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Second Generation PFBC Systems Research and Development Phase 2 Topping Combustor Testing at UTSI

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Conference Location:

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Conference Sponsor:

U.S. Department of Energy Morgantown Energy Technology Center

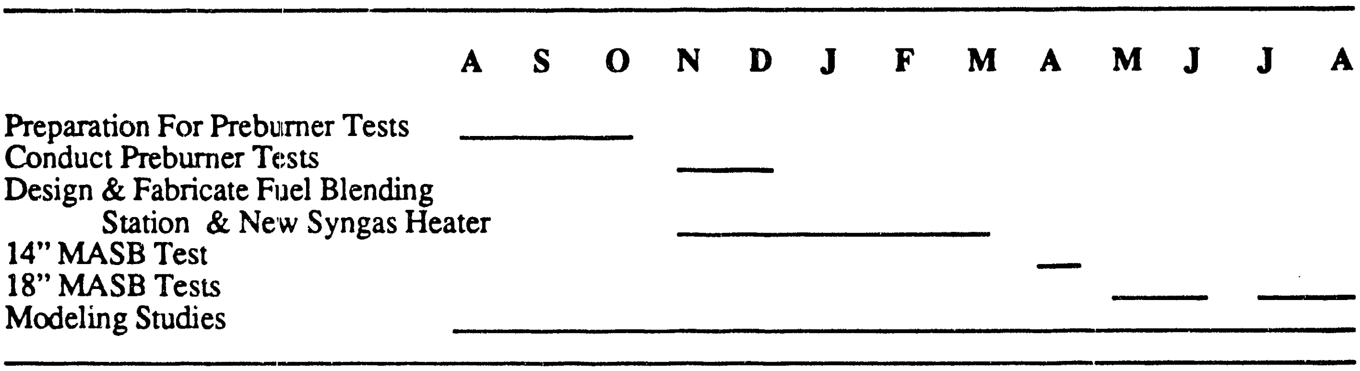
DISCLAIMER

Second Generation PFBC Systems Research and Development Phase 2
Topping Combustor Testing at UTSI

CONTRACT INFORMATION

Contract Number	DE-AC21-86MC21023
Contractor	University of Tennessee Space Institute Tullahoma, Tennessee 37388 (615) 455-0631
Contractor Project Manager	Norman R. Johanson
Principal Investigator	John P. Foote
METC Project Manager	Donald L. Bonk
Period of Performance	December 10, 1991 to December 31, 1992

1992 - 1993 TOPPING COMBUSTOR TEST SCHEDULE



OBJECTIVES

The objectives of the UTSI program are to provide testing services for development of the Westinghouse topping combustor for second generation pressurized fluidized bed power plants, and to support the combustor design and evaluation efforts by performing numerical combustor simulations.

BACKGROUND INFORMATION

Testing of a topping combustor for second generation PFBC power plants is presently being conducted at the University of Tennessee Space Institute (UTSI) as part of a DOE sponsored program. The tests are being conducted at the DOE Coal Fired Flow Facility, located adjacent to the UTSI campus. UTSI is a subcontractor to Westinghouse Electric Corporation, which is responsible for the topping combustor development program. Foster Wheeler Development Corporation is the prime contractor for the overall second generation PFBC plant program.

The topping combustor is a critical component in the second generation PFBC power plant. The topping combustor burns low Btu fuel gas produced by substoichiometric combustion of coal in a pressurized carbonizer. Char produced in the carbonizer is burned in a PFBC. Heat is extracted in the PFBC to generate steam, which is used for power generation. The PFBC also supplies preheated oxidant for the topping combustor. Both the fuel gas and oxidant are filtered and enter the combustor at about 150 psi and 1600°F. Temperatures over 2300°F can be achieved at the exit of the topping combustor. The second generation PFBC plant is shown schematically in Figure 1.

Requirements for the topping combustor are significantly different from typical gas turbine combustor installations. Heating value of the fuel is less than one-tenth that of natural gas, requiring a much larger volume flow of fuel relative to oxidant. Air is supplied at 1600°F, rather than the typical 700° to 800°F, making cooling of metal combustor surfaces more difficult. In addition, the fuel contains a significant amount of ammonia produced from the fuel-bound nitrogen in the coal. Thus, the combustor must be designed to minimize conversion of NH_3 to NO_x. The combustor must also be able to burn fuel oil or natural gas during plant startups and when the carbonizer is out of service.

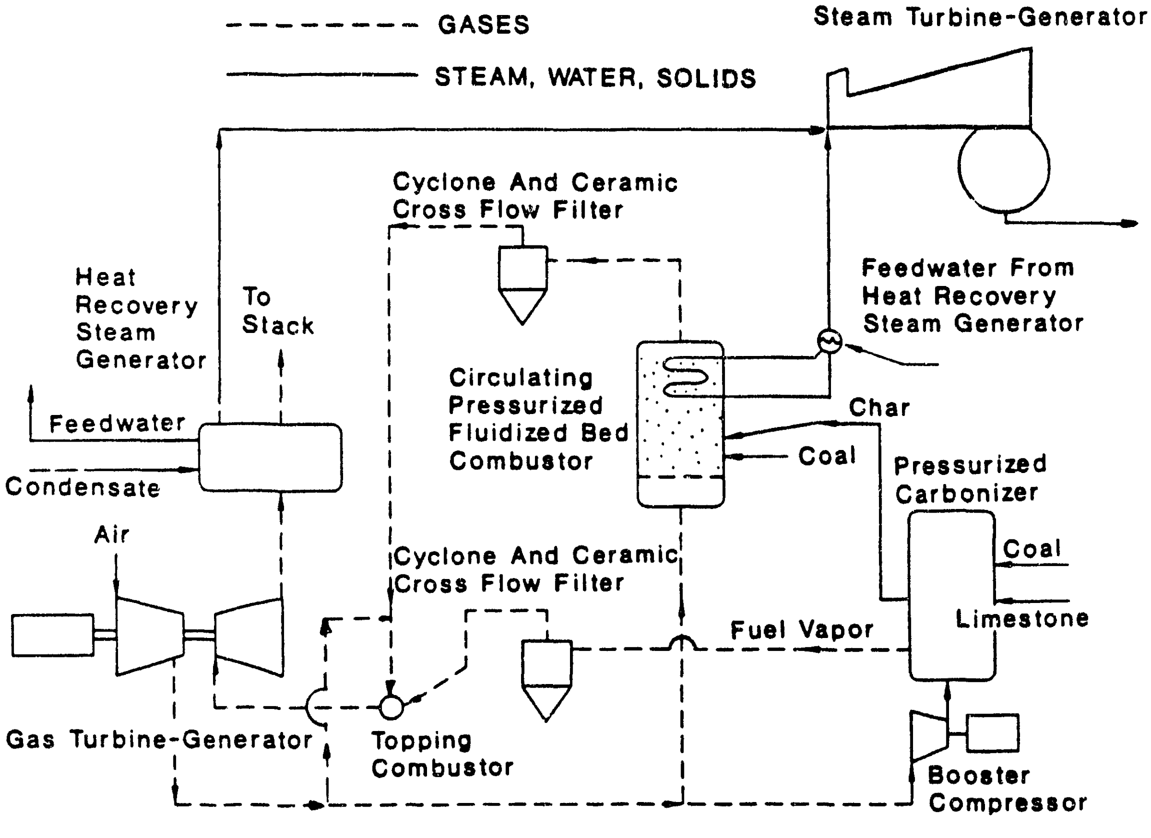


Figure 1. Second Generation PFBC Power Plant

The combustor design selected by Westinghouse is a multiannular swirl burner (MASB). The MASB is an all-metal combustor consisting of a series of concentric cylinders separated by annular swirlers. The swirling action of the combustion air provides a blanket of cooling air between the flame and metal combustor surfaces, and the flame chemistry is controlled to produce rich-quench-lean combustion, thus minimizing NO_x formation. A 14 inch diameter MASB design previously tested at UTSI is shown in Figure 2.

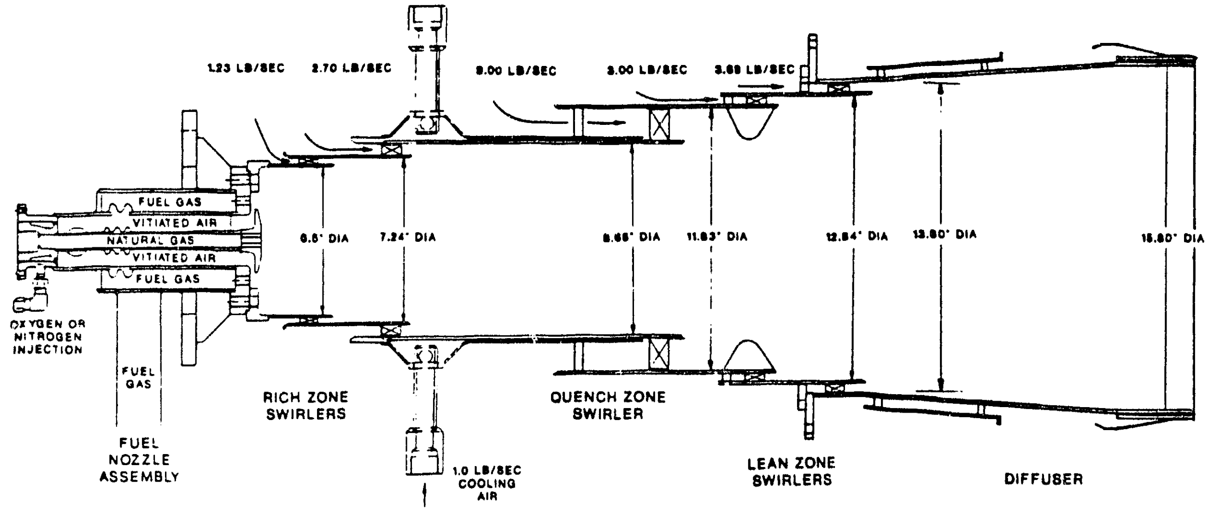


Figure 2. 14-Inch MASB Designed For 2350°F Exit Temperature

PROJECT DESCRIPTION

MASB Test Program

The topping combustor tests are being conducted at the DOE Coal Fired Flow Facility (CFFF). The CFFF was originally constructed to perform coal-fired MHD development work, and MHD bottoming cycle proof of concept testing is currently underway. The facility is designed to accommodate multiple experiments, and the Westinghouse tests use the same utilities and data acquisition system as the MHD tests. A list of the utilities available at the CFFF is presented in Table I. UTSI also has extensive fabrication capabilities, including a machine shop and ASME coded welding capability.

The CFFF data acquisition system is capable of sampling up to 2048 channels at 1 Hz (20 kHz for short durations). Additionally, up to 32 channels can be sampled at 1 MHz for characterization of high speed fluctuations. Typical data acquisition system inputs for Westinghouse combustor tests include approximately 210 thermocouple inputs, 15 voltages, 70 pressures, and 20 flow measurements.

TABLE I. CFFF UTILITIES AND SUPPORT SYSTEMS

FLUID	CAPACITY	TEMPERATURE (°F)	PRESSURE (PSIG)
1) No. 2 Fuel Oil	4.0 lb/sec	ambient	525
2) Natural gas	1.0 lb/sec	80	100
3) Compressed Natural Gas	0.6 lb/sec	120	250
4) Pulverized Coal	4.8 tons/hr	100	200
5) Oxidizer Air	7.0 lb/s	200	200
6) N_2 Gas	52,000 lb/hr	70 - 90	200
7) O_2 Gas	46,000 lb/hr	70 - 90	200
8) Softened Water	100 GPM	ambient	30
9) Cooling Water	4,500 GPM	95	140
10) Steam	21,000 lb/hr	350	150

200 HP Forced Draft Fan - 8,000 ACFM @ 70 In H_2O
350 HP Induced Draft Fan - 22,000 ACFM @ - 28 In H_2O

The Westinghouse combustor test rig, shown in Figure 3, contains the MASB combustor and a distillate oil-fired preburner combustor. About 17 lb/s of air is supplied to the test rig at 115°F and at up to 165 psia. The MASB is held within a series of containment cylinders. The entering air travels back along the outside of the containment cylinders and enters the preburner, where oil is burned to raise the air temperature to 1600°F simulating the hot PFBC exhaust gas.

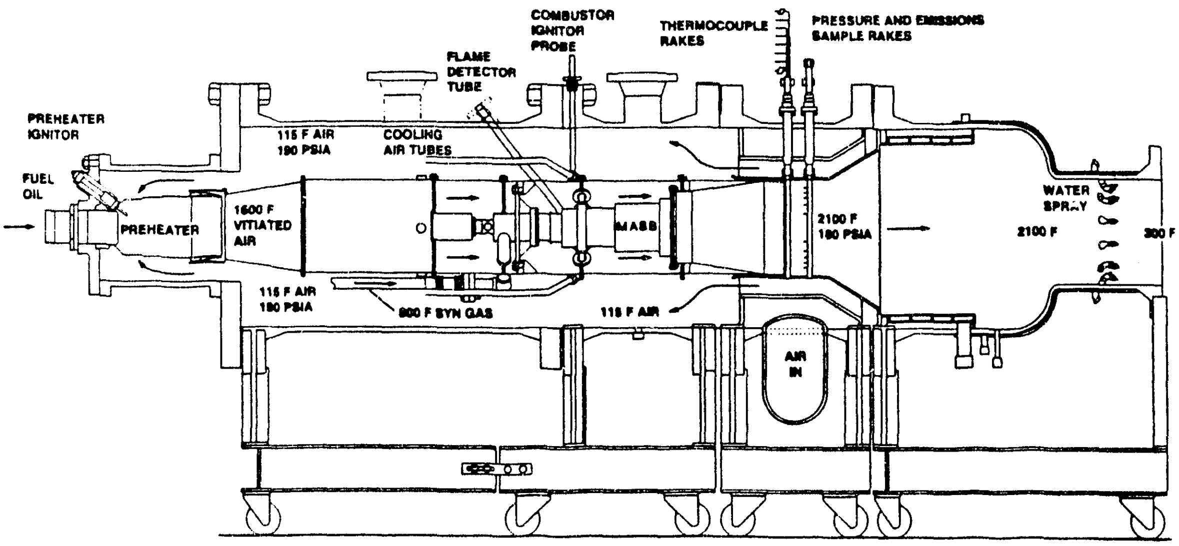


Figure 3. Preheater And MASB Installed In Test Rig

A total of four topping combustor tests have been performed at UTSI to date. Both 12 and 14 inch diameter MASBs have been tested. Three tests were conducted using a preblended syngas containing CH_4, H_2, and N_2 supplied in tube trailers. During the fourth test, natural gas and fuel oil were fired. Results of the syngas tests were discussed in a paper presented by Westinghouse at last year's contractors review meeting (Garland, et al., 1991), and the results of the natural gas/fuel oil test are discussed in the Westinghouse paper for this meeting (Pillsbury, et al., 1992). The tests performed to date are summarized in Table II, along with the tests planned through 1993.

Fuel System Upgrade

The fuel supply system is currently being upgraded to provide capability for blending syngas on site and to increase the fuel temperature entering the combustor to 1200°F. The fuel blending station, shown in Figure 4, will make it possible to more closely match the fuel composition for tests to the composition in the real plant, and will also make it possible to change fuel composition on line. The fuel cost is also reduced significantly compared to the cost for preblended gas supplied in tube trailers. CO and H_2 will be supplied in tube trailers, while N_2 will be supplied by a portable cryogenic system. Natural gas will supplied by the local gas utility distribution system and will be compressed on site to 250 psig. Steam will be supplied by a portable packaged boiler, and ammonia will be added in liquid form as NH_4OH.

During previous tests, an indirectly fired heater was used to heat the syngas entering the combustor to 800°F. Test results indicated that with 800°F syngas the air-fuel mixture in the combustor was

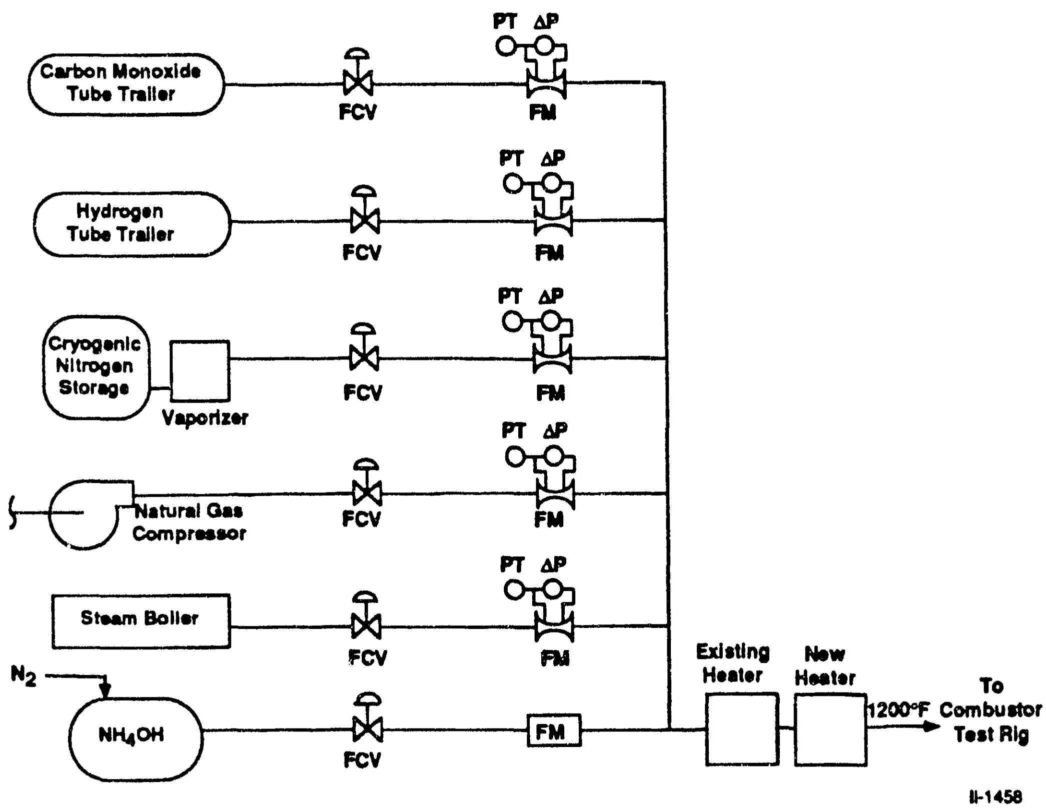


Figure 4. Fuel Delivery System

not hot enough to autoignite. The resulting ignition delay was detrimental to the staged combustion process required for low conversion of NH_3 to NO_x, and did not accurately reproduce conditions in the real plant, where the syngas will enter at 1600°F. Therefore, an additional heater is being added in series with the existing heater to raise the syngas temperature to 1200°F. A syngas temperature of 1200°F was selected because 1200°F is near the upper temperature limit for standard commercial gas heaters. Chemical kinetics calculations indicate that with 1200°F syngas, the air-fuel mixture in the combustor will be hot enough to autoignite in less than 50 ms.

Numerical Modeling

In addition to performing topping combustor tests, UTSI is also supporting Westinghouse by performing computer simulations. Various MASB configurations are being modeled using a modified version of the KIVA-II computer program (Amsden, et al., 1989). KIVA-II is a computer program for the calculation of time dependent, two or three dimensional chemically reactive fluid flows with sprays. KIVA is applicable to laminar or turbulent flows, subsonic or supersonic flows, and to single-phase or dispersed two-phase flows. As received, the program was set up to simulate an internal combustion engine. It has been adapted to model combustion in the MASB combustor.

Table II. Completed and Planned MASB Tests at UTSI

Tests Completed	Test Conditions	Date
12 inch diameter MASB	2100°F exit temperature firing syngas	October 4-5, 1990
12 inch diameter MASB	2100°F exit temperature firing syngas	October 19, 1990
14 inch diameter MASB	2350°F exit temperature firing syngas	April 13, 1991
12 inch diameter MASB	2100°F exit temperature firing natural gas and No. 2 fuel oil	July 19, 1991
Tests Planned	**Test Conditions**	**Date**
700°F and 1600°F preburners		November 1992
Redesigned 14 inch diameter MASB	2350°F exit temperature firing syngas	April 1993
18 inch diameter MASB	natural gas with 700°F preburner natural gas with 1600°F preburner syngas with 2100°F exit temperature syngas with 2350°F exit temperature	Summer 1993

In the MASB designs tested to date, a small amount of air is introduced in the fuel nozzle area, and additional air is introduced through two swirlers in the primary zone. The total primary air flow rate is selected to produce an equilibrium flame temperature in the primary zone in the range of 2700° to 3000°F, corresponding to a fuel-air ratio of about 1.6. When this arrangement is modeled using the CFD code, the results indicate that combustion occurs mostly downstream of the two primary air swirlers. A cold inner core of syngas exists, and chemical reactions occur mostly near the edge of this core, where the fuel-air ratio is near 1.0. The model results are somewhat confirmed by the observation that the metal temperatures in the nozzle area drop when syngas flow is started during tests.

Although the CFD model does not include any NH_3 reactions, it can be inferred that no ammonia reactions occur in the cold core of syngas. The NH_3 reactions occur near the edge of the syngas core, resulting in higher conversion of NH_3 to NO_x. This conclusion is supported by the test results to date, which show that NH_3 conversion to NO_x is significantly higher than expected.

Based on the test results and the CFD model results, the MASB is being redesigned to produce more rapid mixing of the air and syngas in the primary zone. The CFD code is being used to evaluate options for the new primary zone design.

FUTURE WORK

During November 1992, tests of two preburners to be used in the 18 inch MASB test program will be performed. The 18 inch MASB is designed for use in the Wilsonville Pilot Plant, and two preburners are required to simulate operation of the plant. One preburner will provide preheated oxidant at 1600°F to simulate normal plant operation, and the other preburner will heat the air to 700°F to simulate compressor discharge air that would be used in the topping combustor during startups and when the PFBC is off line. Poor temperature distribution exiting the preburner has been a concern throughout the test program, and the tests are being performed to insure that the exit temperature is uniform for the upcoming MASB tests.

Work is underway on design of the fuel blending station. The fuel blending station and new syngas heater will be installed in time to support the next MASB test, which is scheduled for April 1993. The next MASB test will be a retest of the 14 inch MASB, with a redesigned rich zone intended to produce more rapid mixing of the fuel and primary air. Four tests of the 18 inch MASB are planned for the summer of 1993. These tests include a test firing natural gas with the 700°F preburner to simulate plant startup, a test firing natural gas with the 1600°F preburner to simulate plant operation with the carbonizer out of service, and two tests firing syngas with the 1600°F preburner to simulate normal plant operation.

CFD and kinetics modeling studies will continue in support of the design efforts for the 14 inch and 18 inch combustors, and to aid in analysis of the test results.

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