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Title: "Materials Exposure Test Facilities for Varying Low-Btu Coal-Derived Gas"

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Abstract: As a part of the United States Department of Energy's High Temperature Turbine Technology Readiness Program, the Morgantown Energy Technology Center (METC) is participating in a Ceramics Corrosion/Erosion Materials Study. The objective is to create a technology base for ceramic materials which could be used by stationary gas power turbines operating in a high-temperature, coal-derived, low-Btu gas products of combustion environment. Two METC facilities have been designed, fabricated and will be operated simultaneously exposing ceramic materials dynamically and statically to products of combustion of a coal-derived gas. The current studies will identify the degradation of ceramics due to their exposure to a coal-derived gas combustion environment.

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149

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INTRODUCTION:

The current options for fuels used by electrical power generation plants have been limited by shortages and increasing prices of oil. There exists a need for alternative fuels and one such fuel is low-Btu, coal-derived gas. To make such a fuel competitive, the capital investment of gasifying coal and gas stream cleanup could be offset by operating the turbine more efficiently. This can be done by increasing inlet turbine temperatures, however, current turbine material limits are exceeded. Therefore, exotic materials or complex cooling techniques are needed. To date there is little data from which design criteria can be drawn in a coal combustion high temperature-environment.

The Morgantown Energy Technology Center (METC) Ceramic Corrosion/Erosion (C/E) Studies are part of the Department of Energy (DOE) High Temperature Turbine Technology Program. The program's overall goal is to advance the firing temperatures of gas turbines from the current 1900^o-2000^oF to the range of 2600^o-3000^oF as well as offer a long life in a combustion of products of coal or coal-derived fuel (Reference 1).

The primary objective of the METC project is to create a technology base for ceramic materials to be used in stationary gas power turbines. These turbines will function in a high-temperature, coal-derived, low-Btu gas products of combustion (POC) environment. The technology base will consist of describing the exposure environment, characterizing the resulting chemical corrosion and mechanical erosion to the materials, and measuring the effects of low-Btu gas POC on the materials by comparing exposed specimens with similar materials that have not been exposed to the POC.

The DOE, Division of Fossil Fuel Utilization (FFU), has overall responsibility of the project. A variety of different ceramic test specimen materials have been provided through separate DOE/FFU contracts with Westinghouse and AiResearch. Illinois Institute of Technology Research Institute (IITRI) and the Air Force Material Lab, Wright-Patterson Air Force Base (AFML) have the responsibility of characterization of the materials. METC has the responsibility of providing the coal producer gas, methodology of subjecting the materials, and a characterization of the exposure environment. The relationship between organizations is shown on Figure 1.

This project involves using a coal-derived, low-Btu gasifier as the fuel source. The low-Btu gas has made the following considerations necessary in the design and operation of the exposure test facilities as compared to oil or natural gas.

- o The percentage of fuel to total flow volume must be increased to achieve the same heating value.
- o The achievable flame temperature is reduced.
- o The gas heating value is variable.
- o The flammability limits are different.

For these exposure tests the METC 42-Inch Gas Producer (Reference 2) will supply a low-Btu gas to both the Static and Dynamic Facilities at maximum flow rate of 50,000 scfh total. The gas is manufactured from a reaction of bituminous (Pittsburgh No. 8 seam) coal, super heated steam, and air. The gas is passed through a clean-up system prior to entering the C/E facilities.

Two facilities (Figure 2) have been designed and fabricated and will be operated simultaneously (Reference 3) exposing ceramic materials to products of combustion of the coal-derived gas. The facilities are designed to burn the low-Btu gas in a controlled manner. The "Dynamic Facility" will operate at a temperature of 2600°F and a gas velocity of 1,000 feet per second for a scheduled 1,000 hours. The "Static Facility" will operate at a test matrix of three temperatures (2600°F, 2200°F, and 1850°F) and three durations (100, 300, and 1,000 hours) at relatively zero gas velocity.

There are fourteen (14) different material types (Figure 3) and a total of 760 different test specimens. Of the total, 700 are specifically for the Static test and 60 are specifically for the Dynamic test. During the tests, 504 Static test specimens will be exposed to nine (9) different conditions (three temperatures and three time durations) in a products of combustion environment. The remaining 196 Static specimens will be used for the baseline characterization. The Dynamic test will have all 60 specimens dedicated for the exposure tests, but 48 specimens will be used as spares.

The material characterization to be performed by IITRI and AFML (Reference 4) will include pre-exposure, baseline, and post-exposure, which will measure physical, chemical, and mechanical properties of the ceramic specimens. Although the characterization may not be statistically valid, a sufficient number of specimens will be exposed to permit a qualitative measure of the materials degradation.

The "Dynamic" test should give an indication of the combined corrosive/erosive effects while the "Static" test should indicate the predominately corrosive effects. By comparison of both tests, there should be a measure of each effect on the ceramic specimens. At a minimum the tests should eliminate materials that are not suited to function in a combustion in a coal-derived gas environment. Although follow-on tests may be needed, the current studies will identify the degradation of ceramics due to their exposure in a coal-derived gas combustion environment. This will serve as ceramic materials technology base for future stationary gas power turbines.

STATIC FACILITY:

The major components of the Static facility (Figure 4) are: test cells, temperature conditioning chambers, test specimen racks, exhaust section, and air/fuel system.

Test Cells: The furnace consists of four separate test cells enclosed by a single-steel housing. The cells are constructed with an inner row in each of the four cell walls of high-density, 85 percent alumina brick.

The high alumina is used to minimize spalling and test specimen contamination. An additional two rows of refractory brick between adjoining chambers, the steel housing and the center exhaust column provide insulation that should keep the exterior metal temperature to less than 300°F. The roof and floor of each cell are of cast one-piece refractory construction. Three cells operate from coal-derived producer gas at the respective temperatures of 1,850°F, 2,200°F, and 2,600°F. The fourth cell is operated with natural gas at approximately 2,600°F and will be equipped with heat tubes to provide preheat combustion air to the producer gas burners. The natural gas cell will also help the pilots in preheating the other cells and maintain temperature of the furnace in the event of a producer gas shutdown or other problems. Each cell has a single top-fired nozzlemix burner that will be placed about four feet above the higher of the two test racks. This should be enough distance to prevent flame impingement on the specimens and provide uniform velocity and heat profiles at the test specimens. There will be a sapphire window in the roof of each cell to allow viewing on the upstream side of the test specimens.

Temperature Conditioning Chambers: Additional chambers are attached to the metal housing at the entry/exit port to the producer gas test cells. There are two doors that the test racks must pass through before the racks can be positioned in the test cell or brought out into the room. One door is located on the metal housing and the second on the temperature conditioning chamber. The chambers are used to control preheating and cooling of the test specimens before entering and after leaving the test cells. The chamber doors have quartz windows to view into the test cell and chamber.

Test Specimen Racks: There are two rack locations in each producer gas test cell of the furnace. Each rack will hold 60 specimens. The specimens are supported in two places 0.25 inches from each end. The supports are of a tubular construction, so that there is only line contact between support and specimen. Looking down at a fully loaded rack, spacing of the specimens is alternated between the upper and lower racks so as to help prevent shadowing the specimens from one another in the flow of POC. The racks are constructed of a high-alumina refractory material. Figure 5 shows the configuration of the test specimen rack.

Exhaust Section: The four cells have a common exhaust flue located at the center of the furnace. The exhaust POC is cooled by air blown in through a duct near the floor of the furnace. The exhaust is piped to the stack which is vented out of the building. The exhaust gas is cooled to approximately 500°F.

The Air/Fuel System: The system consists of preheated air and producer gas supplying three separate burners with natural gas and non-preheated air supplying the fourth cell.

The air supply to the producer gas fired cells is taken from the station air supply and regulated. The combined air temperature and pressure is determined after a standard orifice flowrate measurement. The flowrate is divided into three separate lines where it is preheated to approximately 500°F in the natural gas fired test cell before being injected into the burner.

The producer gas flow is taken from the 42-Inch Gas Producer supply line. The Static facility flowrate is measured using a standard orifice before the flow is divided into the three separate lines to the burners. Each line has a manually reset safety shutoff valve controlled by an Ultra Violet (UV) detector at the burner, a pressure control valve receiving thermocouple signals originating from the respective test cell, and a solenoid to shut-off burner. The burners are Pyronics nozzle mix burners adapted for low-Btu gas through modified air tubes. The pilot flames in addition to the fourth burner will operate on natural gas and instrumentation air.

DYNAMIC FACILITY:

The major components of the Dynamic Facility are: the combustion chamber, test section, specimen holders, exhaust section, and air/fuel system.

Combustion Chamber: The chamber is made up of low-carbon steel metal housings that have alumina-lined inner surfaces and other refractory materials to maintain an approximate uniform metal temperature of less than 300°F.

The chamber consists of: the burner section, the combustion section, and the transition section. The combustion chamber provides an inner combustion zone with a diameter of 42 inches and a length of approximately 51 inches. The three sections' metal housings are bolted together, with the inner layers of the refractory materials overlapping to reduce heat paths.

The burner section is a frustrum configuration with six equally spaced nozzle mixing burners around the circumference offset by 30 degrees. With this arrangement the flow within the combustion section should be a swirl or vortex type pattern. On the flat end of the section located in the center is a sapphire window which will be used to view the upstream side of the test specimens.

The combustion section is in a cylindrical configuration. The volume of this section should be large enough to allow a residence time for complete combustion to take place and long enough to prevent any direct flame impingement on the test specimens. There will be two pressure ports located 90 degrees apart to measure the total pressure in the section. Two temperature probes located 90 degrees apart will measure the internal temperature in the section. There are three thermocouples at different depths on each side to measure the refractory temperature. The pressure ports and temperature probes all lie in the same plane.

The transition section is a cylindrical configuration which allows the diameter of the combustion section to reduce to the diameter of the test section. The reduction is done with the inner refractory material in the shape of standard ASME nozzle. The increase of velocity is achieved during this transition. In addition, there are two pressure ports located in line with the pressure ports in the combustion section to measure the static pressure after the reduction in cross sectional flow area.

Test Section: The test section is a cylindrical configuration with an inside diameter of 5.5 inches. The refractory material is tapered before and after the test specimens to provide a smooth transition of flow by maintaining the approximate same cross sectional area in the plane of the specimen (i.e., at

the plane where specimens are inserted, the refractory has been constructed such that material approximately equal to the cross sectional area of the 12 specimens has been removed). There are 12 equally spaced radial ports through which the test specimen holders position each specimen.

Test Specimen Holder: The test specimen will be held in place by an air-cooled stainless steel specimen holder (Figure 7). The holders can be individually inserted, positioned, or removed from the test section. Each test specimen is held in place in the holder by clamping on a one-half inch length of one end of the specimen. Four spring-loaded jaws will provide a uniform clamping force around the circumference of the test specimen. There will be a layer of cloth alumina between the jaws and the test specimens. By air cooling the holder, the base of the jaws will be at or below 1100°F to reduce any chemical interaction between materials. The temperature of the base will be monitored continuously. The fully inserted position should expose a length of 2.25 inches to the POC stream. A second position locating the test specimen in the refractory liner of the test section will keep the specimen warm, but will prevent exposure to moving gases which is required if the facility is operating on natural gas pilot burners. In addition, the holder is designed to protect the specimen when removed from the test section by totally enclosing the specimen.

Exhaust Section: This section is made up of a catcher, elbow, spray ring, extension, recuperator, and stack.

The catcher includes an expansion nozzle from the test section's 5.5-inch diameter to a 12-inch diameter. This section has a trap which will hopefully contain any broken test specimens for retrieval. It also contains the gas sampler probe (Venturi Pneumatic Pyrometer) which has a dual function of drawing gas to be analyzed and measuring the gas temperature of the test section. In addition, the catcher section will contain two sapphire window viewing ports with a diameter of two inches each. The window will be used to view the downstream side of the specimens.

The elbow section is to allow insertion of the gas sampler probe and personnel access to the rear viewing ports. The POC path inner diameter is twelve inches. The first spray ring is to allow cooling water to mix with the hot flue gas to reduce the flue gas temperature to approximately 1800°F before entering the recuperator. An extension section is used to allow mixing of steam and POC for cooling. All sections to this point are refractory lined. The recuperator is used to heat the combustion air to approximately 500°F. POC gas is further cooled by injecting water to the stack, such that the maximum temperature is 500°F. A metal bellow allows for expansion of the exhaust piping.

The Air/Fuel System: The system consists of preheated air and producer gas supplying six burners.

The combustion air system begins with a turbo-compressor which is rated at 1450 cfm at 100 inches water. The turbo-compressor forces room temperature air through the POC gas-to-air recuperator which heats the air to approximately 500°F. The preheated air then goes through an automatic damper system which regulates the pressure of the air to 2.5 psig. The excess air is exhausted. The air temperature and pressure are monitored as well as its flowrate through a standard orifice. The hot air flow is divided into the three separate lines which contain a control valve to maintain the required air flowrate. The control valve is slaved by a mechanical linkage to the producer gas control valve. After the control valve, each of the three lines are divided again so that each divided line supplies air to one burner. The burners are in sets of two (2) i.e., 1-2, 3-4, and 5-6.

The producer gas is taken from the 42-Inch Gas Producer where it is divided from the Static facility. The flowrate, pressure, and temperature are measured. The pressure is regulated to set the air/fuel ratio as controlled by a temperature measurement from the test section. The flow is divided into three separate lines where each line has a manual tripped safety valve and a control valve to control flowrate. The control signal for the valve comes from the differential pressure reading from the test chamber. Each line is further separated so that each divided line supplies one burner. Each burner set line has a solenoid valve to shut off individual burners.

The burners are 4-inch Maxon series "WR" Wide-Range burners specially drilled for low-Btu gas. The burners are a nozzle mixing type with multiple-stage burner block tunnels. Each burner is rated at 1,000,000 Btu/hr. The pilot assemblies will operate on natural gas and instrument air. Each burner is equipped with an Ultra Violet (UV) Flame Detector which controls the manually reset safety valves. The detector shuts off the producer gas in the event flame is lost. In addition, if the pilot flame is lost a solenoid closes the natural gas line.

CONTROL SYSTEMS:

The Static and Dynamic Facilities temperature and velocity control systems are designed to operate in either manual or automatic mode. The manual mode is used during start-up, whereas the automatic mode is for steady-state operation. Because the producer gas heating content may have wide variations and may vary in an unknown fashion, the facilities have a significantly different temperature control method than natural gas, oil, or even direct coal-fired systems. Since both the Static and Dynamic Facilities have a constant heat load, to maintain a constant temperature within each chamber, the fuel to air ratio must be adjusted to compensate for the variability of heat content of the producer gas. The method chosen for the METC facilities is to control fuel to air ratio by varying the producer gas supply pressure while maintaining a constant combustion air pressure. In addition to the temperature control which is similar for both the Static and Dynamic control systems, the Dynamic Facility is designed to control the velocity of the POC at the test

specimens. Velocity is a derived parameter from the measurement of the gas stream temperature and the pressure drop due to the acceleration from combustion section to test section. The velocity is varied by altering the producer gas and combustion air lines mass flow rate through butterfly valves. These valves are mechanically linked to maintain the same fuel to air ratio. The constant temperature systems then allows the velocity to be controlled by the pressure drop. The velocity and temperature control parameters are only weakly coupled (Reference 5).

INSTRUMENTATION:

The facilities instrumentation is depicted in Figure 8. Approximately 50 temperatures and pressures are measured by conventional thermocouples and transducers, respectively. Several pieces or packages of specialized equipment are described below.

Gas Analysis System: Characterization of the environment to which the ceramic specimens are subjected is of primary importance for a successful test. A gas analyzer system packaged by Beckman Instruments will measure the composition of the products of combustion generated from the Static and Dynamic facilities. The primary unit will be time-shared between the Static and Dynamic facilities. A second oxygen analyzer will monitor a facility while one is on the primary analyzer system. It is important that both facilities maintain an oxidizing atmosphere in order to avoid rapid degradation of the ceramic test specimens. The products of combustion (POC) primary analyzer consists of seven instruments, i.e., analyzers for hydrocarbons, oxygen, oxides of carbon, oxides of sulfur, oxides of nitrogen, and water. Particle and minor composition sampling will be performed by the METC Analytical Laboratory.

Venturi Pneumatic Pyrometer: A Land Venturi Pneumatic Pyrometer (VPP) (Reference 6) measures gas temperature by comparing the gas density at the unknown "hot" temperature with its density at a lower temperature measured by means of a platinum resistance thermometer. The VPP consists of a watercooled stainless steel probe which contains two venturis. Pressure tap fitted across each of the two venturis allow the pressure drop to be measured and thus a hot and cold density which yields a hot gas temperature. A Land Model VPP4 is being used.

Calorimeter: A high-speed calorimeter, FLO-CAL (Reference 7), is used to continuously measure the gross heating value Btu/scf of the producer gas prior to combustion. The FLO-CAL operates on the simple principle that variations in the heat released from the continuous burning of a fuel gas sample in a test burner can be exactly offset by adjustment of the burner air flow rate. This rate, in turn, can be measured and calibrated within a desired calorific range.

Thermovision Camera: An AGA Model 680 (Reference 8) thermovision camera is used to monitor thermal characteristics of the materials during the test. The unit measures the infrared radiation emitted by the test specimens and is transmitted by an IR optical system to an IR detector element and display.

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FIGURE 1: Participants Flow Chart

FIGURE 2: Corrosion/Erosion Studies Facilities

FIGURE 3: Test Specimen Material Types and Usage

	MATERIAL	VENDOR	SPECIMENS PER MATERIAL	SPECIMENS FOR STATIC TEST	SPECIMENS PER 9 STATIC CONDITIONS	SPECIMENS FOR DYNAMIC TEST	SPECIMENS STATIC BASELINE	SPARE (COMPARISON) SPECIMENS DYNAMIC
1	SINTERED SIC	AIRESEARCH (CARBORUNDUM)	55	36	4	1 WITH 3 SPARES	14	1
2	CVD Si_3N_4 COATING ON REACTION BONDED NITRIDE	AIRESEARCH (UCI/NORTON)	55	36	4	1 WITH 3 SPARES	14	1
3	CNTD AlN COATING ON HOT PRESSED AlN	AIRESEARCH (CHEMETAL/CARDOLUNA)	55	36	4	1 WITH 3 SPARES	14	1
4	HOT PRESSED Al_2O_3 ZrO_2	AIRESEARCH (MLRO, INC.)	55	36	4	1 WITH 3 SPARES	14	1
5	50/50 MOLE % SPINEL	AIRESEARCH (GREENLEAF)	55	36	4	1 WITH 3 SPARES	14	1
6	HOT PRESSED PHASE SIALON	AIRESEARCH (NORTON)	55	36	4	1 WITH 3 SPARES	14	1
7	IPSN (NC 34)	WESTINGHOUSE (NORTON)	55	36	4	1 WITH 3 SPARES	14	1
8	SSC WITH CVD COATING (A SIC/SI CNTD COAT)	WESTINGHOUSE (CHEMETAL/CARBORUNDUM)	55	36	4	1 WITH 3 SPARES	14	1
9	IPSC (NC 203)	WESTINGHOUSE (NORTON)	55	36	4	1 WITH 3 SPARES	14	1
10	SINTERED Si_3N_4	WESTINGHOUSE (GTE SYLVANIA)	55	36	4	1 WITH 3 SPARES	14	1
11	IPSC WITH CVD COAT (NC 203/SIC CNTD COAT)	WESTINGHOUSE (CHEMETAL/NORTON)	55	36	4	1 WITH 3 SPARES	14	1
12	IPSN (EXPERIMENTAL)	WESTINGHOUSE	55	36	4	1 WITH 3 SPARES	14	1
13	Al_2O_3 -SIC COMPOSITE	WESTINGHOUSE (CERADYNE)	50	36	4	0	14	0
14	HS- Si_3N_4 (NC-350)	WESTINGHOUSE (NORTON)	50	36	4	0	14	0
TOTALS			760	504	56	12 WITH 36 SPARES	198	12

FIGURE 4: Static Facility

FIGURE 5: Static Facility Test Specimen Rack

FIGURE 6: Dynamic Facility

FIGURE 7: Dynamic Facility Test Specimen Holder

FIGURE 8: Corrosion/Erosion Studies Instrumentation