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APPENDICES TO THE MODEL DESCRIPTION DOCUMENT

FOR

A COMPUTER PROGRAM FOR THE EMULATION/SIMULATION OF A SPACE STATION ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM

BY

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ABSTRACT

A Model Description Document for the Emulation Simulation Computer Model was published previously. The model consisted of a detailed model (emulation) of a SAWD CO_2 removal subsystem which operated with much less detailed (simulation) models of a cabin, crew, and condensing and sensible heat exchangers. The purpose was to explore the utility of such an emulation/ simulation combination in the design, development, and test of a piece of ARS hardware - SAWD.

Extensions to this original effort are presented in the manual. The first extension is an update of the model to reflect changes in the SAWD control logic which resulted from test. In addition, slight changes were also made to the SAWD model to permit restarting and to improve the iteration technique. The second extension is the development of simulation models for more pieces of air and water processing equipment. Models are presented for: EDC, Molecular Sieve, Bosch, Sabatier, a new condensing heat exchanger, SPE, SFWES, Catalytic Oxidizer, and multifiltration. The third extension is to create two system simulations using these models. The first system presented consists of one air and one water processing system. The second system consists of a potential Space Station air revitalization system complete with a habitat, laboratory, four modes, and two crews.

FOREWARD

This Model Description Document has been prepared by Hamilton Standard Division of United Technologies Corporation for the National Aeronautics and Space Administration's Langley Research Center in accordance with Contract NAS1-17397, "Development of an Emulation/Simulation Computer Model of a Space Station Environmental Control and Life Support System (ECLSS)". This manual describes the analytical models used in the three computer simulation programs developed under this contract.

Appreciation is expressed to the Technical Monitors, Messrs. John B. Hall, Jr. and Lawrence F. Rowell of the NASA Langley Research Center for their guidance and advice.

This manual was written by Dr. James L. Yanosy, Program Engineer, with assistance from Mr. Stephen A. Giangrande. The extensions to the program presented in this manual were performed under the direction of Mr. John M. Neel, Program Manager. Thanks is given to Mr. Joseph M. Homa for his efforts in the development of the Space Station Model.

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1.0 INTRODUCTION

The purpose of the original ESCM program was to demonstrate the utility of an emulation simulation computer program in the design, development and test of a piece of life support equipment. The piece of life support equipment selected for emulation was the SAWD CO_2 removal subsystem. A continuation of the effort called for an update of the computer model following testing of the SAWD unit. In addition, extensions to the contract called for the development of "lightweight" or low fidelity simulation models of contending life support equipment and the configuring of this equipment into two different systems.

This document provides three appendices to the original model description document[1]*. The appendices are:

A. Emulation Simulation Computer Model Update
B. Life Support System Model
C. Space Station Model

The following errata were found in the original document:

(1) Cover page: Report number should be SVHSER 9504.
(2) Page 25, fifth line: Should be "HA = Total enthalpy of gas entering header, Btu"

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*Numbers in brackets denote references listed in Section 2.0

2.0 REFERENCES

(1) Yanosy, J., "Model Description Document for a Computer Program for the Emulation/Simulation of a Space Station Environmental Control and Life Support System (ESCM)", Hamilton Standard Report SVHSER 9504 for NASA Langley Research Center, NASA CR-181737, September 1988.

(2) "G189A Generalized Environmental/Thermal Control and Life Support System Computer Program Manual", McDonnel Douglas Corporation MDAC-G2444; September, 1971.

(3) Yanosy, J., "User's Manual for a Computer Program for the Simulation of a Space Station Environmental Control and Life Support System (ECLSB)", Hamilton Standard Report SVHSER 10630 for NASA Langley Research Center, September, 1986.

APPENDIX A

ESCM UPDATE

A.1 Introduction

The Space Station Environmental Control and Life Support System (ECLSS) Emulation/Simulation Computer Model (ESCM) has been updated to include: (1) the capability of restarting the SAWD CO_2 removal subsystem from a transient start-up, (2) placing clamps on the SAWD bed segment temperature when iterating the bed segment temperature during the energy balance of the bed segment, and (3) the addition of an energy balance control method where the amount of CO_2 on the bed is determined from the time for the CO_2 to begin coming off the bed as detected by the flow sensor. This latter change was made to reflect a change made to the control logic in the hardware. Each of these updates to ESCM as they pertain to the Model Description Document are presented in this Appendix.

A.2 SAWD Bed

The capability to start the SAWD subsystem without first running the steady state analysis was incorporated into the IR45 subroutine. The inlet and exit heater parameters, as well as SAWD bed segment parameters (i.e. temperature, pressure, molecular weight, and flow rates) were initialized in the IR45 subroutine; in a similar manner, they are initialized in the STEADY subroutine which is only called by IR45 in steady state. Therefore, the SAWD CO_2 removal subsystem can be started from a transient start-up as well as a steady state start-up.

Additional logic was also added to the IR45 BALANCE subroutine. Limits were placed on the SAWD bed segment temperature while iterating on the bed segment temperature for an energy balance of the segment. One of the limits employed was as follows: if the temperature entering the bed segment was greater than the SAWD bed temperature at the start of the time step, then the resulting bed segment temperature must increase.

A.3 SAWD Control Model

A new control method has been incorporated into the SAWD CO_2 removal subsystem model (IR45). This type of control uses an energy balance control scheme as opposed to the relative humidity method which as previously used. The energy balance method uses energy principles to determine the absorption time of the next cycle based on the bed's past desorb cycle. The total amount of energy for desorb can be calculated form the amount of steam added to the bed during desorb. The amount of CO_2 desorbed from the bed is known from techniques using the accumulator on the flow sensor; thus, the energy required to remove the CO_2 form the bed can be calculated. Also, the energy required to heat up the bed resins and canister before the desorption of CO_2 can be calculated. Therefore, from an energy balance, the amount of energy to heat the water which was on the bed at the start of the desorb can be calculated. Thus, the bed water loading at the start of the desorb can be determined. Knowing the amount of water on the bed at the start of the desorb, the next absorption time can be determined. The following SAWD control logic has been incorporated in ESCM Subroutine GPOLY1 to determine the absorb time.

Control Constants (Set in subroutine GPOLY1):]

K0 = 1.11
K1 = 0.045
K16 = 115.01
K41 = 0.25
K42 = 2.5
K43 = 60.0
K44 = 3.808
K46 = 0.6996
K47 = 7480.0
K48 = 60.87
K49 = .00028205
K50 = 0.0034246
K51 = 1085
K52 = 157.37
K53 = 4.3167
K54 = 0.040259

Input:

CO2TIME = Time CO_2 goes to cabin during desorb, minutes
DETIME = Time for desorption, minutes
INT1 = Previous INT1 value.
NEWABTIME = Previous absorb cycle time, minutes.
ONTIME = Time steam generator is on during desorption, sec.
P = Accumulator pressure at end of desorption, sec.
PH2OPAST = Past value of bed loading for this bed. %.
TIN = Inlet temperature at end of desorbing bed's post absorb cycle, F
TOUT = Exit temperature at end of desorbing bed's past adsorbing cycle, F

All the following calculations are done at the end of desorption.

Calculate Bed CO_2 loading fraction which was at start of this desorb "FCO2".

```
Power    = ONTIME/(0.05769 * DETIME)
Power    = Clamp (Power, 1, 1040)
TSAT     = K54 * P**2 + K53 * P + K52
T3       = K16 * (TSAT - 212)/Power
T3       = Clamp (T3, 0.0, 17.5)
Ratio    = (CO2 Time - T3)/DETIME
FCO2     = K51*RATIO**2+K50*RATIO-K49
FCO2     = Clamp (FCO2, 0.0, 0.05)
```

Calculate Bed H_2O loading percent which was at start of this desorb "PCTH2O".

```
WGTH2O   = (K0 * ONTIME - K46 * (TSAT-TIN) - K47 * FCO2 - K48)/
           (TSAT-TOUT) - K1 * DETIME - K44
OCTH2O   = 100.0 * WGTH2O
IF((PCTH2O - OCTH2OPAST).LT.-3.0) PCTH2O = PCTH2OPAST-3.0
IF((PCTH2O-PCTH2OPAST).LT.-3.0) PCTH2O = PCTH2OPAST-3.0
PCTH2O = Clamp (PCTH2O, 10.0, 40.0)
```

Calculate new absorb cycle time, "NEWABTIME" in minutes.

INT1 = K41 * (PCTH20 - 25.0) + INT1

INT1 = Clamp (INT1, -35.0, 35.0)

NEWABTIME = K43 + K42 * (PCTH20 - 25.)

NEWABTIME = NEWABTIME + INT1

NEWABTIME = Clamp (NEWABTIME, 20., 90.)

The steam flow rate determines the desorption time. The control of the steam flow is not calculated based on the relative humidity in the cabin during the previous absorption cycle. The steam flow for the next desorption of the bed is based on the steam flow rate during the past desorb multiplied by the calculated steam generation power ratio.

$$M_{SN} = M_{SO} * P_R$$

The steam generator power ratio is set equal to 1.0 for the first desorption of each SAWD bed. For all subsequent desorptions, the power ratio is calculated by squaring the actual time of the last desorption and dividing it by the product of the calculated time of the last desorption and the calculated time of the new desorption time.

$$PR = \frac{t_a * t_a}{t_{co} * t_{cn}}$$

where:

M_{SN} = New bed desorb steam flow, pph

M_{SO} = Old bed desorb steam flow, pph

P_R = Steam generator power ratio

t_a = Actual time of last bed desorb, sec

t_{co} = Calculated time of last bed desorb, sec

t_{cn} = Calculated time of next bed desorb, sec

APPENDIX B

MODEL DESCRIPTION DOCUMENT FOR ECLSB MODEL

B.1 Introduction

An extension to the original ESCM program is to develop lightweight simulation models of various life support equipment and to combine them into a system. The utility of using all lightweight models to enhance system design could then be explored. This differs from the original program which was to investigate the utility of a combined emulation and simulation model.

This manual provides the model description for one of the systems simulated. This system consists of one air revitalization group of equipment working in conjunction with one group of waste water processing equipment. The principal pieces of equipment are:

Function	Subsystem
CO_2 Removal	Electrochemical Depolarized Concentrator
CO_2 Reduction	Sabatier
O_2 Generation	Static Feed Solid Polymer Electrolysis
Trace Gas Removal	Catalytic Oxidizer
Condensate Processing	Multifiltration
Urine Reclamation	Vapor Compression Distillation

B.2 Modelling of System

The life support system to be analyzed is shown in Figure B-1. The following discusses how this system represents real hardware.

The system shown in Figure B-1 consists of many components; however, some are the same. Therefore, models of only the following components are needed:

(1) Crew
(2) Cabin
(3) Fan
(4) Heat Exchanger
(5) SPE Cells
(6) Catalytic Oxidizer
(7) Sabatier
(8) EDC Cells
(9) Fan
(10) Splitter
(11) Mixer
(12) All Purpose Component
(13) VCD

These components are arranged as required for use with G189A. Accordingly, particular items are arranged for modelling purposes but do not represent their actual physical location. First of all, the crew which consumes oxygen and produces carbon dioxide and water vapor is placed in series with other components before the cabin. This was done to keep the schematic simple and to minimize the number of components required. In actuality, the crew is in the cabin.

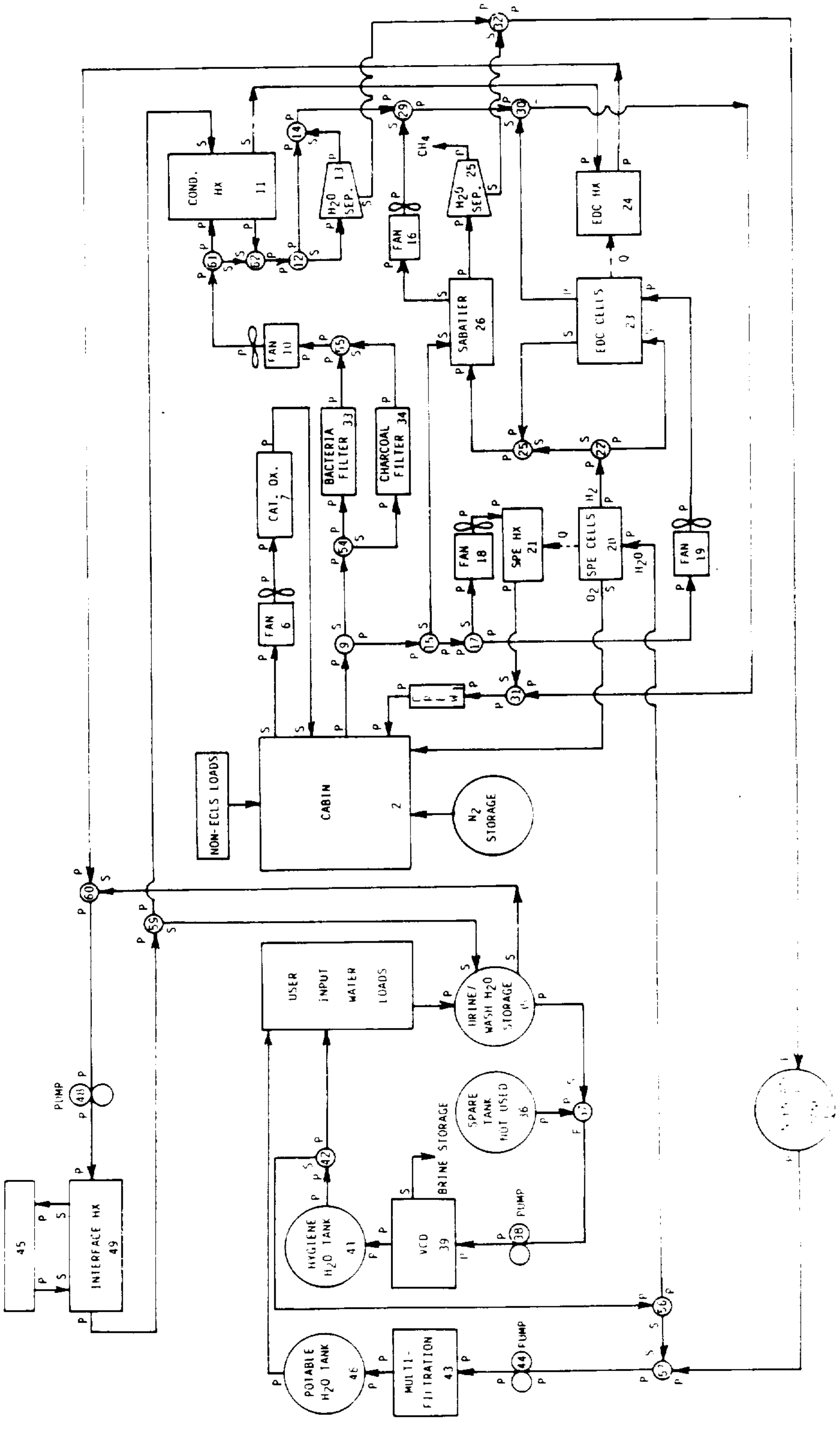


FIGURE B-1
ECLSS SYSTEM B SCHEMATIC FOR G189 TYPE COMPUTER MODEL

In the model in Figure B-1, it appears that the cabin has only four ports for gas flows - two entry and two exit. This is a restriction of G189A and again does not represent actuality. Air for the condensing heat exchanger, Sabatier cooling and the EDC are all drawn directly from the cabin. Since G189A has a limited number of ports, one port is used and then splitters are used to direct flow to each of the components. The end result is the same.

B.3 Modelling of Components

As discussed in Section B.2, only thirteen component analytical models need be available to analyze the life support system. The following sections will discuss these analytical models, the generation of performance constants, and any other parameters necessary to describe the analytical model. In many instances, the analytical model is already described in the G189A manual [2]. In those cases, the reader will be referred to the G189A manual for a description of the analytical model.

In addition to the thirteen components, the control of the cabin air conditions and the water tank levels are discussed.

Of the thirteen components, many were discussed previously in the ESCM Model Description Document [1]. The following are discussed here:

SPE Cells
Catalytic Oxidizer
Sabatier
EDC Cells
VCD
Bacteria Filter
Charcoal Filter
Multifiltration
Controls

B.3.1 SPE Cells

The solid polymer electrolysis cells convert water to hydrogen and oxygen and give off heat to a heat exchanger with the coolant being air. The following constants and operating conditions are used:

A_c = unit cell area = 0.239 ft^2
P_c = cell operating pressure = 200 psia
T_c = cell operating temperature = 155^oF
N_c = number of cells = 20

The cell current density is determined from:

$$J_c = I/A_c$$

where I = cell current, amps
J_c = cell current density, $amps/ft^2$

A cell efficiency is then determined by linear interpolation of the tables in Table B-1 for the cell pressure P_c, current density J_c, and cell temperature T_c. In addition, the voltage V_c across each cell is determined by linear interpolation of the tables in Table B-2 for the cell pressure P_c, current density J_c, and cell temperature T_c.

The total watts consumed by the cells becomes:

$$w_e = I\ V_c\ N_c$$

where V_c = voltage across each cell, volts
w_e = total electrical power of cells, watts

The amount of oxygen and hydrogen produced is given by:

$$m_{O2} = 0.000659\ I\ \frac{\quad}{100}\ N_c$$

$$m_{H2} = m_{O2}/8$$

where: m_{O2} = mass flow of oxygen produced, lbm/hr
m_{H2} = mass flow of hydrogen produced, lbm/hr

The water consumed by electrolysis is given by:

$$m_{H2O,E} = 1.125\ m_{O2}$$

TABLE B-1

SPE CELL OPERATING EFFICIENCY

Percent Efficiency at $T_C = 140^oF$

Cell Pressure (psia)

J_C (AMPS/FT^2)	100	200	300
50	91.1	84.7	82.7
100	95.0	90.0	86.4
150	96.8	93.5	90.3
200	97.5	95.1	92.6
250	98.0	96.0	94.0
300	98.3	96.6	94.9
350	98.6	97.2	95.7
400	98.7	97.6	96.2
450	98.9	97.8	96.7
500	99.1	98.1	97.0

Percent Efficiency at $T_C = 180^oF$

Cell Pressure (psia)

J_C (AMPS/FT^2)	100	200	300
50	87.8	82.4	79.0
100	93.0	86.7	82.9
150	95.4	90.7	86.3
200	96.6	92.9	89.1
250	97.2	94.2	91.2
300	97.7	95.1	92.6
350	98.0	95.8	93.7
400	98.3	96.4	94.5
450	98.4	96.7	95.1
500	98.0	97.1	95.6

TABLE B-2
SPE CELL VOLTAGE

Cell Voltage at T_c = 140°F
Cell Pressure (psia)

J_c (AMPS/FT^2)	100	200	300
50	1.556	1.568	1.577
100	1.594	1.602	1.609
150	1.623	1.632	1.638
200	1.650	1.662	1.667
250	1.678	1.690	1.697
300	1.714	1.725	1.733
350	1.760	1.772	1.777
400	1.832	1.843	1.857

Cell Voltage at T_c = 180°F
Cell Pressure (psia)

J_c (AMPS/FT^2)	100	200	300
50	1.503	1.514	1.522
100	1.537	1.548	1.553
150	1.562	1.573	1.581
200	1.587	1.599	1.606
250	1.614	1.624	1.632
300	1.639	1.651	1.657
350	1.670	1.682	1.689
400	1.701	1.722	1.728

where: $m_{H2O,E}$ = mass flow of water consumed by electrolysis, lbm/hr

Water is also present as saturated vapor in the oxygen and hydrogen gas flows.

The amount is determined from the following relation:

$$Y_v = \frac{P_{sat}(T_c)}{P_c}$$

$$M_{H2O,O2} = \frac{Y_v}{1-Y_v} \quad \frac{m_{O2}}{MW_{O2}} \quad MW_{H2O}$$

$$M_{H2O,H2} = \frac{Y_v}{1-Y_v} \quad \frac{m_{H2}}{MW_{H2}} \quad MW_{H2}$$

where: Y_v = mole fraction of water vapor

MW_{O2} = molecular weight of oxygen, lbm/mole

MW_{H2} = molecular weight of hydrogen, lbm/mole

P_{sat} = saturation pressure at given temp., psia

$m_{H2O,O2}$ = mass flow of water vapor in oxygen, lbm/hr

$m_{H2O,H2}$ = mass flow of water vapor in hydrogen, lbm/hr

Therefore, the total water consumed becomes:

$$m_{H2O,T} = m_{H2O,E} + m_{H2O,O2} + m_{H2O,H2}$$

The waste electrical power is given by:

$$w_w = w_e \, (1 - 1.48 \, \eta / V_c)$$

The heat given off to the ambient is given by:

$$Q = (w_w + 0.11 \, w_e + 27.3) \, 3.413$$

where Q = heat lost to ambient, Btu/hr.

All this heat is transferred to a heat exchanger which is cooled by ambient air.

B.3.2 Catalytic Oxidizer

The model of the catalytic oxidizer is a simple model which computes the temperature of the air stream exiting the unit. The composition of the air remains unchanged. The following constants are used:

w_{htr} = heater power = 28 watts
M_c = mass of high temperature bed catalyst = 2.0 lbm
T_c = operating temperature of high temp. catalyst = 600^{o}F
s = fraction of air flow to high temp. catalyst = 0.1111
η_{HX} = heat exchanger effectiveness = 0.9
c_p = specific heat of air = 0.24 Btu/lbm-F

First the temperature leaving the high temperature bed is computed as:

$$T_h = T_c - \eta_{HX} (T_c - T_i)$$

where T_h = exit temp. from high temp. bed, ^oF

T_i = air inlet temp. to cat ox., ^oF

This high temperature air mixes with the air not going to the high temperature bed to give the resultant exit temperature.

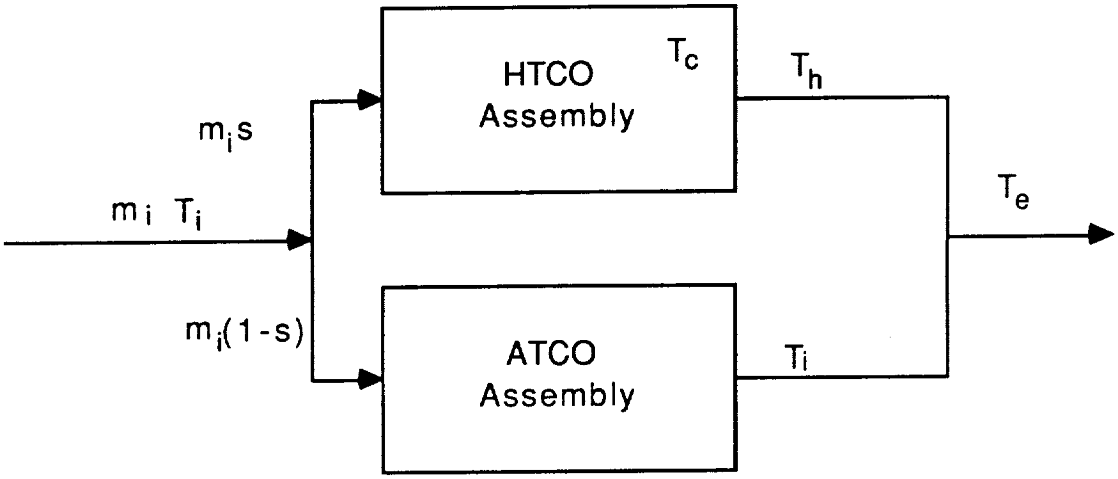
$$T_e = \frac{s\ m_i\ T_h\ c_p + (1-S)\ m_i\ T_i\ c_p}{m_i\ c_p}$$

Figure B-2 shows a schematic of the catalytic oxidizer subsystem and the location of the above discussed temperatures and flows.

B.3.3 Sabatier CO_2 Reduction Subsystem

The Sabatier CO_2 reduction subsystem consists of the Sabatier reactor, a fan and a water separator as modeled for G189A.

A listing of the Sabatier subroutine SABHS is given in the ECLSB User's Manual [3]. The model is a simplified block box model which provides the gas composition exiting the reactor and the mixed temperature of the cooling air leaving the reactor and condensing heat exchanger.



HTCO=High Temperature Catalytic Oxidizer
ATCO=Ambient Temperature Catalytic Oxidizer

FIGURE B-2
CATALYTIC OXIDIZER SUBSYSTEM SCHEMATIC

The Sabatier reaction is assumed to go to completion. First a test is made on the incoming gases to determine whether excess hydrogen or carbon dioxide exists. The reaction is:

$$CO_2 + 4\ H_2 \longrightarrow CH_4 + 2\ H_2O$$

If $\dfrac{m_{H2,i}}{2.016} < \dfrac{4\ m_{CO2,i}}{44.01}$

then excessive carbon dioxide exists and all the hydrogen is consumed. For this case, the following relations hold:

$$m_{CH4,e} = \frac{m_{H2,i}}{4\ MW_{H2}}\ MW_{CH4}$$

$$m_{H2O,e} = \frac{m_{H2,i}}{4\ MW_{H2}}\ 2\ MW_{H2O} + m_{H2O,i}$$

$$m_{H2,e} = 0.0$$

$$m_{CO2,e} = m_{CO2,i} - \frac{m_{H2,i}}{4\ MW_{H2}}\ MW_{CO2}$$

$$Q_{sen} = 8864.\ \frac{m_{H2,i}}{4\ MW_{H2}}$$

where: $m_{H2,i}$ = mass flow of hydrogen entering reactor, lbm/hr

$m_{H2,e}$ = mass flow of hydrogen exiting reactor, lbm/hr

$m_{CO2,i}$ = mass flow of carbon dioxide entering reactor, lbm/hr

$m_{CO2,e}$ = mass flow of carbon dioxide exiting reactor, lbm/hr

$m_{CH4,e}$ = mass flow of methane exiting reactor, lbm/hr

$m_{H2O,e}$ = mass flow of water exiting reactor, lbm/hr

$m_{H2O,i}$ = mass flow of water entering reactor, lbm/hr

MW = molecular weight, lbm/mole

Q_{sens} = sensible heat produced by reaction, Btu/hr

On the other hand, if excess hydrogen exists, the following relations hold:

$$m_{CH4,e} = \frac{m_{CO2,i}}{MW_{CO2}} \quad MW_{CH4}$$

$$m_{H2Oe} = \frac{m_{CO2,i}}{MW_{CO2}} \quad 2MW_{H2O} + m_{H2O,i}$$

$$m_{CO2,e} = 0.0$$

$$m_{H2,e} = m_{H2,i} - \frac{m_{CO2,i}}{MW_{CO2}} \quad 4MW_{H2}$$

$$Q_{sens} = 8865. \frac{m_{CO2,i}}{MW_{CO2}} \quad 4MW_{H2}$$

The latent heat load to condense the water produced is

$$Q_{LAT} = 1050. \quad m_{H2O,e}$$

The temperature of the cooling air leaving the Sabatier is:

$$T_{air,e} = T_{air,i} + (Q_{lat} + Q_{sens})/m_{air}\, c_p$$

where: m_{air} = mass flow of air, lbm/hr

The fan draws air around the reactor for cooling and through a condensing heat exchanger to condense the product water. The fan operational characteristics are:

cfm = 20.0
power = 34 watts

The condensed water and product gases pass through a water separator which is modeled as an alternate component for use with G189A. All the water is separated from the product gases and 0.13 Btu/hr is added to the product gases in the form of heat.

B.3.4 EDC CO_2 Removal Subsystem

The EDC CO_2 removal subsystem removes carbon dioxide from the air stream through a fuel cell type process which requires hydrogen and produces electricity. Heat is removed through a water cooled heat exchanger. Again, simple black box models are used. See Figure B-3 for a schematic representation.

A listing of the EDC subroutine EDCHS is contained in Appendix A of the ECLSB User's Manual [3]. The following constants are used:

J_d = design current density = 11 Amps/ft^2
R_{CO2} = CO_2 transfer rate = 0.001736 lbm CO_2/amp-hr
A_c = area per cell = ft^2/cell
T_c = cell operating temperature = 70°F
P_c = cell operating pressure = 14.7 psia
c_{PCO2} = 0.211 Btu/lbm-F
c_{PH2} = 3.437 Btu/lbm-F
c_{PO2} = 0.221 Btu/lbm-F
N_C = number of cells = 30

First, the carbon dioxide removal at design conditions is calculated using the following:

$$m_{CO2,d} = R_{CO2}\, J_d\, A_c\, N_c$$

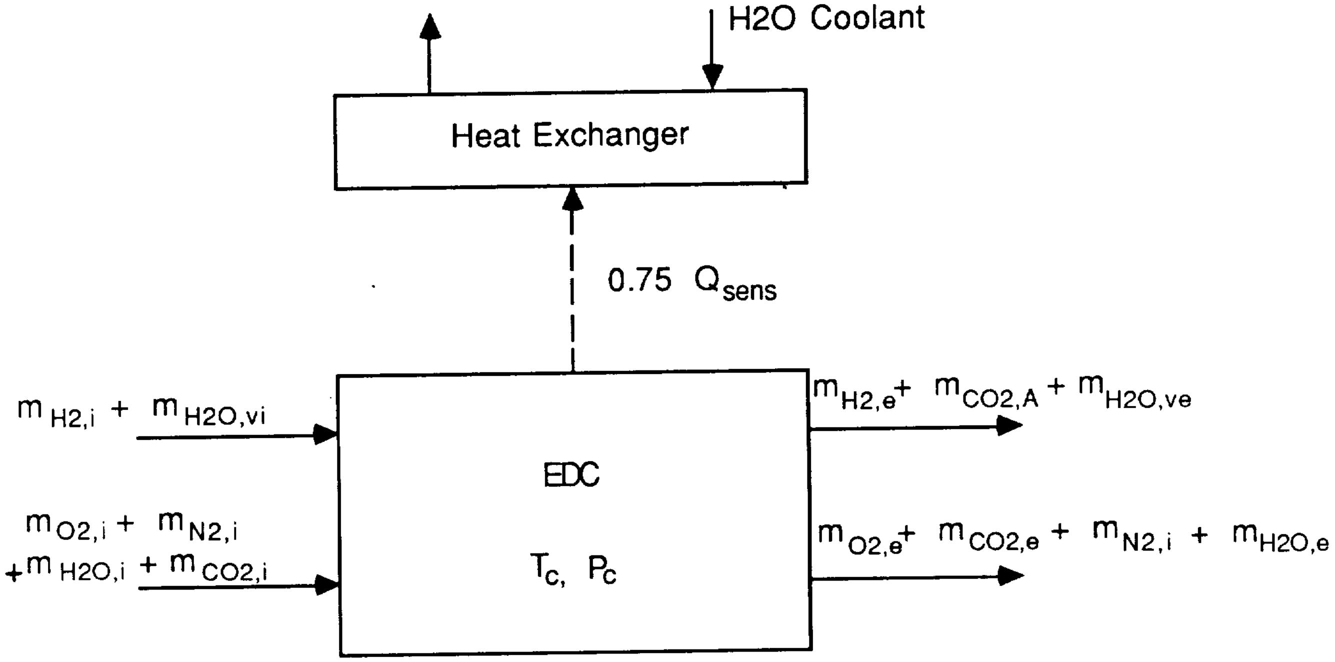


FIGURE B-3
EDC CO_2 REMOVAL SUBSYSTEM

Then, a factor is computed for use in determining the actual CO_2 removed. This factor is given by:

$$J_{CO2} = \left(\frac{J_A}{J_D} + 0.27 \right) \frac{1}{1.27}$$

The actual CO_2 removed becomes:

$$m_{CO2,A} = m_{CO2,d} \quad K_{CO2}$$

$$m_{CO2,e} = m_{CO2,i} - m_{CO2,A}$$

where: J_A = actual current density,amps/ft^2

$m_{CO2,i}$ = mass flow of CO_2 into EDC, lbm/hr

$m_{CO2,e}$ = mass flow of CO_2 exiting EDC in air stream, lbm/hr

The actual electrical characteristics required are:

$$I = 1.27 \; K_{CO2} \; J_D \; A_C$$

$$V = \frac{J_A}{J_D} \; 0.5 \; N_C$$

dividing line on separate half space

$$w = I \; V$$

In the process, oxygen is consumed; the amount is given by the following relations:

$$P_{CO2} = \frac{m_{CO2,i}}{MW_{CO2}} \; P_i \; \frac{760}{14.696}$$

$$\eta = 1.02 + \frac{0.19}{P_{CO2}} - \frac{0.718}{P_{CO2}^{2}}$$

$$M_{CO2,c} = \frac{M_{CO2,A}}{2\ MW_{CO2}} \; MW_{O2}$$

$$m_{O2,e} = m_{O2,i} - m_{O2,C}$$

where: P_i = inlet pressure of air to EDC, psia

$m_{CO2,i}$ = inlet mass flow of CO_2 into EDC, lbm/hr

MW_{CO2} = molecular weight of CO_2 = 44.01 lbm/mole

P_{CO2} = partial pressure of CO_2 in inlet air, mm Hg

η = effectiveness of conversion

MW_{O2} = molecular weight of oxygen = 32 lbm/mole

$m_{O2,C}$ = mass flow of oxygen consumed, lbm/hr

$m_{O2,i}$ = mass flow of oxygen into EDC, lbm/hr

$m_{O2,e}$ = mass flow of oxygen exiting EDC air stream, lbm/hr

The factor of 2 in the preceding equation arises from the overall reaction taking place in the EDC cells:

$CO_2 + 1/2\ O_2 + H_2 \dashrightarrow CO_2 + H_2O$ + electricity + heat

Accordingly, the amount of hydrogen consumed is given by:

$$m_{H2,C} = 2\ \frac{m_{O2c}}{MW_{O2}}\ MW_{H2}$$

The amount of water produced is:

$$m_{H2O,P} = \frac{m_{H2,c}}{MW_{H2}}\ MW_{H2O}$$

Some of the water available leaves with the hydrogen and carbon dioxide gases. It is assumed that the vapor is saturated and that the pressure in the H_2-CO_2 exit port is 20 psia. The amount of water leaving with the H_2-CO_2 mixture is given by the following:

$$m_{H2,e} = m_{H2,i} - m_{H2,C}$$

$$mW_{mix} = \frac{m_{H2,e} + m_{CO2,A}}{\frac{m_{H2,e}}{MW_{H2}} + \frac{m_{CO2}}{MW_{CO2}}}$$

$$P_V = P_{sat}(T_c)$$

$$= \frac{MW_{H2O}}{MW_{mix}} \quad \frac{P_V}{P_T - P_V}$$

$$M_{H2O,VE} = \omega (m_{CO2,a} + m_{H2,e})$$

$$m_{H2O,e} = m_{H2O,p} + m_{H2O,i} + m_{H2O,Vi} - m_{H2O,ve}$$

where: $m_{H2,i}$ = mass flow of hydrogen into EDC, lbm/hr

$m_{H2,e}$ = mass flow of hydrogen exiting EDC, lbm/hr

MW_{H2} = molecular weight of hydrogen, lbm/moles

MW_{H2O} = molecular weight of water, lbm/moles

MW_{mix} = molecular weight of H_2-CO_2 mix exiting EDC, lbm/moles

P_v = vapor pressure of water in H_2-CO_2 stream, psia

P_{sat} = saturation pressure for given temp, psia

ω = humidity ratio

P_T = total pressure in H_2-CO_2 exit line, psia

$m_{H2O,ve}$ = vapor leaving with H_2 and CO_2, lbm/hr

$m_{H2O,i}$ = mass flow of water into EDC from air stream, lbm/hr

$m_{H2O,vi}$ = mass flow of water into EDC with H_2 stream, lbm/hr

The total heat generated is given by:

$$Q_d = 65.7 + 766.8\ m_{CO2,d}$$

$$Q_{sens} = (1.06\ K_{CO2} - 0.06)\ Q_d$$

where: Q_d = design heat production, Btu/hr
Q_{sens} = actual heat production, Btu/hr

Of this heat, 25% is added to the air stream and 75% must be removed by the heat exchanger. Accordingly, the exit air temperature is given by:

$$T_e = T_i + \frac{0.25\ Qsens}{(m_{air,i} + m_{H20,vi})\ ep}$$

where: T_i = inlet air temperature, F
$m_{air,i}$ = inlet air flow, lbm/hr
c_p = specific heat of inlet air = 0.24 Btu/lbm-F

B.3.5 VCD Water Processing Subsystem

Vapor compression distillation process purifies water through a distillation type process. The model at present is simple and determines the amount of power consumed and the amounts of water and brine delivered. The following relations and constants are used:

$$m_{H2O,e} = 0.96\ m_{H2O,i}$$

$$m_b = 0.04\ m_{H2O,i}$$

$$w = \frac{m_{H2O,e}}{40.1}\ 120$$

where: $m_{H2O,i}$ = mass flow of water into VCD = 2.30 lbm/hr for 3 man units or 2.73 lbm/hr for 6 man unit.

$m_{H2O,e}$ = mass flow of clean water exiting VCD, lbm/hr

m_b = mass flow of brine, lbm/hr

w = power required, watts

B.3.6 Filtration Models

Three filtration devices are modeled in ECLSB by the use of the Alternate Component subroutine. The three components are the bacteria filter, charcoal filter, and multifiltration. For each of these, the inlet flows and conditions pass through unchanged.

B.3.7 Control

A variety of items require control to operate the system effectively. CO_2 and O_2 levels in the cabin atmosphere need to be maintained, and water levels in the various tanks need to be regulated. This control logic is contained in subroutines GPOLY1 and GPOLY2, and listings of these are contained in Table B-3 and Table B-4 respectively.

TABLE B-3

LISTING OF GPOLY1 FOR ECLSB MODEL

```
      SUBROUTINE GPOLY1
C
C
C     THIS SUBROUTINE PROVIDES THE CONTROL LOGIC FOR SYSTEM "B" ECLS
C     SIMULATION USING THE G189A COMPUTER PROGRAM.
C
C
C     TYPE STATEMENTS:
C
      INTEGER ONCE
      REAL    MR,INOM
      LOGICAL STEADY,CYCLIC,LTSIDE,OPEN,VCDON,MFTON
C
C     DIMENSION STATEMENTS:
C
      DIMENSION V(1),K(1)
      DIMENSION TURINE(8),THWASH(11),TSHOWR(2),TDRINK(8),TFOODP(5)
C
C     COMMON STATEMENTS:
C
      COMMON /COMP/ DS(15),N,NA1,NB1,NC,NCAB,NCFL,NEXT,NEXV,NK,
     1 NKEX,NKS,NKT,NLFL,NP,NPASS,NPF,NPFT(6),NQ,NS,NSF,NSFT(6),
     2 NSTR(18),NSUBR,NV,NVT,Y(12)
      COMMON /RARRAY/  IMAXR,R(0250)
      COMMON /ECLST1/  KCHOUT,KPRNT,KPTINV(4),KWIT,KWIT1,KWIT2,
     1 KWIT3,KWIT4,NUFF,KSTEDY
      COMMON /KANDV/ K
      COMMON /MISC/  DTIME,GRAV,KFLSYS,KOUTPT,KPDROP,KSYPAS,KTRANS,
     1 LPSUM(5),MAXCI,MAXLP,MAXSLP,MAXSSI,NCOMPS,NEWDT,NLAST,NPASPD,
     2 MINSSI,PGMIN,PLMIN,START,STEADY,TIME,TIMEMX,TMAX,TMIN,WTMAX
      COMMON /CASE/ NCASE,NRSCS,NRECS
      COMMON /PROPTY/ CP0,CP(99),CPCONL,CPCONV,CPCO2,CPDIL,CPOXY,CPTC,
     1 GAMGAS,RHO0,RHO(99),VISC0,VISC(99),VISGAS,WTM0,WTM(99),WTMCON,
     2 WTMDIL,WTMTC,XK0,XK(99),XKGAS,XKLIQ,VISLIQ
      COMMON /SOURCE/ A(19),B(19),CPA,CPB,IA1,IB1,NA,NB,NPFS,NPFST(6),
     1 NSFS,NSFST(6),RHOA,RHOB,VISCA,VISCB,WTMA,WTMB,XKA,XKB
      COMMON /VLOC/ IP,IS,IC,IQ,IV,IVT,IEX,INEXK
      COMMON /LRC/ IDATE(2),ISCHM
C
C     DATA INITIALIZATION:
C
      DATA TURINE / 0.1,3.0,6.0,9.0,12.0,15.0,20.0,25.0/
      DATA THWASH / 0.1,3.0,5.0,6.0, 9.0,10.0,11.0,12.0,15.0,20.0,25./
      DATA TSHOWR / 15.0,25./
      DATA TDRINK / 0.1,3.0,6.0,9.0,12.0,15.0,20.0,25.0/
      DATA TFOODP / 0.1, 5., 10., 14., 25./
      DATA KU,KH,KS,KD,KF / 1, 1, 1, 1, 1/
C
      EQUIVALENCE (V(1),K(1))
```

```
C       INITIALIZE AT START OF STEADY STATE SOLUTION.  DONE ONLY ONCE.
C
        IF(STEADY .AND. KSYPAS .LE. 1) THEN
            LTSIDE = .TRUE.
            TCABO  = 0.0
            TDESO  = 0.0
            IFREQ  = VV(2,184)
            NMEN   = KK(1,16)
            H2OADD = VV(2,128)
            CYCLIC = VV(2,185) .GT. 0.9
        END IF
C
        IF(N .EQ. 1) THEN
C
C           READ TABLE OF METABOLIC RATE VS MISSION TIME (24 HR CYCLE).
C
            TIMCYC = AMOD(TIME,86400.)
            MR     = VALUE(1,TIMCYC,0.0)
            TCAB   = VV(2,104)
            TCAB   = 70.
            QL     = MR-480.+(MR/1000.+ 10.)*(TCAB-60.0)
            QLMIN  = 0.22*MR+2.6*(TCAB-60.0)
            QL     = AMAX1(QL,QLMIN)
            QS     = MR-QL
            R(66)  = QS
            R(67)  = QL
            R(82)  = MR
        END IF
C
        IF(N .EQ. 2) THEN
            IF(STEADY .OR. MOD(KSYPAS,IFREQ) .EQ. 0) ISCHM = 1
            R(181) = DTIME
            R(182) = DTIME/60.
C
C           LIGHTSIDE - DARKSIDE?
C
            IF(CYCLIC) THEN
                TIMORB = AMOD(TIME,5400.)
                LTSIDE = TIMORB .LE. 2700.
            END IF
C
C           NITROGEN ADDITION RATE
C
            R(166) = 0.0
            WCN    = 0.0
            PT     = R(4)
            PO2    = R(94)
            IF(PT .GE. 14.819) GO TO 220
            IF (PT .GE. 14.818 .AND. PO2 .GE. 8.28) GO TO 220
            IF (PO2 .LT. 3.09) GO TO 220
```

```
C
C          REGULATOR LOGIC.
C
           IF(OPEN) GO TO 210
C
C          N2 OPENING CURVES.
C
           WCN  - VALUE(22,PT,0.0)
           OPEN - .TRUE.
           GO TO 220
C
C          N2 CLOSING CURVES.
C
 210       WCN   - VALUE(28,PT,0.0)
           IF(WCN .LE. 0.0) OPEN - .FALSE.
C
 220       R(166) - WCN
C
C          OXYGEN AND H2O VAPOR ADDITION FROM SPE, LBM/HR
C
           R(128) - H2OADD+VV(20,68)
           R(165) - V(IV+2)
C
C          TRACE CONTAMINANTS ADDITION
C
       END IF
C
       IF(N .EQ. 8) THEN
           IF(.NOT. STEADY .OR. KSYPAS .GE. 4) THEN
               WSEC   - VV(7,1)
               WPRI   - VV(5,1)
               WTOT   - WSEC+WPRI
               SR     - WSEC/WTOT
               R(65)  - SR
           END IF
       END IF
C
       IF(N .EQ. 6) THEN
           R(84) - 0.0
           IF(VV(7,68) .GE. 560.) R(84) - 1.0
       END IF
C
       IF(N .EQ. 9) THEN
           IF(.NOT. STEADY .OR. KSYPAS .GE. 4) THEN
               WSEC   - VV(14,1)
               WPRI   - VV(16,1)+VV(23,1)+VV(21,1)
               WTOT   - WSEC+WPRI
               SR     - WSEC/WTOT
               R(65)  - SR
           END IF
```

```
      END IF
C
      IF(N .EQ. 11) THEN
          W8      = A(1)*R(72)/CPA
          W8      = AMAX1(W8,A(1))
          R(66)   = EXP(2.809-0.00169*B(1))*W8*(0.52+0.00026*B(1))
      END IF
C
C     EXTRACT CONDENSATE WATER.
C
      IF(N .EQ. 13) THEN
          R(67) = A(7)
          A(1)  = A(1)-A(7)
          A(7)  = 0.0
          CPA   = (A(5)*A(8)+A(6)*CPCONV)/A(1)
      END IF
C
      IF(N .EQ. 15) THEN
          IF(.NOT. STEADY .OR. KSYPAS .GE. 4) THEN
              WSEC   = VV(16,1)
              WPRI   = VV(28,1)+VV(21,1)
              WTOT   = WSEC+WPRI
              SR     = WSEC/WTOT
              R(65)  = SR
          END IF
      END IF
C
      IF(N .EQ. 16) THEN
          R(84) = 1.0
          IF(.NOT. LTSIDE) R(84) = 0.0
      END IF
C
 17   IF(N .NE. 17) GO TO 1799
      IF(STEADY .AND. KSYPAS .LT. 4) GO TO 1799
      WSEC   = VV(21,1)
      WPRI   = VV(28,1)
      WTOT   = WSEC+WPRI
      SR     = WSEC/WTOT
      R(65)  = SR
1799  CONTINUE
C
 18   IF(N .NE. 18) GO TO 1899
      R(84) = 1.0
      IF(.NOT. LTSIDE) R(84) = 0.0
1899  CONTINUE
C
 19   IF(N .NE. 19) GO TO 1999
      R(84) = 1.0
      IF(.NOT. LTSIDE) R(84) = 0.0
1999  CONTINUE
```

```
C
 20     IF(N .NE. 20) GO TO 2099
        INOM  = R(72)
        PO2   = VV(2,94)
        R(69) = INOM
        IF(PO2 .GE. 8.1) R(69) = 0.9*INOM
        IF(PO2 .LE. 2.9) R(69) = 1.1*INOM
        CALL SK(1,20,16)
        IF(LTSIDE) GO TO 2099
        R(69) = 0.0
        CALL SK(0,20,16)
 2099   CONTINUE
C
 21     IF(N .NE. 21) GO TO 2199
        R(65) = VV(20,65)
 2199   CONTINUE
C
 28     IF(N .NE. 28) GO TO 2899
        PCO2  = VV(2,100)
        R(68) = R(69)
        IF(PCO2 .GT. 8.0) R(68) = R(69)
        IF(PCO2 .LT. 2.0) R(68) = R(69)
        IF(LTSIDE) GO TO 2899
        R(68) = 0.0
 2899   CONTINUE
C
 24     IF(N .NE. 24) GO TO 2499
        R(65) = VV(28,65)
 2499   CONTINUE
C
 28     IF(N .NE. 28) GO TO 2899
C
C       EXTRACT CONDENSATE WATER.
C
        R(67) = A(7)
        A(1)  = A(1)-A(7)
        A(7)  = 0.0
        CPA   = (A(5)*A(8)+A(6)*CPCONV)/A(1)
 2899   CONTINUE
C
 82     IF(N .NE. 82) GO TO 8299
        CPA   = CPCONL
        RHOA  = RHO(1)
        CPB   = CPCONL
        RHOB  = RHO(1)
        WTMA  = WTM(1)
        WTMB  = WTM(1)
        VISCA = VISC(1)
        VISCB = VISC(1)
        XKA   = XK(1)
```

```
       XKB    - XK(1)
 8299  CONTINUE
C
 85    IF(N .NE. 85) GO TO 8599
C
C      URINE DUMP TO STORAGE TANK, LBM/HR
C
       A(1)    - 0.0
       IF (NMEN .EQ. 8) WDMP - 17./7.
       IF (NMEN .EQ. 6) WDMP - 26.28/7.
       TIMCYC - AMOD(TIME,86400.)
       IF(TIMCYC .LT. TURINE(7)*8600. .AND. KU .EQ. 8) KU - 1
       IF(TIMCYC .LT. TURINE(KU)*8600.) GO TO 8510
       KU      - KU+1
       KU      - MINO(KU,8)
       A(1)    - WDMP/DTIME*8600.
C
C      WASTE HAND WASH WATER DUMP TO STORAGE TANK, LBM/HR
C
 8510  WHWASH - 0.0
       IF(TIMCYC .LT. THWASH(10)*8600. .AND. KH .EQ. 11) KH - 1
       IF(TIMCYC .LT. THWASH(KH)*8600.) GO TO 8520
       KH      - KH+1
       KH      - MINO(KH,11)
       WHWASH - 11.5/10.
       A(1)    - A(1)+WHWASH/DTIME*8600.
C
C      WASTE SHOWER WATER DUMP TO STORAGE TANK, LBM/HR
C
 8520  WSHOWR - 0.0
       IF(TIMCYC .LT. TSHOWR(1)*8600. .AND. KS .EQ. 2) KS - 1
       IF(TIMCYC .LT. TSHOWR(KS)*8600.) GO TO 8530
       KS      - KS+1
       KS      - MINO(KS,2)
       WSHOWR - 22.5
       A(1)    - A(1)+WSHOWR/DTIME*8600.
C
C      FLOW EXITING URINE WASH WATER STORAGE TANK, LBM/HR
C
 8530  R(1)    - 0.0
       IF(R(69) .LE. 80.) GO TO 8540
       VCDON   - .TRUE.
       GO TO 8550
 8540  IF(R(69) .GE. 27.) GO TO 8550
       VCDON   - .FALSE.
 8550  IF(.NOT. VCDON) GO TO 8599
       IF(NMEN .EQ. 8) R(1) - 2.80
       IF(NMEN .EQ. 6) R(1) - 2.78
 8599  CONTINUE
C
```

```
 41     IF(N .NE. 41) GO TO 4199
        H2OSPE - VV(20,67)
        R(1) - (WHWASH+WSHOWR)/DTIME*8600.+H2OSPE+WMFLT
 4199   CONTINUE
C
 42     IF(N .NE. 42) GO TO 4299
        WSEC - (H2OSPE+WMFLT)*DTIME/8600.
        WTOT - WSEC+WHWASH+WSHOWR
        IF(WTOT .LE. 0.0) GO TO 4299
        SR   - WSEC/WTOT
        R(65) - SR
 4299   CONTINUE
C
 46     IF(N .NE. 46) GO TO 4699
        R(1)   - 0.0
        WDRINK - 0.0
        TIMCYC - AMOD(TIME,86400.)
        IF(TIMCYC .LT. TDRINK(7)*8600. .AND. KD .EQ. 8) KD - 1
        IF(TIMCYC .LT. TDRINK(KD)*8600.) GO TO 4610
        IF (NMEN .EQ. 8) WDRINK - 19.56/7.
        IF (NMEN .EQ. 6) WDRINK - 81.82/7.
        KD     - KD+1
        KD     - MINO(KD,8)
        R(1)   - WDRINK/DTIME*8600.
C
C       FOOD PREPARATION WATER DUMP TO STORAGE TANK, LBM/HR
C
 4610   WFOODP - 0.0
        IF(TIMCYC .LT. TFOODP(4)*8600. .AND. KF .EQ. 5) KF - 1
        IF(TIMCYC .LT. TFOODP(KF)*8600.) GO TO 4699
        KF     - KF+1
        KF     - MINO(KF,5)
        IF(NMEN .EQ. 8) WFOODP - 4.74/4.
        IF(NMEN .EQ. 6) WFOODP - 9.48/4.
        R(1)   - R(1)+WFOODP/DTIME*8600.
 4699   CONTINUE
C
 56     IF(N .NE. 56) GO TO 5699
        WSEC - WMFLT
        WTOT - WSEC+H2OSPE
        IF(WTOT .LE. 0.0) GO TO 5699
        SR   - WSEC/WTOT
        R(65) - SR
 5699   CONTINUE
C
 58     IF(N .NE. 58) GO TO 5899
        WMFLT - 0.0
        R(1)  - 0.0
        WPOT  - VV(46,69)
        IF(WPOT .GE. 40.) GO TO 5810
```

```
      MFTON - .TRUE.
      GO TO 5820
 5810 IF(WPOT .LE. 45.) GO TO 5820
      MFTON - .FALSE.
 5820 IF(.NOT. MFTON) GO TO 5899
      IF(R(100)*DTIME/8600. .LE. R(69)) GO TO 5880
      R(1)  - 0.0
      WMFLT - R(100)
      GO TO 5899
 5880 R(1)  - R(100)
 5899 CONTINUE
C
 61   IF(N .NE. 61) GO TO 6199
      IF(STEADY .AND. KSYPAS .LT. 4) GO TO 6199
      TCAB - VV(2,104)
      TDES - V(IV+28)
      TTOL - 0.1
      IF(ABS(TCAB-TDES) .LT. TTOL) GO TO 6199
      A1   - 0.025
      ITER - 1
      CALL ESTIM(R(65),TCAB,TDES,R65OLD,TCABO,TDESO,A1,ITER,NSTR(1))
      R(65) - AMAX1(R(65),0.0)
      R(65) - AMIN1(R(65),0.9)
 6199 CONTINUE
C
      RETURN
      END
```

TABLE B-4

LISTING OF GPOLY2 FOR ECLSB MODEL

```
      SUBROUTINE GPOLY2
C
      COMMON /COMP/ DS(15),N,NA1,NB1,NC,NCAB,NCFL,NEXT,NEXV,NK,
     1 NKEX,NKS,NKT,NLFL,NP,NPASS,NPF,NPFT(6),NQ,NS,NSF,NSFT(6),
     2 NSTR(18),NSUBR,NV,NVT,Y(12)
      COMMON /RARRAY/  IMAXR,R(0250)
      COMMON /ECLST1/  KCHOUT,KPRNT,KPTINV(4),KWIT,KWIT1,KWIT2,
     1 KWIT3,KWIT4,NUFF,KSTEDY
      COMMON /KANDV/ K
      COMMON /MISC/  DTIME,GRAV,KFLSYS,KOUTPT,KPDROP,KSYPAS,KTRANS,
     1 LPSUM(5),MAXCI,MAXLP,MAXSLP,MAXSSI,NCOMPS,NEWDT,NLAST,NPASPD,
     2 MINSSI,PGMIN,PLMIN,START,STEADY,TIME,TIMEMX,TMAX,TMIN,WTMAX
      COMMON /CASE/    NCASE,NRSCS,NRECS
      COMMON /PROPTY/ CPO,CP(99),CPCONL,CPCONV,CPCO2,CPDIL,CPOXY,CPTC,
     1 GAMGAS,RHOO,RHO(99),VISCO,VISC(99),VISGAS,WTMO,WTM(99),WTMCON,
     2 WTMDIL,WTMTC,XKO,XK(99),XKGAS,XKLIQ,VISLIQ
      COMMON /SOURCE/ A(19),B(19),CPA,CPB,IA1,IB1,NA,NB,NPFS,NPFST(6),
     1 NSFS,NSFST(6),RHOA,RHOB,VISCA,VISCB,WTMA,WTMB,XKA,XKB
      COMMON /VLOC/ IP,IS,IC,IQ,IV,IVT,IEX,INEXK
C
      DIMENSION V(1),K(1)
C
      EQUIVALENCE (V(1),K(1))
C
      LOGICAL  STEADY
C
 1    IF(N.NE.1)  GO TO 199
C
C     CALC NET FLOWS DUE TO CABIN PRI & SEC FLOW LOOPS
C
      SBCO2 = 0.0
      SBH2O = 0.0
C
C     CALC NET H2O VAPOR CHANGE
C
 125  XH2O = R(70) - SBH2O - VV(18,67) +  VV(23,75) + VV(20,68)
      CALL SV(XH2O,2,187)
C
C     CALC NET O2 CHANGE
C
      XO2 = -R(68) - VV(23,78) + VV(20,66)
      CALL SV(XO2,2,175)
C
C     CALC NET CO2 CHANGE
C
      XCO2 = R(69) - SBCO2 - VV(23,79)
      CALL SV(XCO2,2,177)
 199  CONTINUE
C
 2    IF (N .NE. 2) GO TO 299
```

```
       R(2)   - 70.
       R(21)  - 70.
       R(89)  - 0.42
       R(98)  - 46.
       R(104) - 70.
 299   CONTINUE
C
 18    IF(N.NE. 18) GO TO 1899
       R(20) - R(67)
       R(21) - R(2)
       R(22) - 24.7
       R(28) - 24.7
 1899  CONTINUE
C
 28    IF(N.NE. 28) GO TO 2899
       R(20) - R(67)
       R(21) - R(2)
       R(22) - 24.7
       R(28) - 24.7
       R(68) - VV(26,68)
 2899  CONTINUE
C
       RETURN
       END
```

B.3.7.1 Nitrogen Addition Control

Nitrogen is added to maintain the total pressure in the cabin at a level of 14.813 psia. The same control as used and described in the ESCM Model Description Document [1] is used in the ECLSB model.

B.3.7.2 Oxygen Production Control

The oxygen level is controlled by adjusting the electrical current to the SPE cells according to the following:

$P_{O2} \geq 3.1$ psia $\quad I = 0.9\ I_{NOM}$

$P_{O2} \leq 2.9$ psia $\quad I = 1.1\ I_{NOM}$

where: P_{O2} = partial pressure of O_2 in cabin, psia
I = current to SPE cells, amps
I_{NOM} = nominal current to cells = 22 amps

This nominal electrical current corresponds to a nominal oxygen consumption rate for three men at 0.255 lbm/hr.

B.3.7.3 CO_2 Partial Pressure Control

At present, the EDC production current is not adjusted in response to changes in the CO_2 partial pressure in the cabin. The current density is maintained at a constant 11.0 amps per square foot. The user may change this control logic by making desired changes in the GPOLY1 subroutine.

B.3.7.4 Cabin Temperature and Humidity Control

Control of cabin temperature and humidity is accomplished by regulating the fraction of air flow from the cabin which passes through the condensing heat exchanger. The more air through the heat exchanger, the cooler the cabin should become. The technique to regulate the fraction to the heat exchanger is described by the following relations:

For $$|T_1 - T_s| < 0.1^{o}F$$

the fraction remains unchanged. Otherwise;

$$f = f_1 + 0.025 \frac{f_2 - f_1}{T_1 - T_2} \quad T_1 - T_s$$

and f is clamped between 0 and 0.9.

Where: f = new flow fraction bypassing heat exchanger

f_1 = last flow fraction

f_2 = flow fraction prior to f_1

T_1 = last cabin temperature, ^{o}F

T_2 = cabin temperature prior to T_1, ^{o}F

T_s = set point cabin temperature, ^{o}F

This is tantamount to a straight integral control technique with a varying integration gain constant.

The effects of this control on cabin temperature and humidity are negated, however, by the logic in GPOLY2. GPOLY2 simply sets the cabin temperature to 70°F, the humidity to 42%, and the dew point to 46°F. This was done to give reasonable temperatures until a new control low can be developed.

B.3.7.5 Water Tank Level Control

Four water tanks are used for storage of clean and waste water; they are:

(1) Urine and Wash Water Storage Tank
(2) Clean Hygiene Water Storage Tank
(3) Potable Water Storage Tank
(4) Condensate Water Storage Tank

For each of these tanks, the calculations for the entering and exiting water flows are presented in the following paragraphs.

B.3.7.5.1 Urine and Wash Water Storage Tank

The Urine and Wash Water Storage Tank receives water from crew urination, hand washing, and showering. The amount of water for each of these activities is considered to be dumped into the tank over a period of one time step which is currently 120 seconds or two minutes. Table B-5 gives the amount and time of day at which water is dumped into the tank for each of these activities. This table, of course, may be altered by the user by appropriate changes to the logic in GPOLY1.

Flow will exit the tank only if the VCD unit is on. The VCD unit turns on whenever the tank level is greater than 30 percent full and turns off if the tank level falls below 27 percent full. When the VCD is on, it draws water at 2.3 lbm/hr for a three man unit and 2.73 lbm/hr for a six man unit.

B.3.7.5.2 Clean Hygiene Water Storage Tank

The Clean Hygiene Water Storage Tank receives water from the VCD unit at the rate processed by the VCD. Water is used from this tank for handwashing and showers and to supply the needs of the SPE and Multifiltration units. Accordingly, water for handwashing and

TABLE B-5
SCHEDULE FOR DUMPING INTO URINE AND WASH WATER STORAGE TANK

Water Dumped (lbm)

Time of Day	Urine 3 Men	Urine 6 Men	Hand-wash	Shower
8:06 AM	2.429	3.754	1.15	
9:00				
10:00				
11:00	2.429	3.754	1.15	
12:00				
1:00 PM			1.15	
2:00	2.429	3.754	1.15	
3:00				
4:00				
5:00	2.429	3.754	1.15	
6:00			1.15	
7:00			1.15	
8:00	2.429	3.754	1.15	
9:00				
10:00				
11:00	2.429	3.754	1.15	22.5
12:00				
1:00 AM				
2:00				
3:00				
4:00	2.429	3.754	1.15	
5:00				
6:00				
7:00				
8:00				
	17.00	26.28	11.5	22.5

showers is drawn from the tank according to the schedule in Table B-5. Again, all the water for a given time in the table is presumed to be drawn over one time step, i.e., two minutes.

The water required by the SPE unit is given in Section B.3.1 by the relation for $m_{H2O,t}$. The water required for the multifiltration unit is 2.55 lbm/hr. However, water is drawn from the Hygiene Tank only if the condensate tank is unable to supply the multifiltration needs.

B.3.7.5.3 Potable Water Storage Tank

The potable water storage tank receives water from the multifiltration unit. The multifiltration unit is supplied by a water pump which draws water from the condensate storage tank or the clean hygiene water storage tank if the condensate tank has insufficient water. The pump draws water at 2.55 lbm/hr. The multifiltration unit pump turns on when the tank level falls below 90% full and turns off if the level rises above 45%.

Water is drawn from the tank for drinking and food preparation. Again, the amount of water drawn for each of these activities is considered to be drawn from the tank over a period of one time step which is currently two minutes. Table B-6 gives the amount and time of day for each of these activities.

TABLE B-6
USAGE SCHEDULE FOR POTABLE WATER TANK

Water Used (lbm)

Time of Day	Drinking 3 Men	Drinking 6 Men	Food Preparation 3 Men	Food Preparation 6 Men
8:06 AM	2.794	4.474	1.185	2.370
9:00				
10:00				
11:00	2.794	4.474		
12:00				
1:00 PM			1.185	2.370
2:00	2.794	4.474		
3:00				
4:00				
5:00	2.794	4.474		
6:00			1.185	2.370
7:00				
8:00	2.794	4.474		
9:00				
10:00			1.185	2.370
11:00	2.794	4.474		
12:00				
1:00 AM				
2:00				
3:00				
4:00	2.794	4.474		
5:00				
6:00				
7:00				
8:00				
	19.560	31.320	4.740	9.480

B.3.7.5.4 Condensate Water Storage Tank

The condensate water storage tank receives condensate water from the condensing heat exchanger and the Sabatier reactor water separator. Water is drawn from the condensate tank as required by the multifiltration unit to supply the potable water needs. When water is drawn, it is drawn at 2.55 lbm/hr.

APPENDIX C

SPACE STATION MODEL

C.1 Introduction

This manual provides the model description document for a Space Station model which includes a habitat, laboratory, and four nodes. Only the air revitalization equipment is modelled; waste water management tanks and processing equipment are not included in the model. The principal pieces of equipment are:

Function	Subsystem Option Available
CO_2 Removal	EDC, Molecular Sieve
CO_2 Reduction	Bosch, Sabatier
O_2 Generation	SPE, KOH
Trace Gas Removal	Catalytic Oxidizer
Condensate Processing	Plate-fin shuttle type heat exchanger

Options are also available for hydrogen or CO_2 bussing.

C.2 Modelling of System

Figures C-1 through C-14 present the schematics of the system as modeled using G189A. The following discusses how this system represents real hardware. Further descriptions of the system can be found in the User's Manual [4].

In these schematics, extra lines, mixers, and splitters are inserted to provide the user with flexibility to select various options without having to rewrite the programs. These lines do not represent actual plumbing arrangements of a Space Station. For example, a duct does not exit the habitat then tee to two modes as shown in Figure C-1. In actuality, a node is adjacent to the habitat and a fan draws air directly from the habitat into the node. Therefore, these are functional schematics and do not represent actual plumbing.

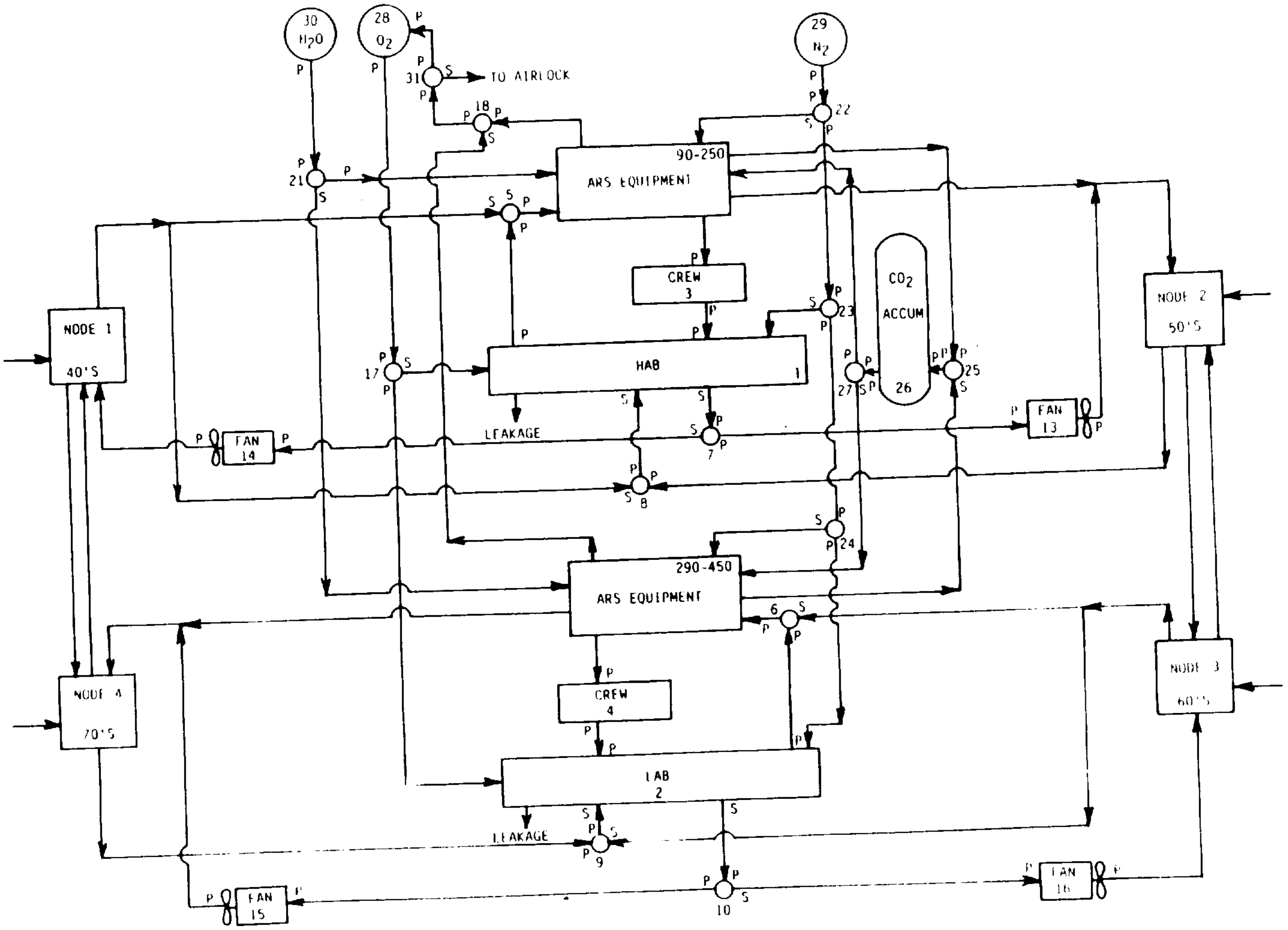


FIGURE C-1
SPACE STATION MODEL OVERVIEW

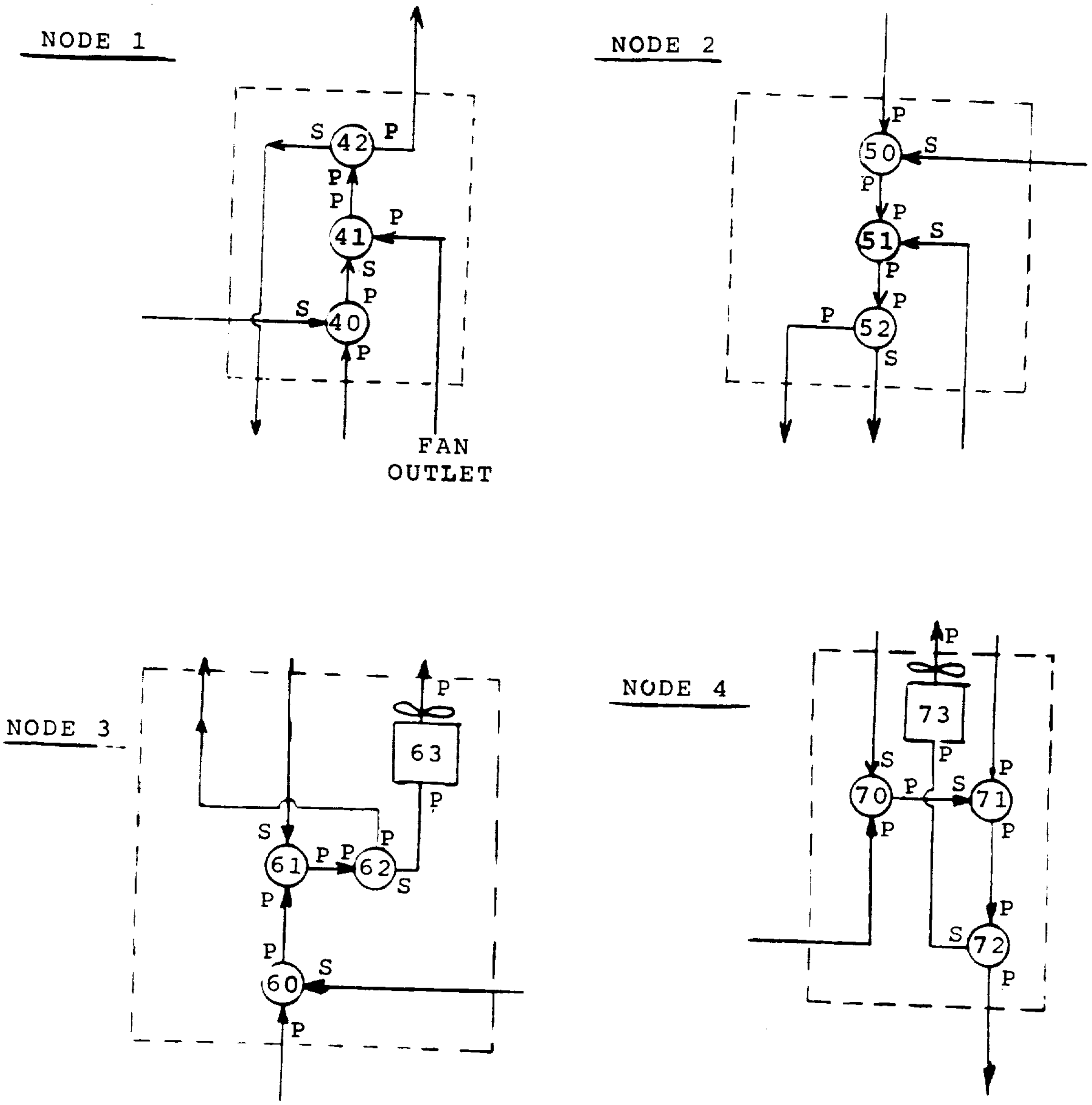


FIGURE C-2
SPACE STATION NODES

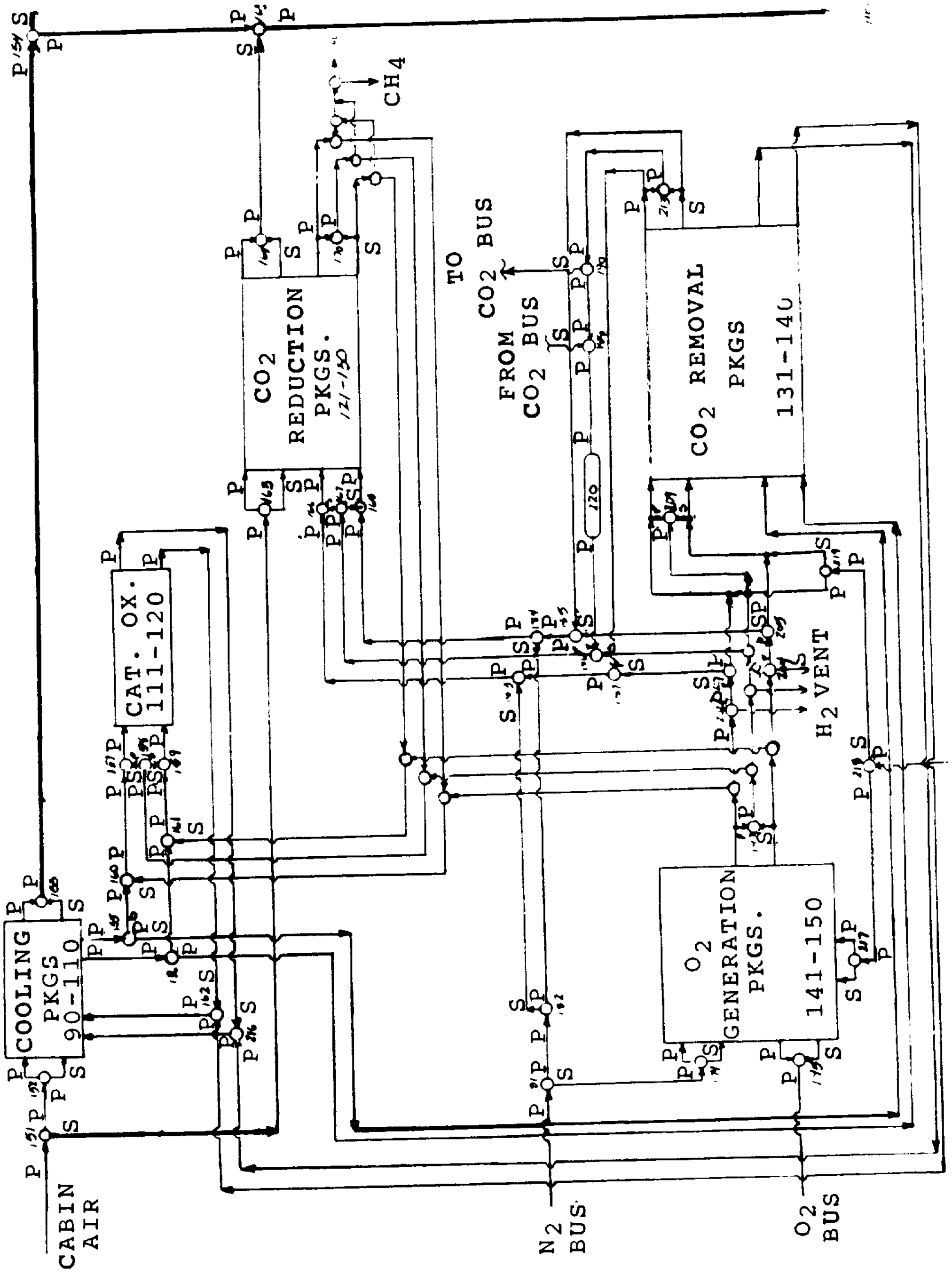


FIGURE C-3
OVERVIEW OF HABITAT ARS

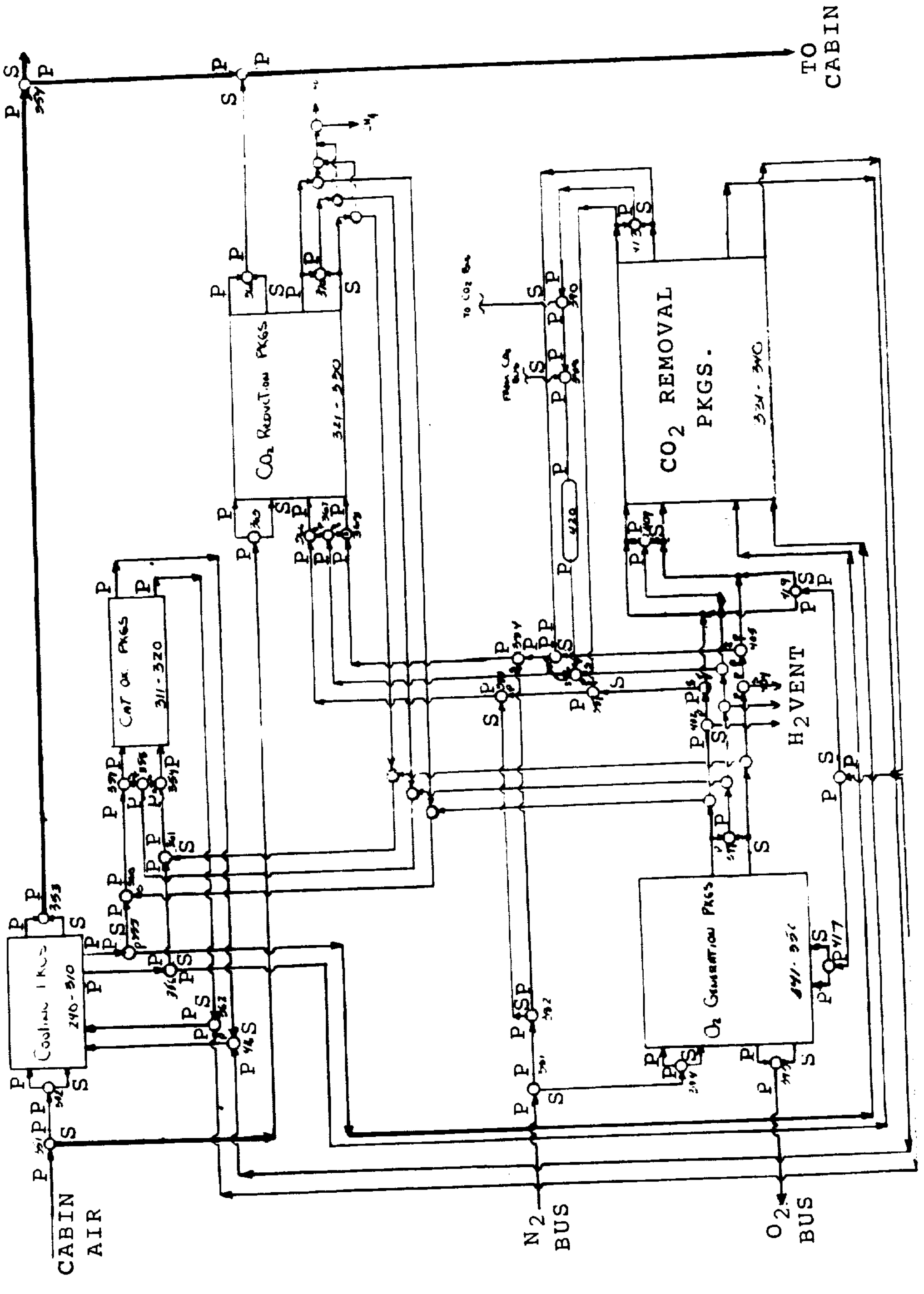


FIGURE C-4
OVERVIEW OF LABORATORY ARS

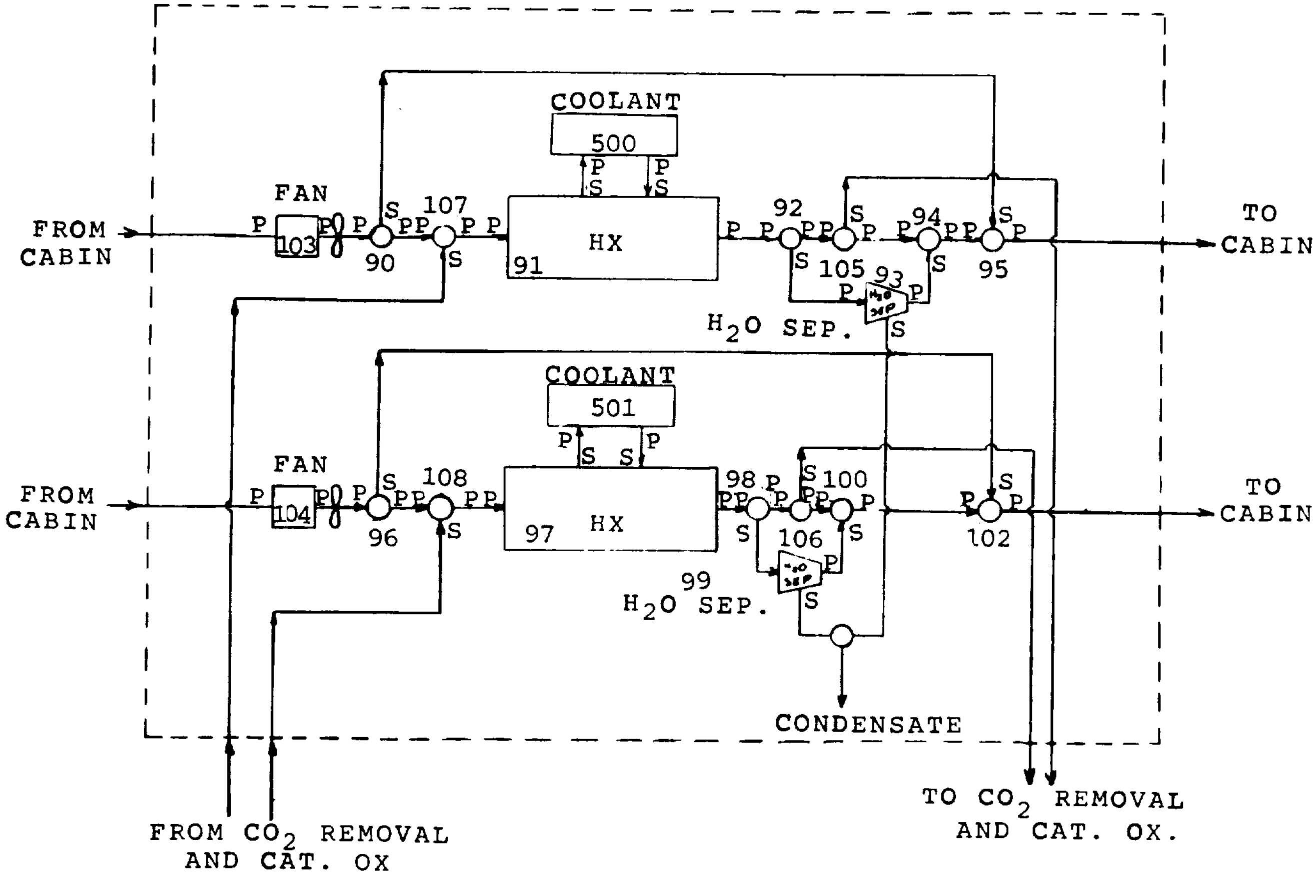


FIGURE C-5
HABITAT COOLING PACKAGES

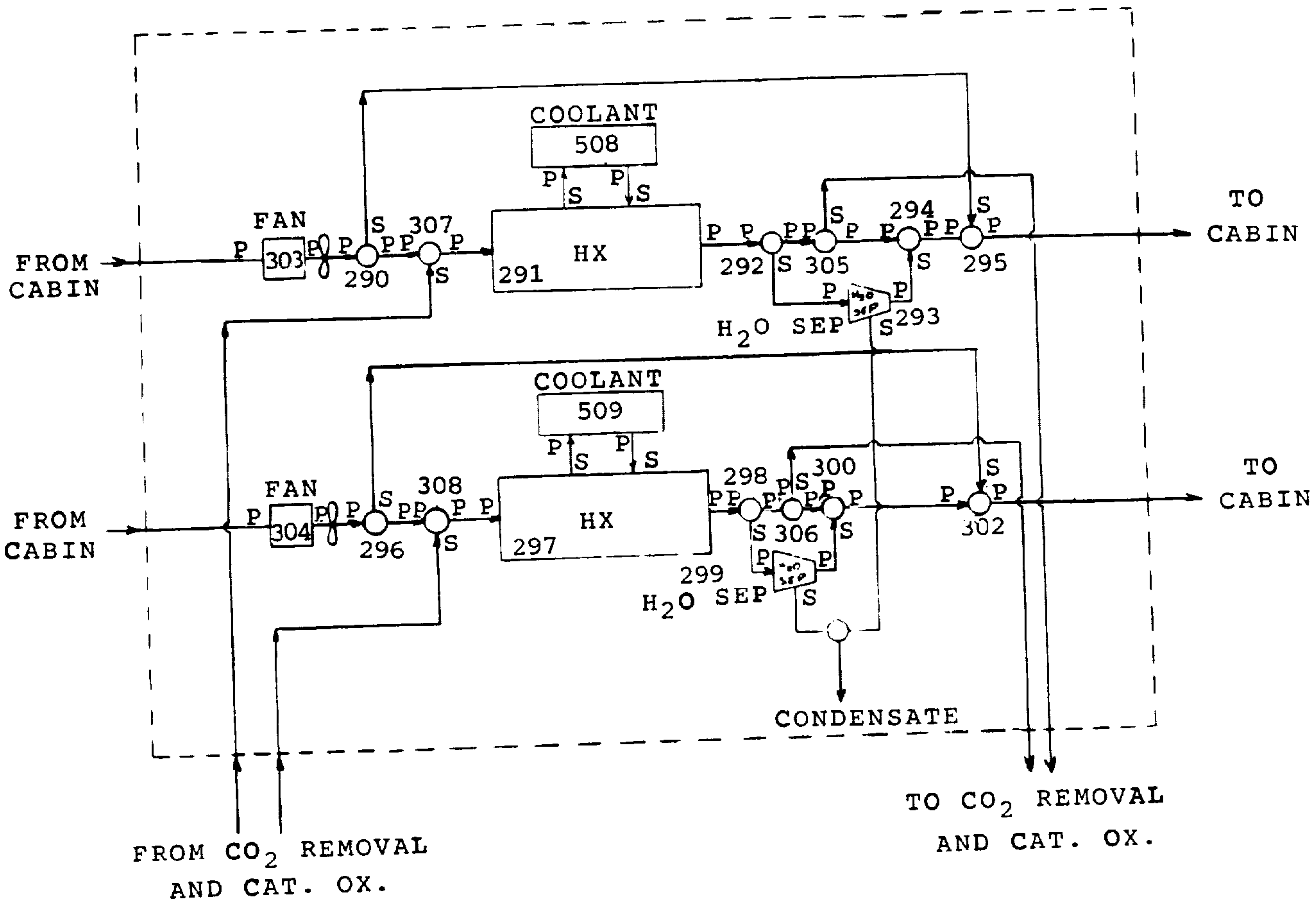


FIGURE C-6
LABORATORY COOLING PACKAGES

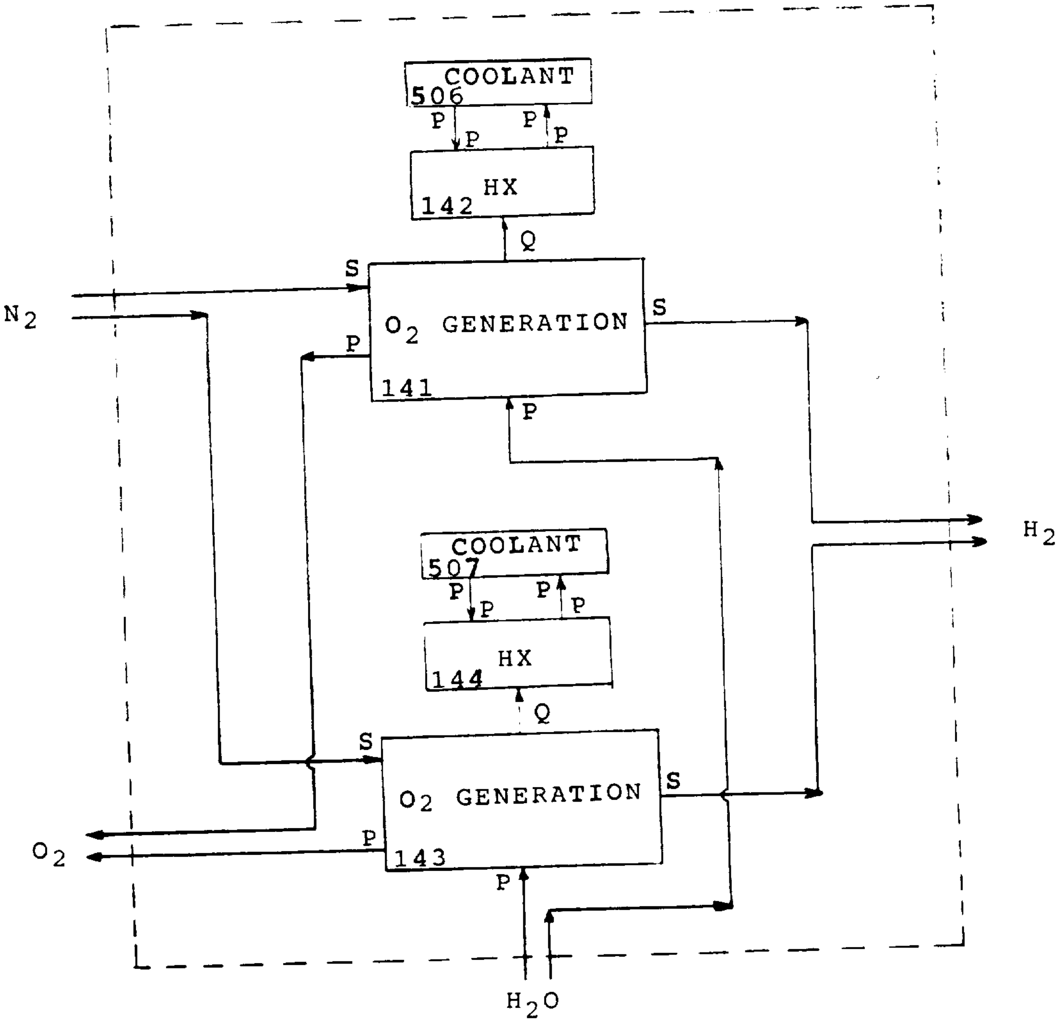


FIGURE C-7
HABITAT OXYGEN GENERATORS

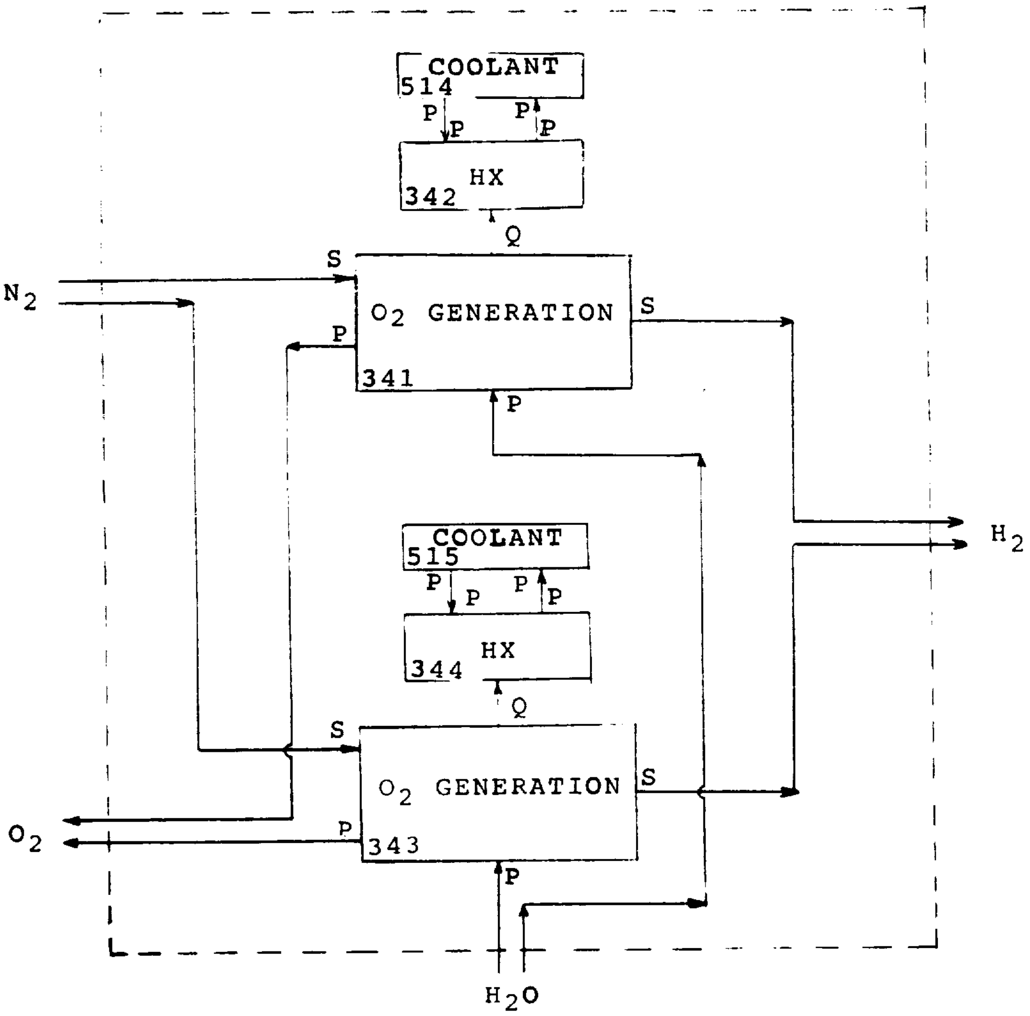


FIGURE C-8
LABORATORY OXYGEN GENERATORS

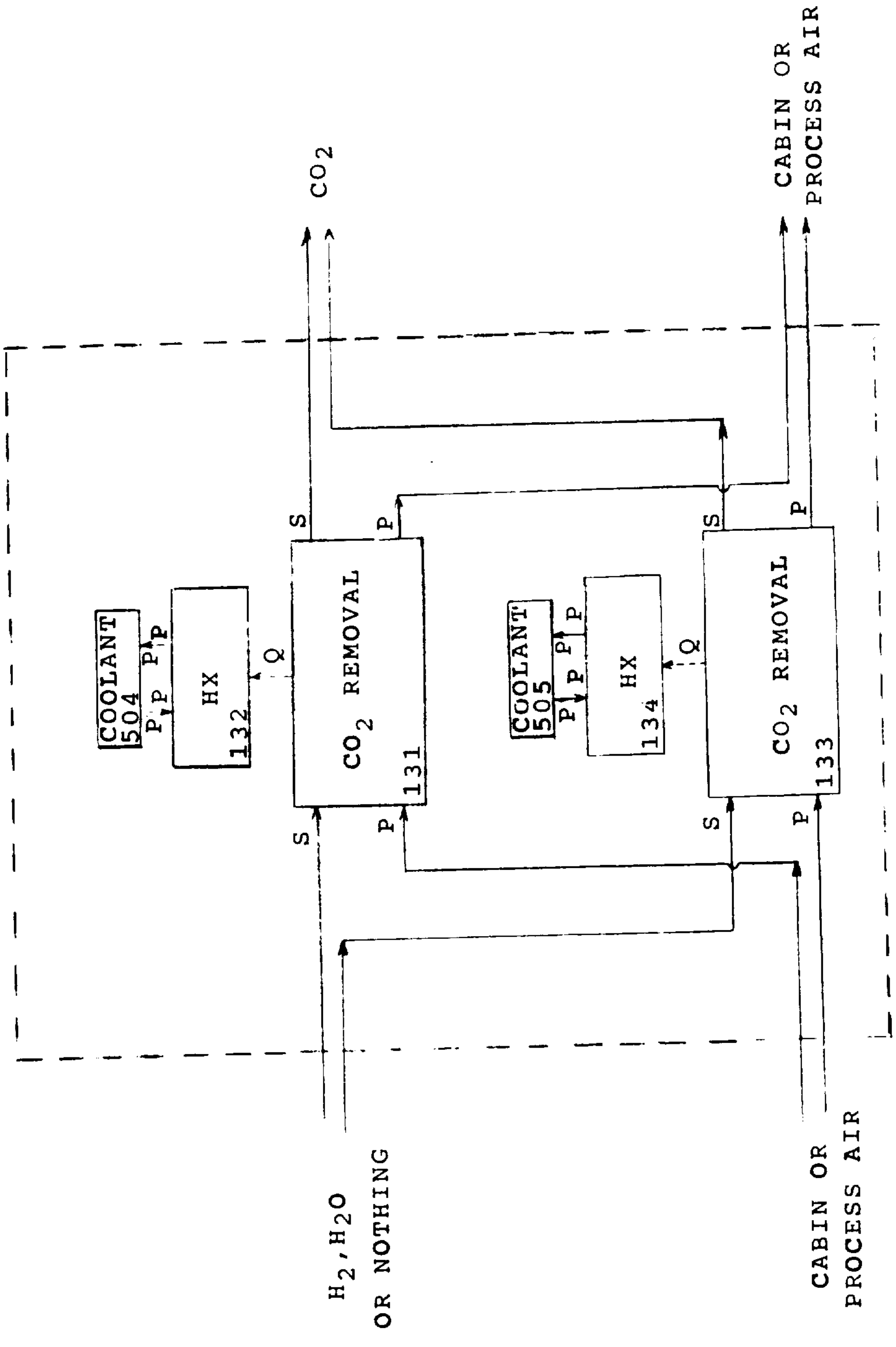


FIGURE C-9
HABITAT CO_2 REMOVAL UNITS

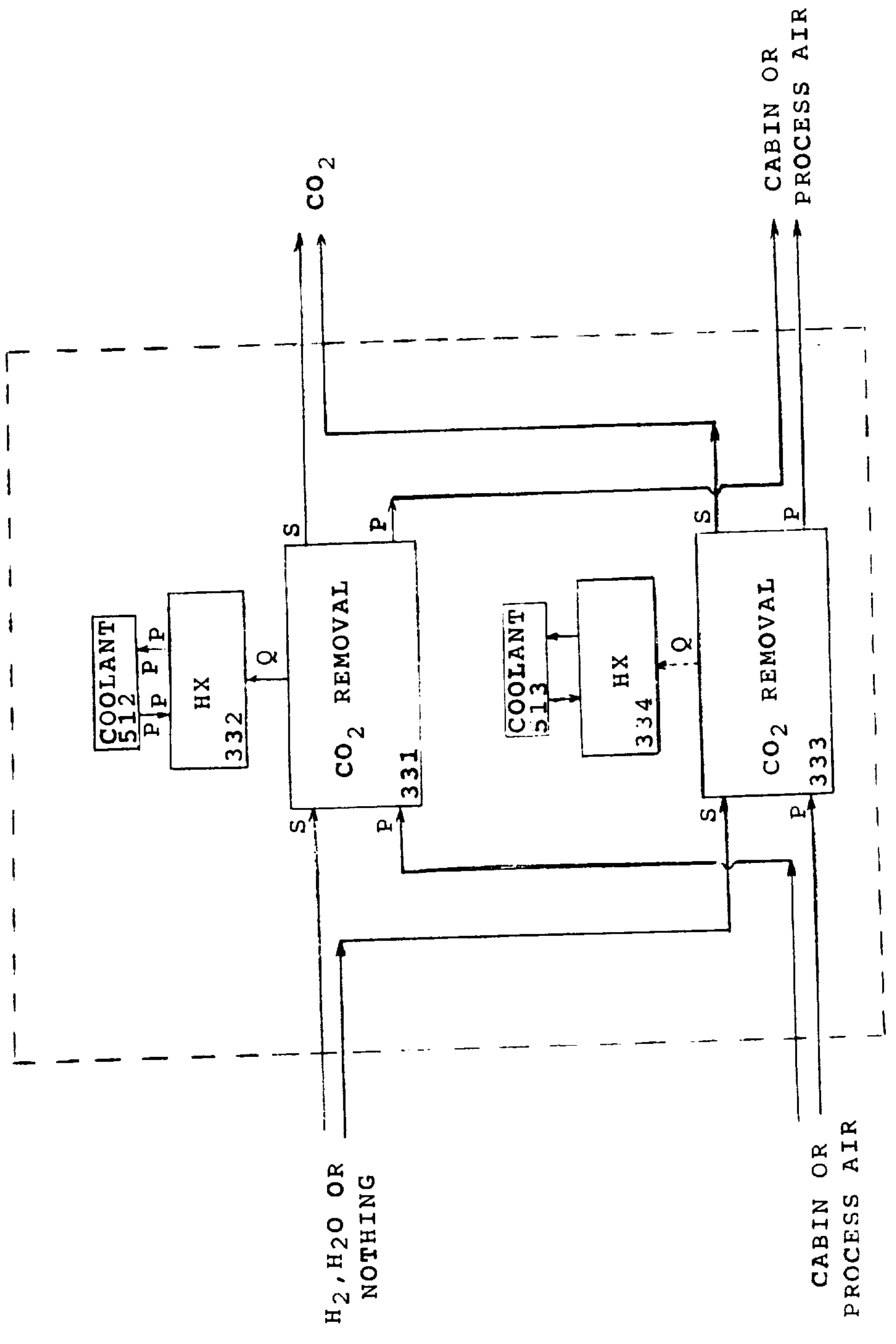


FIGURE C-10
LABORATORY CO_2 REMOVAL UNITS

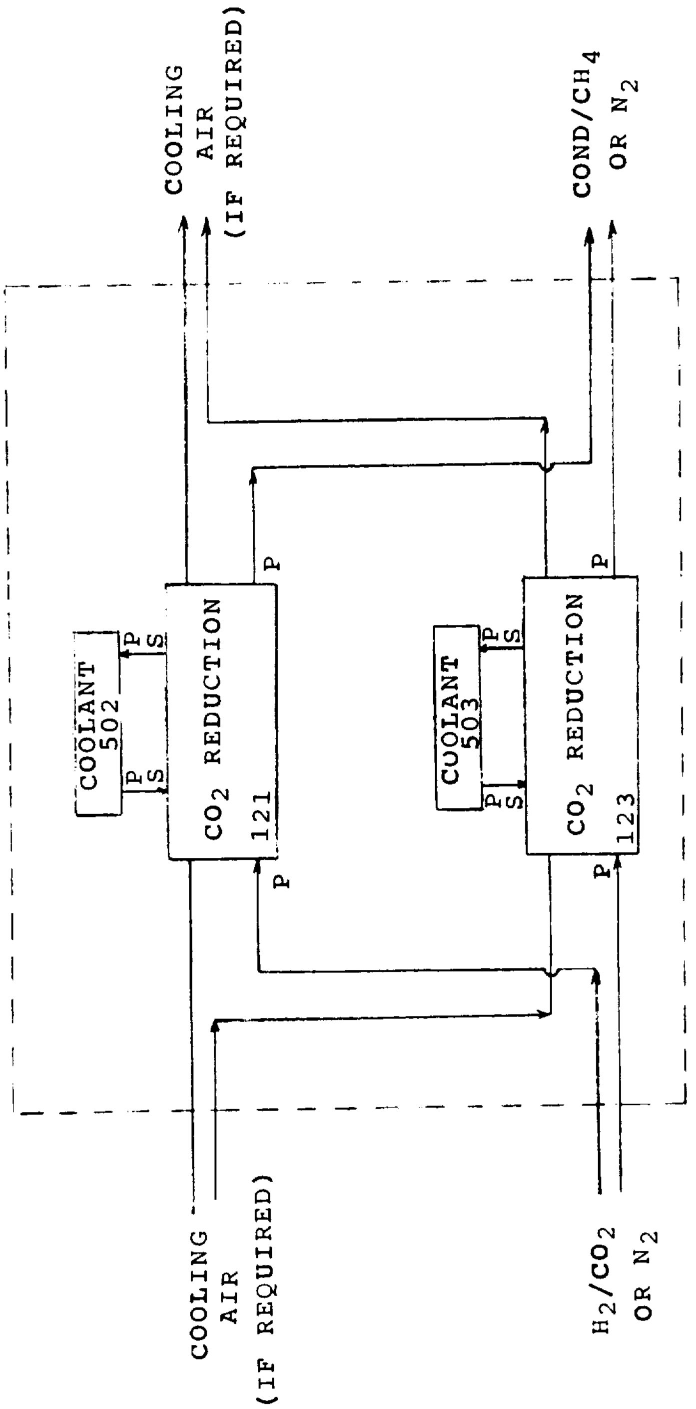


FIGURE C-11
HABITAT CO_2 REDUCTION UNITS

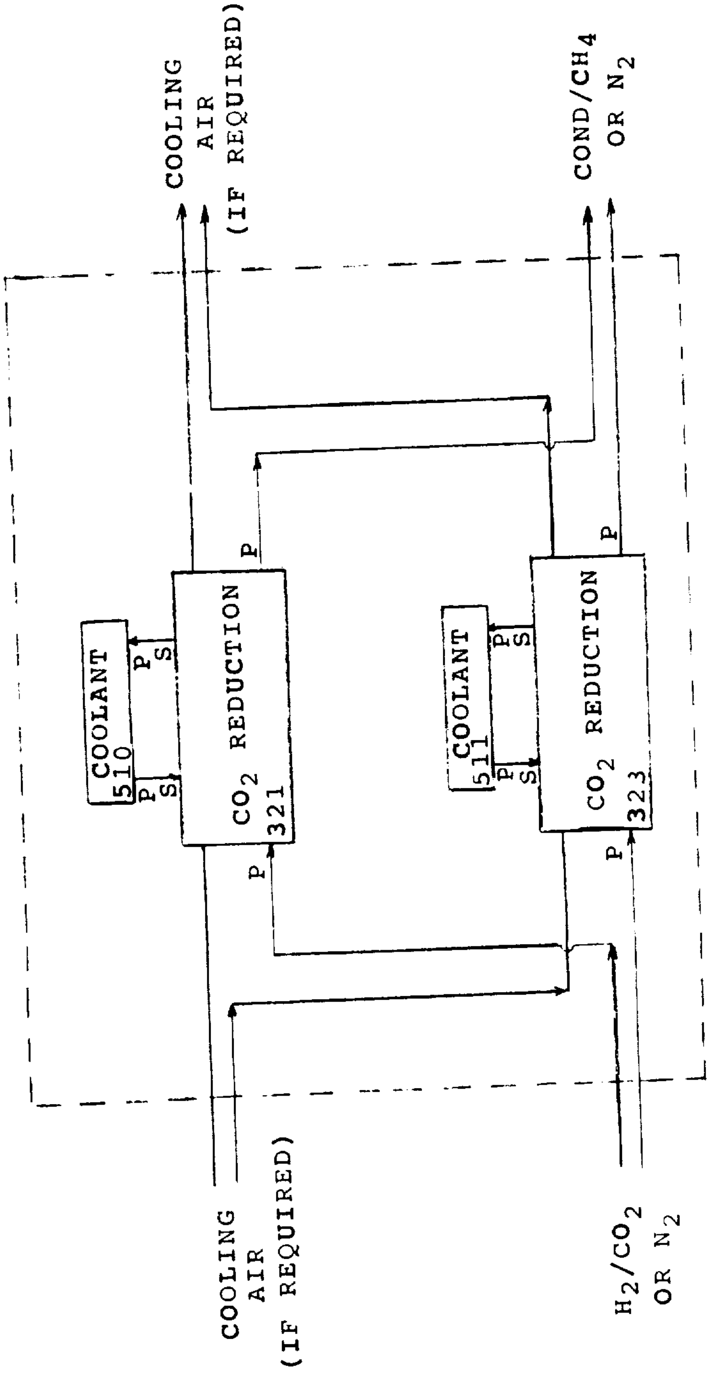


FIGURE C-12
LABORATORY CO_2 REDUCTION UNITS

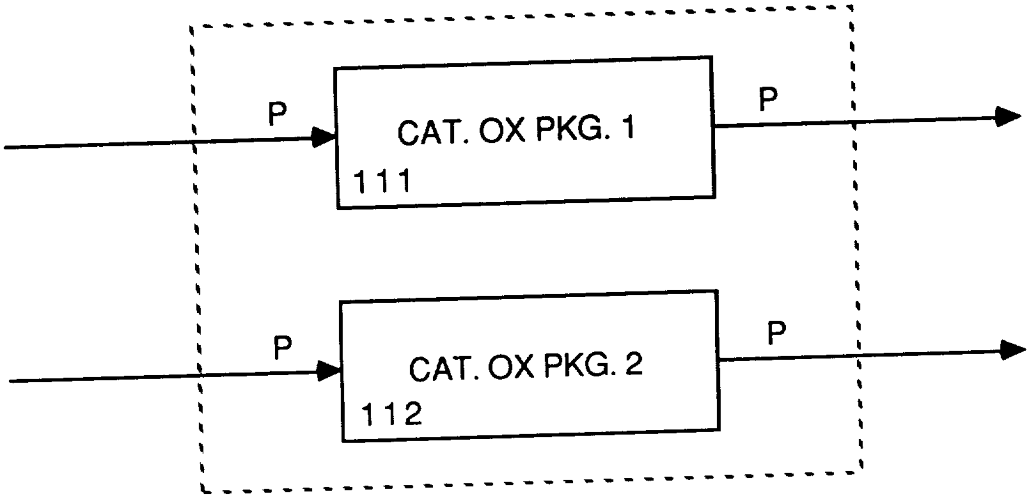


FIGURE C-13
HABITAT CATALYTIC OXYDIZERS

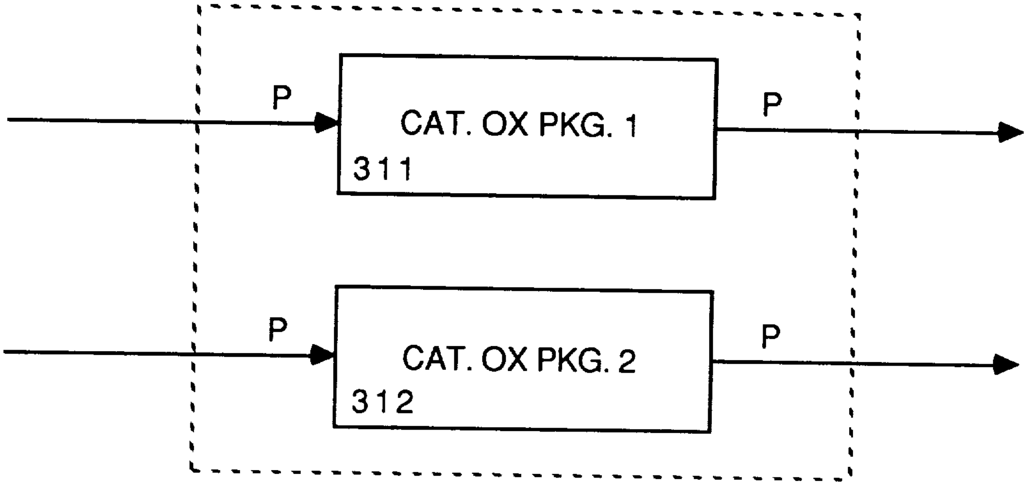


FIGURE C-14
LABORATORY CATALYTIC OXIDIZERS

C.3 Modelling of Components

The following sections discuss the analytical models of the components available in this Space Station model. Some of these have been described elsewhere. The following lists the subsystems and where they have been discussed.

Subsystem	Reference
SPE	Appendix B
Catalytic Oxidizer	Appendix B
Sabatier	Appendix B
EDC	Appendix B

The following subsystems are discussed below:

Molecular Sieve
Bosch
KOH
Plate Fin Heat Exchanger
Control Logic

C.3.1 Molecular Sieve

Molecular Sieve removes carbon dioxide from incoming air. Some constants are:

t_h = half cycle time = 60 minutes
P_{min} = min. pressure of desorbing mole sieve bed = 1.0 psia
T_{MMS} = max. temperature of desorbing mole sieve bed = 360°F
T_{MSG} = max. temperature of desorbing silica gel bed = 180°F
cfm = fan cfm = 23.25
ΔP_{fan} = 11 in H_2O
= fan efficiency = 0.35
= CO_2 removal efficiency = 0.65
ΔH_{SG} = enthalpy change for adsorbing silica gel bed = 1400 Btu/lb H_2O
ΔH_{MS} = enthalpy change for adsorbing mol sieve bed = 1800 Btu/lb CO_2
CFM_c = compressor cfm = 1.05

In order to understand the analytical description, the schematic of the molecular sieve subsystem shown in Figure C-15 should be reviewed.

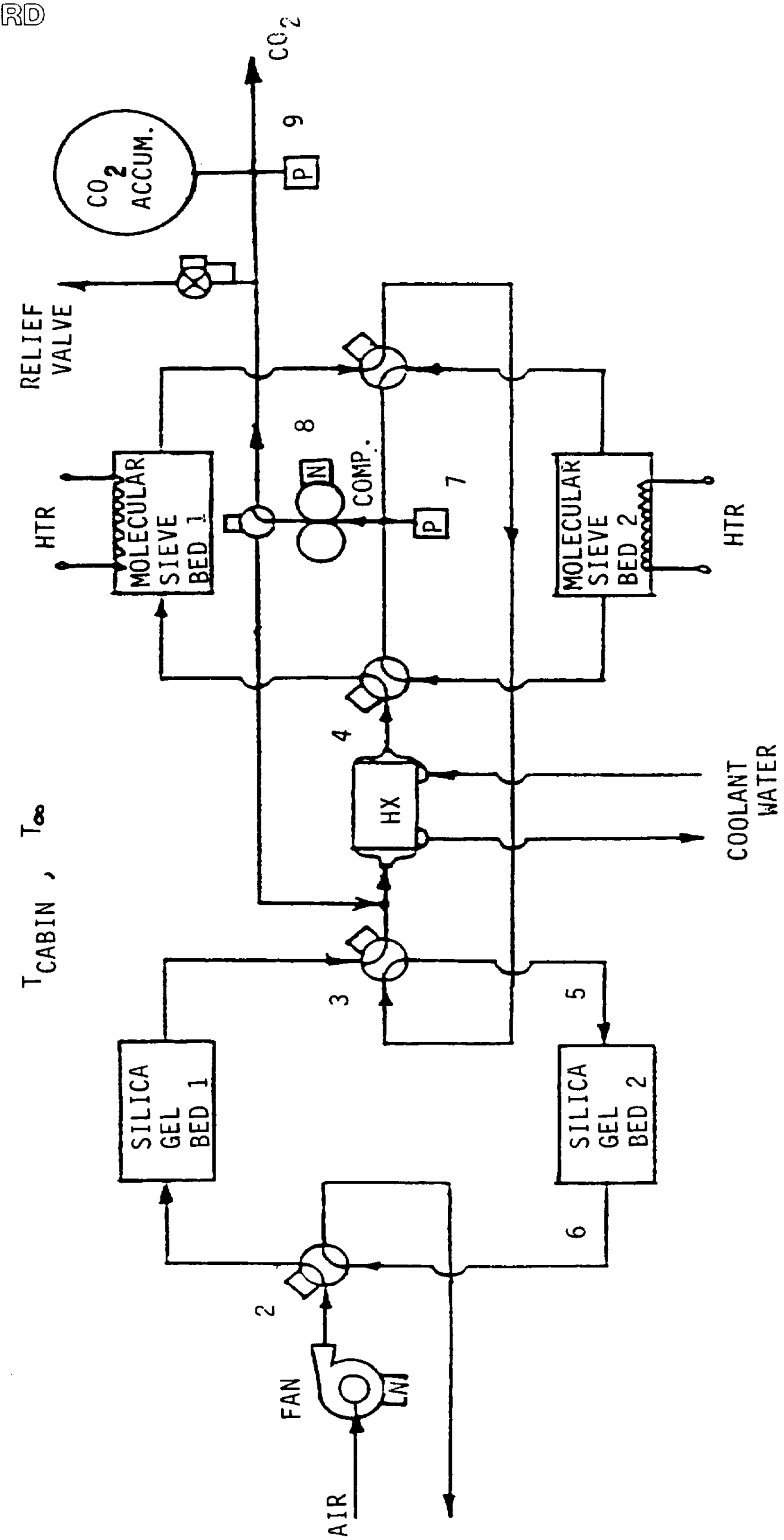


FIGURE C-15
MOLECULAR SIEVE SUBSYSTEM SCHEMATIC

First, the temperture leaving the fan is computed by the following:

$$T_2 = T_1 + \frac{Q_{FAN}}{m_a c_p}$$

where: T_2 = temperatures leaving fan, F

T_1 = temperature entering fan, F

Q_{FAN} = fan power, Btu/lb

$$Q_{FAN} = \frac{cfm\ \Delta P_{FAN}}{8.5\ \eta} \quad 3.413$$

m_a = air inletmass flow to fan, lbm/hr

c_p = specific heat of air, Btu/lbm-F

Next, the temperature of the process air leaving the adsorbing silica gel bed is calculated from the following:

$$T_{3MAX} = T_2 + \frac{\omega \Delta h_{sg}}{c_p}$$

$$m_{sg} = \frac{T_{3MAX} - T_3}{600 - t_h}$$

$$T_3 = T_3 + m_{sg}\ \Delta t$$

where: ω = absolute humidity of air entering molecular sieve

T_{3max} = maximum temperature of air leaving the adsorbing silica gel bed, F

m_{sg} = change of air temperature leving silica gel bed with time, F/sec

Δt = simulation time step, sec

t_h = time into half cycle, sec

After 10 minutes into the half cycle, the temperature of the air leaving the silica gel bed is limited to T_{3max}.

The water removed by the silica gel bed is:

$$M_{H2O} = M_{H2O} + (M_{H2O,in}) \quad \Delta t$$

where: M_{H2O} = mass of water removed by silica gel bed during half cycle, lbm

$M_{H2O,in}$ = flow of vapor and entrained liquid entering system, lbm/hr

Thus the assumption is that all the moisture entering the system is adsorbed onto the silica gel bed. Now, the temperature and mass flow of cool dry air leaving the heat exchanger is:

$$T_4 = T_{cool} + 5^{o}F$$

where: T_{cool} = temperature of coolant water entering HX, F

T_4 = temperature of air leaving HX, F

The heat transferred by the heat exchanger to the water is:

$$Q_{HX} = m_d \, c_p \, (T_3 - T_4)$$

where: m_d = mass flow of dry air which entered molecular sieve subsystem, lbm/hr

The air flows next to the CO_2 adsorbing molecular sieve bed. The temperature of the air leaving that bed is given by the following calculations:

$$m_{CO2,a} = m_{CO2,i} \; \varepsilon_{CO2}$$

$$M_{CO2,a} = M_{CO2,a} + m_{CO2,A} \; \Delta t$$

$$P_{CO2,e} = P_{CO2,i} \, (1 - \varepsilon_{CO2})$$

$$m_{CO2,e} = m_{CO2,i} \, (1 - \varepsilon_{CO2})$$

$$T_{5,MIN} = T_4 + \frac{M_{CO2,a} \, \Delta h_{ms}}{m_d \, c_p}$$

$$m_{ms} = \frac{T_{5,min} - T_5}{1800 - t_h}$$

$$T_5 = T_5 + m_{ms} \; \Delta t$$

where: $m_{CO2,i}$ = inlet CO2 mass flow into molecular sieve bed, pph

ε_{CO2} = CO_2 removal efficiency of molecular sieve bed

$m_{CO2,a}$ = rate of CO_2 adsorption, lbm/hr

$M_{CO2,a}$ = total mass of CO_2 present on bed, lbm

$P_{CO2,i}$ = partial pressure of CO_2 in inlet air, psia

$P_{CO2,e}$ = partial pressure of CO_2 in molecular sieve exit bed, psia

$m_{CO2,e}$ = exit CO_2 mass flow out of molecular sieve bed, pph

$T_{5,min}$ = minimum temp. exiting molecular sieve bed, F

After 1,800 seconds into the half cycle, the exit temperature cannot be less than $T_{5,min}$.

The process air then flows to the desorbing silica gel bed. The temperature of the bed rises for the first 17 minutes, peaks, then falls for 17 minutes until the temperature reaches a minimum $T_{5,min}$. The equations are:

For the first 17 minutes:

$$M_{sgd} = \frac{T_{MSG} - T_6}{1020 - t_h}$$

$$T_6 = T_6 + M_{sgd} \Delta t$$

where: t_6 = temperature leaving, desorbing silica gel bed, F

M_{sgd} = temperature change with time of airleaving desorbing silica gel bed, F/sec

This temperature T_G cannot exceed T_{msg}.

For the next 17 minutes:

$$M_{sgd} = \frac{T_{5,min} - T_6}{2040 - t_h}$$

$$T_6 = T_6 + M_{sgd} \Delta t$$

For these 17 minutes, the air temperature is limited to a minimum of $T_{5,min}$. From 34 minutes into the half cycle to the end of the half cycle, the temperature exiting the desorbing silica gel bed is set to $T_{5,min}$.

The properties of the air leaving this silica gel bed are:

$$P_{H2O} = P_{SAT}(T_6)$$

$$m_{H2O} = \frac{MW_{H2O}}{MW_d} \quad \frac{P_{H2O}}{P_T - P_{H2O}} \quad m_d$$

$$M_{sgd} = M_{sgd} + m_{HSO} \Delta t$$

where: P_{HSO} = partial pressure of water vapor in air, psia

m_{H2O} = mass flow of water leaving silica gel bed, pph

M_{sgd} = mass of water desorbed from bed this half cycle, lbm

Of course, the mass desorbed is limited to the mass adsorbed from the previous cycle.

The electrical power to the desorbing silica gel bed is given by:

For $t_h < 240$ seconds $\quad W_{htr} = 0$ watts

$t_h \geq 240$ seconds $\quad W_{htr} = 657$ watts

The average heat given up by the desorbing silica gel bed to the cabin is:

$$Q_{sg} = \frac{46}{290} (T_{msg} - T_{cab})$$

where: T_{cab} = cabin air temperature, F

The final calculation is that for the mass of CO_2 desorbed from the molecular sieve bed. The following equations are used for $t_h > 480$ seconds.

$$\upsilon_7 = \frac{R \ (T_4 + 460)}{144 \ P_{min} \ MW_{CO2}}$$

$$M_{CO2,d} = \left[1.01 + 0.01\left(\frac{P_8}{P_{min}}\right)^{0.769}\right] \frac{cfm_c}{\upsilon_7}$$

where: R = Universal gas constant = 1545 ft-lbf/mole R

MW_{CO2} = Molecular weight of CO_2 = 44 lbm/mole

P_{min} = Minimum pressure of desorbing molecular sieve, psia

P_8 = Accumulator pressure, psia

cfm_c = Compressor cfm_c

$m_{CO2,d}$ = Mass flow of CO_2 desorbed, lbm/hr

For $t_h < 480$ seconds, $m_{CO2,d} = 0$.

The total carbon dioxide desorbed during the present half cycle is given by:

$$M_{CO2,d} = M_{CO2,d} + m_{CO2,d} \ \Delta t$$

Of course, the total amount desorbed is limited to the amount of CO_2 that was originally present on the bed.

C.3.2 Bosch

The Bosch is a process that reduces carbon dioxide and hydrogen to carbon and water while giving off heat. The model used here is based on the one described in the G189A Manual [2]. A functional schematic of the process is shown in Figure C-16. The chemical reaction is described by:

$$2H_2 + CO_2 \text{ ----> } C + 2H_2O$$

A listing of the program is provided in the User's Manual Appendices [4].

First the molecular weight of bone dry condenser exit gas and the inlet molar flows of H_2 and CO_2 are computed.

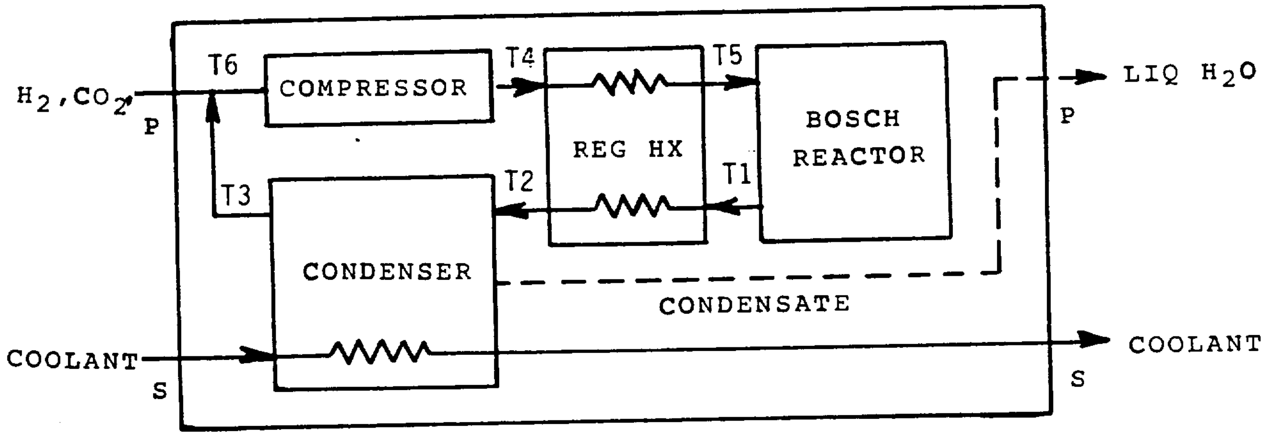


FIGURE C-16
BOSCH PROCESS SUBSYSTEM SCHEMATIC

$n_{H2,i} = m_{H2,i}/2.016$

$n_{CO2,i} = m_{CO2,i}/44.011$

$MW_{BDG} = 16.043\ Y_{CH4} + 44.011\ Y_{CO2} + 2.016\ Y_{H2} + 28.011\ Y_{CO}$

where: $m_{H2,i}$ = Mass flow of H_2 entering Bosch system, pph
$n_{H2,i}$ = molar flow of H_2 entering Bosch system, moles/hr
$m_{CO2,i}$ = mass flow of CO_2 entering Bosch system, pph
$n_{CO2,i}$ = molar flow of CO_2 entering Bosch system, pph
Y_{CH4} = mole fraction of methane in dry cond. exit gas = .235
Y_{CO2} = mole fraction of CO_2 in dry cond. exit gas = .163
Y_{H2} = mole fraction of H_2 in dry cond. exit gas = .327
Y_{CO} = mole fraction of CO in dry cond. exit gas = .275
MW_{BDG} = molecular weight of bone dry cond. exit gas

The amount of carbon processed and water produced for a quasi-equilibrium assumption is given by the following which is based on the reaction formula:

If CO_2 limiting:

$$m_{c,p} = m_{CO2,i} * MW_c$$
$$m_{H2O,p} = 2\ m_{CO2,i} * MW_{H2O} + m_{H2O,i}$$

If H_2 limiting:

$$m_{c,p} = m_{H2,i}\ MW_c/2$$

$$m_{H2O,p} = m_{H2,i}\ MW_{H2O} + m_{H2O,i}$$

where: MW_c = molecular weight of carbon = 12.011 lbm/mole

MW_{H2O} = molecular weight of water = 18.016 lbm/mole

$M_{H2O,i}$ = mass flow of vapor and entrained liquid entering Bosch system, lbm/hr

$m_{c,p}$ = mass rte of carbon production, lbm/hr

$m_{H2O,p}$ = mass rate of water production, lbm/hr

Therefore, flow out of condenser is:

$$m_3 = m_r - m_{c,p} - m_{H2O,p}$$

where: m_r = recycle flow rate on more specifically the mass flow at the compressor = 6.80 lbm/hr

The temperature at the condenser exit is iterated upon. Its initial value is assumed to be 20°F hotter than the inlet coolant temperture:

$$T_3 = T_{cool} + 20$$

The iteration begins with the calculationof the flow rate of bine dry condenser exit gas

$$m_{BDG} = \frac{m_3}{1 + \frac{MW_{H2O}}{MW_{BDG}} \quad \frac{P_{H2O}}{P_{COND} - P_{H2O}}} \qquad P_{H2O} = P_{sat}\,(T_3)$$

where: P_{H2O} = partial pressure of vapor leaving condenser, psia

P_{COND} = total pressure of recycle gas in condenser = 16.9 psia

m_{BDG} = mass flow of bone dry gas leaving condenser, pph

Accordingly, the flows out of the condenser and compressor are:

$$n_{BDG} = \frac{m_{BDG}}{MW_{BDG}}$$

$$m_{H2O,\ 3} = \frac{P_{H2O}}{P_{cond}} \; n_{BDG} \; MW_{H2O}$$

$$m_{H2O,\ 4} = m_{H2O,\ 3} + m_{H2O,\ 2}$$

$$m_{H2,\ 3} = n_{BDG} \, Y_{H2} \, MW_{H2}$$

$$m_{H2,\ 4} = m_{H2,\ 3} + m_{H2,\ 4}$$

$$m_{CO2,\ 3} = m_{BDG} \, Y_{CO2}$$

$$m_{CO2,\ 4} = m_{CO2,\ 3} + m_{CO2,\ 4}$$

$$m_{CH4,\ 3} = n_{BDG} \, Y_{CH4} \; MW_{CH4}$$

$$m_{CH4,\ 4} = m_{CH4,\ 3}$$

$$m_{CO,\ 3} = n_{BDG} \, Y_{CO} \; MN_{CO}$$

$$m_{CO,\ 4} = m_{CO,\ 3}$$

The properties of the flow exiting the compressor are:

$$Cp_4 = (3.42\ m_{H2,4} + 0.21\ m_{CO2,4} + 0.55\ m_{CH4,4} + 0.25\ m_{CO,4} + 0.49\ m_{H2O,4} + 0.22\ m_{O2} + 0.299\ m_{N2})\ /\ m_r$$

$$MW_4 = m_r\ /\ (m_{H2,4}/2.016 + m_{CO2,4}/44.011 + m_{CH4,4}/16.043 + m_{CO,4}/28.011 + m_{H2O,4}/18.06 + m_{O2}/32 + m_{N2}/28.088)$$

$$\gamma_4 = \frac{Cp_4}{Cp_4 - \dfrac{1{,}987}{MW_4}}$$

where:

Cp_4 = Specific heat of gas at compressor exit, BTU/lbm-F

MW_4 = Molecular weight of gat at compressive exit, lbm/mole

γ_4 = Ratio of constant pressure to constant volume specific heats

m_{O2} = Mass flow of oxygen in recycle gas = 0.0 lbm/hr

m_{N2} = Mass flow of nitrogen in recycle gas = 0.0 lbm/hr

The mixed temperature of inlet gases and the recycle gases exiting condenser is given by:

$$T_6 = [(m_{BDG}\ 1\ Cp_{BDG} + 0.49\ m_{H2O,3})\ T_3 + 0.21\ m_{CO2,i} + 3.42\ m_{H2,i} + 0.49\ m_{H2O,iv} + 1.0\ m_{H2O,ie}]\ /\ (m_r\ Cp_4)$$

$$Cp_{BDG} = [3.42\ m_{H2,3} + 0.21\ m_{CO2,3} + 0.55\ m_{CH4,3} + 0.25\ m_{CO,3} + 0.22\ m_{O2,} + 0.299\ m_{N2})/m_{BDG}$$

where:

T_6 = Mixed temperature of gases entering, compressor, F

$m_{H2O,\ iv}$ = Mass flow of vapor entering system, pph

$m_{H2O,\ ie}$ = Mass flow of entrained liquid entering system, pph

Cp_{BDG} = Specific heat of dry gas exiting condenser, Btu/lbm-F

The energy required to raise the pressure of the recycle flow gases across the compressor is given by:

$$Q_c = \frac{m_r\ R\ (T_G + 460)\ \gamma_4 \left[\left(\frac{P_r}{P_{cond}} \right)^{\frac{\gamma_4 - 1}{\gamma_4}} - 1 \right]}{778\ MW_4\ (\gamma_4 - 1)\ \eta_a}$$

where: R = Universal gas constant = 1545 ft-lbf/mole-R

P_r = Reactor pressure = 24.3 psia

η_a = Aerodynamic efficiency of compressor = 1.0

Q_c = Compressor energy into recycle gas, Btu/hr

The total power consumed by the compressor is given by:

$$W_c = \frac{Q_c}{\varepsilon_c \; 3.41}$$

where: W_c = Power to run compressor, watts

ε_c = Motor efficiency of compressor

Therefore, the heat lost to the ambient is:

$$Q_a = 3.41 \; W_c - Q_c$$

The heat of reaction in the reactor is:

$$Q_r = 973 \times m_{CO2,i}$$

Essentially, it is assumed that the input gases are stoichiometric in ratio which then causes the mole fractions of the gases to remain constant in the recycle loop. The temperature out of the compressor is:

$$T_4 = T_6 + \frac{Q_c}{m_r \; C_{P_4}}$$

The temperature out of the reactor is:

$$T_1 = T_r - \frac{Q_{LR}}{m_r \, C_{P4}}$$

where: Q_{LR} = Heat loss from reactor = 0.0 Btu/hr

The temperature into the condenser is:

$$T_2 = T_1 - \varepsilon_{HX} \, (T_1 - T_4)$$

where: ε_{HX} = Heat exchanger efficiency = 0.85

Finally, the temperature of the gases leaving the condenser is:

$$T_3 = T_2 - \varepsilon_c \, (T_2 - T_{cool})$$

where: ε_c = Condenser efficiency = 0.90

This T_3 is compared with the original gressed T_3. If they agree within 0.3 F, the iteration is complete; otherwise, this T_3 is tried as the next gress.

C.3.3 Static Feed Water Vapor Electrolysis (KOH)

The Static Feed Water Vapor Electrolysis subsystem uses KOH as the medium for electrolysis to produce oxygen. This model is based on the ELCELL subroutine in G189A [2]. The following assumptions are used:

(1) The unit is isothermal within the cells.

(2) Product gas streams exit at the prevailing cell temperature.

(3) The cell Faradaic efficiency is 100%; the cells are voltage inefficient only.

(4) All cells are connected in series, i.e., the same input current passes through each cell.

(5) The thermoneutral voltage is 1.48 volts; the voltage efficiency is equal to the thermoneutral voltage divided by the actual voltage.

The gas production is calculated as follows:

$$J = I/A$$

$$m_{H2O,e} = N_C \; I/1350$$

$$m_{H2,p} = M_{H2O,e}/ \; MW_{H2O}$$

$$n_{O2,p} = n_{H2,p}/2$$

where: I = Input current to cells, amps

A = Area of one cell, ft^2

N_c = Number of cells

$m_{H2O, e}$ = Mass flow of O2 consumed by electrolysis lbm/hr

J = Cell current density, amps/ft^2

$n_{H2, p}$ = Molar flow of hydrogen produced, moles/hr

$n_{O2, p}$ = Molar flow of oxygen produced, moles/hr

The details of the analytical method are described fully in the G189A manual for the subroutine ELCELL. However, the calculation of the energy required for electrolysis is computed according to the following equations and tables:

First, the cell voltage at 150 amps/sq. ft. current density for any cell temperature is determined by interpolation of the following table:

T_c (F)	V_o (Volts)
110	1.660
120	1.620
130	1.575
140	1.550
150	1.530
160	1.500
170	1.475
180	1.465
190	1.450

For cell temperatures less than 110 F, the voltage is set to 1.70 volts.

Next, the effect of a current density different from 150 amps/sq. ft. is found by interpolating the following table:

J (amps/ft)	Delta V/Delta J (Volts/ASF)
0	0.01460
100	0.00060
200	0.00055
300	0.00050
400	0.00050
500	0.00045
600	0.00045

Then the following is used to calculate the cell voltage:

$$V_C = V_O + \frac{V}{J} (J-150)$$

The cell efficiency is:

$$\eta = \frac{1.48}{V_C} 100$$

and is limited to a peak value of 99%.

Lastly, the energy required for electrolysis is given by:

$$Q = N_C I V_C 3.413$$

C.3.4 Plate Fin Condensing Heat Exchanger

This subroutine models the performance for a plate fin condensing heat exchanger. Basically, the program iterates on the condenser

C.3.4 Plate Fin Condensing Heat Exchanger (Continued)

outlet temperature until the outlet temperature does not change from iteration to iteration.

First, the inlet dew point is calculated:

$$\omega_i = \frac{m_{v,i}}{m_{o,i}}$$

$$P_{v,i} = \frac{\omega_i P_{t,i}}{\omega_i + 0.622}$$

$$T_{dp,i} = T_{sat} (P_{v,i})$$

where: $m_{v,i}$ = Mass flow of inlet vapor, pph

$m_{da,i}$ = Mass flow of dry air, pph

ω_i = Inlet absolute humidity

$P_{T,i}$ = Inlet air total pressure, psia

P_{vi} = Inlet air partial pressure of water, psia

The initial guess at the exit temperature is one quarter of the way from the coolant inlet temperature to the air inlet temperature:

$$T_{a,e} = T_{c,i} + 1/4 (T_{c,i} + T_{a,i})$$

From the exit temperature, the outlet absolute humidity and vapor pressure are calculated:

$$P_{v,e} = P_{sat}\,(T_{a,e})$$

$$\omega_e = 0.622\ \frac{P_{v,e}}{P_T - P_{v,e}}$$

The heat loads are then:

$$Q_L = M_{da,i}\,(\omega_i - \omega_e)\,h_{fg}$$

$$Q_s = m_{a,i}\,C_{p,a}\,(T_{a,i} - T_{a,e})$$

$$Q_t = Q_s + Q_L$$

where:
h_{fg} = Heat of vaporization, Btu/lbm
Q_L = Latent heat, Btu/hr
Q_s = Sensible heat, Btu/hr
Q_t = Total heat loss, Btu/hr
$m_{a,i}$ = Total mass flow of air into Hx, lbm/hr

The coolant exit temperature is:

$$T_{c,e} = T_{c,i} + \frac{Q_t}{m_c\,C_{p,c}}$$

where:
m_c = Coolant flow, pph
$c_{p,c}$ = Specific heat of water, Btu/lbm-F

From here, various properties of the air and coolant are calculated as a function of the average temperature. The properties and nondimensional numbers calculated are:

μ = Viscocity
K = Thermal conductivity
P_r = Prandtl number
R_e = Reynolds number
C_{ol} = Colburn factor
C_{mod} = Modified Colburn factor

The conditions are shown in the listing presented in the User's Manual [4]. Also shown there are various geometric dimensions such as fin height.

The film coefficient is chosen as the maximum of the following two equations:

$$h = 3.65\ K/D_h$$

$$h = C_{mod}\ C_p\ G\ P_r^{-.6667}$$

Overall fin efficiency is then computed from the following fin equations:

$$m = \sqrt{\frac{2h}{KW}}$$

C-2

where: h = Film coefficient

k = Thermal conductivity of fin

W = Fin thickness

L = Fin length

$$k = \frac{\tanh mL}{mL}$$

$$\eta = 1 - \frac{A_f}{A}(1-k)$$

where: A_f = Surface area of fins only, ft^2

A = Total exposed surface area, including the fins and the unfinned primary surface, ft^2

k = Fin effectiveness

η = Total surface temperature effectiveness or overall fin efficiency

The effective UA becomes:

$$UA = \eta hA$$

The total effective dry UA is calculated as:

$$UA_{dry} = \frac{1}{\frac{1}{UA_c} + \frac{1}{UA_a}}$$

where: UA_c = Cold side effective UA, Btu/hr-F

UA_a = Hot or air side effective UA, Btu/hr-F

The pinch point temperatures for the air side and coolant side are given by:

$$T_{pp,a} = \frac{\left(\frac{UA_a}{UA_c} T_{dp,i} + T_{dp,i} - T_{c,e}\right) C_{p,c}\, m_c + m_{a,i}\, C_{p,a}\, T_{a,i}}{m_{a,i}\, C_{p,a} + m_c\, C_{p,c}\, \frac{UA_a}{UA_c}}$$

The pinch point temperatures for the air and the coolant are those which occur at the location where the wall temperature equals the inlet dew point temperature:

$$T_{pp,c} = T_{dp,i} - \frac{UA_a}{UA_c} (T_{pp,a} - T_{dp,i})$$

These above equations can be derived from the simultaneous solution of the following two energy balances:

$$UA_a (T_{pp,a} - T_{dp,i}) = UA_c (T_{dp,i} - T_{pp,c})$$

$$m_{a,i}\, C_{p,a} (T_{pp,a} - T_{a,i}) = M_c\, C_{p,c} (T_{pp,c} - T_{c,e})$$

The wet side and dry side log mean temperature differances are:

$$T_{w,lm} = \frac{(T_{a,e} - T_{c,i}) - (T_{pp,a} - T_{pp,c})}{\ln\left(\frac{T_{a,e} - T_{c,i}}{T_{pp,a} - T_{pp,c}}\right)}$$

$$T_{d,lm} = \frac{(T_{ppa,} - T_{pp,c}) - (T_{a,i} - T_{c,e})}{\ln\left(\frac{T_{pp,a} - T_{pp,c}}{T_{a,i} - T_{c,e}}\right)}$$

Now, the wet and dry section dry UA's are:

$$UA_{d,ws} = \frac{\frac{m_c\,(T_{pp,c} - T_{c,i})}{T_{w,lm}}\,\frac{UA_c}{UA_h} + \frac{Q_t}{Q_s}}{\frac{Q_t}{Q_s}\,\frac{UA_c}{UA_h} + 1}$$

$$UA_{d,ds} = \frac{m_c\,(T_{c,e} - T_{pp,c})}{T_{d,lm}}$$

The total effective dry UA is:

$$UA_{d,tot} = UA_{d,ws} + UA_{d,ds}$$

The air exit temperature is iterated upon until:

$$UA_{d,tot} = UA_{dry}$$

C.3.5 Control

The control of the Space Station model is done in subroutine GPOLY1. The following paragraphs describe the control laws used to control:

(a) Oxygen partial pressure

(b) Total cabin pressure

(c) Oxygen accumulator pressure

(d) Temperature control

(e) CO2 accumulator exit flow control

(f) H2-CO2 mix to CO2 reduction unit

Oxygen partial pressure is controlled by using the same technique as described in the original ESCM Model Description Document [1]. The controller maintains oxygen partial pressure between 3.09 and 3.23 psia.

Total cabin pressure is maintained by the addition of nitrogen. The controller admits nitrogen to bring the pressure up to 14.813 psia only after the oxygen pressure is above 3.09 psia. The original Model Description Document [1] should be seen for more detail.

The oxygen accumulator pressure is maintained by addition of oxygen from the oxygen generators as oxygen is drawn from the accumulators to maintain cabin O_2 partial pressure. The current to the oxygen generators is regulated to each of the generators according to the following law:

For $P_{O2} \geq 1050$ $\quad I = 0.9\ I_{nom}$

For $P_{O2} \leq 950$ $\quad I = 1.1\ I_{nom}$

For 950 $P_{O2} < 1050$ $\quad I = I_{nom}$

As the current is increased, the oxygen generation by the electrolysis unit increases.

For temperature control, the bypass flow around the condensing heat exchanger is regulated. A proportional plus integral scheme is used:

$$R = 0.05\ E + \int 0.0001\ E\ dt$$

where: R = Fraction of flow to bypass Hx.

E = Temperature error = $T_{set} - T_{act}$

As more flow bypasses the Hx, the mixed flow after the Hx is hotter.

Carbon dioxide removed from the air is sent to an accumulator. Each CO2 removal unit has its own accumulator in a nonbussed system. The flow out of the accumulator is regulated to maintain pressure in the accumulator above 21 psia. Essentially, the average CO2 removal rate during the past molecular sieve cycle is used as the flow out of the accumulator for the present cycle.

Lastly, the H2-CO2 mixture into the CO2 Reduction unit is regulated to be stoichiometric by venting excess hydrogen after being produced by the oxygen generators. The required H2 flow and the amount to be vented is given by:

$$m_{H2} = 2\, m_{CO2} \frac{MW_{H2}}{MW_{CO2}}$$

$$R = m_i - \frac{m_i - m_{H2}}{m_i}$$

where: m_{CO2} = Flow of CO2 to reduction, pph

m_{H2} = Stoichiometric flow of H2 to reduction, pph

m_i = Inlet flow to splitter, pph

R = Fraction of H2 inlet flow to be vented

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16. Abstract

A Model Description Document for the Emulation Simulation Computer Model was published previously. The model consisted of a detailed model (emulation) of a SAWD CO_2 removal subsystem which operated with much less detailed (simulation) models of a cabin, crew, and condensing and sensible heat exchangers. The purpose was to explore the utility of such an emulation/simulation combination in the design, development, and test of a piece of ARS hardware - SAWD.

Extensions to this original effort are presented in the manual. The first extension is an update of the model to reflect changes in the SAWD control logic which resulted from test. In addition, slight changes were also made to the SAWD model to permit restarting and to improve the iteration technique. The second extension is the development of simulation models for more pieces of air and water processing equipment. Models are presented for: EDC, Molecular Sieve, Bosch, Sabatier, a new condensing heat exchanger, SPE, SFWES, Catalytic Oxidizer, and multifiltration. The third extension is to create two system simulations using these models. The first system presented consists of one air and one water processing system. The second system consists of a potential Space Station air revitalization system complete with a habitat, laboratory, four modes, and two crews.

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