p. 5

AUTOMATION OF CLOSED ENVIRONMENTS IN SPACE FOR HUMAN COMFORT AND SAFETY

KANSAS STATE UNIVERSITY

N91-18137

INTRODUCTION

Project Description

The Environmental Control and Life Support System (ECLSS) for the Space Station *Freedom* and future colonization of the Moon and Mars presents new challenges for present technologies. Current plans call for a crew of 8 to live in a safe, shirt-sleeve environment for 90 days without ground support. Because of these requirements, all life support systems must be self-sufficient and reliable.

The ECLSS is composed of six subsystems. The temperature and humidity control (THC) subsystem maintains the cabin temperature and humidity at a comfortable level. The atmosphere control and supply (ACS) subsystem insures proper cabin pressure and partial pressures of oxygen and nitrogen. To protect the space station from fire damage, the fire detection and suppression (FDS) subsystem provides fire sensing alarms and extinguishers. The waste management (WM) subsystem compacts solid wastes for return to Earth, and collects urine for water recovery.

Because it is impractical, if not impossible, to supply the station with enough fresh air and water for the duration of the space station's extended mission, these elements are recycled. The atmosphere revitalization (AR) subsystem removes CO_2 and other dangerous contaminants from the air. The water recovery and management (WRM) subsystem collects and filters condensate from the cabin to replenish potable water supplies, and processes urine and other waste waters to replenish hygiene water supplies.

These subsystems are not fully automated at this time. Furthermore, the control of these subsystems is not presently integrated; they are largely independent of one another. A fully integrated and automated ECLSS would increase astronauts' productivity and contribute to their safety and comfort.

THREE-PHASE DESIGN PLAN

The Kansas State University Advanced Design Team is in the process of researching and designing controls for the automation of the ECLSS for Space Station *Freedom* and beyond. The approach chosen to solve this problem is to divide the design into three phases.

The first phase is to research the ECLSS as a whole system and then concentrate efforts on the automation of a single subsystem. The AR subsystem was chosen for our focus.

During the second phase, the system control process will then be applied to the AR subsystem. To aid in the development of automatic controls for each subsystem and the overall ECLSS, mathematical models are used for system simulation on a computer. Once the simulation has been completed, various methods of control can be tested. Using the AR subsystem control system as a "proof of concept," the other ECLSS subsystems will be automated.

Finally, during phase three, the six subsystem control systems will be combined to form a control system for ECLSS. The control system will perform routine control duties as well as provide fault diagnosis and isolation.

The Kansas State University Design Team has completed phase one and is currently in the midst of phase two. Mathematical models have been developed and numerous AR subassembly components have been simulated on a computer. Phase two development will continue through the next two semesters. Phase three will be initiated upon the completion of the second phase.

This paper describes a portion of the work done at Kansas State University during the 1989/90 academic school year. First, the components of the AR system are discussed. Then the paper focuses on the four-bed molecular sieve, which is described in detail along with a proposed control scheme. The mathematical models of the AR components developed by the group are not discussed in this paper, but can be found in the complete report. Similar work was done for the other components of the AR subsystem. That work also is discussed in the complete report.

DESIGN TEAM DESCRIPTION

The Kansas State University Advanced Design Team is composed of engineering students from several disciplines, a student from general science and education, a graduate student assistant, and engineering faculty members. Chemical, electrical, industrial, and mechanical engineering disciplines are represented by both students and faculty.

To complete the first semester's work, the design team appointed three lead engineers to work with the faculty and teaching assistant to organize and direct the activities of the group. Initial breakdown of the group assigned two or three students to each ECLSS subsystem to collect information. Once this preliminary investigation had taken place, the AR subsystem was selected for further study.

During the second semester, the design team was organized into three groups to study the AR subsystem in detail. One group focused on mathematical models, another group studied control strategies, while the third concentrated on physical operations.

PAGE 98 INTENTIONALLY BLANK

PRECEDING PAGE BLANK NOT FILMED

ATMOSPHERE REVITALIZATION CARBON DIOXIDE REMOVAL

Figure 1 is a diagram of the AR subsystem. The subsystem's purpose is to produce oxygen for respiration. The AR subsystem removes water vapor, CO_2, and trace contaminants from the cabin atmosphere. It produces oxygen and potable water. The subsystem is composed of four parts, the CO_2 removal system, the CO_2 reduction system (CRS), the oxygen generation assembly (OGA), and the trace contaminant control system (TCCS). Only the CO_2 removal system is discussed here.

Metabolic CO_2 is removed from the cabin atmosphere by a four-bed molecular sieve. The sieve consists of two desiccant beds to remove water vapor from the incoming air, two CO_2 adsorption beds, a blower to force the air through the system, a CO_2 pump, a CO_2 accumulator, a precooler, and five multiple-flow selector valves.

Figure 2 is a diagram of the four-bed molecular sieve. During a typical adsorption cycle, air enters the four-bed molecular sieve from the temperature and humidity control (THC) subsystem (1). After passing through a directional control valve (2), the air enters the desiccant bed (3). Dry air leaves the desiccant bed and passes through another directional control valve (4) before passing through the blower (5). The air, which has been warmed by the desiccant bed and blower, then passes through a precooler (6). After leaving the precooler and passing through a third directional control valve (7), the air enters an adsorbent bed (8). The CO_2 adsorbent bed, which was heated to release CO_2 earlier, now cools as it adsorbs CO_2. Air leaves the adsorbent bed, passes through a check valve (9), then enters the second desiccant bed (10). This warm dry air evaporates water accumulated in the desiccant bed during its adsorption cycle. This humid, cool air passes through a final directional control valve (11) before returning to the THC subsystem (12).

While one bed is adsorbing CO_2 (8), the other bed (14) is desorbing CO_2. The desorbing begins with an initial pumpdown of the bed to draw off residual air. A check valve (13) prevents pumping air through the desiccant bed during the desorption cycle. The CO_2 pump (16) pumps air through a valve (15) and back to the THC subsystem through a directional control valve (17). After the initial pumpdown, the pump is shut off while heat is steadily applied to the CO_2 sorption bed by electric heaters. After the bed is sufficiently heated, the pump is restarted. Now the directional valve (17) is set to send CO_2 to the pressurized, fixed-volume accumulator (18).

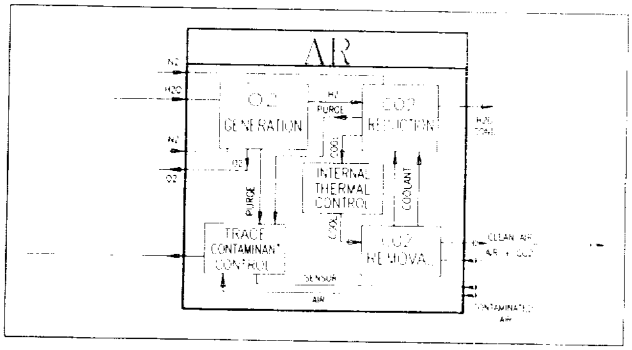

Fig. 1. Atmosphere Revitalization Block Diagram

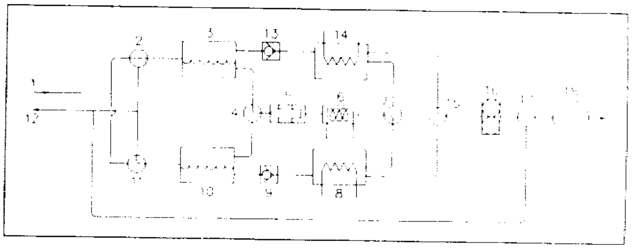

Fig. 2. Four-Bed Molecular Sieve

After the desorption cycle is complete, the valves switch positions and the CO_2-free desorbing bed becomes the adsorbing bed, and the CO_2-filled adsorbing bed becomes the desorbing bed. Likewise, the now water-filled adsorbing desiccant bed becomes the desorbing bed, and the drier desorbing bed becomes the adsorbing desiccant bed.

Desiccant Bed

Each desiccant bed is filled with a water-adsorbent material. The adsorbent materials used in these beds are zeolite 13X and silica gel. Silica gel and zeolite 13X are placed in separate layers and the incoming air stream passes over both layers. These two layers are necessary because the silica gel adsorbs water vapor well at high relative humidities, but its efficiency decreases for relative humidities of less than 50%. Zeolite 13X, however, is more efficient for relative humidities of 35% or less. In tests performed by NASA, the combination of these two layers removed nearly 100% of the water vapor in the incoming stream. As a result of this water removal, the temperature of the air stream increases. These adsorbents readily desorb water when the warm air stream from the CO_2 beds pass over them.

Blower

The blower is a motor-driven centrifugal fan. The motor is designed to operate with 115/220-V AC, three-phase, 400-Hz power. Deswirl vanes help convert swirl energy into useful static pressure. The blower is made of corrosion-resistant material with bearings designed to isolate grease from working air.

Precooler

The precooler is a double-pass coolant and single-pass process-air-flow heat exchanger that is made of stainless steel.

**ORIGINAL PAGE IS
OF POOR QUALITY**

Carbon Dioxide Removal Bed

The CO_2 beds contain heater cores as well as CO_2 adsorbent material. The adsorbent used to remove CO_2 is zeolite 5A. It was chosen because of its high CO_2 capacity, its good kinetic qualities, and its low water poisoning factor. Zeolite 5A can be poisoned by water, therefore it is necessary to use desiccant beds to remove water vapor from the incoming air stream. Since zeolite 5A must be heated to release CO_2, the beds contain heaters.

Carbon Dioxide Pump

The CO_2 pump is an electric-motor-driven rotary vane pump. Except for sealed shaft bearings, the pump is unlubricated to prevent air contamination. The rotor vanes are made of self-lubricating carbon graphite.

Carbon Dioxide Accumulator

The CO_2 accumulator is a composite fiber/metal tank. The tank's initial CO_2 pressure of 90 psia will provide 90 minutes of continuous CO_2 flow for the CO_2 reduction portion of the AR subsystem. If the accumulator ever becomes too full, the excess CO_2 is vented.

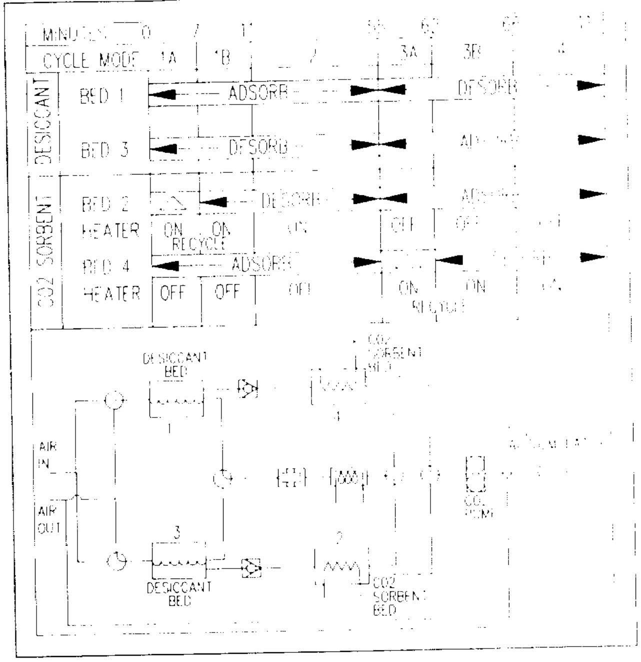

Fig. 3. Four-Bed Operation as a Function of Time

CONCEPTUAL CONTROLS OF FOUR-BED MOLECULAR SIEVE

Introduction

This section details the progress made by the Conceptual Controls Group toward the design of a control system for the four-bed molecular sieve of the ARS.

When formulating the control scheme, astronaut safety was paramount. However, factors such as control system complexity, reliability, cost, system efficiency, and power consumption were also taken into account.

This section contains a description of the current control scheme, the proposed control scheme, and a sensor layout detail. In addition, a comparison is made between the current and proposed control systems.

Current CO_2 Removal Control Scheme

The control scheme that is presently used is a two-cycle process based solely on time. The removal system runs continuously with the role of each pair of desiccant and adsorbent beds performing the opposite function of the other pair in each half cycle. Each half cycle is 55 minutes long. All selector valves and major system components are controlled using electrical signals and specific time increments. It is not known if there are any sensors in place to allow for failure detection. Figure 3 shows the state of each bed in the system vs. time.

During the CO_2 desorbing phase, three primary operations occur. These individual operations are sequenced in time. The first operation is the residual air pumpdown. The desorbing bed is pumped down using the CO_2 pump. Residual air is removed and routed to the cabin via the THC subsystem. Next the CO_2 pump is turned off and the heater in the adsorbent bed is activated. Finally, the CO_2 pump and heater are activated for the remainder of the half cycle and the CO_2 concentrate is channeled into the fixed volume CO_2 accumulator.

Proposed CO_2 Removal Control

This new control system will be based on the current concentration of CO_2 in the cabin. The control will be achieved by using the signals from several CO_2 gas detectors placed throughout the cabin. Using these signals, an average CO_2 concentration will be determined. Each gas sensor will sample the cabin air once every 10 seconds. Once the CO_2 concentration has been obtained, the microprocessor will determine what action is necessary. There are three primary modes of operation: CO_2 maximum removal mode, power efficiency mode, and off mode.

CO_2 removal mode. When the concentration of cabin CO_2 exceeds the high level (Table 1), the computer will direct the removal system into the CO_2 maximum removal mode. This mode uses a fixed half-cycle time increment similar to the current control system. However, this cycle-time will be derived with the idea of removing CO_2 from the cabin at the fastest rate possible. Because the ability of the desiccant bed system to remove CO_2 over time is an exponentially decaying function, it would be best to have a short cycle time and switch the functions of the pairs of beds as rapidly as possible.

This time interval will be obtained using our math modeling techniques, and information about switching lags and set-up times. In particular, the CO_2 adsorbent bed cool-down time as it relates to efficiency, will be important. The goal will be to remove the greatest amount of CO_2 per unit time.

This mode would be used when large amounts of CO_2 are present in the cabin, for example, during emergency situations of increased astronaut numbers.

Table 1. CO_2 Operating Modes

Level	Mode	CO_2 Concentration (ppm)*
Hi	CO_2 Removal	> 1000
Lo	Power Efficiency	$300 < x < 1000$
Off		< 300

* Concentration levels were formulated using standard threshold limit values and information from Dr. Stephan Konz, Kansas State University.

Power efficiency mode. When the level of cabin CO_2 is between the Hi and Lo levels indicated in Table 1, the power efficiency mode would be activated. This mode uses a fixed half-cycle time that allows for adequate CO_2 removal, but minimizes the amount of electrical power used per unit of CO_2 removed. This time interval will be determined in a fashion similar to the manner in which the time internal for the CO_2 removal mode was found.

This mode will be useful when electrical power is limited on the station, for example, when a solar panel is damaged or a power shortage occurs.

Off mode. During this operation the removal system will not be operating. This would allow astronauts to make repairs on the system.

System Monitoring Scheme

Below is a list of all the major system components in the CO_2 removal subsystem. A sensor is described for each component. This monitoring scheme will allow the system to be controlled, as outlined above, and also allow component failures to be detected. For each component, the output of the sensor(s) will be compared with a desired output and an error signal will be generated. The monitoring microprocessor, using an artificial intelligence program, will determine if a component failure has occurred. In the event of failure, the astronauts would be alerted via a computer terminal. Figure 4 is a pictorial of the system monitoring scheme.

Cabin. CO_2 gas sensors will be placed throughout the cabin to obtain an average CO_2 gas concentration. Using this information the microprocessor will select the appropriate operating mode for the CO_2 removal system.

Air selector valves. These valves have end-of-position switches that can be used to determine if they have been completely switched into a valid position. This also allows the current position of the valve to be known.

Desiccant bed. A humidity sensor will be placed just in front of the blower to measure the water content of the air stream. The system requires that a dew point of -70°F be maintained for air entering the adsorbent. This sensor will indicate if a desiccant bed has malfunctioned.

Blower. A pressure sensor will be placed in front of the blower and directly downstream from the blower to measure the pressure drop. A power sensor will be used to monitor the power consumed by the blower. Using the information from these sources it will be possible to determine if the blower is friction dragging, turning too slowly, or otherwise failed.

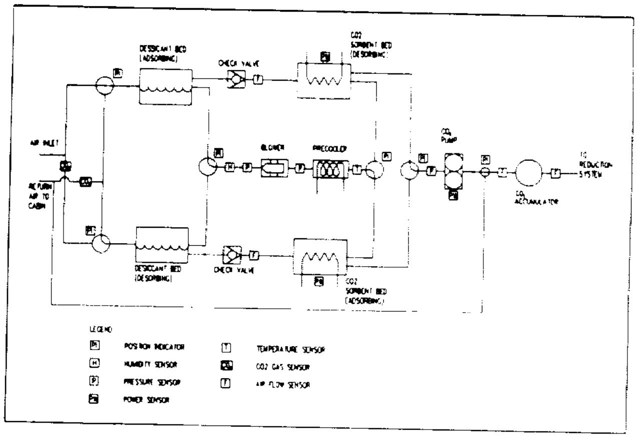

Fig. 4. Proposed CO_2 Removal Sensor Locations

Precooler. A temperature sensor will be placed on the airstream line after the precooler to determine if the air entering the adsorbent bed is cool enough to allow for effective adsorption.

CO_2 adsorbent bed. A CO_2 gas sensor will be placed on the air-return-to-cabin pipe. By comparing the gas concentration at the bed exit with the gas concentration in the cabin it will be possible to determine if the bed is saturated or malfunctioning. A sensor will be used to monitor the power consumption of the adsorbent bed heater.

Check valve. An air-flow-rate sensor will be placed between the check valve and the CO_2 adsorbent bed to determine if the valve is leaking. The check valve assures that cabin air is not drawn directly into the system and stored in the CO_2 accumulator.

CO_2 pump. A pressure sensor will be placed between the pump and the CO_2 selector valve. This sensor will allow leaks to be detected in the CO_2 selector valve, check valve, post-precooler air select valve, and adsorbent bed. This sensor will also aid in monitoring the pump. The pump's power consumption will also be monitored using a sensor.

CO_2 accumulator. An air-flow-rate sensor will be placed directly on both sides of the CO_2 accumulator to allow leaks to be detected.

Comparison of Control Schemes

The newly devised control scheme has several advantages over the current method. The primary advantage is that the new system has feedback. It operates on measured cabin CO_2 gas concentration. This allows the system to operate on a situational basis. The addition of three operating modes allows the new system to respond to different levels of CO_2 in the most effective manner. When CO_2 levels are high and threaten crew safety, the system will operate to remove CO_2 as rapidly as possible, with power consumption by the removal system being of secondary importance. When cabin CO_2 concentrations are between high and low, (Table 1) the CO_2 removal system will focus on power efficiency, freeing up power for higher priority needs. Finally, the CO_2 removal system will be completely shut down if the cabin CO_2 level is very low.

The proposed control scheme has two main disadvantages over the old: it will be more complex and costly to implement. The new method will require a study to determine the cycle times for the CO_2 removal and power efficiency modes. The cost of the new system monitoring scheme may also be a drawback.