GAS TURBINE DEMONSTRATION OF PYROLYSIS - DERIVED FUELS

THIRD TECHNICAL PROGRESS REPORT
FOR THE PERIOD

JULY 1, 1979 - DECEMBER 31, 1981

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PREPARED FOR THE:

U.S. DEPARTMENT OF ENERGY
DIVISION OF ENERGY TECHNOLOGY
UNDER CONTRACT DE-AC03-78ET-13333

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TABLE OF CONTENTS

	Page
Introduction.....	2
Objective.....	3
Progress	
Design, Analysis and Project	
Management.....	4
Hardware Fabrication and Procurement.	11
Fuel Chemistry and Properties.....	12
Combustor Rig Tests.....	14
References.....	20

INTRODUCTION

As part of the National Petroleum Conservation effort, a potential non-petroleum base alternate fuel for gas turbines has been identified. This fuel is derived from agricultural and forestry products/wastes through a pyrolysis conversion. Three combustible products are produced - a heavy oil, residual char and gas. Blending of the char and oil products yields a two-phase (slurry) fuel with a heating value that is approximately 85 percent (volumetric) of typical petroleum base fuels. The work under this contract is directed to evaluate this pyrolysis derived fuel slurry in a direct fired gas turbine application.

This report summarizes the work conducted during the months, July 1979 through December 1981 under contract titled, "Gas Turbine Demonstration of Pyrolysis-Derived Fuels", No. DE-AC03-78ET-13333. The report structure follows the program's work breakdown structure with progress summarized for the following active sub-tasks:

1. Design, Analysis and Project Management
2. Hardware Fabrication and Procurement
3. Fuel Chemistry and Properties
4. Combustor Rig Tests

OBJECTIVE

The objective of this program is to demonstrate the feasibility of utilizing pyrolytic oil and char as a fuel for a combustion turbine engine.

This is the first phase of an extended program with the ultimate goal of commercializing a gas turbine engine and electrical generating system which is independent of petroleum-based fuels. Maximum use of existing technology and current production engine hardware (Teledyne CAE Model J69-T-29 Turbojet Engine) is being incorporated for a sequence of test evaluations rating from isolated combustor component tests to full scale engine demonstration tests.

The technical goals to be achieved during the course of this project are:

1. Pyrolytic fuel characterization in terms of its properties and constituents.
2. Pyrolytic fuel combustion technology in gas turbine application in terms of pyrolytic oil atomization, quantity of char burned, emissions, performance and associated combustion system aerothermodynamics.
3. Pyrolytic fuel (oil and char slurry) handling, mixing, and storage technology.
4. Engine materials compatibility with the the pyrolytic fuel and its combustion products.

PROGRESS

Design Analysis and Project Management

The design and analysis work leading to definition and procurement of test hardware and subsystems is reported in the first two technical progress reports (References 1 and 2). Since the last progress report a number of events have combined to delay execution of contract schedule milestones. These are summarized as follows:

- a) Wood pyrolysis fuel (oil and char) procurement slipped scheduled delivery by twelve months due to technical difficulties at vendor. Consequently, testing and evaluation could not be initiated on schedule.
- b) Upon fuel receipt, contract was at FY expenditure limit and also required a re-negotiation. This Teledyne CAE recommended modification was finalized in early 1981 and reflects a reduced work scope.
- c) During above interim and uncertainty, the required test facility at Teledyne CAE was committed to other existing contractual obligations until late 1981.

Current schedule to complete is shown in Figure 1. Combustor rig test section assembly has been completed and awaits facility availability in late December 1981. Facility preparation has been initiated with detail plans of required electrical, pneumatic and hydraulic services in progress. All test and adaptive hardware is on hand (including fuel) and available for installation starting in January 1982. Project test completion is scheduled for April 1982.

The Slurry Fuel Supply System is complete. Designed and built by The Omnisyn Corporation for Teledyne CAE it is a combination of electronic, pneumatic, and hydraulic devices resulting in a highly controllable delivery system for liquids or solid/liquid slurries with widely varying viscosities. The use of stainless steel, Teflon, or Viton in virtually all areas contacting the process material permits the pumping of corrosives. Batch sizes of 5 gallons to 300 gallons can be handled; batch temperature is automatically controlled. All elements of the system except the operator control console are explosion proof. A hydrostatic transmission type drive effectively provides an "infinite ratio" gear box with automatic load torque limiting. The system consists of four major subassemblies: the fuel delivery pallet, hydraulic power supply, motor starters/heaters controller assembly, and operator control console (Figures 2 and 3).

The fuel delivery pallet, requiring approximately 4' x 8' of floorspace supports a stainless steel batch tank with three sets of agitator blades through the volume of the tank. A maximum of 300 gallons of process material can be accommodated in the tank: the residual sump volume which can be mixed is slightly less than 2.5 gallons. Approximately 2.5 gallons of additional process material is contained in the pump and piping system downstream of the batch

tank sump. The batch tank is connected to the pump plumbing by way of a four-bolt flange and a manually operated globe-type shut off valve permitting complete removal of the batch tank from the fuel delivery pallet to facilitate moving the sytem into the test cell. The agitator is driven by a hydraulic motor controlled by a pressure compensated flow control valve which establishes the agitator speed regardless of the operating pressure (torque). The flow control valve is manually adjusted, and is located on the agitator support structure so that the operator can observe the mixing action of the mechanism while setting the agitator speed. The hydraulic pressure applied to the agitator drive motor is directly proportional to the agitator shaft torque and is limited to the maximum level adjusted at the hydraulic power supply.

The output of the batch tank is fed through a basket type strainer which limits particle size to 1/8 inch. The elevation of the batch tank assists in flooding the process pump inlet. The pump input pressure (or vacuum) is monitored by way of an isolating diaphragm which transmits the process pressure across a stainless steel diaphragm to meter-oil filled capillaries actuating a compound gage for visually monitoring pump input pressure, and an adjustable pressure/vacuum switch, modified for pneumatic operation, which is used to shut down the process pump in the event pump input pressure approaches cavitation conditions.

The process pump is of the progressing cavity type with a Viton lining and a stainless steel rotor machined .020 inches undersize to accomodate liner swelling with elevated process temperature and high viscosity process material. The process pump is driven through a timing belt drive by a reversible hydraulic motor. A manually operated reversing valve is used in conjunction with a manually operated globe type purge valve for back flushing.

The pump output piping includes a tap for instrumentation purposes along with another isolating diaphragm which drives a capillary connected to an output pressure gage. Pump output is divided between two paths, a weir-type metering valve which throttles flow to the combustor and a second weir-type valve controlling return flow to the batch tank, and paralleled by a relief valve set to approximatey 300 psi. Both weir-type valves are remotely controlled by way of pneumatic actuators through manually adjusted needle valves which individually establish the rate of response of the valves.

The piping system is flanged at a multitude of locations to facilitate the clearing of impactions should they occur.

Attached to the bottom of the tank is a 9 kw cast aluminum heater used to maintain batch temperature. The outside of the batch tank is insulated with a fiberglass blanket, and a fiberglass enclosure surrounding the pump and piping system utilizes the backside output from the heater to maintain an elevated temperature in the pump and plumbing. A vapor-tension thermometer bulb mounts in a thermowell in the batch tank sump for visual monitoring of process temperature. The only electrical connections to the delivery pallet besides the heater are for two thermocouples, one monitoring process temperature and the second monitoring heater skin temperature.

The hydraulic power supply (Figure 3) requires approximately 3' x 6' of floor space and consists of two virtually independent systems sharing the 80 gallon reservoir and a return line filter. Figure 4 is a schematic of the hydraulic circuit with a listing of major components.

The right half of the supply consists of a 5 HP explosion proof motor (1) driving a fixed displacement pump (3) face mounted to the motor with a flexible drive gear coupling (2). The pump, as powered, is capable of delivery approximately 8 GPM at up to 1000 psi to the torque motor (9) driving the batch tank agitator. The relief valve (4) with its air pilot control (5) is always shunting fluid back to the reservoir at 65 psi except when air pressure is applied, at which time the pump pressure rises to the level corresponding to the torque required by the agitator. Maximum pressure at the relief valve is manually set to limit the maximum torque from the agitator drive. Adjustment of maximum pressure is most easily achieved when the flexible pressure line to the delivery pallet is disconnected at the hydraulic power supply and the Fixed Drive On pushbutton is actuated on the operator control console. The pressure compensated flow control (8) maintains agitator speed as set regardless of hydraulic pressure variation.

The left half of the hydraulic power supply consists of a 20 HP explosion proof squirrel cage motor (16) driving a variable displacement hydraulic pump (18), capable of delivering up to 20 GPM and 1500 psi to the torque motor (24) driving the process pump. The stroke of the hydraulic pump is adjusted with a lead screw mechanism (19) driven by a small hydraulic motor (20) which taps the output pressure of the variable stroke pump through a priority valve (22). Rotation of the lead screw drive is controlled by a pneumatically operated 4-way, 3-position, center-off valve (21). Lead screw mechanism speed is manually set by the flow control valve (15). The relief valve (4) with its air pilot control (5) is always shunting fluid back to the reservoir at 65 psi except when air pressure is applied, at which time the pump pressure rises to the level corresponding to the torque required by the process pump. Maximum pressure at the relief valve is manually set to limit the maximum torque for the process pump drive. Adjustment of maximum pressure is most easily achieved when the flexible pressure line to the delivery pallet is disconnected at the hydraulic power supply, the Variable Drive On pushbutton is actuated on the operator control console, and the Pump Speed is raised to maximum.

The hydraulic power supply is connected to the fuel delivery pallet with hydraulic hose. The quick-disconnect fittings on the hoses are arranged so that it is impossible to improperly connect the hoses. The manually operated 4-way valve (27) on the fuel pallet is used to control the direction of rotation of the process pump.

The filter (12) has a built-in check valve which opens when the filter pressure exceeds 25 psi. Also connected to the filter is a pneumatic switch which opens when the filter pressure drop exceeds 25 psi. The filter alarm light will energize on the control panel

when this occurs. There are also pneumatic switches which open when the reservoir oil temperature exceeds 145°F and when the reservoir oil level is low. Activation of these switches energizes the corresponding alarm lights on the control panel. Two other pneumatic switches signal the control console that minimum or maximum stroke has been reached by the variable stroke pump.

Motor Starters/Heater Drive.

The 5 HP and 20 HP motors are each powered individually through explosion proof across-the-line starters equipped with overload protection. The starters are sized to drive the motors at 460 VAC, 3 phase. Control voltage for the starter solenoids is 115 VAC from the control console. The auxiliary contacts on the starters are brought back to the control console. The SCR controller for the batch tank heater and its associated contractor are mounted in an explosion proof enclosure. Power for this subsystem is 230 VAC, single phase, approximately 50 amperes. The contactor control voltage is 115 VAC from the control console. The two control lines for the SCR unit also originate in the control console.

The operator control console (Figure 3) is approximately 20" wide, 10" high, and 26" deep. It is not explosion proof and is meant to operate in a non-hazardous area (facility control room). Power requirements are 115 VAC, single phase, 3 amperes, and 3 SCFM of filtered instrument air regulated at about 50 psi. The operator control console consists of two major subsystems: heater control/temperature indicating and hydraulic/pneumatic. The heater control and temperature indicating function is operative, regardless of the status of the System Power On/Off pushbuttons, so long as the console is plugged into 115 VAC and the Emergency Off has not been actuated. This provides the capability of maintaining batch temperature when the fuel delivery portion of the system is not needed. A brief description of each of the controls follows.

PROCESS TEMPERATURE CONTROLLER

The front panel three-mode temperature controller provides a thumbwheel selectable target temperature for the process material and displays the process temperature monitored by the type J thermocouple in the batch tank sump. Temperature controllers within the console monitor heater skin temperature and limit it to a preset value.

HEATER ON/OFF

Provides remote control of the contactor supplying 230 VAC to the SCR controller for the batch tank heater.

HEATER RESET

Restores normal operation to the heater control system after a heater skin overtemperature alarm.

SYSTEM ON

Turns system power on to all electronics other than heater control circuitry.

FIXED
PUMP ON

Energizes the 5 HP electric motor which drives the fixed hydraulic pump. Relief valve is de-energized such that oil flow is directed back to the reservoir.

FIXED
DRIVE ON

Applies air pressure to the pneumatic pilot valve, energizing the relief valve so that pump will supply oil to the agitator torque motor.

VARIABLE
DRIVE ON

Energizes the 20 HP electric motor which drives the variable displacement hydraulic pump. Relief valve is de-energized such that oil flow is directed back to the reservoir.

VARIABLE
DRIVE ON

Applies air pressure to the pneumatic pilot valve, energizing the relief valve so that pump will supply oil to the process pump torque motor when speed command is made. Enables the Fuel Delivery pushbuttons. This pushbutton is disabled until the variable pump is at minimum stroke.

FUEL DELIVERY
FUEL PUMP SPEED
INCREASE/DECREASE

When the variable pump drive is on these pushbuttons are enabled. When INCREASE is depressed air pressure is supplied to the stoker mechanism control valve causing a counter clockwise rotation of the lead screw and a resultant increase in pump displacement and process pump speed. When DECREASE is depressed air pressure is supplied to the reverse position of the control valve, resulting in a speed reduction. At minimum speed, the DECREASE pushbutton will be automatically turned off. Likewise, at maximum speed the INCREASE pushbutton will be automatically deactivated.

FUEL DELIVERY
METERING VALVE
INCREASE/DECREASE

When the variable pump drive is on these pushbuttons are enabled. When INCREASE is depressed air pressure is supplied to the actuator mechanism so as to variably open the weir valve delivering process material to the combustor. When DECREASE is depressed air pressure is supplied in the reverse direction to the actuator mechanism causing the weir valve to close down. When the actuator mechanism has reached its upper or lower extent of travel, pneumatically actuated limit switches disable the corresponding pushbutton on the console.

FUEL DELIVERY
RETURN VALVE
INCREASE/DECREASE

When the variable pump drive is on these pushbuttons are enabled. When INCREASE is depressed air pressure is supplied to the actuator mechanism so as to variably open the weir valve returning process material to the batch tank. When DECREASE is depressed air

pressure is supplied in the reverse direction to the actuator mechanism causing the weir valve to close down. When the actuator mechanism has reached its upper or lower extent of travel, pneumatically actuated limit switches disable the corresponding pushbutton on the console.

EMERGENCY OFF

Instantly turns off power to the total system including motors and heater. Not to be used for normal shutdown procedures. Reset is accomplished by pressing System On pushbutton.

FIXED DRIVE OFF

Rapidly returns agitator to zero speed; pump remains on.

FIXED PUMP OFF

Shuts down 5 HP motor; forces Fixed Drive to Off.

VARIABLE DRIVE OFF

Rapidly returns process drive to zero speed; pump remains on.

VARIABLE PUMP OFF

Halts variable pump. If depressed before DRIVE OFF button, pump will remain on. DRIVE OFF will be illuminated, PUMP ON will flash until minimum stroke is achieved, then pump will turn off.

SYSTEM OFF

Shuts off all hydraulic/pneumatic components (not heater control). If depressed before DRIVE OFF and PUMP OFF, the system will remain on. DRIVE OFF will be illuminated, PUMP ON and SYSTEM ON will flash until minimum stroke is achieved, then the pump and the system will turn off in quick succession.

ALARM LIGHTS

FUEL PUMP INLET

Lights when pneumatically actuated limit switch on fuel supply pallet exceeds a manually adjustable limit of process pump input vacuum. Only the variable displacement pump circuit will be effected, as though the Variable Pump Off pushbutton had been pressed. Light will remain on until variable pump is restarted.

HEATER SKIN TEMP

Flashes (along with Heater Reset) when thermocouple monitoring heater temperature (not process temperature) exceeds a preset limit as established at the overtemperature switch inside the control console. Disconnects 220 VAC from SCR controller driving heater. Has no effect on hydraulic/pneumatic circuitry. This alarm is operative, regardless of the status of the System On/Off pushbuttons, so long as the console is plugged into 115 VAC and the Emergency Off has not been actuated. Once the heater temperature has cooled below the trip point, pressing the Heater Reset pushbutton clears the alarm light and restores normal operation to the heater control system.

- HYDRO FILTER CLOG Lights when pressure drop across the filter exceeds 25 psi causing pneumatic switch to actuate. This light indicates the need for filter element replacement. Shuts the system down as if Variable Pump Off and Fixed Pump Off were selected. Light remains on until either pump is restarted.
- HYDRO FLUID LEVEL Lights when hydraulic fluid drops below a predetermined level in the reservoir causing pneumatic switch to actuate. Shuts the system down as if Variable Pump Off and Fixed Pump Off were selected. Light remains on until either pump is restarted.
- HYDRO FLUID TEMP Lights when hydraulic fluid temperature exceeds 145°F. Shuts the system down as if Variable Pump Off and Fixed Pump Off were selected. Light remains on until either pump is restarted.

The system is programmed to automatically return the variable pump to minimum stroke before the process pump drive can be actuated. Pressing the Variable Drive Off, Variable Pump Off, or System Off pushbuttons automatically returns the variable pump to minimum stroke. The variable pump hydraulic circuitry can be operated independently of the fixed hydraulic circuit. The fixed pump hydraulic circuitry can be operated independently of the variable hydraulic circuitry. The Hydro Filter Clog, Hydro Filter Level, and Hydro Fluid Temp alarms will cause the system to sequence down to minimum stroke as though Pump Off had been pressed, then automatically shut down the motors and return the controls to the Pump Off condition. The Heater Skin Temp alarm has no effect on the variable pump or fixed pump circuits. The Fuel Pump Inlet alarm will shut down only the variable displacement pump as though Variable Pump Off had been pressed.

Two pairs of wires run from the console to the enclosure housing the SCR controller and provide a 4-20 ma control signal for the SCR unit and the 115 VAC for actuating the contactor. Two type J thermocouples on the fuel delivery pallet connect to the operator console.

Two pairs of wires run from the console to each motor starter, one pair providing 115 VAC for the starter coil, and the other pair monitoring the status of the starter auxiliary contacts. An air supply line and four pneumatic control lines run from the console to the hydraulic power supply, a second set of five run from the console to the fuel delivery pallet. Five pneumatic limit switch lines run from the pallet to the console, and a second set of five pneumatic limit switch lines run from the hydraulic power supply to the console.

The system is adaptable to automatic control of delivery rate and pressure at a future date.

Prior to shipment to Teledyne CAE the system was acceptance tested using water and SAE 50 motor oil. The results of these tests are shown in Figure 5. Compared to Teledyne CAE's specification, the performance as demonstrated meets actual requirements and with pyrolytic fuel at 200°F the growth requirement can also be met. The higher temperature would cause the pump liner to swell, decrease clearance and improve efficiency. Other pertinent data generated during the course of these tests includes:

- a. With fuel metering the pressurizing valves fully closed (pump dead-ended), the pressure relief valve in the by-pass circuit opened at approximately 300 psi pump discharge pressure.
- b. Volume of fuel in sump at bottom of tank up to main tank valve is 2.5 gallons.
- c. Volume of fuel in plumbing downstream of main tank valve up to metering valve is 2.5 gallons.
- d. Main fuel pump was operated in purge mode, i.e. reversed in rotation, and operated satisfactorily.
- e. Maximum fuel pump speed is set for 550 rpm and is the recommended upper limit for pyrolytic fuel application.
- f. The heater raised the temperature of approx. 300 gal. of water in the tank 79°F in 8.5 hours for an average of 9.3°F/hour (water temp. range: 92-171°F, heater skin temperature range 199-275°F) as shown graphically on Figure 6. Using the curve's slope at 170°F a minimum (losses to ambient not included) heat input rate of 6200 watts is demonstrated. Specification called for maintenance of oil at 200°F which is calculated to require a total of 6600 watts with tank not insulated. Insulation of tank reduced this requirement to approximately 3000 watts. Hence with tank insulation (to be provided) the tank heating system capability is considered satisfactory.

Hardware Fabrication & Procurement.

This task has been completed and all test and rig hardware is on hand for assembly, instrumentation, and installation into facility. Some of the major new items are shown in Figures 7 thru 12 (Ref. 1 & 2). Also, where possible, existing Model J69-T-29 engine parts are to be used. A loan agreement between Department of the Air Force and Department of Energy has been reached allowing use of this hardware.

Total pyrolysis derived fuel procurement under this contract is as follows:

1. Source: Engineering Experiment Station, Georgia
Institute of Technology, Atlanta, Georgia
(EES). 15 drums (55 gal each) of pyrolytic
oil. Derived from wood using fixed bed
pyrolysis process.

2. Source: Energy Resources Company, Inc., Cambridge, Massachusetts. (ERCO) 11 drums (55 gal each) of pyrolytic oil. Derived from wood using fluid bed pyrolysis process. 48 drums (55 gal each) of char. Derived from same feed as above oil and processed concurrently.

The ERCO char was consequently ground to reduce particle size (Ref. 2). This was processed at Particle Size Technology, Inc., Lakewood, New Jersey and yielded 36 drums of finished product due to change in char bulk density and some loss during the grinding process development. Particle size distribution after grinding was measured on their Rayco HiAc Particle Size Analyzer. Some agglomeration of large particles appeared during particle size measurements. For this reason, composite samples were made of every fifth drum, each sample was measured 3 times, and the results averaged. The measured particle size distribution does not meet the goal set (Figure 13). However, the reduction in particle size achieved by the grinding process is significant. Maximum particles size was reduced to about 150 microns in most tests with no particles over 211 microns in any test.

Fuel Chemistry and Properties

Chemical analyses of the ERCO pyrolytic oil and char were performed (ERCO quoted values) and the results were shown in earlier progress report (Ref. 1). The molar proportions of C, H, and O and N yield chemical formulas of $C_{168}H_{219}O_{60}N_1$ for the oil, $C_{175}H_{168}O_{64}N_1$ for the char. This can be compared to $C_{10}H_{20}$ which is a commonly used nominal chemical formula for JP4.

As shown, the ERCO pyrolytic oil has a pour point of 150°F. This made the ERCO oil so difficult to work with that its use become impractical given the limited scope of this program. An agreement was reached with DOE to use pyrolytic oil purchased from Georgia Tech's Engineering Experiment Station (EES). EES oils' advantage is its low pour point, -20°F. Use of this fuel greatly simplifies the fuel system and eliminates many of the handling problems associated with ERCO oil.

The equivalent chemical formula for the EES oil is $C_{103}H_{160}O_{57}N_1$. This oil is produced by a fluidized bed process. Earlier work done as part of this program included grinding of 3500 lb of ERCO char and a particle size analysis of the char. This work was done before the poor handling properties of the ERCO oil became physically evident during trial mixing efforts. The ERCO char will still be used to avoid regrinding and resizing the required amount of char.

Fifteen 55 gal. drums of the EES oil are on hand at Teledyne CAE along with thirty-six drums of ground char. The contents of ten oil drums were mixed in a single large container and the oil then replaced in the drums. This eliminated any drum to drum variation in the oil and guaranteed that samples taken for analysis would be representative of the complete batch of oil.

The actual test fuels will be mixtures (slurries) of char with either JP4 or pyrolytic oil. Specifying fuel flows and fuel/air ratios required calculation of adiabatic flame temperatures as a function of equivalence ratio. These calculations were made using a computer program designed specifically for this purpose (Ref. 3). This program requires as input the fuel chemical formula and enthalpy of reactants. Another computer program was generated to calculate these inputs and other thermochemical properties of the fuel mixtures. These properties are shown in Table I. Enthalpies of formation were calculated using the method of Ref. 4 with corrections as required for the oxygen and nitrogen contained in most fuel mixes.

Reactant enthalpies were calculated at various equivalence ratios with air at 300°F and ambient pressure and fuel at 77°F. The results were then used to calculate ideal temperature rise as a function of fuel type and fuel/air ratio; this data is plotted in Figures 14 through 17. Complete combustion is assumed so that these charts can be used to calculate combustion efficiency. Temperature rise data for mixtures of ERCO oil and char are given for comparison to EES oil. Adding char to either JP4 or pyrolytic oil increases maximum adiabatic flame temperature due to the relatively higher temperatures obtained with the char. However, in a real combustor, temperature rise may be less due to incomplete combustion.

The combustion analysis was based on preliminary property measurements of the pyrolytic oil and char. Oil and char properties may change over time, and because of the length of time since the last measurements, the fuel analysis will be repeated shortly before testing begins. The results of the latest measurements will be used to set test points and analyze data. Only small changes are expected, however, and the changes can be handled quickly since the fuel thermochemical properties and temperature rise calculations can be done with existing computer programs.

Combustor Rig Tests

Schematics of fuel system and test cell installation have been completed (Figures 18 & 19). The test rig, fuel system and instrumentation are presently being built up. Set up and check out of the complete system is presently scheduled for February 1982.

A test plan has been developed to investigate the effects of fuel/air ratio, aerodynamic loading and pressure drop, and char/fuel oil ratio on combustor metal temperatures and performance. After initial shakedown, the test plan is as follows:

Test #1 - Baseline performance calibration with JP-4 fuel. The combustor parameters varied will be fuel/air ratio and aerodynamic loading. Aero loading is changed by varying airflow $\pm 20\%$ around design point. Maximum fuel/air ratio is limited to 0.0225 by turbine inlet nozzle design temperature capability. Test point schedule is:

TEST 1

TEST POINTS FOR BASELINE TEST WITH JP4

<u>POINT</u>	<u>FUEL</u>	<u>W_a</u>	<u>T₃</u>	<u>P₃</u>	<u>W_f</u>	<u>f/a</u>
101	JP4	6.32PPS	300 ⁰ F	15.3 psia	330 PPH	.0145
102	"	"	"	"	423	.0186
103	"	"	"	"	512	.0225
104	"	"	"	"	LB0	LB0
105	"	5.06	"	"	264	.0145
106	"	"	"	"	339	.0186
107	"	"	"	"	410	.0225
108	"	"	"	"	LB0	LB0
109	"	7.58	"	"	396	.0145
110	"	"	"	"	508	.0186
111	"	"	"	"	614	.0225
112	"	"	"	"	LB0	LB0

Test #2 - Performance evaluation with JP-4 and pyrolytic char. Having obtained performance data from Test #1, this will evaluate combustion changes due to addition of char only. Constant aero loading will be run with fuel air ratios varied to provide same combustor temperature rise. Test point schedule is:

TEST 2

TEST POINTS FOR BASELINE TEST WITH JP4 + CHAR

<u>POINT</u>	<u>FUEL</u> <u>%JP4/%CHAR</u>	<u>Wa</u>	<u>T3</u>	<u>P3</u>	<u>Wf</u>	<u>f/a</u>
201	90/10	6.32 PPS	300°F	15.3 PSIA	TBD	LB0
202	"	"	"	"	346 PPH	.0152
203	"	"	"	"	444	.0195
204	"	"	"	"	535	.0235
205	70/30	"	"	"	TBD	LB0
206	"	"	"	"	364	.0160
207	"	"	"	"	466	.0205
208	"	"	"	"	569	.0250
209	50/50	"	"	"	TBD	LB0
210	"	"	"	"	394	.0173
211	"	"	"	"	507	.0223
212	"	"	"	"	607	.0267

Test #3 - Performance evaluation with pyrolytic oil only. Scheduled test points are identical to Test #1 except for fuel flow and fuel/air ratios. If first four points provide good correlation the remaining schedule at different aero loadings may be truncated to conserve pyrolytic oil for following tests. Test point schedule is:

TEST 3
TEST POINTS WITH PYROLYTIC OIL ONLY

<u>POINT</u>	<u>FUEL</u>	<u>Wa</u>	<u>T3</u>	<u>P3</u>	<u>Wf</u>	<u>f/a</u>
301	PYRO OIL	6.32 PPS	300°F	15.3 PSIA	687 PPH	.0302
302	"	"	"	"	894	.0393
303	"	"	"	"	1088	.0478
304	"	"	"	"	LB0	LB0
305	"	5.06	"	"	550	.0302
306	"	"	"	"	716	.0393
307	"	"	"	"	871	.0478
308	"	"	"	"	LB0	LB0
309	"	7.58	"	"	8.24	.0302
310	"	"	"	"	1072	.0393
311	"	"	"	"	1304	.0478
312	"	"	"	"	LB0	LB0

Test #4 - Performance evaluation with pyrolytic oil & char slurries. This test is directed to evaluate effect of oil/char ratio on combustor performance. Aero loading is held constant while oil/char and fuel/air ratio is varied to maintain same temperature rise. Test point schedule is:

TEST 4

TEST POINTS WITH PYROLYTIC OIL AND CHAR

<u>POINT</u>	<u>FUEL</u> <u>%PYRO OIL/%</u> <u>CHAR</u>	<u>Wa</u>	<u>T3</u>	<u>P3</u>	<u>Wf</u>	<u>f/a</u>
401	90/10	6.32 PPS	300°F	15.3 PSIA	TBD PPH	LB0
402	"	"	"	"	655 "	.0288
403	"	"	"	"	853 "	.0375
404	"	"	"	"	1040 "	.0457
405	70/30	"	"	"	TBD "	LB0
406	"	"	"	"	610 "	.0268
407	"	"	"	"	792 "	.0348
408	"	"	"	"	960 "	.0422
409	50/50	"	"	"	TBD "	LB0
410	"	"	"	"	569 "	.0250
411	"	"	"	"	739 "	.0325
412	"	"	"	"	894 "	.0393

Test #5 - Performance evaluation with best pyrolytic oil/char ratio. Data analysis of previous data will indicate optimum oil/char ratio based on efficiency and indicated minor changes (if any) to combustor flowpath. This test is directed to develop a wider data base on performance at varying aero loadings and fuel/air ratios at a given oil/char ratio. Test point schedule is:

TEST 5
PARAMETRIC TEST POINTS WITH BEST OIL/CHAR MIX

<u>POINT</u>	<u>FUEL</u> % PYRO OIL/ % CHAR	<u>Wa</u>	<u>T3</u>	<u>P3</u>	<u>Wf</u>
501	TBD	6.32 PPS	300°F	15.3 PSIA	TBD
502	"	"	"	"	"
503	"	"	"	"	"
504	"	"	"	"	"
505	"	506 "	"	"	"
506	"	"	"	"	"
507	"	"	"	"	"
508	"	"	"	"	"
509	"	7.58 "	"	"	"
510	"	"	"	"	"
511	"	"	"	"	"
512	"	"	"	"	"

Test # 6 - Ignition performance evaluation. On all above tests main fuel ignition will first be on JP-4 fuel with gradual switch-over to the pyrolytic fuel. This test is directed to evaluate ignition characteristics using the oil/char ratio main fuel of Test #5 only. Rig inlet conditions simulate the J69-T-29 engine start conditions. The primer nozzle on this and all tests will use JP-4 fuel to avoid potential flow blockage within its relatively small swirl atomizing flow passages. Test point schedule is:

TEST 6

IGNITION TEST POINTS

<u>POINT</u>	<u>FUEL</u>	<u>W_a</u>	<u>T₃</u>	<u>P₄</u>	<u>W_f JP4</u>	<u>W_f PYRO OIL</u>
601	OIL/CHAR	.75 PPS	AMB	AMB	PRIMER	TBD
602	"	1.50	"	"	"	"
603	"	2.25 LB/S	"	"	"	"

PROCEDURE:

1. Set airflow and primer fuel flow and ignite primer.
2. Slowly increase pyro oil flow and note first sign of ignition.
3. Increase pyro oil flow with primer system on until full light off is achieved - note flow.

REFERENCES

1. "First Technical Progress Report, Sept. 1, 1979 - March 31, 1979" Contract No. DE-AC03-78ET15313, Gas Turbine Demonstration of Pyrolysis-Derived Fuels.
2. "Second Technical Progress Report, April 1, 1979 - June 30, 1979", Contract No. DE-AC03-78ET15313, Gas Turbine Demonstration of Pyrolysis Derived Fuels.
3. C. Olikara and G. L. Borman, "A Computer Program for Calculating Properties of Equilibrium Combustion Products with Some Applications to I. C. Engines", ASME Paper 750468, Feb. 1975.
4. H. N. Powell, "Applications of an Enthalpy - Fuel/Air Ratio Diagram to 'First Law' Combustion Problems" Trans. ASME, pp 1129-1138, July 1957.

TABLE I

TEST FUEL THERMOCHEMICAL PROPERTIES

FUEL MIXTURE (Wt %)	ENTHALPY OF FORMATION (770F)	HEAT OF COMBUSTION (Higher/Lower)	MOLECULAR WT.	EQUIV. CHEM. FORMULA	f/a STOICH.
JP4	-781.4 Btu/lb	- / 18400 Btu/lb	140.3	C10 H20	.06762
90 JP4/10 Char	N/A	N/A	33089.7	C2298 H4415 064 N1	.07100
70 JP4/30 Char	N/A	N/A	11037.2	C726 H1269 064 N1	.07891
50 JP4/50 Char	N/A	N/A	6619.7	C411 H640 064 N1	.08881
ERCO Char	987.22	12900/12420	3309.3	C175 H168 064 N1	.12934
EES 011	-1996.6	9498/8849	2332.4	C103 H160 057 N1	.14761
90 EES 011/10 Char	N/A	N/A	2403.5	C108 H161 058 N1	.14556
70 EES 011/30 Char	N/A	N/A	2558.9	C120 H162 059 N1	.14161
50 EES 011/30 Char	N/A	N/A	2736.9	C133 H163 060 N1	.13788
ERCO 011	-2052.8	10800/10155	3212.6	C168 H219 060 N1	.12052

**GAS TURBINE DEMONSTRATION OF PYROLYSIS DERIVED FUELS
SCHEDULE TO COMPLETE**

1982

49534A

Figure 1. Schedule to Complete

49524

a) Fuel Delivery Pallet

45925

b) Main Fuel Pump and Drive

Figure 2. Slurry Fuel Supply System

a) Hydraulic Power Supply

49522

b) Operator Control Console

49523

Figure 3. Slurry Fuel Supply System

1. WESTINGHOUSE 5 HP EXPLOSION PROOF MOTOR
STYLE 680B285G21, 184 TEPC, FOOT MOUNT,
C-FACE, 1800 RPM, 230/460 VAC
2. UCC MOTOR PUMP ADAPTER #UC-1952, DC42
FLEXIBLE DRIVE GEAR COUPLING
3. DENISON TMB-006-21L PUMP
4. DENISON RELIEF VALVE RAV03-511-10-A1
5. DYNEX AIR PILOTED VALVE 6910-01-72
6. 0/2000 PSI PRESSURE GAGE
7. 3/4" QUICK CONNECT COUPLER
8. PRESSURE COMPENSATED FLOW CONTROL
WATERMAN 1423R4-9
9. HYDRAULIC TORQUEMOTOR, TRW ROSS MAB24-010
10. 1/4" QUICK CONNECT COUPLER
11. 1" QUICK CONNECT COUPLER
12. RETURN LINE FILTER, MARVEL 851161-2501-
629206-5125
13. SUCTION STRAINER, UCC #UC-8B-1324
14. 60 GALLON JIC RESERVOIR
15. FLOW CONTROL, WATERMAN 14921-2
16. 20 HP EXPLOSION PROOF MOTOR, WESTINGHOUSE
STYLE 7738787C21, 256 TEPC, FOOT MOUNT,
C-FACE, 1800 RPM, 230/460 VAC
17. UCC MOTOR PUMP ADAPTER # UC-1955, DC42
FLEXIBLE DRIVE GEAR COUPLING
18. VARIABLE DISPLACEMENT PUMP
VICKERS PVB15-RDH
19. LEAD SCREW ACTUATOR, OMNISTYN
20. ACTUATOR DRIVE MOTOR, BOSTON
HYDRAULIC J5G20-0014, J6G8-1
21. 4-WAY, 3-POSITION, CENTER OFF
AIR PILOTED VALVE DYNEX 6950-
01-72, SPRING CENTERED
22. PRIORITY VALVE, DENISON RIV12
23. 4-WAY VALVE, EMERGY DCVA-200
24. PROCESS PUMP TORQUEMOTOR
TRW ROSS MAB08-010

FIGURE 4

TOLERANCES (EXCEPT AS NOTED)	REVISIONS			HYDRAULIC SCHEMATIC TELDYNE CAE		
	NO	DATE	BY	THE OMNISTYN CORP (CONSULTING ENGINEER)		
DECIMAL	1			DRAWN BY	SCALE	MATERIAL
FRACTIONAL	2			CHK'D	DATE	DRAWING NO.
ANGULAR	3			TRACED	APP'D

Figure 5. Pyrolytic Fuel System Acceptance Test at Vendor.

Figure 6. Pyrolytic Fuel System Tank Heating Demonstration at Vendor.

49529

49516

a) Inlet View

49517

b) Discharge View

Figure 7. Pyrolytic Fuel Combustor Rig, Inlet Drive Duct Assembly

a) Radial Diffuser

49520

b) Axial Diffuser Segments

49521

Figure 8. Pyrolytic Fuel Combustor Rig. Diffusers at Combustion Chamber Inlet

a) Fuel Distributor (Alternate P/N 706460)

49514

b) Shaft Assembly

49515

Figure 9. Pyrolytic Fuel Combustor Rig. Fuel Distributor and Main Shaft Assembly

49518

a) Inlet View

49519

b) Discharge View

Figure 10. Pyrolytic Fuel Combustor Rig. Turbine Inlet Nozzle

49512

a) Fuel Transfer Tube, Drive Shaft, and Fuel Supply Tube

49513

b) Total Temperature Survey Rake

Figure 11. Pyrolytic Fuel Combustor Rig

49510

a) Outer Combustor Linear Assembly

49511

b) Exhaust Probe Duct

Figure 12. Pyrolytic Fuel Combustor Rig

Figure 13. CHAR Particle Size Distribution - Fluidized Bed Process Yield

Figure 14. Ideal Temperature Rise Chart for Mixtures of JP4 and ERCO CHAR

Figure 15. Ideal Temperature Rise Chart for Mixtures of EES Pyrolytic Oil Base Fuel and ERCO CHAR.

49535

Figure 16. Ideal Temperature Rise Chart For Mixtures of Erco Pyrolytic Oil And Char

Figure 17. Ideal Temperature Rise of ERCO CHAR

Figure 18. Pyrolytic Fuel System Schematic

- ① DRUM HEATER DISCONNECT
4.4 KV 460 V 3Ø
- ② TRANSFER PUMP DISCONNECT
1/2 HP 460 230 V 3Ø
- ③ HYDRAULIC UNIT & TANK HEATER DISCONNECT
460 V 3Ø
- ④ TANK HEATER SCR TRANSFORMER
460 V IN 230 V OUT 9.5 KW
- ⑤ HYDRAULIC PUMP MOTOR CONTACTORS
& HEATER SCR 230V 3Ø 9.5 KW
- ⑥ HYDRAULIC UNIT
- ⑦ PYROLYTIC FUEL TANK & PALLET
- ⑧ FUEL TRANSFER PUMP
- ⑨ FUEL DRUM (S)
- ⑩ FUEL DRUM HEATER 607057
- ⑪ PURGE BARREL
- ⑫ TOLEDO SCALES
- ⑬ FLOWMETER 647064 & 607073
- ⑭ IGNITER COIL 24VDC 1AM²
- ⑮ IGNITERS
- ⑯ GAS SAMPLE OUT
- ⑰ EROSION TEST SPECIMEN ASSEMBLY
- ⑱ WATER IN (D)
- ⑲ PROBE DRIVE GEAR MOTOR
- ⑳ INSTRUMENTATION OUT

- ㉑ MAGNETIC SPEED PICKUP
- ㉒ AIR TURBINE
- ㉓ IPA WATER
460 V 3Ø 7.5 KW
- ㉔ LUBE PUMP MOTOR
1/2 VAC 1Ø 1/2 HP
- ㉕ OIL TANK
- ㉖ IPA FUEL SYSTEM (LH20 SH2)
- ㉗ DIGITAL FLOWMETER READOUT
- ㉘ PYROLYTIC FUEL SYSTEM CONTROL
- ㉙ TRAILER POWER DISCONNECT
- ㉚ GAS ANALYSIS TRAILER
- ㉛ 15 KVA TRANSFORMER
AND RECTIFIER

- ㉜ OVERHEAD BOOM (S)
- ㉝ PIPING OBSTRUCTION (S)
- ㉞ STAIR
- ㉟ CABINET
- ㊱ NITROGEN SUPPLY
- ㊲ CART
- ㊳ GAUGE PANEL
- ㊴ BENCH
- ㊵ CABINET
- ㊶ BENCH

49526

Figure 19. Pyrolytic Fuel Combustor Rig Installation Schematic