6 Environmental Control and Life Support System

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6.1 Introduction

In a manned space mission, the dangers of the space environment present many problems for the crewmembers as well as the spacecraft systems engineer. The Environmental Control and Life Support System (ECLSS) must be able to support the daily needs of the crewmembers. The major problem areas include: maintaining the cabin atmosphere; potable and waste water management/distribution; and nourishment for the crewmembers.

Numerous options are available for providing solutions to these problems, and these options have different degrees of cycle closure. The various degrees of cycle closure that exist are: open cycle, partially closed cycle, and the fully closed cycle. For the open cycle, all necessary consumables are stored and air purification is accomplished through chemical absorption of CO2 and any trace elements using Lithium Hydroxide (LiOH), catalytic oxidizers, and filters - no recycling is used. For the partially closed cycle (physico-chemical), varying degrees of atmosphere revitalization and water recycling are accomplished through the use of physical and chemical processes and all necessary food items are stored. Finally, the fully closed cycle provides a food source as well as atmosphere and water recycling. This may be done by a series of biological processes (i.e. a fully closed bio-regenerative eco-system) or a combination of bio-regenerative and physical/chemical processes. The fully closed bio-regenerative system, however, is still in conceptual phases and is more suited to a colony-type base rather than a spacecraft subsystem. Thus, it will not be discussed in this document.

The goals of this document are to provide a description of the various current technologies that can be employed by the ECLSS and examine certain aspects of system integration. The three major areas that will be dealt with include: cabin atmosphere; water and waste management; and food supply. Additionally, TK Solver and FORTRAN subroutines are provided to aid in ECLSS system sizing.

6.2 ECLSS Requirements

Numerous factors drive the design of the ECLS subsystem. A summary of the major current ECLSS performance requirements is given in Table 6.2.1. These requirements are based on the current baseline for the Space Station ECLS subsystem [Guerra 1987].

Parameter	Operational	21 Day Emergency
Temperature, ˚C	18 - 24	16 - 32
Dew Point, ˚C	4 - 16	2 - 21
Ventilation, m / min	5 - 12	2 - 61
CO_2 partial pressure, N / m^2	400	1600
O_2 partial pressure, N / m^2	18,616 - 22,063	15,858 - 26,890
N_2 partial pressure, N / m^2	79,290 - 82,737	53,090 - 74,463
Total pressure, N / m^2	101,353	68,948 - 101,353
Trace contaminants	24 hr industrial standard	8 hr industrial standard

Table 6.2.1 ECLSS Performance Requirements

Table 6.2.2 presents the ECLSS average design loads. These important variables, driven by the ECLSS performance requirements of Table 6.2.1, define the usage rates of all the life support commodities. They were developed during the Space Operations Center (SOC) study.[2]

Load	Value (kg/man-day)
H_2O Required	
Drink H_2O	0.83
Food Preparation H_2O	1.86
Clothes Wash	12.50
Personal Hygiene	5.44
Commode Flush	0.47
H_2O Produced	
Metabolic Waste Products	3.67
Evaporation (Food Preparation and Hygiene Stations)	0.53
O_2 Required	
Metabolic O_2	0.84
EVA O_2 (kg/man-hr)	0.07
CO_2 Produced	
Metabolic CO_2	1.0
EVA O_2 (kg/man-hr)	0.04
Food Solids Required	0.62
Waste Solids Produced	
Metabolic Waste Products	0.11
Hygiene H_2O Solids	0.15
Trash	0.45

Table 6.2.2 ECLSS Average Design Loads

The requirements and design loads tabulated above are the basis for the sizing subroutines. Note that these requirements are meant to indicate the average and will change somewhat depending on the mission profile and given conditions.

6.3 Subsystem Components

6.3.1 Cabin Atmosphere Maintenance

One of the most important aspects of the ECLSS is cabin atmosphere maintenance. For the open ECLSS, this mainly involves removal of CO_2 and maintenance of O_2 and N_2 partial pressure. The closed system is more complex. CO_2 is removed from the air and concentrated. The concentrated CO_2 is then combined with hydrogen and reduced to water and methane and the methane is vented from the cabin. O_2 is produced by electrolysis of water. This also produces hydrogen, which can be used for the CO_2 reduction process. Finally, both the open and closed systems require components that control trace contaminant levels, ventilation, temperature, and humidity. Various atmosphere maintenance technologies that exist are given in Table 6.3.1 along with their descriptions and interface requirements.

Function	Description	Interface
CO_2 Removal		
Open System		
LiOH	Absorbs CO_2	Low power consumption Disposable Non-regenerative High maintenance penalty
Closed Systems		
Electrochemical Depolarized Cell (EDC)	Chemical Battery $2CO_2+O_2+2H_2 \rightarrow 2CO_2+2H_2O$ +elec. energy+heat	Generates electricity Requires O_2 and H_2 CO_2 and H_2 concentrated for CO_2 reduction
Solid Amine Water Desorbed (SAWD)	CO_2 adsorption on a porous substrate Use steam to desorb	Large load on humidity control CO_2 made available for reduction
CO_2 Reduction		
Open System		
No CO_2 reduction, all H_2O is obtained from stores		
Closed System		
Sabatier Reactor	$CO_2+4H_2 \rightarrow 2H_2O+CH_4+heat$	Potable water source Requires H_2 Methane (CH_4) must be vented

O_2 Generation

Open System

No O_2 generation, all O_2 is obtained from stores

Closed System

Static Feed (SF)	Liquid water is split by electrolysis: $2H_2O \rightarrow 2H_2 + O_2$	Uses potable water Supplies H_2 for CO_2 reduction
Water Vapor Electrolysis (WVE)	Water vapor from cabin air is split by electrolysis O_2 is supplied directly to the cabin	Affects humidity control Provides H_2 for CO_2 reduction Not useful for charging pressurized storage bottles
Solid Polymer	Liquid water split by electrolysis, O_2 is supplied at pressures sufficient for storage bottle recharge	Contamination sensitive Provides H_2 for CO_2 reduction Able to recharge O_2 bottles

Nitrogen Storage / Generation

Open System

High Pressure Gaseous N_2 Storage	N_2 (gas) stored at 3000 psia Direct line to N_2/O_2 panel	No byproducts, no reagents No byproducts, no reagents
Cryogenic N_2 Storage	Low temperature N_2 (liquid) Direct line to N_2/O_2 panel	Possible boil-off and thermal control problems

Closed System

Hydrazine dissociation	$N_2H_4 \rightarrow N_2 + 2H_2$ N_2 is directed to the O_2/N_2 control panel	Shares storage facilities with propulsion system Provides H_2 for CO_2 reduction

Trace Contaminant Control Combination

Activated charcoal Catalytic oxidation	Adsorbs contaminants C_6H_6, CO, CH_4, H_2 combined to form CO_2 and H_2O	Must be properly arranged so that contaminant removal occurs without catalyst poisoning Operate continuously
Chemical absorbers	Absorption of contaminants	Operate continuously
Bacterial filters	Microbial filtration	Operate continuously

Cabin Ventilation and Humidity Control

Air revitalization subsystem (ARS) fans	Air pulled from major sources of contamination (shower/ toilet) into ARS for processing, clean air reissued at ceiling	Operates continuously
Condensing heat exchanger and water/gas separator	Heat exchanger 4.5˚C (40˚F) water coolant Centrifugal separation of condensate and cooled air	Removes heat from ECLSS and non-ECLSS sources Potable water source

Table 6.3.1 Atmosphere Maintenance Technologies

6.3.2 Potable and Waste Water Management

Waste water and potable water management present another important problem. For the open cycle, all potable water is provided from stores and any waste water is dumped overboard. The use of fuel cells, which produce drinkable water as a by-product of electricity generation, is a weight-saving, volume-saving and proven technology (used on the space shuttle) and can be used with either an open system or a closed system. For the closed cycle, varying degrees of recycling of waste water and condensate are used. This results in a drastic decrease in mass of the ECLSS. The various technologies that exist are given in Table 6.3.2, along with their descriptions and interface requirements.

Function	Description	Interface
Hygiene Water Distillation		
Open System		

All necessary H_2O is stored and all waste water is dumped		
Closed System		
Vapor Compression Distillation (VCD)	Phase change purification Conserves latent heat Initial processing treatment	Processes urine, shower/ hand-wash water
Thermoelectric Integrated Membrane Evaporation Subsystem (TIMES)	Phase change purification Uses thermoelectrics Initialprocessing treatment	Processes urine, shower/ hand-wash water
Hygiene Water Filtration		
Closed System		
Multifiltration (MF)	Activated charcoal adsorption Iodine impregnated resin Ion-exchange resin Organic oxidation	Adsorbs organics, biocide; removes salts and ammonia; burns organics
Potable Water Production		
Open System		
Fuel Cells or Stored Water		
Closed System		
Cabin Humidity Control CO_2 Reduction Fuel Cells	Condensation removed directly from cabin air from atmosphere revitalization system	
Potable Water Treatment		
Closed System		
Multifiltration	Activated charcoal adsorption Iodine impregnated resin Ion-exchange resin Organic oxidation	Adsorbs organics, biocide; removes salts and ammonia; burns organics

Table 6.3.2 Water Management Technologies

6.3.3 Food Supply

Supplying the crewmembers with adequate nourishment to keep them in optimal physical shape is another very important task. An ideal caloric intake level has been set at 2,200-2,800 kCal/man-day.[3]

Depending on the mission duration and number of crewmembers, the food preparation/storage areas can range from the size of a passenger aircraft galley to an entire compartment or module. In the design of the food preparation area, opportunities exist for integration with the thermal control subsystem, i.e. heat and chilled water or heat for food preparation from internal heat exchange loops.

Several different types of foods are currently available which allow a wide variety of menus. Dehydrated and intermediate moisture foods are items which can be reconstituted by the addition of water. These types of foods result in considerable weight and storage area savings and a long shelf life. Thermostabilized, a fancy way of saying heat pasteurized, food is another type. These foods come in aluminum cans, flexible pouches and semirigid containers and require no addition of water. They may be heated in and eaten from their containers. Irradiated foods are items which have been subjected to microwave radiation to kill any microbes present. Along with thermostabilized foods, these items are generally more appetizing than dehydrated foods and they require no preparation except possibly heating. Finally, there are ready-to-eat items which are packaged in thin film vacuum packs and are usually bite size. However, these foods typically do not have the longevity of the other types of foods and are best used for short duration or frequent resupply interval missions.

For the space shuttle, a typical man-day of food consists of approximately 20 packages including: 4-7 rehydratables, 1-4 thermostabilized/irradiated, 8 beverages, and 4 ready to eat items. Food preparation takes about 1/2 hour which entails assembling the food trays and containers and heating in the oven.

6.4 FORTRAN Routine for ECLSS System Sizing

```
       PROGRAM ECLSS
      IMPLICIT REAL (A-H,O-Z)
C...THIS PROGRAM SIZES AN ECLSS SUBSYSTEM SUBJECT TO THE
C    USER'S CHOICE OF THE DEGREE OF CLOSURE
C    THE FOLLOWING TECHNOLOGIES ARE CONSIDERED:
C    OPEN SYSTEM:  LiOH FOR CO2 CONCENTRATION, STORAGE OF ALL
C       H2O AND O2
C    PARTIALLY CLOSED SYSTEM:  ELECTRO-CHEMICAL DEPOLARIZED
C       CELL (EDC) FOR CO2 CONCENTRATION, STORED H2O FOR CO2
C       REDUCTION & URINE/WASTE WATER, STORED O2, MULTI-
C       FILTRATION (MF) FOR WASH WATER AND CONDENSATE
C       RECOVERY
C    CLOSED SYSTEM:  ELECTRO-CHEMICAL DEPOLARIZED CELL (EDC)
C       FOR CO2 CONCENTRATION, SABATIER (SAB) REACTOR FOR CO2
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```
C       REDUCTION, STATIC FEED (SF) ELECTROLYSIS FOR O2 GENER-
C       ATION, VAPOR COMPRESSION DISTILLATION (VCD) FOR
C       URINE/WASTE WATER, MULTIFILTRATION (MF) FOR WASH
C       WATER AND CONDENSATE RECOVERY
      WRITE(6,*)'INPUT THE NUMBER OF CREW TO BE SUPPORTED:'
      READ(5,*)C
      WRITE(6,*)' '
      WRITE(6,*)'INPUT THE NUMBER OF DAYS THAT THEY MUST BE SUPPORTED:'
      READ(5,*)T
      WRITE(6,*)' '
      WRITE(6,*)'INPUT THE TYPE OF ECLSS SYSTEM DESIRED.  TYPE THE '
      WRITE(6,*)'NUMBER NEXT TO YOUR CHOICE:'
      WRITE(6,*)'    1. OPEN'
      WRITE(6,*)'    2. PARTIALLY CLOSED'
      WRITE(6,*)'    3. CLOSED'
      READ(5,*)IE
C...USER INPUT COMPLETE
      IF(IE.EQ.1) THEN
       PR=C*.195
       WH=C*.21
       SCM=((C*3131.0775+83.61)/90.0)*T
       SCV=((C*3.241)/90.0)*T
       HWM=C*76.1-83.61
       TOTSM=SCM+HWM
       HWV=C*7.4165
       TOTSV=SCV+HWV
       PI=PR*359.0
       HI=WH*109.0
      ELSE IF(IE.EQ.2) THEN
       PR=C*.2475
       WH=C*.3225
       SCM=((C*617.6345+83.61)/90.0)*T
       SCV=((C*.8585)/90.0)*T
       HWM=C*87.018-83.61
       TOTSM=SCM+HWM
       HWV=C*1.6095
       TOTSV=SCV+HWV
       PI=PR*359.0
       HI=WH*109.0
      ELSE IF(IE.EQ.3) THEN
       PR=C*.4475
       WH=C*.390
       SCM=((C*152.4826+83.61)/90.0)*T
       SCV=((C*.42202)/90.0)*T
       HWM=C*108.314-83.61
       TOTSM=SCM+HWM
       HWV=C*.73353
       TOTSV=SCV+HWV
       PI=PR*359.0
      END IF
      DO 10 I=1,10
       PRINT*,' '
 10   CONTINUE
      WRITE(6,5)'POWER REQUIRED, IN kW = ',PR
      WRITE(6,5)'WASTE HEAT GENERATED, IN kW = ',WH
      WRITE(6,5)'MASS OF SPARE PARTS AND CONSUMABLES, IN kg = ',SCM
      WRITE(6,5)'VOLUME OF SPARE PARTS AND CONSUMABLES, IN m^3 = ',SCV
      WRITE(6,5)'MASS OF SYSTEM HARDWARE, IN kg = ',HWM
```

```
      WRITE(6,5)'VOLUME OF SYSTEM HARDWARE, IN m^3 = ',HWV
      WRITE(6,5)'TOTAL SYSTEM MASS, IN kg = ',TOTSM
      WRITE(6,5)'TOTAL SYSTEM VOLUME, IN m^3 = ',TOTSV
      WRITE(6,5)'POWER IMPACT PENALTY, IN kg = ',PI
      WRITE(6,5)'WASTE HEAT IMPACT PENALTY, IN kg = ',HI
 5    FORMAT(1X,A,F10.3)
      END
```

6.5 TK! Solver Routine for ECLSS System Sizing

Variable Sheet

Input	Name	Output	Unit	Comment
4	N			Number of Crewmembers
14	t		day	Duration of mission (days)
				Results for Open System (LiOH, Stored H2O, Stored O2)
	PRO	.78	kw	Power Required
	WHO	.84	kw	Waste Heat Generated
	MSCO	1961.232	kg	Mass of Spares and Consumables
	MHWO	220.79	kg	Mass of System Hardware
	LMO	2182.022	kg	Total System Mass
	VSCO	2.0166222	m^3	Volume of Spares and Consumables
	VHWO	29.666	m^3	Volume of System Hardware
	LVO	31.682622	m^3	Total System Volume
	PIO	280.02	kg	Power Impact Penalty
	HIO	91.56	kg	Waste Heat Impact Penalty
				Results for Partially Closed System (Electrochemical Depolarized Cell (EDC) Stored H2O, Stored O2, and Multifiltration (MF))
	PRM	.99	kw	Power Required
	WHM	1.29	kw	Waste Heat Generated
	MSCM	397.31191	kg	Mass of Spares and Consumables
	MHWM	264.462	kg	Mass of System Hardware
	LMM	661.77391	kg	Total System Mass
	VSCM	.53417778	m^3	Volume of Spares and Consumables
	VHWM	6.438	m^3	Volume of System Hardware
	LVM	6.9721778	m^3	Total System Volume
	PIM	355.41	kg	Power Impact Penalty
	HIM	140.61	kg	Waste Heat Impact Penalty

			Results for Closed System (EDC, Sabatier Reactor, Static Feed Electrolysis, Vapor Compression Distillation, MF)
PRP	1.79	kw	Power Required
WHP	1.56	kw	Waste Heat Generated
MSCP	107.88406	kg	Mass of Spares and Consumables
MHWP	349.646	kg	Mass of System Hardware
LMP	457.53006	kg	Total System Mass
VSCP	.26259022	m^3	Volume of Spares and Consumables
VHWP	2.93412	m^3	Volume of System Hardware
LVP	3.1967102	m^3	Total System Volume
PIP	642.61	kg	Power Impact Penalty
WIP	170.04	kg	Waste Heat Impact Penalty

Rule Sheet

```
"VALUES FOR OPEN SYSTEM (LIOH, STORED WATER, STORED H2O)
PRO=INT(N)*.195
WHO=INT(N)*.210
MSCO=((INT(N)*3131.0775+83.610) / 90)*t
VSCO=((INT(N)*3.2410) / 90)*t
MHWO=INT(N)*76.1-83.61
LMO=MSCO+MHWO
VHWO=INT(N)*7.4165
LVO=VSCO+VHWO
PIO=PRO*359.0
HIO=WHO*109.0
"VALUES FOR MINIMALLY CLOSED SYSTEM (ELECTROCHEMICAL DEPOLARIZED
"CELL, STORED H2O, AND STORED O2)
PRM=INT(N)*.2475
WHM=INT(N)*.3225
MSCM=((INT(N)*617.6345+83.61) / 90)*t
VSCM=((INT(N)*.85850) / 90)*t
VHWM=INT(N)*1.60950
MHWM=INT(N)*87.018-83.61
LMM=MSCM+MHWM
LVM=VSCM+VHWM
PIM=PRM*359.0
HIM=WHM*109.0
"VALUES FOR PARTIALLY CLOSED SYSTEM (ELECTROCHEMICAL DEPOLARIZED
"CELL, SABATIER REACTOR, STATIC FEED ELECTROLYSIS, VAPOR COMPRESSION
"DISTILLATION, AND MULTIFILTRATION)
PRP=INT(N)*.4475
WHP=INT(N)*.390
MSCP=((INT(N)*152.4826+83.61) / 90)*t
```

```
VSCP=((INT(N)*.42202) / 90)*t
VHWP=INT(N)*.73353
MHWP=INT(N)*108.3140-83.61
LMP=MSCP+MHWP
LVP=VSCP+VHWP
PIP=PRP*359.0
WIP=WHP*109.0
```

6.6 References

Boston, Penelope J., "Mars Mission Life Support Systems," The NASA Mars Conference, July 21-23, 1986, Science and Technology Series Volume 71.

Bourland, Charles T., R.M. Rapp, and M.C. Smith Jr., "Space Shuttle Food System," Food Technology, September, 1977.

Guerra, Lisa, "A Commonality Assessment of Lunar Surface Habitation," University of Texas Thesis, 1987.

Hall, J.B., S. Pickett, and K. Sage, "Manned Space Station ECLSS Computer-Aided Technology Assessment Program," SAE Technical Paper Series, Paper #840957, July, 1984.

Lin, C.H., and M.S. Meyer, "Systems Engineering Aspects of a Preliminary Conceptual Design of the Space Station ECLSS," SAE Technical Paper Series, Paper #831109, July, 1983.

Purser, Faget, and Smith, Manned Spacecraft Engineering and Design, Fairchild Publication Inc., 1964.

Space Shuttle Spacecraft Systems Document, Environmental Control and Life Support System sub-section.