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PERFORMANCE AND RELIABILITY OF THE NASA BIOMASS PRODUCTION CHAMBER

R. E. Fortson,* J. C. Sager** and P. V. Chetirkin*

* *The Bionetics Corporation, J.F. Kennedy Space Center, FL 32899, U.S.A.*

** *NASA Biomedical Operations and Research Office, J.F. Kennedy Space
Center, FL 32899, U.S.A.*

REPRINT
JN-51-7M
7721
P-4

ABSTRACT

The Biomass Production Chamber (BPC) at the Kennedy Space Center is part of the Controlled Ecological Life Support System (CELSS) Breadboard Project. Plants are grown in a closed environment in an effort to quantify their contributions to the requirements for life support. Performance of this system is described. Also, in building this system, data from component and subsystem failures are being recorded. These data are used to identify problem areas in the design and implementation. The techniques used to measure the reliability will be useful in the design and construction of future CELSS. Possible methods for determining the reliability of a green plant, the primary component of a CELSS, are discussed.

INTRODUCTION

NASA, the National Aeronautics and Space Administration, has been investigating aspects of a CELSS since 1978. These systems would provide regenerative life support for human exploration of space and long term lunar and planetary habitats. The most probable approach would combine physicochemical and biological systems to produce food, potable water and breathing air by recycling biological material /2/. In 1985, NASA personnel at the Kennedy Space Center began development of a CELSS Breadboard Project to test and demonstrate bioregenerative components in an integrated system. Since green plants are central to the operation of a CELSS, the first component in the CELSS Breadboard Project was the BPC. This chamber allowed the application of current controlled environment plant production research. Various environmental parameters for plant growth have been tried, and atmospheric contaminants measured /6/.

The purpose of this paper is to describe current efforts to quantify the reliability of the physical systems of the BPC. A description of the BPC and associated hardware is included. Possible methods for measuring the reliability of the biological components will also be discussed. Fortson, et al. /4/ gives a complete description of the BPC systems, plus the results of system performance tests. For a detailed chronological history of the chamber, including plant experiments, see Wheeler, et al. /10/.

SYSTEM DESCRIPTION

The BPC, originally a hypobaric chamber during the Mercury program, is a two-story cylinder 7.5m high by 3.7m in diameter. Total volume including air ducts is 113m³. On each level are two shelves for hydroponic plant-growth trays. There are 16 trays per shelf for a total of 48 trays. Total tray area is 16m², while plant canopy area is 20m².

The nutrient solution is kept in 325L tanks with each growing shelf having its own supply of nutrient. Supplemental nutrients are added to each tank based on electrical conductivity. Nutrient pH is controlled in each tank by adding dilute nitric acid. Makeup water comes from the condensate in the air ducts. It is collected in small tanks under each air duct and stored in two 70L tanks. It is filtered and deionized and, as the liquid level of a nutrient tank drops, automatically added to the nutrient tank.

The chamber is atmospherically sealed with an average leak rate of 10% of the total volume per day. A pressure control system is used on the lower level to eliminate pressure spikes greater than 50pa caused by temperature transitions. A second system is planned for the upper chamber.

Air is recirculated in each level by two 30kW blowers. The air is filtered by two coarse air filters and a high efficiency particulate air (HEPA) filter before entering the chamber. The air then passes through another coarse air filter and over the light banks (to remove heat) before leaving the chamber. Cooling and dehumidification are provided by two 52kW chillers. Supplemental heat comes from a 150kW water heater. Humidification comes from two spray nozzles in each air handler.

Lighting is provided by 96 400W high intensity discharge (HID) lamps divided among 32 canopies. There are three lamps per canopy and eight canopies per growing shelf, separated for control into two banks of four canopies each. Each bank provides variable lighting from 200 to 700umoles/m²/s PPF. Stainless steel reflectors increase uniformity.

Chamber carbon dioxide (CO₂) and oxygen (O₂) are measured by infrared gas analyzers (IRGAs) and fuel cells. There are separate control analyzers for the upper and lower levels, and a third analyzer for monitoring. Chamber CO₂ is controlled by adding CO₂ from bottles as the plants consume it. Chamber O₂ is measured but not controlled. An oxygen concentrator will be used to remove excess O₂ as it builds up from photosynthesis. Sager, *et al.* /8/ contains a complete description of the original gas system.

The system is controlled by a programmable logic controller (PLC). An engineering workstation provides separate monitoring. Both systems use custom software. Current experimental data can be viewed graphically on the monitoring system, while data from both systems are archived on the facility's minicomputer.

RELIABILITY TRACKING

The fundamental question in prototype development is how well the system performs. This is equivalent to system reliability. Reliability is the probability that an item will perform its intended task for a specified length of time within specified conditions /1/. In a fully functioning CELSS, the task of a BPC will be to produce given amounts of food, potable water and oxygen, while consuming carbon dioxide and recycling other resources. However, since requirements for a specific mission, system life, and operating conditions are undefined, a failure of the BPC can presently be defined as the inability to perform its crop production task. To measure the reliability of the BPC in performing that task, the reliability of the individual parts must be known.

A data collection system was initiated to study and characterize failure rates of these individual parts and gather information on maintenance actions performed on the BPC. Considering the BPC as a single system, the data are gathered into the following subsystems: NDS (nutrient delivery system), ACS (atmospheric control system, or gas system), PLC (programmable logic controller), condensate recovery, HVAC (heating, ventilation, and air conditioning), lighting, monitoring system, and miscellaneous. Some of the subsystems are broken down into groups of similar components, such as pumps, solenoids, and sensors listed under NDS. A typical data entry screen accepts information on who performed the work and how long it took. The exact part worked on is identified, the work performed is categorized and the effect of the work on the system is indicated. Comments can also be added.

In categorizing the work performed, four choices are given: calibration, maintenance, replacement, or repair. These choices are defined as follows:

calibration - adjustment of measuring device to restore to optimal, accurate operation
maintenance - work performed to restore a marginally operating component to optimal operation (exclusive of calibration)
replacement - changing entire component or enough parts so that the component is essentially new (life of component is reset to beginning)
repair - work performed to restore a non-functioning component to complete, normal operation.

Any operation that affects the crop inside the BPC affects the operation of the entire BPC system. In describing the effect, three levels of severity are used. Critical describes a total failure of BPC operations, generally considered BPC crop loss. Marginal is a failure that has an effect on the crop,

whether or not it can be accurately measured. Minimal describes action that has little or no effect on the BPC crop. To date, there have been no critical failures (loss of crop).

Typical output from the database shows trends within subsystems. Type of work and time required to perform the work are given for each subsystem. Once a subsystem of interest is identified (such as the subsystem requiring the most man-hours), the time and frequency breakdown among the individual components of that subsystem are shown. The data will even show amount and type of work for an individual type of component within a particular subsystem. This will allow the identification of specific parts which are prone to fail, or require inordinate amounts of maintenance. Once these parts are identified, they are replaced with more reliable parts, increasing the system reliability.

Determining system reliability by measuring the time until failure is impractical. Therefore, the ability to predict the life of a component or system is essential. Reliability prediction and modeling efforts were pioneered by the military during World War II in an attempt to reduce the high number of failures in the field /1/. The military has developed many methods on how to design for and demonstrate reliability /7/. While NASA does not dictate the use of specific models, they still require high reliability on all flight related systems /5/. However, all of these efforts deal strictly with physical systems. In order to determine the system reliability of a CELSS, the reliability of a green plant must be determined.

Components can experience either primary failure (failure of the component itself) or secondary failure (failure caused by the failure of another component). With primary failure, a pump may fail by itself (bad bearings, broken impeller, etc.). If a valve supplying the pump failed, this could cause secondary failure of the pump by starving it of water. Plants can experience the same phenomena. An example of primary failure of a plant is seeds which fail to sprout. Seed viability, a common measurement of the percentage of seeds which may sprout, and seed vigor, a measure of the ability of the plant sprout to survive /3/, may be directly compared to reliability. Secondary failure of plants is more common. The failure of support equipment will induce a stress on the plant. Salisbury and Ross /9/ discuss biological stress as any environmental condition that will adversely affect a plant's development. Biological strain is the changed plant function, such as food yield, carbon dioxide scrubbing, oxygen production and water purification. These are analogous to physical stress and strain. However, the limits of stress that a plant can endure before it is unable to provide the necessary functions of life support in a CELSS need to be defined.

SUMMARY

The Biomass Production Chamber is the central component in the CELSS Breadboard Project at Kennedy Space Center. As in any life support system, reliability is a primary concern. Efforts are underway to assess the reliability of this particular system, and to develop techniques to measure the reliability of any bioregenerative life support system. This required the development of a failure/maintenance tracking database for the physical components. It also requires the development of an analog to physical reliability for the biological components. For plants, physical reliability may be related to the plant's reaction to environmental stress, and to seed viability. In order to fully equate plant stress reactions to physical reliability, more work will be needed to specify the definite boundaries outside of which plants fail to perform their CELSS functions.

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