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Development of *BIO-GAS* Systems

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Abstract

Four experiment systems which have fundamental significances in the field of biotechnology are developed for the Get Away Special(GAS). Unique considerations were necessary to develop the systems which carry out biotechnological experiments under GAS's restricted conditions: - delicate thermal control, fluid handling and protection from contamination. All experimental processes are controlled by internal sequencers and results of the experiments are recorded as images and numerical data within the systems. Our systems are standardized in order to enable repeated use of a variety of experiments by replacement of the experiment modules and modification of experiment sequencing programs.

1. Introduction

Recently, the use of the space environment such as microgravity has been increasingly emphasized. Thermal convection, buoyancy and sedimentation are all strongly affected by gravity and have extremely weak effects in space. Using this phenomenon, high efficiency and purity can be achieved in processing and refinement of materials. This will be most useful in making semiconductors, metallic materials, compound materials, separating and refining medicinal drugs, growing protein crystals and cell culture, for example.

Biotechnology is receiving a great deal of attention with the rapid development of recombinant DNA technology and cellular fusion techniques. Biotechnology is of great significance, not only for its investigations of the phenomena of life, but also for its applications to medicine, agriculture and industry. Space microgravity is also expected to be profitable in this field. We have planned to aproach the space utilization for biotechnology by making use of the opportunity of GAS.

2. Experiment Subjects

We have selected four themes fundamental in biotechnology, and have developed four GAS experiment systems corresponding to these themes. These are detailed below.

G-456: Electrophoretic separation of biological materials

In the microgravity of space, the effects of sedimentation, buoyancy and thermal convection, all of which involve differences in specific gravity, will decrease. Therefore, the ability to separate and refine materials by electrophoresis is being studied, particularly in the area of drug manufacture.

In our experiment, a mixture of enzymes will be separated by electrophoresis in a microgravity environment. A laminar flow of buffer solution is created in an electrophoretic separation chamber, and then, the sample is injected. Voltage is then simultaneously applied to electrodes. The phenomina of this separation are observed by a video camera above the separation chamber and recorded by video cassette recorders. The electrode voltages are 100 V, 200 V, and 300 V. Results of this separation will be compared to results obtained on the earth's surface. Fig.1 (a) shows the drawing of the experiment module of G-456.

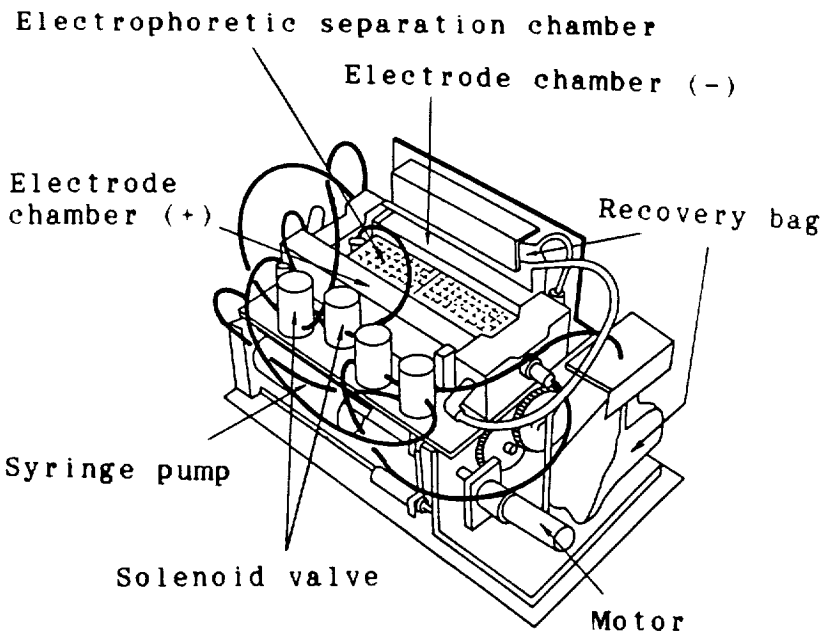

Fig.1 (a) Experiment module of G-456 - Electrophoretic separation of biological materials

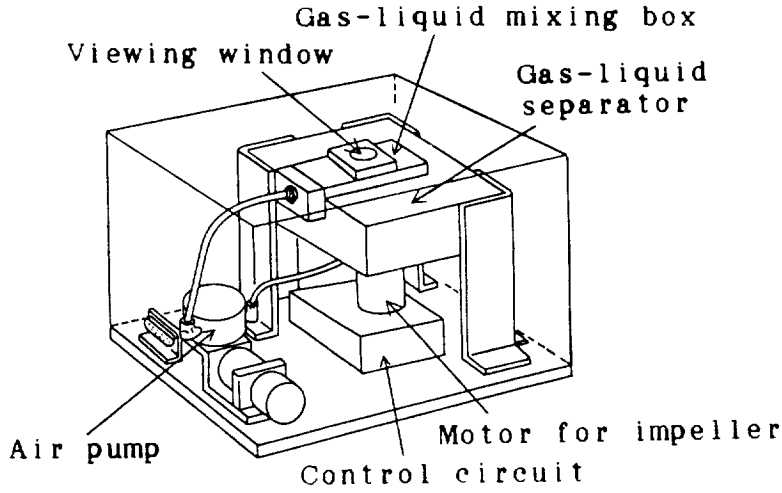

Fig.1 (b) Experiment module of G-457 - Separation of gas bubbles from liquid

G-457: Separation of gas bubbles from liquid

Culturing and fermentation involve the generation of carbon

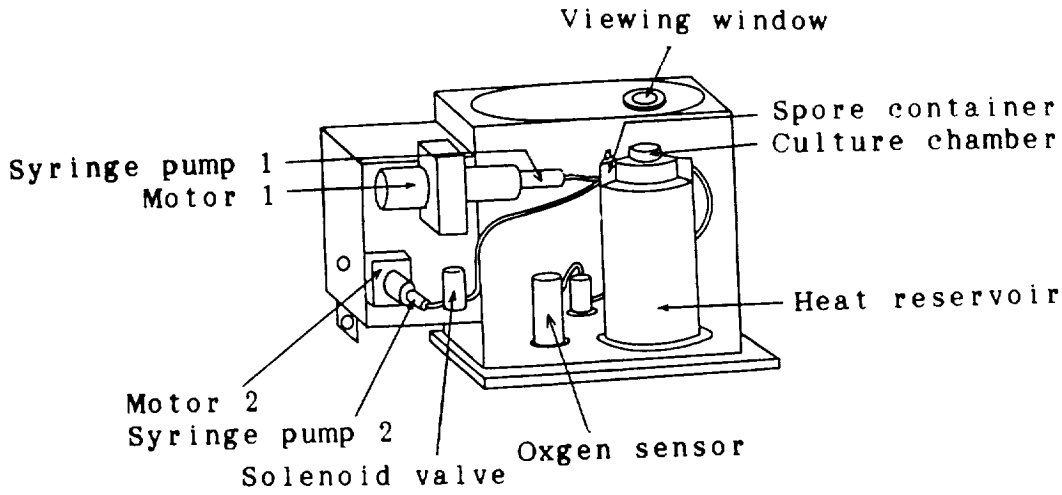

Fig.1 (c) Experiment module of G-458
- Cultivation cellular slime mold

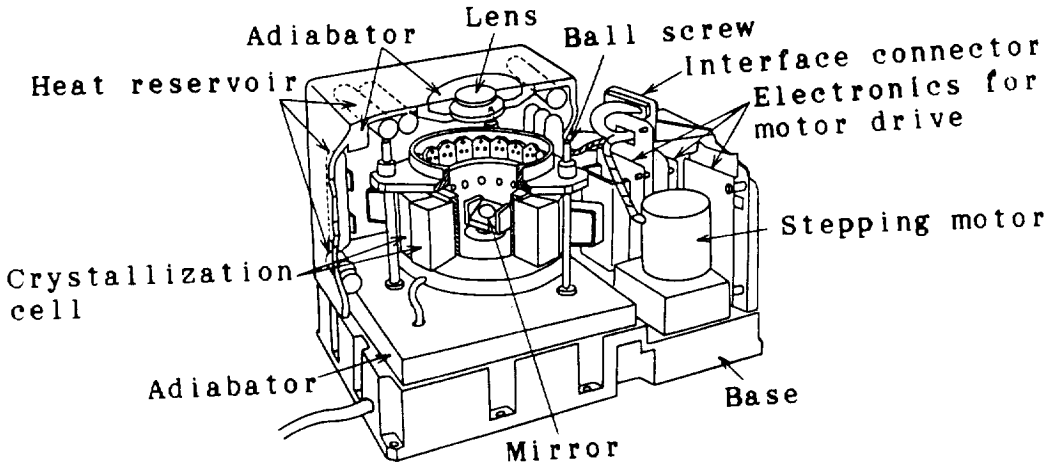

Fig.1 (d) Experiment module of G-459
- Protein crystal growth

dioxide. In a microgravity environment, this gas adheres to living organisms such as yeast and bacteria and the gas interferes with culturing and fermentation, while it can be easily removed from liquid by buoyancy on the earth's surface. Hence, the separating gas from liquid is necessary for culturing and fermentation in space. This technology is related to the development of life-support systems for use in space.

In our experiments, a gas-liquid mixture is placed in a separation chamber. When the blades of the centrifugal separator is rotated, the liquid will gather on the circumference, and gas will collect in the center. The gas in the center will be removed by an air pump, and be injected again into the liguid. The rotating speed of the blades is variable. The movement of bubbles during injection is recorded by a video camera and video cassette recorders to check the separation efficiency. Fig.1 (b) shows the drawing of the

experiment module of G-457.

G-458: Cultivation of cellular slime molds

Evolution of living organisms has occurred in a 1-G environment, however the relationship between their morphogenesis and gravity is not well known. Cultivation experiments in a microgravity environment will yield data that will help to clarify the function of gravity in the evolution of structure.

In our experiments, the culturing of cellular slime mold in a microgravity environment and its development will be recorded by a 35-mm camera to determine the influence of gravity on structure at the cellular-molecular level. We use airtight experiment module with an air atmosphere. Agar is placed in the culture tank, and mixture of water and spores, is prepared separately. Spore culturing begins with the injection of this mixture into the culture tank. Fig.1 (c) shows the drawing of the experiment module of G-458.

G-459: Protein crystal growth

Convection and sedimentation are weakened in microgravitational conditions. It is thus expected that large, high-quality protein crystals can be obtained in microgravity, then they can be used for 3-dimensional X-ray diffraction analysis. This will help contribute to protein engineering.

The G-459 system has 16 crystallization cells and protein crystals will be grown in microgravity in each cell. The growth will be photographed by a 35-mm camera. The protein crystallization cells are designed for the spontaneous mixing of an ammonium sulfate solution and a protein solution by removing a partition. This experiment will be done using three different methods: batch, free surface diffusion and vapor diffusion. Fig.1 (d) shows the drawing of the experiment module of G-459.

3. System Outline

Concepts

In the development of our experiment systems, the following was considered:

1) Standardization of system is needed to enable repeated use for various kinds of experiments. Electrical subsystems and structures were designed to allow standard use.

2) All experiment systems must conform to the safety and interface requirements for the Space Shuttle established by NASA.

3) All controls, other than turning on of an electrical power source, which is made by a baroswitch, must be done automatically by a sequencer in the system.

4) Results of the experiment must be recorded within the system as images and numerical data. These data will be recovered and analyzed after the return of the Shuttle.

5) Commercially produced components were used as much as possible. However, modifications such as mechanical reinforcement must be made to ensure that NASA's environmental durability requirements are met.

Design of Subsystems

Each experiment system consists of the speciallized experiment module and other subsystems which are common for all four systems such as electronics subsystems containing the experiment controllers, recorders and an alarm, a battery assembly and support structures. Fig.2 shows the photograph of the G-459 system. Other three systems have the same configurations.

The experiment systems can be divided into two groups, by the difference in their applicable experiment durations. The G-456 and G-457 have experiment durations of about 30 minutes, and have a relatively small battery capacity, 600 W-hours. Image data of these experiments are recorded by video cassette recorders. The G-458 and G-459 have durations of about 120 hours. For these, the battery capacity is 900 W-hours, and images are recorded by a 35-mm camera. Except for these differences, our experiment systems are standardized as much as possible. Researchers can select the most appropriate system type for their experiment. Fig.3 is a block diagram of the G-459 system, which is common to all four systems except for image observing and recording subsystem. Common design

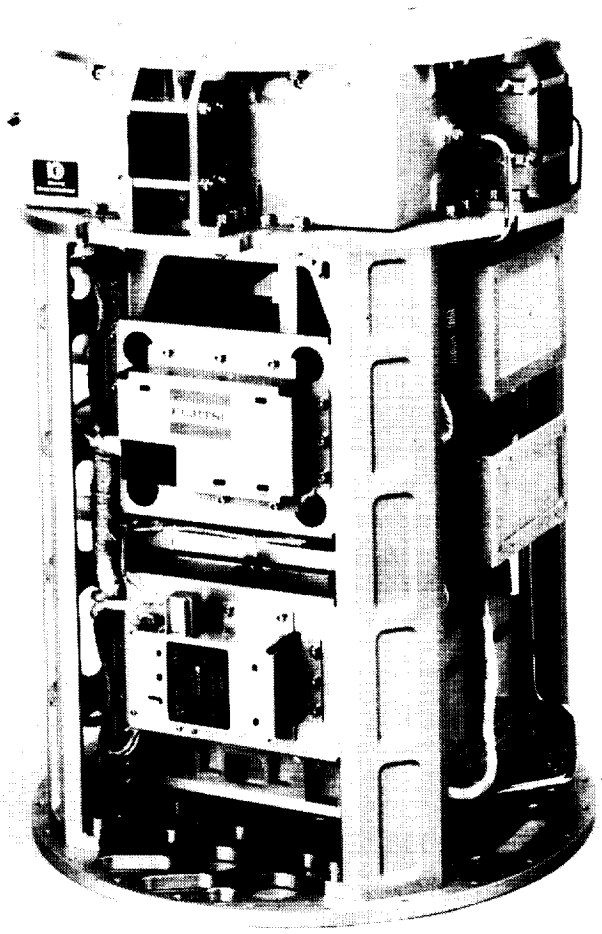

Fig.2 G-459 system

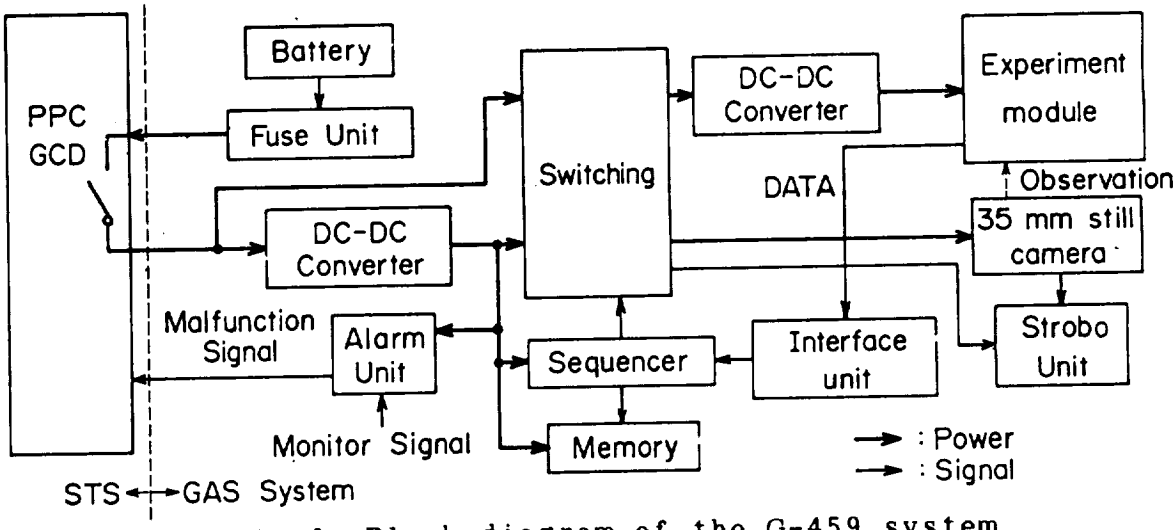

Fig.3 Block diagram of the G-459 system

features are explained below.

1) Subsystems for Experiment Control

For automatic experiment sequencing and for repeating experiments, an 8-bit CMOS microprocessor which consumes little electricity and a PROM are used. The experimental sequence can be changed easily by modifying the program on the PROM.

2) Subsystems for Data Recording

The G-456 and G-457 use a combination of a video camera and video cassette recorders, and the G-458 and G-459 use a 35-mm camera for recording the image data of experiments. The video cameras used have solid-state image sensors and are reliable and environmental resistant. We use two portable video cassette recorders for each system as one for redundancy. All recording equipment have been structurally reinforced.

Power source voltage, container temperature and each subsystem's temperature and voltage supplied to each subsystem are recorded in EEPROMs. In case for G-456 and G-457, they are alse recorded on the audio channel of video tape. If these data exceeds the predefined ranges, an alarm signal will be transmitted to the Shuttle. The system's main switch will be shut off by this signal.

3) Power supply

We selected lead-acid storage batteries made by the Gates Co., for power source. For the G-456 and G-457 systems, the battery assembly has a total capacity of 12.0 V x 50 A-hours (= 600 W-hours) with 24 cells and G-458 and G-459 have 12.0 V x 75 A-hours (= 900 W-hours) with 18 cells. Fuses and diodes are installed for safety measures. Diodes are installed in each series unit of battery cells to prevent current reversals between the battery cells.

DC/DC converters convert and stabilizes the 12-V source power from the batteries and they supply the electricity to each subsystem.

4) Support structure

We used shelves-supported-by-struts structure for our experiment systems (see Fig. 2). This kind of construction is one of recommendations of NASA.

Two discs and four supporting struts are assembled rigidly. All these components are made of aluminum alloy A7075 and A5052. The camera and electronics are mounted on support struts or between struts. Batteries are mounted on the top disc between the lateral supports. The experiment module is mounted on a stand attached to the bottom plate.

Holes for mounting screws are drilled in the supporting struts and in the discs at each constant distance. Position tuning mechanism for the camera is included in its support. These considerations enable standardized use of our systems.

4. Special Considerations for Biotechnological Experiments with GAS

There are many restrictions on the GAS payload. Among them, waiting period for launch of more than two months was most crucial for our systems because delicate biological matters, living organisms and fluids are needed in biotechnological experiments. In such restricted condition, it is difficult to develop a system for carrying out a significant space experiment, especially a biotechnological experiment. Actually, there have been very few

successful biological experiments (Ref. 1). Special considerations are therefore needed as follows.

Thermal control

For our experiment systems, we will use insulated end caps and we have requested the passive thermal control (PTC) mode for the Shuttle flight. In this flight mode, the Shuttle rotates around its X-axis to keep the temperature as constant as possible so temperatures within the GAS container fluctuate between 0 C and 40 C in case that the power consumption within the container is below 30 W (Ref.2). This temperature fluctuation is quite small for space, but is large for experiments whose contents are liquids and biological samples. For example, the liquids cannot be allowed to freeze. Furthermore, if the temperature in the experiment module of G-468 drops below 17 C, the growth of the cellular slime mold is inhibited and if the temperature rises above 27 C, the cellular slime mold is killed. In the G-459, the most efficient temperature for the growth of protein crystals will be room temperature, but this varies with the type of protein used.

Because of battery limitations, we use passive methods for thermal control using heat insulators, heat reservoirs and antifreeze. According to experimental requirements for thermal control, we have carefully selected materials and their compositions for these thermal control methods. It was confirmed by environmental tests that thermal controls of sufficient quality have been achieved for all systems.

Handling of fluids

All systems contain fluids. Leakage, evaporation, and bubble formation must be avoided. Measures must also take the approximately two-month waiting period into consideration. To avoid above problems during this two-mouth period, we have been with great care for materials for sealing, designing containers for liquids and method for sealing. For example water diffuses through acrylic resin containers and silicon rubber packing, so they cannot provide a perfect seal for two month. We therefore used "Viton" packing and a special less permeable resin. We have conducted long-term tests and confirmed their durability for preservation.

Contamination

Protein, slime mold and culture mediums for biological substances are used in all experiments except for the G-456. Therefore, if other bacteria mix with an experiment system, problems of metaplasia and putrefaction will occur during the waiting period. Therefore, containers and transportation tubes that hold these substances are designed so that they can be sterilized. They are also designed so that they can be assembled apart from other mechanical sections.

5. Concluding Remarks

Production of the four biotechnological space exberiment systems for the GAS have been completed (Fig.2). Tests of operation and durability for enviroments such as temperature and vibration were also conducted successfully. We have obtained significant results of ground experiments which will be compared with the result of experiments carried out in space. Some of these results are shown in Fujita et al.(Ref.3). Other than these four systems for biological experiments, we have also developed a GAS system for the crystallization experiment of compound semiconductor materials (GaAs and PbSnTe) which is shown in Ref.4. We hope early launching of our systems soon after the resumption of the Shuttle flight program.

The possibilities for utilization of the space environment are virtually unlimited and many nations have space programs. To encourage major projects, accumulating as much basic data and experiences as possible is of great importance. GAS can easily achieve these goals. Our four experiment systems introduced here are not only significant in biotechnology, but can be adjusted and used for experiments in other fields. We expect these systems will be able to meet future demands to make use of GAS as well as the success of these four experiments.

Acknowledgement

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