Carbon Dioxide Measuring Systems for Manned Spacecraft

WILLIAM H. BUSH

ABSTRACT

For manned space flight to date, three types of CO_2 sensors have been developed. At present, the infrared approach to CO_2 detection is considered the most reliable and sensitive system available for use in manned space flight. The problems of total pressure sensitivity can be offset electronically, if required, on future missions; however, at present, the excellent pressure control which the environmental system supplies the spacecraft makes such refinements unnecessary for normal operations.

THE LEVEL of CO_2 within the breathing atmosphere of manned spacecraft is an important parameter that provides an indication of the well-being of the astronauts, hence, affects to a marked degree the success of a mission. In the Gemini and Apollo spacecraft, as in the Mercury, the internal atmosphere is circulated through a lithium hydroxide canister to remove metabolic CO_2. In order to insure that the atmosphere remains within tolerable limits, measurements of the CO_2 partial pressure in the spacecraft is required.

Man produces, in a spacecraft, between 2.1 and 7.4 pounds per day of CO_2 depending on his activities. The amount of lithium hydroxide provided in the CO_2 absorber is based upon these production rates and considers the astronaut's workload during a mission.[1] The Mercury system used 5.4 pounds of LiOH for the 33-hour MA-9 mission;[3] the Gemini canister contains 81 pounds for a 14-day mission; the Apollo system utilizes canisters which are changed periodically. The present configuration calls for a 4-pound canister which is replaced every 12 hours. In the event of CO_2 absorber depletion or malfunction, the CO_2 partial pressure buildup during suit circuit operation can be rapid. The curves in Figure 1 illustrate typical CO_2 buildup in the Mercury system for a totally failed CO_2 absorber and a gradually depleted absorber. As a result of these possible malfunctions, and, in the case of Apollo, a need to provide an indicator for changing the lithium hydroxide canister, measurement of CO_2 partial pressure is a required monitoring aid in determining the operational status of the spacecraft's environmental control system.

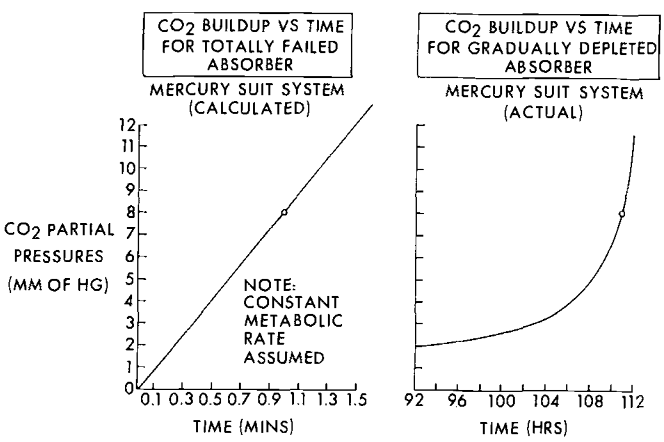

Fig. 1. Typical CO_2 Buildup Rates for Failed LiOH Canister.

DISCUSSION

Because of the difficulty and complexity of the measurement, three types of in-flight CO_2 measuring systems have been developed for manned spacecraft. A pH sensitive electrode was successfully used on the Mercury MA-9 mission. A radiation absorption technique has been fabricated for the Gemini spacecraft, and an infrared adsorption approach is being used in the Apollo program. This paper provides a description and comparison of these three measuring systems.

pH SYSTEM DESCRIPTION

The last Mercury flight, MA-9, was the only manned space flight, to date, to carry a CO_2 measuring system. This unit was developed for the Manned Spacecraft Center by Bechman Instruments, Inc., Fullerton, California.[2] The unit operated successfully and indicated a small partial pressure (4 mm.) of CO_2 during the latter phases of the flight. The unit consisted of a voltage-producing sensor with preamplifier which attached directly to the pressure suit inlet duct. A signal conditioner which further amplified the signal and supplied voltage regulation was located in the spacecraft common instrument package. The system is shown in Figure 2.

Figure 3 shows the sensing portion of the system. The

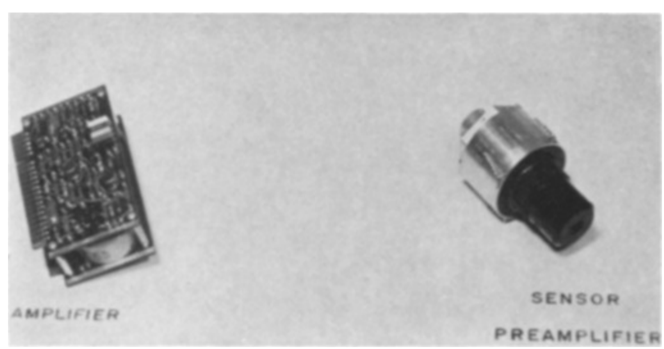

Fig. 2. Mercury CO_2 Sensing System.

From the NASA Manned Spacecraft Center, Houston, Texas.
Presented at the Aerospace Medical Association meeting in Miami, Florida, May 12, 1964.
Data presented was obtained from Beckman Instruments, Inc., under Contracts NAS 9-349 and NAS 9-1199, Lion Research Company under purchase order number Y20639R from the McDonnell Aircraft Corporation under Contract NAS 9-170, and the Perkin-Elmer Corporation under Contracts NAS 9-1191 and NAS 9-2255.

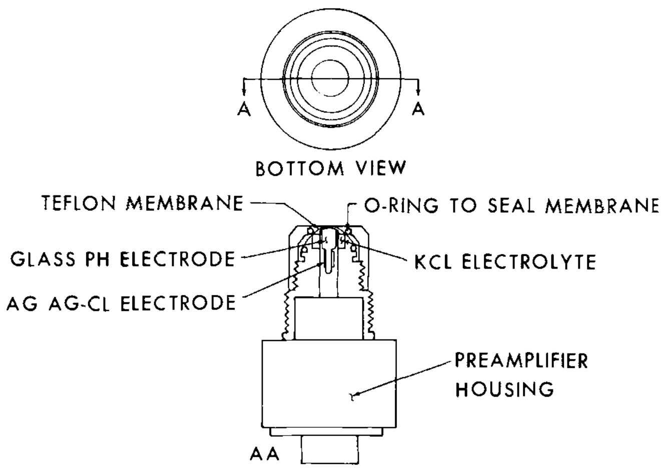

Fig. 3. Mercury CO_2 Measuring System Sensor Portion.

sensor consists of a glass pH electrode with a silver-silver chloride reference electrode immersed in a potassium chloride electrolyte. The electrolyte is maintained around the electrodes by a gas-permeable, 1-mil-thick Teflon membrane. The sensor is attached to the environmental control system duct, and, as the suit circuit gas diffuses through the membrane, the CO_2 reacts with the electrolyte to form carbonic acid. The free hydrogen ions associated with this acid are collected by the pH electrode producing a voltage which is proportional to the CO_2 partial pressure (approximately 55 millivolts per decade change in CO_2 partial pressure). This voltage is amplified by a high-impedance, chopper-stabilized amplifier for meter display. Since the amplifier was required to have a high input impedance, approximately 1,000 megohms, an electrometer tube, CK 5886, was used in the preamplifier. The remainder of the circuit was solid state. This system was very light, but had slow response, limited operating temperature range, and a short life, due to the drying of the electrolyte.

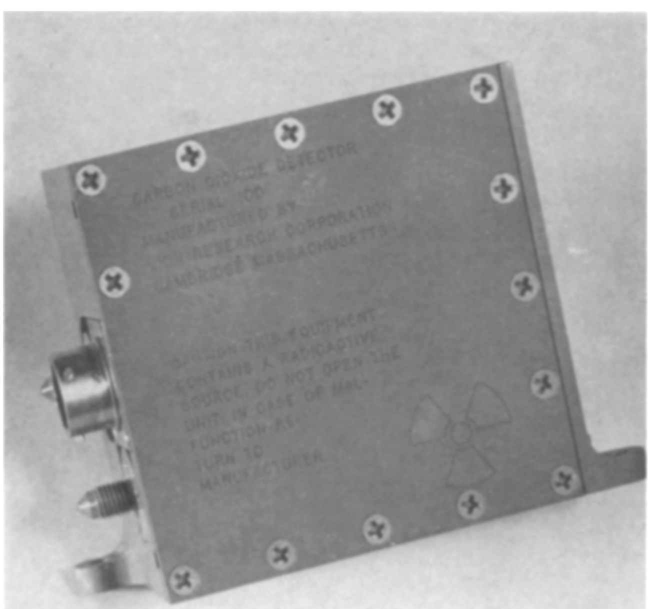

Fig. 4. Gemini CO_2 Measuring System.

RADIATION ABSORPTION SYSTEM

Because of the limited operating life of the pH type device and the anticipated length of future missions, a CO_2 measuring system utilizing a radiation absorption technique was developed for the Gemini program by the Lion Research Company of Boston, Massachusetts, and is shown in Figure 4.

Forty cubic centimeters per minute of the suit inlet gas is diverted through the measuring system and returned to the suit system at the low-pressure side of the circulating fan. This 40 cc./min. flow is further divided within the unit into two flow paths of 20 cc./min. each. In one path an Ascarite filter is placed in series with the flow to remove CO_2; in the other path the unfiltered suit circuit gas flows.

A tritium radiation source is located downstream in each flow path. The tritium ionizes the gas as it flows past and an electric field impressed across the chamber causes a current to flow. The ionization currents from the two chambers are unequal by an amount proportional to the amount of CO_2 removed by the Ascarite filter in the sample chamber. This current difference is detected and amplified by a differential amplifier, utilizing a CK 5886 electrometer tube in the input stage for a high input impedance. The remainder of amplifier circuitry is solid state. Only 27 components are used in the amplifier, maximizing reliability.

The radiation absorption system is a reliable system, although a drier inside the unit is required for operation in high-water vapor environments. Presently, 35.0 grams of Drierite are required to allow operation in 100 per cent RH environment for 14 days. A schematic of this unit is shown in Figure 5. This system experiences a shift in zero calibration for variations in total pressure.

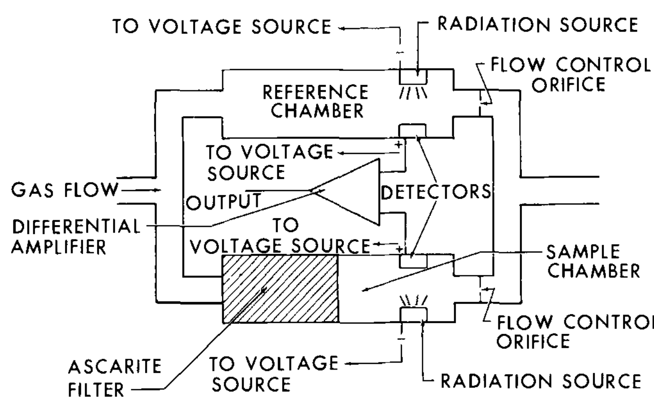

Fig. 5. Radiation Absorption System.

INFRARED APPROACH

To provide a CO_2 sensor for the Apollo program and a backup development for the Gemini program, an infrared sensor was developed by the Perkin-Elmer Corporation of Norwalk, Connecticut. The sensing portion of the system and associated electronics are contained in a single environmentally sealed package which is capable of being attached to the vehicle bulkhead without cold plates. A photograph of the infrared unit is shown in Figure 6.

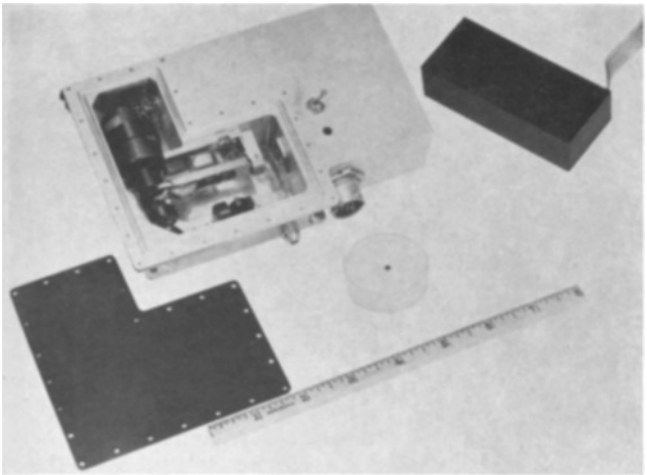

Fig. 6. Apollo CO_2 Measuring System.

The sensing portion of the system consists of a single beam of infrared light, emitted from a miniature source, which impinges on an indium antimonide detector. Prior to reaching the detector, the IR beam passes through focusing lens and a tuning fork filter chopper on which two filters are mounted, with pass bands at approximately 4.1 and 4.3 microns, with a small opaque region between the filters. These two filters are alternately introduced into the IR beam by the vibration of the tuning fork, causing the detector to produce a square wave voltage signal which is proportional to the arriving IR energy. One half of the square wave cycle is due to the energy transmitted by the 4.1 micron filter, a reference signal, since CO_2 does not strongly absorb infrared radiation at this frequency. The other half cycle is due to the IR radiation transmitted through the 4.3 micron filter. The radiation at this wave-length is strongly absorbed by CO_2. The differences of the voltage signal produced during each half of the vibration cycle are proportional to the CO_2 concentration. The output signal generated by this all-transistor electronic system is a 0 to 5 volt d-c signal which is proportional to CO_2 concentration. Figure 7 illustrates this system. This system is small and lightweight and eliminates the necessity to absorb water vapor chemically or carbon

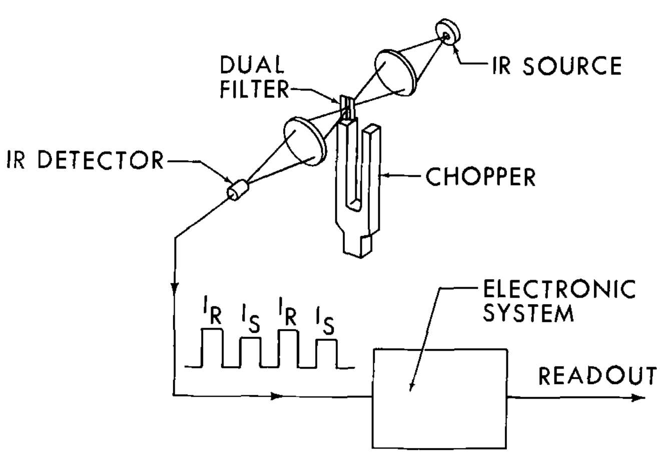

Fig. 7. Infrared CO_2 Sensor.

dioxide inherent in the two previous described systems. However, this unit is sensitive to changes in total pressure.

SYSTEMS COMPARISON

The three systems discussed offer both advantages and disadvantages in application in manned spacecraft. As presently configured, the reliability of the three systems is comparable, considering short mission requirements. The pH and radiation absorption techniques have finite lives due to the chemicals associated with their operation. This makes them somewhat undesirable for long operating times. Calibration, ground service, and maintenance are complicated by the finite chemical life times. The infrared approach eliminates the difficulties inherent in these two systems, with the exception of effects of total pressure sensitivity. Figure 8

SYSTEM	WEIGHT	POWER	SIZE	RANGE	ACCURACY	LIFE
PH SENSITIVE	1 POUND	1 WATT	30 IN CUBE	0-30 MM OF HG	±12% OF READING	3 WEEKS
RADIATION ABSORPTION	2.5 POUNDS	0.5 WATT	32 CU IN	0-20 MM OF HG	± 2 MM OF HG	2 WEEKS WITH PREFILTER
INFRARED	1.7 POUNDS	0.75 WATT	33 CU IN	0-30 MM OF HG	±5% OR 0.5 MM WHICH EVER IS LARGER	INDEFINITE

Fig. 8. Comparison of Physical Parameters.

compares the operating environment of the three approaches and figure 9 compares physical parameters of the three systems.

SYSTEM	HUMIDITY	OPERATING TEMPERATURE RANGE	VIBRATION	TOTAL PRESSURE VARIATION	RESPONSE TIME
PH SENSITIVE	REQUIRES HIGH OPERATING RH DRY ENVIRONMENT SHORTENS LIFE	40-90°F	SOMEWHAT AFFECTED BY LAUNCH VIBRATIONS	NO EFFECT	3 MIN FOR 63% VALUE OF STEP CHANGE
RADIATION ADSORPTION	REQUIRES PREDRIER IN SERIES WITH SYSTEM	0-160°F	NO EFFECT	APPROXIMATELY 10% OF FULL SCALE "O" SHIFT PER PSI	LESS THAN 30 SECONDS FOR STEP CHANGE
INFRARED	NO EFFECT	0-200°F	TEST TO BE CONDUCTED NO EVIDENCE OF VIBRATION SENSITIVITY TO DATE	APPROXIMATELY 5% OF FULL-SCALE SENSITIVITY PER PSI	LESS THAN 10 SECONDS FOR 63% VALUE OF STEP CHANGE

Fig. 9. Operating Environment Comparison.

1. Boynton, J. H., et al.: Spacecraft Systems Development and Performance. Mercury Project Summary, page 39, May 15 and 16, 1963. U. S. Government Printing Office.
2. Cooper, L. C.: Astronaut's Summary Flight Report. Systems Difficulties Encountered Towards the End of the Flight. Mercury Project Summary. Page 356, May 15 and 16, 1963. U. S. Government Printing Office.
3. Watkins, H. D.: Basic Gemini ECS Keyed to 14 Day Flight. Contaminated Oxygen. Aviation Week and Space Technology, August 19, 1963.