High Temperature, High Pressure Gas Loop - the Component Flow Test Loop (CFTL)*

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ABSTRACT

The high-pressure, high-temperature, gas-circulating Component Flow Test Loop located at Oak Ridge National Laboratory was designed and constructed utilizing Section III of the ASME Boiler & Pressure Vessel Code. The quality assurance program for operating and testing is also based on applicable ASME standards. Power to a total of 5 MW is available to the test section, and an air-cooled heat exchanger rated at 4.4 MW serves as heat sink. The three gas-bearing, completely enclosed gas circulators provide a maximum flow of 0.47 m³/s at pressures to 10.7 MPa. The control system allows for fast transients in pressure, power, temperature, and flow; it also supports prolonged unattended steady-state operation. The data acquisition system can access and process 10000 data points per second. High-temperature gas-cooled reactor components are being tested.
Experiments

The CFTL was originally designed to test simulated segments of GCFR core elements, (i.e., fuel and blanket elements) under all normal and off-normal operating conditions including clad melting. The loop is now assigned to the HTGR program. The initial HTGR component being tested in the CFTL is the core support structure for the prismatic fueled HTGR. This support structure has vertical graphite posts mating with post seats; the interface has spherical surfaces of different radii. At the point of contact, Hertzian stress concentrations are produced; these result from the load caused by the weight of the core and the pressure gradient. This load is simulated in the loop. The effects of stress and oxidation, accelerated to simulate the 40-year reactor life in several months, are being studied.

It is planned to perform tests in support of the design, development, and performance confirmation of HTGR heat exchangers. In particular, the core auxiliary heat exchanger must perform at depressurized conditions. Thus, it is planned to equip the facility with a low-pressure, high-volume circulator specifically designed to provide the desired flow at depressurized conditions.

SUMMARY

The CFTL is a versatile high-pressure gas loop. Test vessel design with an attemperation flow at the pressure boundary permits very high temperature testing. The effective use of the ASME-BPVC provides a high quality and safe loop. The gas bearing, completely enclosed circulators assure that no parasitic contaminants will enter the loop. A fast data acquisition system augmented by a complete quality assurance program, enables the collection and presentation of the results of tests and guarantees their usefulness in reactor licensing procedures. An adequate power supply and a reliable heat removal system impose few limitations on the scope of the experiments. A sophisticated and elaborate control system makes possible the operation of extremely fast transients in pressure, temperature, power and flow while also facilitating prolonged unattended steady state operations. The loop has the versatility for further expansions as other testing needs arise.

ACKNOWLEDGMENT

The authors are indebted to many persons, in several organizations, who participated and contributed throughout the various phases of conceiving, designing, constructing, testing and operating the CFTL. We want to extend thanks to Albert G. Grindell who was the prime mover of the CFTL, and who, together with R. E. MacPherson, are the two who have participated throughout the CFTL program. Their diligent and able leadership has guided and directed the project through all its stages. Had it not been for Mr. Grindell's retirement, he would have been the primary author of this paper.
The Component Flow Test Loop (CFTL) is a high-pressure, high-temperature, high-power, closed-circuit gas loop. The loop utilizes primarily helium, but it can be used to circulate any gases inert to the loop components. Installed impurities measurement instruments and controls facilitate accurate maintenance of the concentrations of gas additives. The ten million dollar loop, (about twenty million dollar total when including research, development and test program to date) is installed at the Oak Ridge National Laboratory. The CFTL is funded by and operated for the U.S. Department of Energy.

The CFTL, conceived as the Core Flow Test Loop, was designed to the requirements for testing simulated segments of the core assemblies of the Gas-Cooled Fast Reactor (GCFR) (1). Thus, the loop acquired an elaborate and sophisticated data acquisition system capable of following and recording the fast transients in pressure, temperature, and flow that can be imposed on the test object.

In 1980 the CFTL was assigned to the High Temperature Gas Reactor (HTGR) Program. Some of the pressure and temperature requirements specified for the GCFR program were relaxed. The range of controlled gas impurity concentrations was increased, with special emphasis on graphite oxidation products. In contrast to the GCFR program where core elements simulated by groups of electric heaters were to be tested, the HTGR Program focuses on the effects of high-temperature helium on graphite and other components. This required the installation of a dedicated heater to raise the helium temperature to the level specified for the various tests. The first, partially completed, test related to the HTGR is the Core Support Performance Test, CSPT (2). The development and construction of the loop are described in a series of ORNL Gas-Cooled Program Reports (3-8).

The CFTL Facility

The paramount part of the CFTL is the test vessel discussed below. The gas is circulated through this vessel by three completely enclosed, gas-bearing circulators connected in series. From the vessel the gas flows to the heat exchanger, which is air-cooled, and then through a full-flow filter back to the circulator (9). Figure 1 is a schematic of the loop, and Figure 2 depicts an isometric drawing of the loop.

The loop is planned with a wealth of peripherals in support of its various functions and capabilities. Most of these are installed. An artist's rendition, Figure 3, shows prominently the control room and adjacent signal conditioning equipment that includes the impurity monitoring and control systems. Individual power supplies for the helium heaters and solid-state frequency control- lers, which are required for circulators speed control, are located on the first floor. The air supply equipment for the heat exchanger is placed on the roof.

Major Components

Test Vessel. The test vessel is fabricated of 16 in. sched. 80, type 304H stainless steel. The overall length is about 6 m. It is equipped with blind Graylock flanges at either end made of type 316 austenitic stainless steel. Due to the temperature and pressure specifications (and by agreement with AEC/ERDA/DOE) the vessel is designed to the ASME Boiler and Pressure Vessel Code (BPVC) Section
CFTL STAGE ALPHA

Fig. 1. CFTL loop schematic
Fig. 2. CFTL loop isometric
Fig. 3. CFTL facility showing planned and installed support equipment.
Ill, Division 1, Class 2 (HC) component rules. For those portions exceeding 427°C, Code Case N-47 was invoked. The vessel, shown in Figure 4, is designed with an inner liner that separates an attemperation gas flow from the gas flow past the heaters and test piece. The liner is not subjected to a differential pressure. The attemperation flow retains the vessel pressure boundary within design temperatures, while the gas temperature past the test piece may approach the melting point of the materials used. The gas exiting from the volume around the test piece mixes with the attemperation flow; this reduces the mixed stream temperature to the design limits of the pressure boundaries downstream from the test section.

The test vessel is also equipped with two observation ports that facilitate in-situ inspection of the test piece without opening the entire vessel. This arrangement is useful for interim non-destructive examinations during a test sequence.

The present (1984) arrangement includes two grade HT molybdenum heaters each rated at 250 kW, that can raise the helium temperature to 1000°C. The heaters are installed at the bottom of the vessel. Figure 4 also indicates a graphite test structure, which is one of the primary test objects of the CSTT (2).

Circulators. Three gas-bearing circulators installed in series were developed for the CFTL. Each circulator is completely housed in a vessel designed and built to the standards of the ASME-BPVC Section III, Class 2. The circulators are described in great detail elsewhere in these proceedings (10) and, therefore, no further details are provided here.

Heat Exchanger and Piping. The 4.4 MW air-cooled heat exchanger was designed and constructed by ORNL and is "N stamped." The heat exchanger is specified to remove heat over the range of possible operating conditions accommodating a maximum inlet temperature of 593°C. To achieve accurate control of the energy transfer, the forced air circulation for the exchanger is provided with a variable speed blower and remotely controlled louvers at both the inlet and exit of the heat exchanger. For the extreme case of high temperatures but low energy transfer, when the losses through the piping system exceed the energy additions, the heat exchanger is equipped with heaters to maintain specified conditions.

Loop piping segments, mostly nominal 6 in. and 8 in. sched. 80 304H stainless steel and one pipe section of 10 in. sched. 80 to house the full flow filter, were manufactured to the ASME BPVC Section III, Division 2, and assembled to the intent of the code.

Measurements and Controls

Data Acquisition System. Measurements acquisition and recording is based on a data acquisition system (DAS), the heart of which is a Digital Equipment Corporation PDP-11/34 with a computer controllable analog-to-digital converter. The DAS has a scanning and recording capability of 10,000 values per second. Special attention was devoted throughout the design, construction, and operation to the quality assurance of tests and test results. The principles and criteria used assure the applicability of 10 CFR 50, Appendix B, through compliance with the intent of ANSI/ASME N45.2 (11) and
Fig. 4. Test vessel schematic
ANSI/ASHE NQA-I-1979 (12). This was done so the results of testing are useful in the licensing of the nuclear reactors for which the tests are being performed.

Loop Control: The loop is controlled by manual or automatic means utilizing a dedicated direct digital control (DDC) and a programmable logic controller (PLC). Two scram levels are implemented: severe conditions result in a complete, immediate shutdown of the loop to assure safety; controllable excursions result in setbacks and adjustments with alarms. Emphasis is put on prolonged, unattended operation for running long-term — several months to a year — tests at primarily steady conditions.

Impurity Control and Measurement. The impurity concentration is controlled by a feed and bleed method. Very high purity gas (helium) is used as the matrix gas. Noble gas (argon) injection and concentration decay is used for leak rate determination. An automated gas chromatograph measures accurately the gas impurities such as CO, H2, CH4 and Ar. Four dedicated moisture analyzers determine on-line water vapor concentrations.

Flow Control and Measurement. Flow is controlled by varying the circulator speed and by pneumatically operated valves. The valves are used mostly to apportion appropriately the flow between the main test flow and the attemperation flow. Flow measurement is performed by vortex shedding flow meters (VSFM). These are basically commercially available VSFM's modified specifically for the CFTL (13,14). These VSFM's have a wide range of flow measurement of about 100:1 at an accuracy of 1% of reading.

Many temperature sensors, mostly thermoelements, are installed throughout the loop and the test structure.

Features and Capabilities. The major features and capabilities of the CFTL are:

Design limits:
- Pressure: 11.8 MPa (1715 psi)
- Temperature:
  - Loop: 593°C (1100°F)
  - Circulator: 450°C
  - Heat Exchanger: rated at 4.4 MW
- Volume: ~3 m³

Operation:
- Pressure: 10.6 MPa (1540 psi)
- Modified for HTGR: 7.2 MPa
- Temperature: see "Test Vessel" discussion
- Helium Flow: 0.47 m³/s
- Maximum (mass flow): 3.2 kg/s
- Power Available for Test: 5 MW
- Data Acquisition:
  - Channels Installed: 640
  - Acquisition rate: to 10000 s⁻¹
- Transients:
  - Flow rate: to 450 g/s²
  - Power pressure operating: 100% to 10% in 1 s
- Pressure operating: ~to ambient: 1 min (not installed)
A circulator that will increase the flow at low pressures (for low pressures only), is planned (see Experiments).

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10 Young, H. C. and A. O. White, Gas-Bearing Circulators for HTR Component Flow Test Loop, paper to be presented at ASME Winter Annual Meeting, New Orleans, LA, December 10-14, 1984 (these proceedings).
11 ANSI/ASME N45.2-1977, Quality Assurance Program Requirements for Nuclear Facilities.
12 ANSI/ASME NQA-1-1979 Quality Assurance Program Requirements for Nuclear Facilities.