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Gas Turbine Materials Evaluation Program Utilizing Coal Derived Gaseous Fuel

A description of a test facility established by the University of Pittsburgh under the sponsorship of the U.S. Department of Energy for (he purpose of obtaining dynamic and static test data on the erosion-corrosion characteristics of candidate materials being considered in support of the Department of Energy's High Temperature Turbine Technology Program. The goal of this program is to establish a gross relationship between the gas turbine materials and the coke oven gas fuel being furnished by the Jones & Laughlin Steel Corp. 24-7 gas turbine engines reconfigured to burn gaseous fuel. The engines have been furnished by the Department of Defense on a loan basis. The facility is currently operational with data being obtained on INCO-713 rotor material whichis the material currently used in the 24-7 engines. Other materials and coatings will be evaluated.

INTRODUCTION

Within the Department of Energy (DOE) Advanced Gas Turbine Central Power Systems Program, the Open Cycle High Temperature Turbine Technology (HTTT) Program was begun in 1976. This HTTT Program called for the development of advanced cooling techniques, ceramics technology and combustor technology required for gas turbines with nominal turbine inlet temperatures on the order of 1427 C (2600 E). This elevated temperature goal was established in order to maintain overall combined cycle generating plant efficiency over 90%. Phase I of this program was completed in 1977 by four contractors simultaneously; the contractors were; UTC, Westinghouse, G.E. and Curtiss-Wright.

Phase II was begun in 1977 by two contractors, G.E. and Curtiss-Wright, and is presently about 3/4 completed.

The HTTT program had and still has, an ongoing need for substantial materials investigation reflecting the need to select gas turbine materials of construction which will have extremely long operating durability (up to 30 years) when exposed to the hot products of combustion of coal derived fuels. Each of the contractors presently engaged in Phase II activity is pursuing his own materials investigations and, in fact, has made some materials selections based on literature searches as well as his own test programs. However, almost all of these test programs, both screening tests and later corrosion/endurance material evaluation have been done with simulated coal-derived fuels rather than with fuels actually derived from coal. (One test of approximately 60 hours duration used the output, of a coal gasifier.)

This desire to obtain materials test results using real coal-derived fuel rather than simulated, both static and dynamic, was what prompted the DOE to obtain the very small gas turbine and to operate it for extended periods of time using coke oven gas as a fuel. (Static tests using the same fuel will also be performed.)

The goal of this program is to establish a gross relationship between the gas turbine materials already selected by the two manufacturers engaged in the Phase IT program while burning coke oven gas furnished by the Jones and Laughlin Steel Corporation. The small gas turbine is a Williams Research Corporation 29-7 engine reconfigured to burn gaseous fuel (furnished by the Department of Defense on a loan basis -- one operating and one spare). As these programs progress, both contractors will accumulate more of their own test data; however, the University of Pittsburgh program is intended to augment the acquisitions for the materials selected. The basic thrust is the desire to build up several thousand actual test hours operating on real gas derived from coal.

TEST FACILITY

The turbine test facility is designed to be a mobile unit. Figure 1 shows the test facility located at the By-Product Plant of the Jones & Laughlin Steel Corporation, Pittsburgh, Pennsylvania. Five batteries of coke ovens are normally in operation at this plant, providing sufficient excess gas capacity above normal plant requirements to easily provide fuel for engines of the size that can be accommodated in the trailer.

Instrumentation is installed to monitor the key engine operating conditions, such as exhaust gas and bearing temperatures as well as performance characteristics (air and fuel flow rates). A standard ASME bellmouth is used to determine air flow rates; the fuel flow rate is determined using a standard ASME sharp edge orifice.

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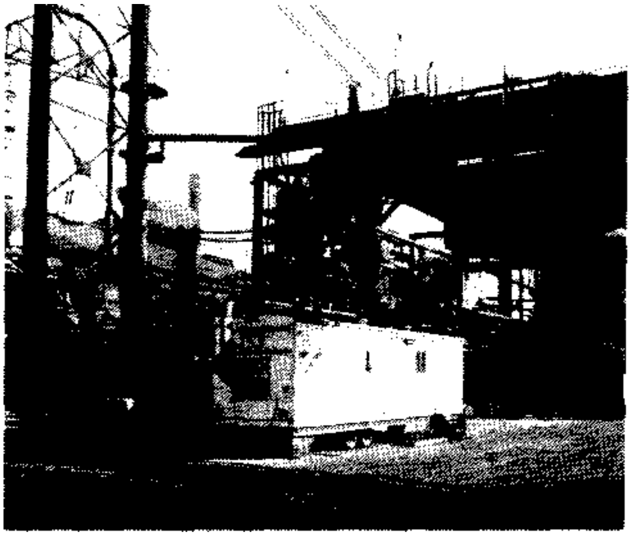

Fig. 1 Gas turbine test facility

The coke oven gas supplied to the engines is "clean" gas that has been processed through the By-Product Plant. Supply line pressures range from 2 to 6 psig (14 to 40 kPa) so the gas must be compressed to approximately 100 to 120 psig (690 to 825 kPa) to provide adequate pressure for control of the flow rate and for injection into the engine combustion chamber. Prior to compression the gas is filtered to remove particles and some residual tar which survives the by-product removal processes.

The approximate composition of the coke oven gas as measured during the initial tests of the WR 24-7 engine was as follows;

Component	Percent by Volume
CO_2	2.5
0	1.0
C6	6.o
H,	51.2
4	29.5
N_2	6.7
Higher Hydro-carbons	3.1

Of more importance in the present work, however are the sulfur compounds, two of which, Carbonyl sulfide (CQS) and Carbon disulfide, (CS) are present in small amounts ranging frog 3 to 1 grains per 100 dry scf,(0.07 to 0.35 g/m)• Hydrogen sulfide (H S)is present in larger amounts, ranging frog 50 to 50 grains per 100 dry scf (1 to 8 g/m).

Net hating value of the fuel averages about 480 Btu/ft (18 mJ/m) and the relative density is approximately 0.40.

DESCRIPTION OF ENGINE

The engine utilized for the test is the Williams Research Corporation WR 24-7 aircraft turbojet unit. It was designed for use with JP-4 aviation fuel. The WR 24-7 was selected as the test device because it was a turbojet unit which required a minimum of additional test stand facilities. For example, no dynamometer was necessary nor was jet thrust to be measured for this materials elevation run.

Figure 2 is a frontal view of the 24-7 engine mounted on the test stand. The gas regulators and other auxiliary equipment required for operation with the gas phase fuel are visible on each side of the engine.

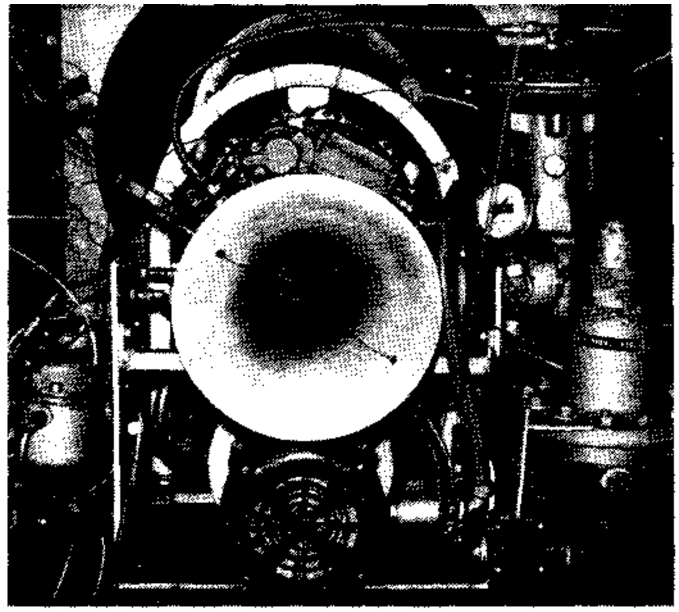

Fig. 2 WR 24-7 engine with auxiliary equipment on test stand

The major conversion efforts involved in the engine were the switchover from JP-4 to coal-derived coke oven gas and consideration of operating times of very short duration (such as a cruise missile would encounter) changing to long-term endurance operation. To make the fuel change, it was necessary to design and fabricate internal and external gas manifolds and modify the diffuser, heat shield and burner. The new external manifold consists of a formed aluminum tube mounted on the diffuser front face and feeds the gaseous fuel to the internal manifold. The internal manifold is made of steel tubing and includes the fuel nozzles for discharging the gas into the burner primary zone. The internal manifold is brazed to the heat shield which is mounted on the diffuser labyrinth seal. The feeder tubes are held in place with brackets on the diffuser rear face. The burner cover which also mounts on the diffuser labyrinth seal has been reworked with access holes for the fuel nozzles to discharge into the burner.

To increase engine life potential, the oil mist lubricated bearing system, normally supplied with compressor discharge pressure, was charged to utilize an independent source of compressed shop air to ensure increased bearing cooling air for extended bearing life and reliability.

RESULTS OF INITIAL TESTS

Approximately 100 hours of engine operating time have been logged to date, amounting to 36 starts. About half of that time was at 58,000 rpm at a 0 turbine inlet temperature of about 788 F (1450 F) and the remainder at 50,000 rpm, corresponding to a turbine inlet temperature of 677 C (1250 F). These turbine inlet temperatures result in metal temperatures closely approximating those expected in HTTT cooled turbines. Initially, visual inspections of the turbine, combustor and rear bearing were made at 10-hour intervals but are now being done every 20 hours.

Within a few hours after start-up, some white deposits accumulated on the turbine nozzles primarily near the nozzle inlet. X-ray scans of samples of the deposits identified Calcium, Titanium, Chromium, Iron and Cobalt as the elements present; however, there is a question whether sulfur compounds were masked by the sample container. Samples of deposits taken from the outside of the combustion chamber showed the same elements and, in addition, silicon. Subsequent inspections show that the amount of deposits have decreased. No visible degradation of the blades or nozzles was evident after 100 hours of operation.

FUTURE PLANS

It is planned that test time amounting to thousands of hours will be built up over the next several years, using combustion products from fuels derived from coal rather than simulated fuels. If this trailer mounted approach does, in fact, produce test results which are useful, the testing will continue and more materials will be evaluated, or, alternatively, the same materials will be tested for extended periods. It is even possible that, if additional coal gasification sources which have streams of gas which can be utilized, are identified and made available, a second trailer mounted test unit could be built and placed into operation, while at the same time continuing the operation of the existing machine.

While operating the small Williams Research Gas Turbine which produces dynamic test data, it is planned that substantial static testing will also be performed. It is planned that a combustor burning the coke oven gas from the same supply pipe be operated to discharge the products of combustion into a container which mounts a number of test pins, small shapes and various other pieces of materials which are to be evaluated. The same materials actually being tested in the gas turbine are to be subjected to these static test conditions as well as other materials not presently in the Williams machine. This approach will provide a means to examine a number of potential gas turbine materials subjected to extended exposure to the products of combustion of a coal-derived fuel.