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AUTOMATIC TEMPERATURE CONTROL OF IRRADIATION
CAPSULES BY A VARIABLE BINARY GAS MIXTURE

by

R. C. Drescher and Dale E. Johnson

September 12, 1962

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ABSTRACT

Because of the extreme need to accurately control irradiation-capsule temperatures, a binary gas temperature-control system was developed. Temperature control is achieved by varying the gas mixture, and therefore the thermal conductivity, in a gas annulus surrounding the capsule. Control systems based on this principle have been used for periods of over one year and have maintained capsule temperature to $\pm 10^{\circ}\text{F}$. The system may be used equally satisfactorily with either fueled or nonfueled capsules. The reliability of the system is extremely high, and all maintenance is limited to the readily accessible instrumentation.

INTRODUCTION

Extensive irradiation testing of promising materials for use in nuclear power reactors has been performed by numerous organizations to obtain information on materials problems associated with reactor design. These tests have been performed in both instrumented and noninstrumented capsules and under a variety of conditions in order to obtain information relating the behavior of a material to the effects of temperature and radiation exposure. Capsules have been designed to irradiate representative samples of numerous materials and to obtain the irradiated-materials data necessary to design today's reactors.

In order to advance reactor technology it has become increasingly important to exercise rigorous control of the material temperatures during irradiation experiments. This may be accomplished by controlling the neutron flux during the irradiation of fuel materials, by controlling the gamma heating rate for nonfuel materials or by controlling the heat-transfer characteristics of the irradiation capsule. The neutron flux and gamma heating rate of the material in any given position in the reactor are very difficult to control because they are dependent on numerous factors such as control-rod position, fuel loading, and nature of adjacent experiments. As a result, one is faced with the necessity of controlling the heat-transfer characteristics of the capsule in order to exercise control of material temperature during irradiation.

One of the first methods employed to control capsule temperatures was the use of an auxiliary electrical heater. This method has not proven to be completely satisfactory because of rather limited heater life relative to the duration of the experiments and because of the cost of capsules equipped with electrical heaters. In addition, the repair of a heater that begins to malfunction during irradiation is extremely difficult, if not

impossible. Another method used was that of moving the capsule vertically in the reactor facility in order to increase or decrease the gamma heating and/or neutron flux and thereby to increase or decrease the temperature. This method is economically unattractive because the experimenter is obliged to pay for the entire irradiation facility even though much of it may be left vacant.

AUTOMATIC CONTROL WITH BINARY GAS MIXTURES

One of the early systems that was developed using a gas mixture (1) was based on the variation in the thermal conductivity of static, binary gas mixtures in an annulus surrounding the test specimens. This system was controlled by injecting helium if the temperature was too high and injecting neon or nitrogen if the temperature was too low. The excess gas was exhausted from the capsule through a pressure relief valve. The temperature response time for this system was slow (10 to 25 min) due to the fact that predetermined amounts of either helium, neon, or nitrogen were injected into the capsule and the capsule was allowed to reach steady-state conditions. If the capsule temperature still was not within the desired temperature range, another aliquot of the appropriate gas was injected.

The system presently in use utilizes a continuous flow of gas through the gas annulus, with the mixture being automatically adjusted as required to maintain the set-point temperature. This refinement of the original system results in very fast temperature response and in temperature control to $\pm 10^{\circ}\text{F}$ over a wide range of heat-generation rates.

The basic capsule design is fairly simple. It consists of five main components: (1) a specimen, (2) a sealed inner can, (3) inlet and exhaust gas tubes, (4) thermocouples, and (5) a sealed outer can. The thermocouples may be placed either inside or outside the inner can. A sketch of a typical capsule is shown in Fig. 1.

This temperature-control system was developed and used by General

Atomic in irradiation experiments conducted as a part of the Experimental Beryllium Oxide Reactor (EBOR) Program. The system works equally well with fueled or with nonfueled samples, providing that a sufficient gamma-heating rate exists in the selected irradiation position.

The capsule temperature-control system provides a continuous flow of helium and/or nitrogen to the capsule. The flow rate of each stream is dependent on the design of the capsule, the heat-generation rate in the capsule, the reference thermocouple emf, and the temperature-recorder-controller set point. For a given capsule design and heat-generation rate, higher temperatures are obtained by increasing the amount of nitrogen in the gas mixture. Conversely, lower temperatures are achieved by increasing the helium content of the gas mixture. The two gases are mixed inside the capsule, thereby providing the fastest temperature response possible. A reserve helium supply is provided to permit operation of the capsule at the lowest possible temperature during any unusual operating condition.

The major pieces of equipment used in the temperature-control system are one circular chart temperature-controller-recorder equipped with a magnetic modulator positioner, one motor valve operator for gas-proportioning control, and one gas-flow valve assembly. A schematic diagram of the system is shown in Fig. 2.

Two 25-psig helium supplies and one 25-psig nitrogen supply are required. The helium enters the system through a 3-way solenoid valve and passes through a Dehydrfilter which removes moisture from the gas. From there, it passes a pressure switch set at 20 psig and enters a gas-pressure regulator which reduces the pressure to 10 psig. The helium then passes through a flow meter located on the front of the instrumentation panel and into the gas-proportioning valve assembly. The flow continues through miscellaneous valves and filters and into the capsule, where it is mixed with the appropriate proportion of nitrogen. The gas mixture flows down through the temperature-control-gas annulus and exits to the reactor exhaust system through exhaust tubes that open at the bottom of the capsule.

The system is designed in such a manner that if either gas supply falls below 20 psig or a temperature excursion occurs within the capsule, helium from the reserve supply is admitted directly to the capsule through the bypass system. An alarm horn is sounded and a trouble light on the front of the panel indicates the source of trouble. With only helium in the gas annulus, the capsule operates at the lowest possible temperature until the source of trouble is corrected.

OPERATING EXPERIENCE

The thickness of the temperature-control-gas annulus is dependent on the heat-generation rate in the capsule and on the temperature requirements. A spacer wire having a diameter the same as the required annulus thickness is wrapped around the inner can to maintain concentricity with the outer can, thereby assuring a uniform temperature distribution in the capsule.

The initial system of this type was built and used with a capsule similar to that illustrated in Fig. 3; this system has been in continuous automatic operation for more than a year, with only the normal instrumentation maintenance being necessary. The results of a heat-transfer mockup of this capsule using electrical-resistance heating indicated that with a set-point temperature of 1420°F , a 15% instantaneous power increase (from 200 to 230 w/cm) produced a maximum temperature of 1500°F in 20 sec. The temperature had returned to 1420°F within an additional 2 min. Other tests with a similar instantaneous power increase and an initial set-point temperature of 1620°F resulted in a 1700°F maximum temperature in 20 sec. In the latter cases, however, four minutes were required for the temperature to return to 1620°F .

Test results obtained with a second temperature-control system used with another capsule showed that an increase in power from 700 to 757 w/cm of capsule length caused the temperature to rise from 950°F to a maximum

of 980°F in 21 sec. In this case, the temperature returned to 950°F within an additional 45 sec. Other tests conducted with a 28% instantaneous power increase from 214 w/cm and a 650°F set-point temperature resulted in a 50°F temperature rise in 36 sec and a return to 650°F in an additional 1-1/2 min. This temperature-control system has been in automatic operation for several months.

Figure 4 shows typical results obtained from a heat-transfer mockup test of a capsule. These results show that a 950°F control thermocouple temperature can be maintained for a heat-generation rate varying from 300 to 800 w/cm of capsule length.

CONCLUSIONS

Operating experience with several of the binary-gas-mixture temperature-control systems has demonstrated that the method is highly satisfactory. In each case, the temperature has been automatically controlled with extreme reliability and the system has been essentially unattended for periods of continuous operation as long as a year. The range of temperature control is dependent upon the heat-generation rate within the capsule, the width of the gas annulus, and the choice of gases used in the binary system. Our choice of helium and nitrogen was based upon the ready availability of both gases, a satisfactory control range, and a minimum of activation products in the gas exhaust stream. The reliability of the system is maximized, since sensitive components such as heaters are eliminated from the capsule and maintenance requirements are confined to the readily accessible instrumentation.

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Fig. 1--Simplified diagram of
irradiation capsule

Fig. 2--Schematic diagram of gas-flow system

1. OUTER CAN END CAP (321 S/S)	11. LEAD TUBE (321 S/S)
2. EXHAUST GAS WELD ADAPTOR (INCONEL)	12. ARGON FILL TUBE (INCONEL)
3. SPECIMEN-HOLDER END PLUG (AGOT GRAPHITE)	13. END CAP, LOWER (INCONEL)
4. SPECIMEN HOLDER (AGOT GRAPHITE)	14. SPACER HELIX (INCONEL)
5. INNER CAN (INCONEL)	15. SPECIMEN CAN (MONEL)
6. END CAP, UPPER (INCONEL) (TC SEAL)	16. THERMOCOUPLES (10 INCONEL SHEATH)
7. EXHAUST GAS TUBE (INCONEL)	17. GAS-SUPPLY TUBES (INCONEL)
8. OUTER CAN (321 S/S)	18. THERMOCOUPLE STABILIZER - LOWER (304 S/S)
9. ADAPTOR (321 S/S) (TC SEAL)	19. THERMOCOUPLE STABILIZER - UPPER (304 S/S)
10. REDUCING ADAPTOR (321 S/S)	

Fig. 3--Longitudinal cross section of irradiation capsule

Fig. 4--Test results of typical heat-transfer mockup