hidden costs of an open loop, expendable driven Space Station design. Some of these are cited in Table 6.

REGENERABLE ECLSS TECHNIQUES ARE AVAILABLE

Regenerable techniques are available and developed, for example, to close the CO_2 removal, O_2 generation and water reclamation loops. The technologies for food closure are under development.

CO_2 Removal

Of the more than nine CO_2 removal concepts evaluated by NASA, two techniques remain as viable candidates. They are the Electrochemical CO_2 Concentrator, or EDC, and the Steam Desorbed Amine Subsystem (SDAS) /10-12/.

TABLE 4 Possible Degree of Closure Options

CLOSURE OPTION	CO_2 REMOVAL	O_2 SUPPLY	N_2 SUPPLY	WATER SUPPLY			FOOD SUPPLY
				DRINKING	HYGIENE	WASH[1]	
OPEN	Expendable (LiOH) Collect. Ship Back, Resupply	Cryogenic, Resupply (Scavenging)	Cryogenic Resupply	Store, Resupply	Store, Resupply	Store, Resupply	Store, Resupply
ENHANCED OPEN	Regenerable Collect, Dump	Same	Same	Same	Same	Same	Same
MINIMUM CLOSED	Regenerable Collect, Reduce To H_2O	Same	Same	Condensed Humidity, CO_2 Reduction	Same	Same	Same
PARTIALLY CLOSED	Same	O_2 From Water Electrolysis	Same	Same	Recycle, Reclaim Urine Water	Recycle	Same
ENHANCED CLOSED	Same	Same (Reclaimed H_2O Feed)	N_2H_4 Cat. Decomposition	Same	Same	Same	Same
CLOSED[2]	Plants	Plants	Plants	Condensed Humidity, Recycled H_2O	Same	Same	Regen-eration

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1. Shower, dish washing, clothes washing.
2. Technology not available for Initial Space Station.

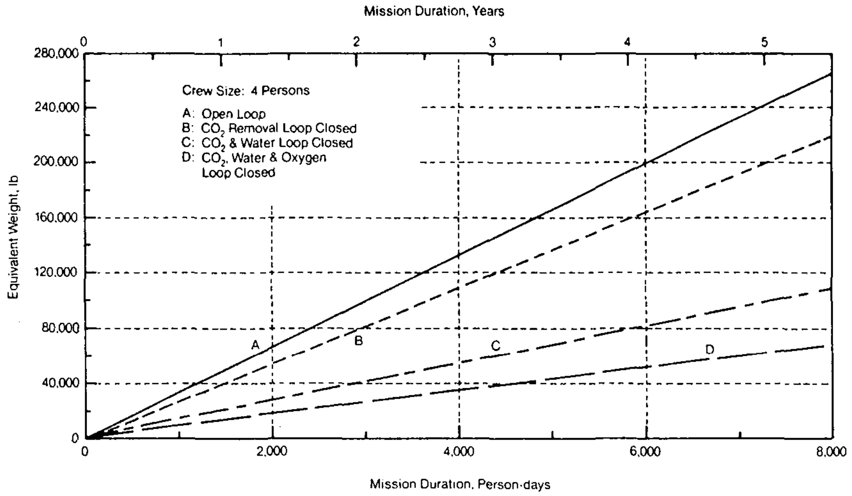


Fig. 1. Regenerative Versus Non-Regenerative ECLSS

O_2 Regeneration

Regeneration of O_2 requires the reduction of the concentrated CO_2 with hydrogen (H_2) to form a carbon product and water. Electrolysis of the latter is then used to regenerate the O_2 and simultaneously provide H_2 for the reduction of CO_2.

Two CO_2 reduction techniques are being actively developed. One involves the reduction to form methane (CH_4) gas (Sabatier Process). The CH_4 would then be vented overboard or be used in a resistojet for attitude control. The other is based on the reduction of CO_2 to form carbon (Bosch Process). This would eliminate overboard venting since the carbon would periodically be returned to earth.

Two O_2 (water electrolysis) generation techniques are being actively developed. One involves the static feed addition of water to the electrolysis cell (SFE) and uses an alkaline electrolyte. The other is based on a recirculating water feed system and is characterized by an electrolysis cell, which employs an acid electrolyte in a solid polymer form.

Water Reclamation

Two basic processes are being developed for recovering water. One is based upon phase change techniques, e.g., vapor compression and distillation. The other is based on filtration techniques, e.g., ultrafiltration and then reverse osmosis.

Open Issues Impacting ECLSS Design

Many issues impacting the ECLSS design remain to be resolved. These include, for example: a) The technology readiness on the specific date the final Space Station design will be initiated; b) The level of extravehicular activity; c) The level of overboard venting to be allowed, and; d) The selected crew size. Many major technology gaps are associated with ECLSS, such as:

1. Regenerative techniques have not flown previously and, therefore, have not reached the highest technology maturity level.
2. Quantitative failure rate data is missing which establishes reliability, defines spares and dictates maintainability approaches.
3. Integration of selected functions or subsystems are only beginning to be implemented.
4. Flight maintainable hardware designs are immature.
5. Fault diagnostic capabilities of instrumentation are limited.

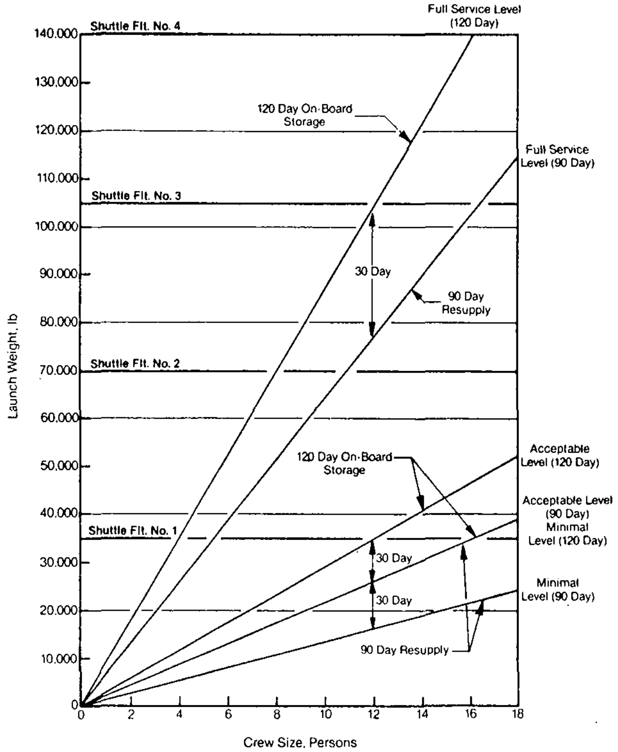
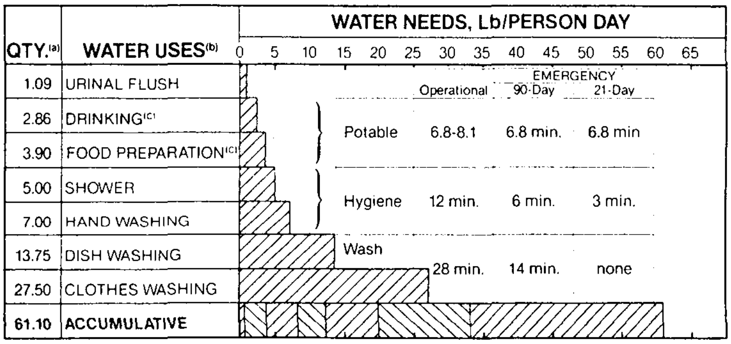


Fig. 2. Space Station ECLSS Block Diagram

TABLE 5 Water Needed: Resupplied or Reclaimed?



QTY.[a]	WATER USES[b]	WATER NEEDS, Lb/PERSON DAY			
				EMERGENCY	
			Operational	90-Day	21-Day
1.09	URINAL FLUSH				
2.86	DRINKING[c]	Potable	6.8-8.1	6.8 min.	6.8 min
3.90	FOOD PREPARATION[c]				
5.00	SHOWER	Hygiene	12 min.	6 min.	3 min.
7.00	HAND WASHING				
13.75	DISH WASHING	Wash	28 min.	14 min.	none
27.50	CLOTHES WASHING				
61.10	**ACCUMULATIVE**				

(a) Lb/Person-Day

(b) EVA cooling water requires additional 3.32 lb/day based on 1,000 EVA hours per 365 days at 9.68 lb water/8 hr. EVA (unless nonventing thermal approach used).

(c) These water users require potable quality water.

TABLE 6 ''Hidden'' Costs of Expendable (Open Loop) Operation

- More Frequent Resupply Flights
  - Non-mission related work
  - Wear and tear on launch vehicles
  - Chance for major failure
- Lower In-Orbit Crew Productivity
  - Expendable replacement time
  - Resupply unloading time
  - Spent expendable loading time
- Increased Logistics Costs
  - Maintaining "supply lines"
  - Maintaining inventory (and associated documentation)
  - Maintaining waste disposal facilities
- High Retrofit Costs[a]

(a) Would probably not be implemented because of high cost, complexity, uncertainty and momentum.

REGENERATIVE ECLSS TECHNOLOGY

Many regenerative ECLSS developments have been completed over the past 25 years. Major developments relating to air revitalization and water reclamation systems will now be reviewed. The Air Revitalization System alternatives are summarized in Table 7.

Regenerable CO_2 Removal Concentration

The EDC and SDAS processes have been described elsewhere /10-12/. Table 8 presents a comparison of total equivalent weight of the EDC versus the SDAS. The EDC has evolved into a simple, low-cost, reliable and flexible system. It has been designed and tested for Space Station and Shuttle Orbiter missions. Currently more than 20,000 hours have been accumulated on an EDC module under just one endurance/performance test program. Table 9 presents the size of the EDC for Space Stations with crew sizes of 4, 6, 8 and 12. Figure 3 shows the four-person hardware (CS-4). The size is shown in Table 9 under Model CS-4.

TABLE 7 Air Revitalization System Alternatives

ARS	Alternatives Open	 Closed	 Technologies
CO_2 Removal	LiOH	Regenerative	Electrochemical Solid Amine
CO_2 Reduction	--	To Yield H_2O	Sabatier (CH_4) Bosch (Carbon)
O_2 Supply	Cryogenic	Electrolysis	Static Feed (Alkaline) Solid Polymer (Acid)
Trace Contam.	Active Carbon & Amb. T. Cat. Ox.	High Temp. Cat. Oxidizer	Expend. Absorbers Regen. Absorbers
Atm. Qual. Mon.	Yes	Yes	Gas Chrom. & Mass Spec

TABLE 8 Total Equivalent Weight EDC Versus Steam-Desorbed Amine

	Requirements		Total Equivalent Weight, lb	
	EDC	Steam-Desorbed Amine	EDC	Steam-Desorbed Amine
Fixed Hardware Weight		•	86	139
Power				
Requirements, W				
AC	150	375		
DC	-97	526		
Weight Penalty			49	577
Heat Rejection				
Requirements, W				
To Air	277	901		
To Liquid	128	—		
Weight Penalty			145	394
Subtotal Equivalent Weight			280	1,110[b]
Assoc. Subsystem Penalties[a]				
Humidity Control				
Water, lb/day	4	32		
Weight Penalty			102	770
Water Processing				
Water, lb/day	4	32		
Weight Penalty			*27*	*206*
O_2 Generation (H_2O, lb/day)				
Water, lb/day	4			
Weight Penalty			309	
Total Equivalent Weight			718	2,086[c]

(a) Including hardware, power and heat load penalties.
(b) Amine is 3.6 times greater equivalent weight than EDC.
(c) Amine is 2.9 times greater equivalent weight than EDC.

The EDC offers many advantages over other regenerable CO_2 removal processes:

1. A lower equivalent weight which becomes more significant as the partial pressure of CO_2 decreases (see Figure 4) /13/.

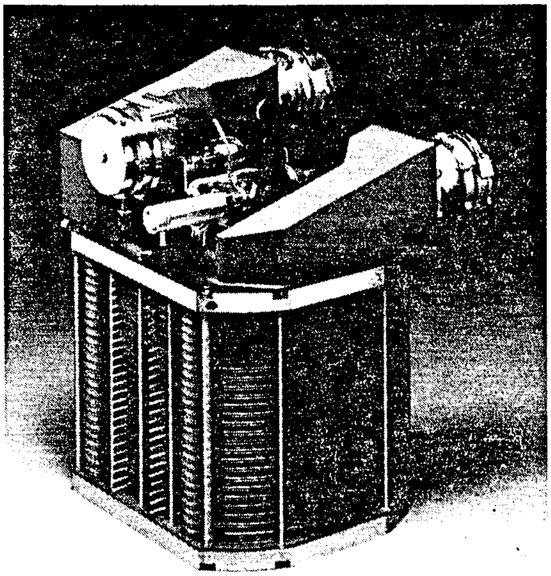


Fig. 3. Electrochemical CO_2 Removal Subsystem, Four-Person Capacity

2. Readily adapts to varying crew sizes since only cells are added or deleted rather than developing completely new canisters for each change in crew size.
3. Avoids the large atmosphere humidity load which is a by-product of the SDAS.
4. Operates continuously or cyclically for user flexibility, rather than only cyclically as characteristic of the SDAS.
5. Premixes the H_2 and CO_2 for transfer to the CO_2 reduction process without contamination with cabin N_2 as characteristic of the SDAS.
6. The CO_2 removal rate can be automatically varied up or down to allow handling variations in loads; not possible with the SDAS.
7. Avoids the compressor, its noise, and CO_2 accumulator as needed by the SDAS.
8. The subsystem is maintainable at the individual electrochemical cell level which provides for greater reliability (e.g., a four-person system consists of 24 cells with each one of these maintainable).
9. Adapts to the integrated O_2, H_2 and water concept for Space Station simplification, cost reduction and flexibility (discussed in more detail below).

CO_2 Reduction Processes

The Bosch /14, 15/ and Sabatier /16/ processes have been described previously. The Bosch CO_2 reduction process reduces CO_2 with H_2 to form solid carbon and water. Complete conversion is obtained by recycling the process gases with continuous deposition of carbon and removal of water. The carbon is collected in an expendable cartridge (see Figure 5) contained in the Bosch reactor. The Bosch process requires a small quantity of expendables (see Table 10).

The Sabatier process reduces CO_2 with H_2 to form CH_4. Complete conversion (>99%) is obtained in one pass through the Sabatier reactor (see Figure 6). The water is condensed and the exhaust gases, primarily CH_4 and unreacted CO_2, are vented overboard. The Sabatier process requires no expendables.

Static Feed Electrolyser (SFE)

The static feed /17, 18/ and solid polymer electrolyte /19/ water electrolysis systems have been described elsewhere. The static

TABLE 9 Electrochemical CO_2 Concentrator Charts

Model No.	Capacity, People @		Weight, Lb	Volume, Ft^3	Dimensions, In			Power, W		Heat Load, W	No. of Cells
	3mm Hg	12mm Hg			Ht	Wd	Ln	DC Out	AC In		
CS-4	4	8	86	2.5	20.6	15.5	13.5	100	50	245	24
CS-6	6	12	110	3.1	25.4	15.5	13.5	160	80	364	36
CS-8	8	16	134	3.7	30.2	15.5	13.5	220	80	450	48
CS-12	12	24	182	4.8	39.8	15.5	13.5	340	80	626	72

a. Based on 2.20 lb CO_2/person-day and all sizes for the nominal partial CO_2 pressure of 3.0mm Hg.

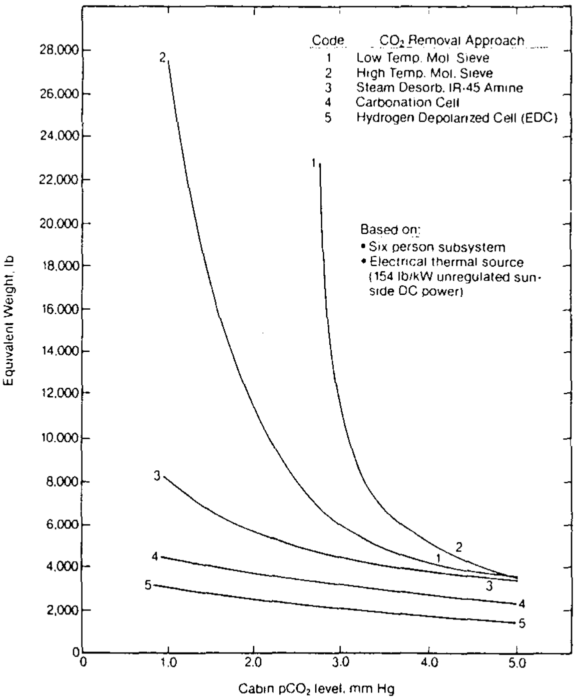


Fig. 4. Space Station Prototype CO_2 Concentrator Study Results

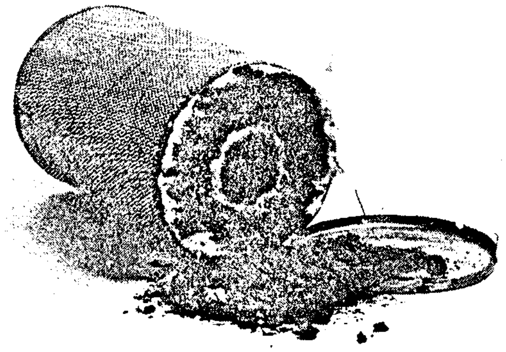


Fig. 5. Bosch CO_2 Reduction Cartridge with Carbon Collected

TABLE 10 Bosch CO_2 Reduction Expendables
(Four People, 90 Days)

Elements	Wt.	Vol.
Canister, blanket filter and catalyst	66.6	8.47
Filter blanket and catalyst only	21.7	2.46
Catalyst only	5.9	0.38
Carbon Formed	216	6.96(a)
Returned canister	292.6	8.47

(a) Assumes a final packing density of 31 lb/ft^3.

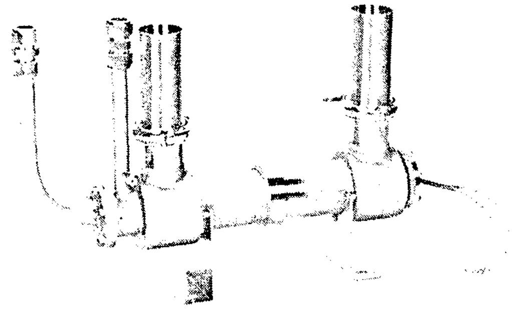


Fig. 6. Sabatier CO_2 Reduction Reactor

feed has evolved into a simple, low-cost, reliable system. It has been designed for the Space Station ECLSS and as a major component of a Regenerative Fuel Cell System (RFCS) approach to energy storage. Currently, more than 30,000 hours have been accumulated on several static feed units under endurance/performance test programs. Figure 7 shows a three-person static feed electrolysis subsystem for ECLSS application.

The static feed approach offers many advantages over other water electrolysis approaches for space application, including:

1. Fewer components for less weight, power and volume.
2. Less complex because the gas/liquid separator of the acid electrolyte, solid polymer subsystem is eliminated.
3. Less costly materials of construction, possible because an alkaline versus an acid electrolyte is used.
4. Less sensitive to quality of feed water because the liquid water remains isolated from the electrolysis cell itself, i.e., internally generates "distilled" water rather than circulating the feed water over the electrodes as with the solid polymer approach.
5. A higher electrolysis operating efficiency at a given set of operating conditions (temperature, pressure and current density) because of the electrodes and alkaline electrolyte used.
6. Avoids the need for additional heating and cooling characteristic of the solid polymer's recirculating water feed system.

The static feed electrolyzer is also adaptable to operating pressures from ambient to over 1,000 psig.

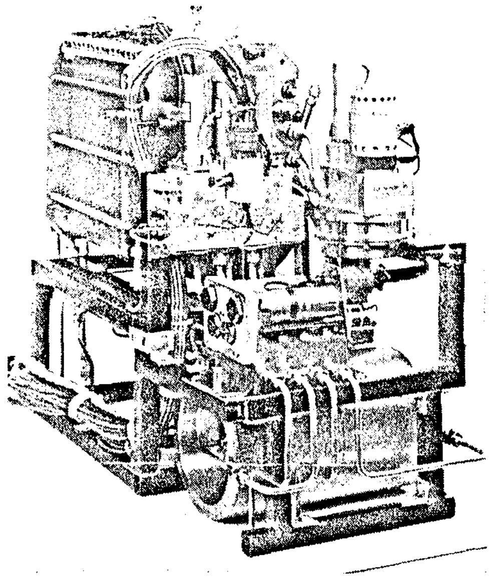


Fig. 7. Static Feed Water Electrolysis Subsystem (SFE)

Water Reclamation

Water reclamation aboard a Space Station is of equal importance to air revitalization. Water reclamation involves processes to reclaim water from wastewater sources. Various processes, including phase change and filtration, have been investigated for these applications. Filtration processes are less developed than the phase change processes for water reclamation.

Figure 8 presents an overview of the water uses and reclamation processes, which functional groups provide water to be recovered

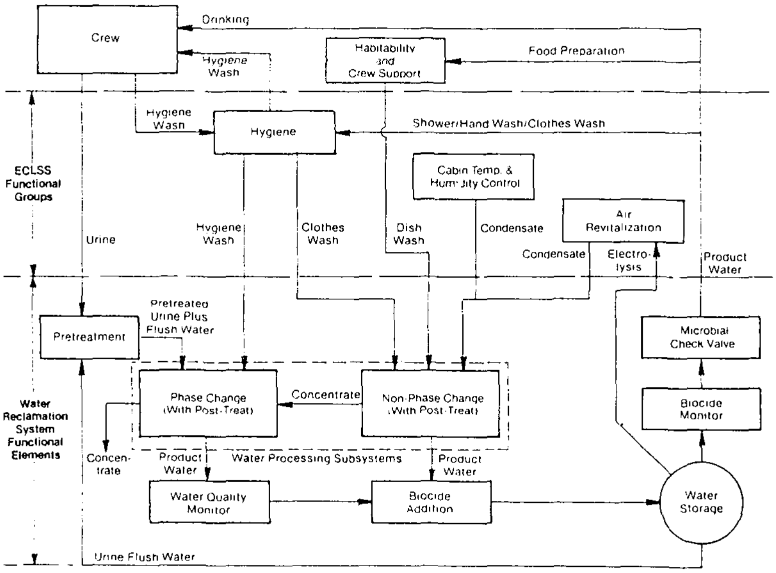


Fig. 8. Water Reclamation/Use Process Overview

and what are the elements of the water reclamation system. Two major water processing techniques have been considered for space use: phase change and filtration. Table 11 summarizes which process is considered most applicable to which waste water source. The goal, however, would be to have one process handle all the water. The preferred process would be the phase change one because of its attractiveness for providing a better quality potable water.

TABLE 11 Space Station Wastewater Sources and Projected Processing Techniques

Wastewater Source	Water Processing Technique	
	Filtration	Phase Change
Hand Wash Water		X
Shower Water		X
Urinal Flush Water		X
Urine		X
EVA Wastewater		X
Perspiration and Respiration	X	?
Hygiene Latent Water	X	?
Food Preparation Latent Water	X	?
Experiments Latent Water	X	?
Laundry Latent Water	X	?
Clothing Wash Water	X	
Dishes Wash Water	X	

Phase Change Processes

Many phase change processes have been considered for spacecraft water reclamation. The two currently under active development include the Vapor Compression Distillation (VCD) process which is shown conceptually in Figure 9. Figure 10 is a photograph of a 72 lb/day VCD subsystem. The recovery of latent heat in the VCD process is accomplished by compressing the vapor to raise its saturation temperature and then condensing the vapor on a surface which is in thermal contact with the evaporator /20/.

The alternative is the thermoelectric/membrane process which is shown conceptually in Figure 11. This concept /21/ recovers the latent heat of condensation and transfers this heat to the evaporator via a thermoelectric heat pump. Wastewater is heated to approximately 150°F in the thermal electric heat exchanger and the heated wastewater pumped through a hollow fiber membrane evaporator module. The exterior of the module tubes is exposed to reduced pressure, and water evaporates from the tube surface and is condensed on a chilled porous plate surface in thermal contact with the cold junction surfaces of the thermoelectric heat exchanger.

The above mentioned water reclamation processes typically require pretreatment and post-treatment with expendable chemicals. A vapor-phase catalytic ammonia-removal process is under development which offers the potential advantage of avoiding these expendables /22/.

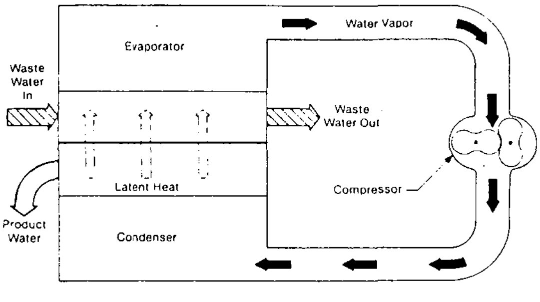


Fig. 9. Vapor Compression Distillation Concept

Automated Control/Monitor Instrumentation (C/M I)

The ECLSS process hardware requires instrumentation to:

- Control and monitor the process functiuons;
- Provide safety for personnel and equipment including fault diagnostics and backup control functions;
- Operate the equipment in a manner that increases reliability and avoids need for maintenance or simplifies it if it is required; and
- Operate the equipment under optimized conditions which can, therefore, reduce power, weight, volume, etc.

NASA has developed two C/M I series as shown in Figure 12. The first series, known as the 100 Series, used a minicomputer for process control and monitor, and incorporated a simulated Space Station Command Center in the area of operator/system interfaces (visual, audio and touch). The second series, known as the 200 Series, used a microcomputer for process control and monitor, but replaced the simulated Command Center with a data link to a remote terminal. The 100 Series, on the left of Figure 12, is approximately 29x22x21 in, the 200 Series, on the right, is 7.4x15.6x15.4 in.

These computerized C/M I Series demonstrated the feasibility of a generic approach to Space Station System C/M I requirements including the ECLSS. The 100 Series was designed, for example, for operation with nine major subsystems. The 200 Series was designed for operation with 12 subsystems. The next generation, under development by NASA, will employ a generic microcomputer with generic software plus subsystem unique software, generic signal conditioning and dedicated actuator signal conditioning.

Water Electrolysis — A Space Station Utility

The merits of a Space Station based on water electrolysis as a station utility was identified over ten years ago /4/. The objective is to achieve development commonality to reduce life cycle costs. The O_2, H_2 and water are common fluids for:

1. Electrochemical CO_2 removal (EDC),
2. O_2 generation for metabolic use and leakage makeup,
3. Potable water for crew consumption and evaporator cooling,
4. Energy storage through a regenerative fuel cell system, and
5. Clean attitude control propellants.

The integrated O_2, H_2 and water concept offers the future growth potential of providing in-flight generation of propellants for use by Orbital Transfer Vehicles as well as process reactants for special uses such as manufacturing process atmospheres. Figure 13

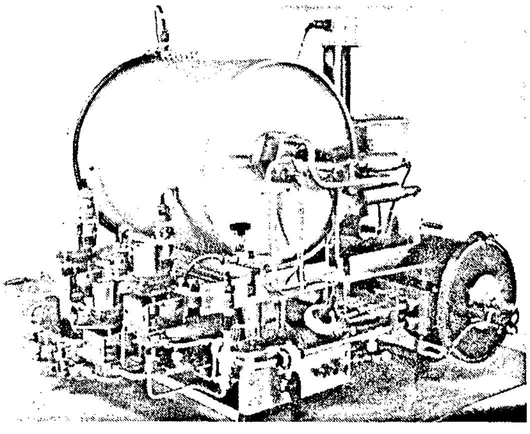


Fig. 10. Preprototype Vapor Compression Distillation Subsystem

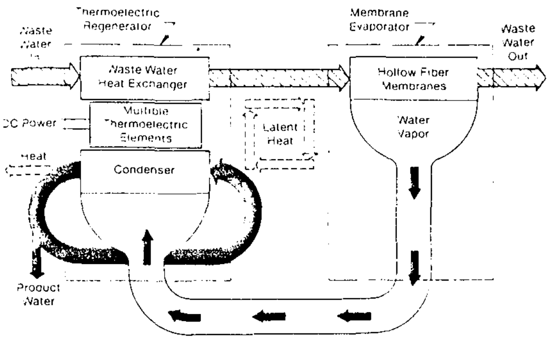


Fig. 11. Thermoelectric / Membrane Evaporator Concept

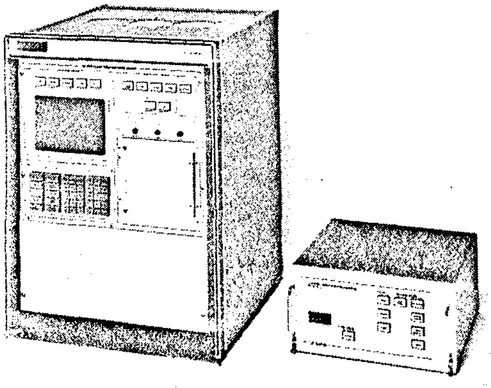


Fig. 12. Series 100 and 200 Computerized Control / Monitor Instrumentation

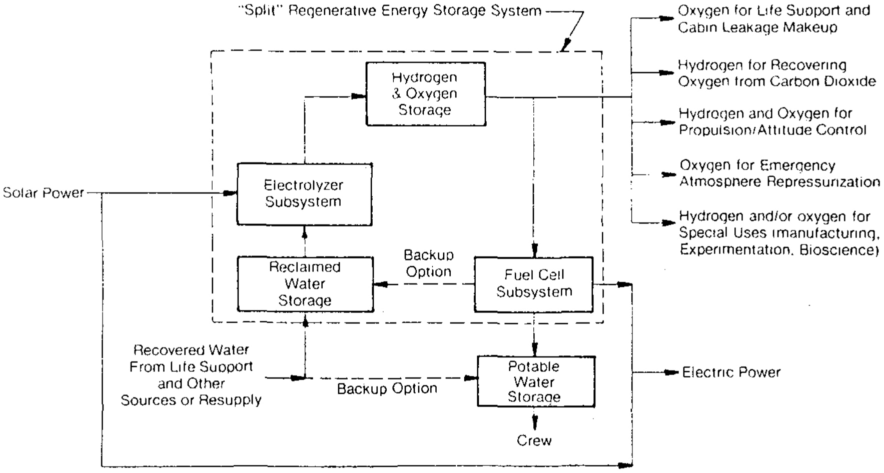
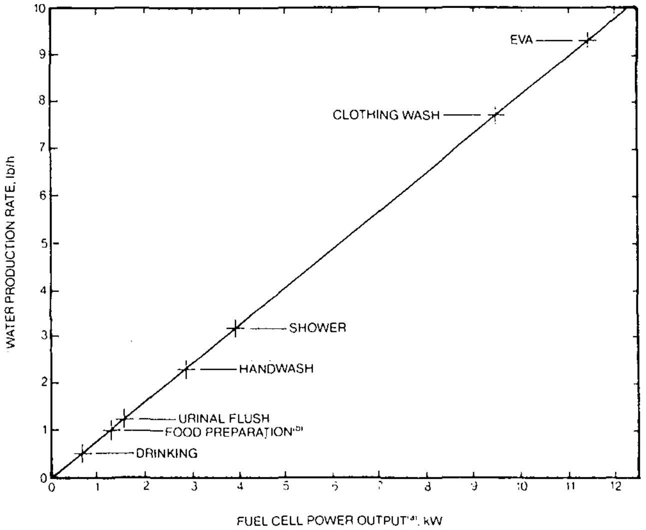


Fig. 13. Water Electrolysis — A Space Station Utility



(a) Based on Shuttle Orbiter Equivalent Fuel Cell Hardware operating at 0.91 V/cell, 200 ASF and 180F

(b) Cited use rates are cumulative and include all lower use rates

Fig. 14. Water Production and Use Rate for Four Persons Versus Fuel Cell Power Output

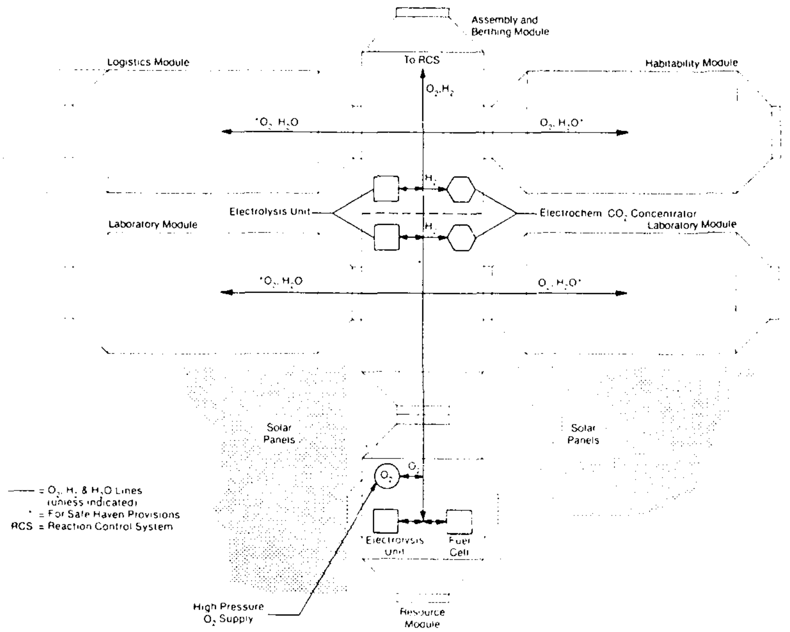


Fig. 15. Integrated O_2, H_2 and Water Distribution

illustrates the concepts. It shows the use of fuel cells for dark side operation and provides an added benefit in that the product water is a flight proven source of potable water for the crew. Reclaimed water is then used directly to provide makeup water for the electrolyzer, which is a possible when using the static feed (SFE) concept. Figure 14 relates water production and use rates versus fuel cell power output for a four-person ECLSS.

Figure 15 reflects the distribution of such an integrated O_2, H_2 and water distribution system aboard a pathfinding architecture for the Space Station.

CONCLUSIONS

The need and requirements of a Space Station have been reviewed. The elements of an ECLSS have been cited including performance requirements, average design loads and fluid interfaces. Open versus closed loop approaches to ECLSS have been quantified. Specific regenerative ECLSS technology has been discussed with some comparisons madse between alternative approaches. The status of control and monitor instrumentation was indicated. The benefits of water electrolysis as a Space Station utility, which results in a Space Station based on an integrated O_2, H_2 and water for common fluids, was reviewed.

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