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Safety Considerations in Testing a Fuel-Rich Aeropropulsion Gas Generator

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ABSTRACT/SUMMARY

A catalyst containing reactor is being tested using a fuel-rich mixture of Jet A fuel and hot input air. The reactor product is a gaseous fuel that can be utilized in aeropropulsion gas turbine engines. Because the catalyst material is susceptible to damage from high temperature conditions, fuel-rich operating conditions are attained by introducing the fuel first into an inert gas stream in the reactor and then displacing the inert gas with reaction air. Once a desired fuel-to-air ratio is attained, only limited time is allowed for a catalyst induced reaction to occur; otherwise the inert gas is substituted for the air and the fuel flow is terminated. Because there presently is not a gas turbine combustor in which to burn the reactor product gas, the gas is combusted at the outlet of the test facility flare stack. This technique in operations has worked successfully in over 200 tests.

INTRODUCTION

One way of improving the combustion process in gas turbine combustors is to use a gaseous, rather than a liquid, fuel in the primary combustion process. But a gaseous form of fuel is not ideal to carry in an aeropropulsion propulsion system. Liquid fuel forms are preferred because of their high energy content per unit of storage volume, their transportability, their handling ease and relative safety, lower costs, and world-wide airport availability.

A technique for incorporating the best features of fuel liquid and gaseous conditions for aeropropulsion applications is to gasify the liquid fuel in a reactor which is part of the propulsion package and then inject the product gas into the primary combustion chamber. By using the right type of catalytic material in the reactor, a product gas rich in hydrogen, carbon monoxide and/or light-end hydrocarbons can be produced from a liquid hydrocarbon fuel such as Jet A. NASA laboratory bench testing has demonstrated that this product gas can be generated at fuel-rich operating conditions without producing soot as a by-product (Ref. 1).

It is necessary to operate this gas reactor at a rich fuel-to-air input ratio so that only enough oxygen is available to partially oxidize the hydrocarbon fuel on the catalyst surface. Prior NASA work has shown that this can be accomplished at an equivalence ratio of 4-8, and an equivalence ratio of 1 would be stoichiometric conditions (Ref. 2). At these conditions a gaseous fuel is generated that contains 2 to 8 vol % hydrogen, 6 to 14 vol % carbon monoxide, and 4 to 5 vol % light-end hydrocarbons; depending on the input parameters.

The chief operating difficulty with such a gas generating reactor has been how to achieve an equivalence ratio of 4-8 without going through stoichiometric fuel-to-air ratios during startup and shutdown conditions. In conventional gas turbine combustors the starting technique is to start with a flowing air stream into which fuel is injected in increasing quantities and, as the overall reaction equivalence ratio increases to something less than stoichiometric, the desired operating reaction temperature is attained. However, if this technique was employed to reach fuel-rich operating conditions, the fuel and air mixture would go through stoichiometric conditions, and no matter how brief a time interval this might be, high operating temperatures would occur that can irreversibly damage the catalyst and/or reactor.

To avoid thermal damaging startup and shutdown conditions when operating fuel-rich catalytic reactors, this paper presents the technique developed at NASA Lewis Research Center. Also a technique is proposed that might be more practical for actual aeropropulsion applications when using this gasification process.

EXPERIMENTAL APPARATUS

The principle focus of this experimental program is the investigation of different catalyst materials and operating parameters in producing a usable fuel gas for primary combustion applications. A simple gas generator reactor was made from stainless steel pipe sections, internally insulated, into which a fuel atomizing injector and catalyst test pieces could be mounted. A schematic drawing of this rig is shown in Fig. 1.

The test rig is located in a test facility that can supply up to 450 g combustion air per second at input temperature up to 1090 K. The facility can also supply gaseous nitrogen at the same conditions. Liquid hydrocarbon fuel (e.g., Jet A) can be supplied up to 250 g per second at 1724 kPa pressure.

The fuel is injected into the test rig through a 19 port air-blast atomizing injector. The injector is mounted about 45 cm upstream of the catalyst reactor section. The reactor section contains catalyst retaining monolithic ceramic or metallic discs. The discs are 25 to 75 mm thick and about 150 mm in diameter. The discs have from 4 to 100 axial flow passages per square centimeter of cross-sectional area. Up to eight discs can be installed at one time in the test rig. The disc walls are sometimes pre-coated with some type of noble metal catalyst by the supplier using proprietary techniques.

Rig instrumentation includes flowmeters for measuring the air, inert gas, and fuel flowrates; pressure and temperature sensors for determining conditions before the fuel injector, after the injector and before the reactor, and after the reactor; and gas analyzers for determining the reactor product gas constituents.

EXPERIMENTAL PROCEDURE DISCUSSION

The major problem in conducting the testing at fuel-rich operating conditions, is how to attain the desired fuel-to-air ratio without going through stoichiometric maximum temperature conditions. The technique devised is to use a nitrogen gas flow through the gas generator reactor when introducing fuel or when terminating a test. At startup, after the desired fuel flowrate has been attained by being injected and vaporized in the nitrogen gas flow, the nitrogen flow is gradually terminated as combustion air flow starts. Both the nitrogen and air streams are at the same temperature and pressure. Figure 2 is a flow schematic showing the procedure where flowrates are plotted as a function of operating time. The test termination sequence is just the reverse of the startup procedure: the air flow decreases and is replaced with the inert nitrogen gas flow, once the air flow is terminated, then the fuel flow into the nitrogen stream is stopped.

Also shown in Fig. 2 is the procedure for emergency shutdown in case combustion air flow is unexpectedly lost during a test. The rig flowmeters will indicate an increase in equivalence ratio and when the flow computer senses that the ratio is greater than 10, then a shutdown procedure will be initiated whereby the nitrogen gas begins flowing and the air control valve is shut, and fuel flow is then stopped. Likewise, if the fuel flow should unexpectedly start decreasing during a test, the equivalence ratio would start decreasing and when it became less than 3, the flow computer will again order a shutdown procedure. During startup the former shutdown situation is held in abeyance till the fuel and air flows are at steady-state conditions.

EXPERIMENTAL PROCEDURE DISCUSSION

The above technique has worked successfully in over 200 tests. This is illustrated for a typical test in Fig. 3 where the gas temperatures at different axial locations in the test rig are plotted as a function of operating time. The gas stream temperatures initially are at approximately the same value with hot nitrogen gas flow. When the fuel is injected, the temperature of the gases downstream of the fuel injector begin to decrease as the fuel vaporizes. As the nitrogen flow is replaced with air flow, the catalyst reactor and downstream gas temperatures begin to increase. Testing is carried out at steady-state input conditions till the gas temperatures stabilize and gas composition has been determined.

In spite of purging the test rig for several minutes at termination of a given test, there was residual fuel and heavy end hydrocarbons on the test reactor elements. This condition could be occurring during the shutdown procedure when the air flow is being replaced with nitrogen flow but the fuel is still flowing through the hot reactor. Then when the nitrogen purge is terminated and air is re-introduced into the rig, the hydrocarbons left on the elements will react and heat up the reactor, probably at stoichiometric conditions but limited mass quantities. If precautions are not taken, localized reaction temperatures can exceed the noble metal catalyst temperature limits and/or the melting point of metallic portions of the reactor. The rig operator has to monitor the local gas temperature readings during this switch back from nitrogen to air flow and if any localized temperature starts to suddenly increase, switch back to nitrogen. It is a matter of switching back and forth between the nitrogen and air flows till the residual fuel on the reactor surfaces has been completely oxidized without exceeding upper temperature limits.

EXPERIMENTAL PROCEDURE DISCUSSION

Another safety aspect in this testing is the disposal of the product gases generated in the test rig. Because there is presently no primary combustor in which to completely burn the gas generator products, another technique had to be employed to render them suitable for atmospheric dispersion. Safety-wise the gaseous product could not just be vented as it was a fire hazard as well as a poison with high concentrations of hydrogen, carbon monoxide, and hydrocarbons.

The solution to disposing of the gases is to burn them in a commercial flare stack. The facility test rig was connected directly into a flare stack whose burner was about 5 meters above the test facility roof. The stack had a natural gas and air pilot burner at its exit and this burner had to be lit before and during any testing in the facility. The burning plume of exhaust gas during testing gave an indication from its appearance of how the reactor was performing. Downwind gas sampling did not indicate any dangerous levels of atmospheric pollution.

FUTURE CONSIDERATIONS

While the startup and termination procedure using a nitrogen purge has been successfully in the current fuel-rich, catalytic reactor test program, it is not a practical technique for flight propulsion applications. It would be a burden to have to use a secondary fluid system (i.e., nitrogen gas) every time the aircraft propulsion system was started or shut down.

The main function of the hot nitrogen gas flow is to provide thermal energy for vaporizing the injected liquid fuel. If the nitrogen were cold, or nonexisting, the injected fuel would find little available energy to vaporize it and it would tend to puddle in the generator. Then when the hot air made contact with it there would be all levels of fuel-to-air mixture ratios in the reactor.

If the injected liquid fuel can be heated to its vaporization temperature, then when the air is introduced it will contact a fuel vapor and there will be a uniform transitions from an infinite equivalence ratio to a desired 4-8 ratio.

A way of imparting energy to the fuel in the injector is to surround each of the injection feed tubes, currently there are nineteen 1 mm tubes, with a heated air flow. The initial fuel flow might be kept low so that the available heat will vaporize the fuel. The air flow can be heated in an auxiliary electric heater.

With minimum fuel flowrates the equivalence ratio will be low but with increasing reactor temperature the fuel flow can be increased to achieve a safer, higher fuel-air mixture. The auxiliary air heater need only be used for startups and shutdowns could be accomplished by ramping the fuel off as the air flow decreases.

Presently these ideas are just concepts, but plans are being made to evaluate them in the present test rig.

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2. Brabbs, T.A., Rollbuhler, R.J., and Lezberg, E.A., "Fuel-Rich Catalytic Combustion - A fuel Processor for High-Speed Propulsion," NASA TM-103177, 1990.

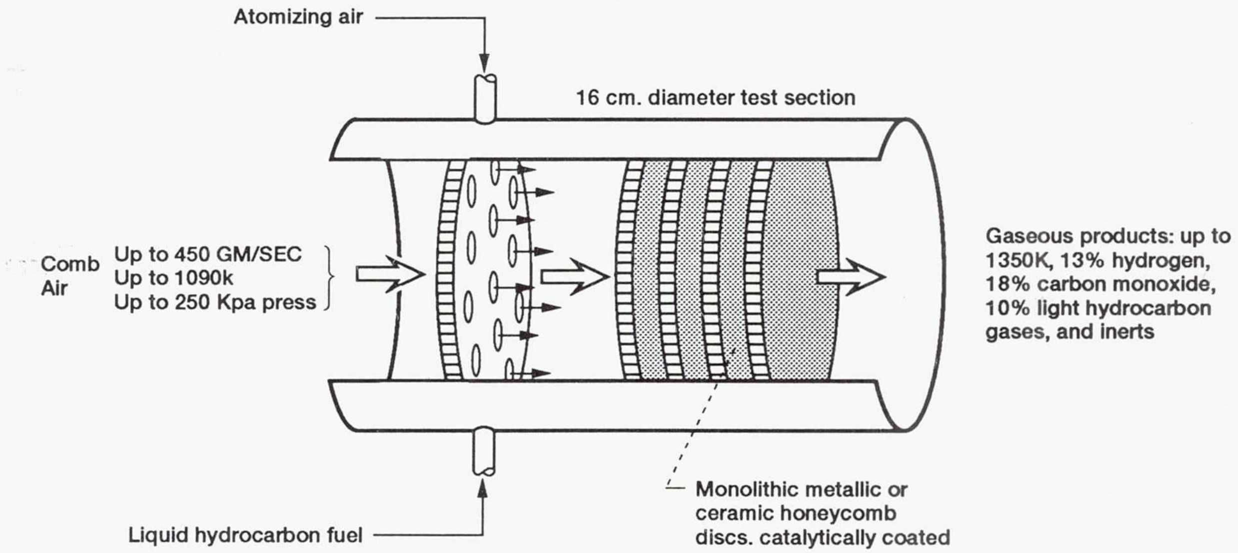
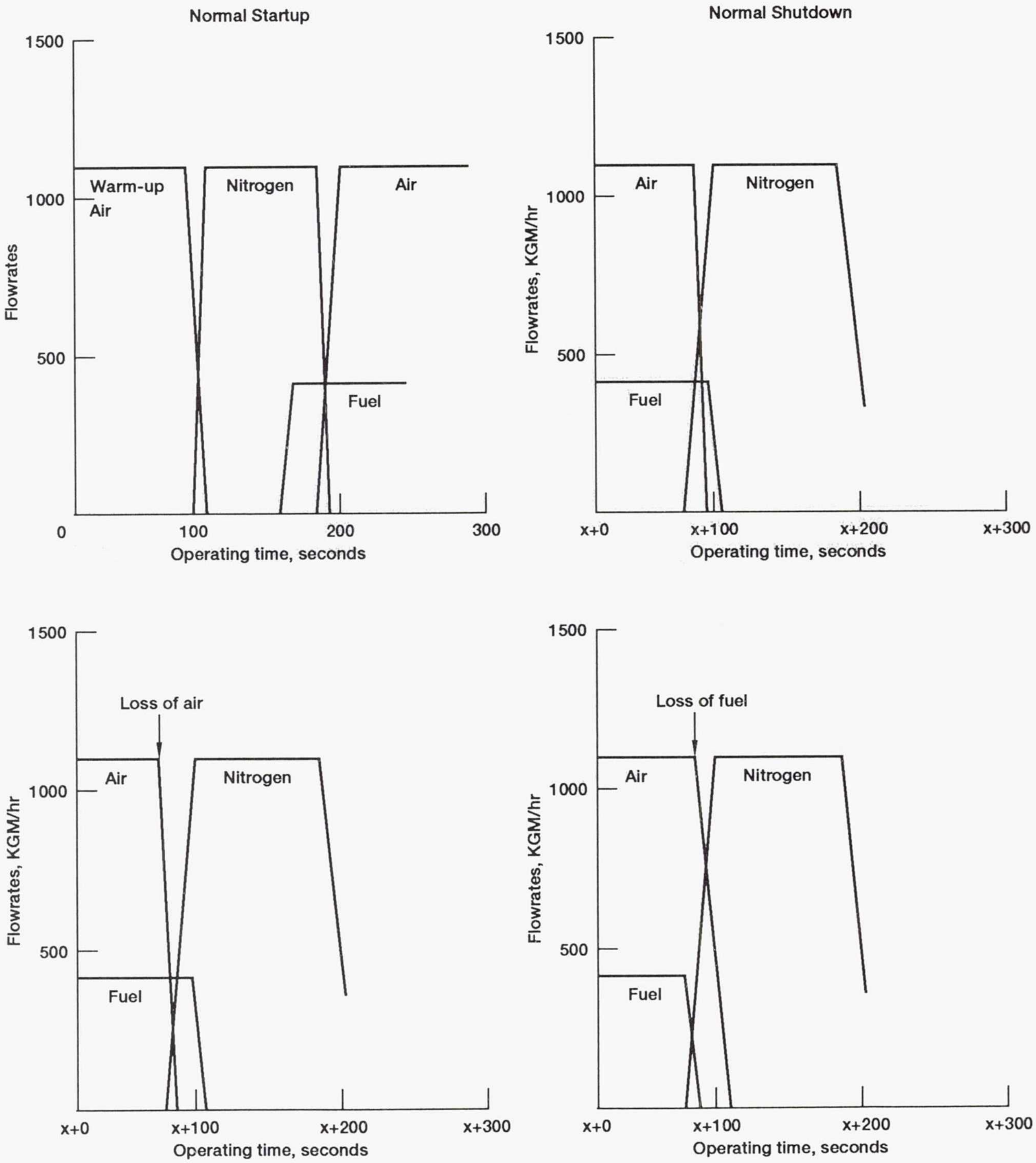


Figure 1.—Fuel-rich, catalytic reactor schematic.



Normal Startup

Normal Shutdown

Figure 2.—Fuel-rich catalytic reactor flow sequencing vs. operating time where x = finite time after starting a given test.

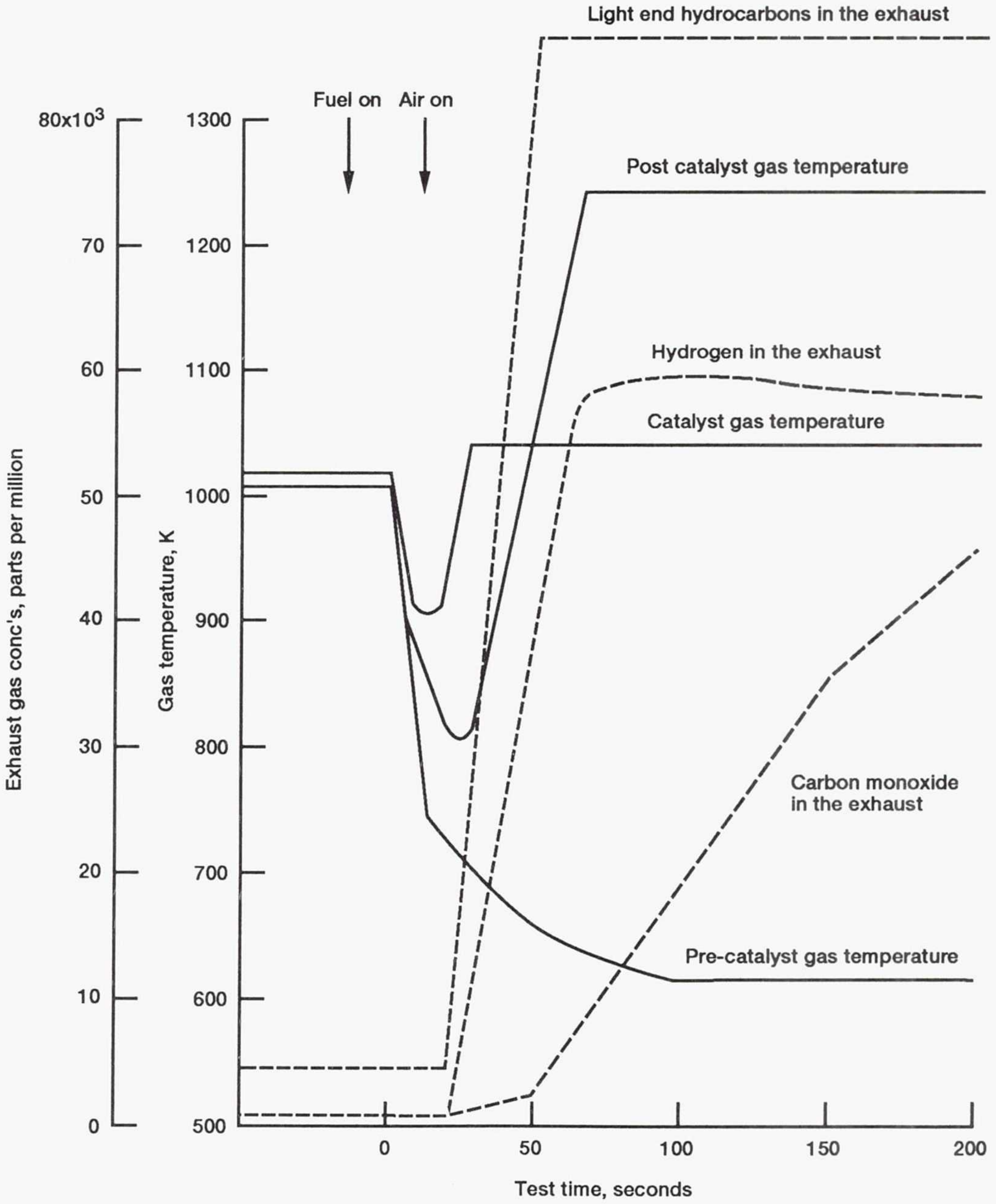


Figure 3.—Fuel-rich catalytic reaction program flow system gas temperatures and exhaust gas conc.

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