Conversion to a Coal-Fueled Industrial ATS (CFATS)

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TASK 4 - CONVERSION TO A COAL - FUELED ADVANCED TURBINE SYSTEM **(CFATS)**

4.1 TASK OBJECTIVES

Identify system changes to the selected Gas Fueled Advanced Turbine System (GFATS) hardware that are necessary to adapt it for the burning of coal-derived fuels.

4.2 COAL-DERIVED FUEL SYSTEM SELECTION AND POWER REQUIREMENTS

Using the Gas Fueled Advanced Turbine System (GFATS) configuration results of Task 6, a study was initiated to determine the required engine system changes that are needed to utilize coal derived gas fuels.

An imposed goal of this Task, was to maintain the following engine conditions, which are the same as the engine Gas Fueled Advanced Turbine System (GFATS) power and airflow levels defined in Task 3, (Figures 3.8.1 and 3.8.2).

Engine Compressor Airflow	496.4 lbs/sec.
Power Output	131.9 MW (Simple Cycle) and 158.6 MW (Combined Cycle)

The initial effort for this study was to select a coal gasification system that had the potential of being used in a commercial environment and then to determine the impact on the engine system.

Four gasifier systems have been reviewed for constituent content, heating value of the gas fuel output, and the engine bleed flow needed to maintain the required power level. After review of four available coal gasification systems as shown in Table 4.2.1, and based on General Electric's experience, the Shell coal gasification system was chosen for additional study. The resulting engine interface schematic is shown in Figure 4.2.1.

4.3 ENGINE SYSTEM AND COMPONENT MODIFICATIONS NEEDED FOR COAL DERIVED FUELS

Based on the analysis of the engine system as defined in Section 4.2, the following modifications are needed:

4.3.1 ENGINE CYCLE

The cycle for coal derived fuels, as shown by the schematic in Figures 4.3.1 and 4.3.2, resulted in the following key parameter changes, shown in Table 4.3.1, and is compared to the cycle engine configuration from Task 3.

Figure 4.2.1. Engine Interface Schematic

ATS COAL GAS CYCLE

Figure 4.3.1. ATS Coal Gas Cycle

ATS COAL GAS AIR TURBOCOOLER CIRCUITRY

Figure 4.3.2. ATS Coal Gas Turbocooler Circuitry

TABLE 4.3.1

Parameter	Coal-Fueled System	Natural Gas-Fueled System
Engine Airflow (Lbs/Sec.)	492.9	496.4
Engine Net Output Power (Simple Cycle)	129	131.9
Engine Net Output Power (Combined Cycle)	160	158.6
Efficiency (Simple Cycle)	47.4	50.1
Efficiency (Combined Cycle)	58.5	60.4
Cycle Pressure Ratio	51.5	51.7
High Pressure Turbine Inlet Temp (F)	2,685	2,685
NOx Emissions	≤ 8ppm	≤ 8ppm
Fuel Flow (Lbs/Sec)	52.83	13.125
Fuel Lower Heating Value (Btu/Lbm)	4,878	19,000

Note: Power levels and cycle efficiencies do not include losses for fuel pumping or other plant auxiliary equipment.

The overall effect on the engine cycle from the use of coal derived fuels is as follows:

- A 2.7% reduction in Simple Cycle Efficiency
- A 1.9% reduction in Combined Cycle Efficiency.

4.3.2 COMBUSTOR SYSTEM

Several features needed for the design for coal gas fuel system are as follows.

4.3.2.1 Fuel Chemistry

A mass balance of the air taken off the engine into the coal gasifier and returning as coal gas shows that the maximum air extraction rate is slightly smaller than that shown in Table 4.2.1 (1.65 lb of air per lb of coal gas compared to max. of 1.88). This difference can be made up with air injection, air (optional) in Figure 4.2.1. The Shell coal gas requires oxygen to be separated from the gas turbine compressor bleed air and combined with coal to form the coal gas fuel (shown in Figure 4.2.1). The input composition for the coal gasifier is shown in Table 4.3.2.1. The constituents of the Shell coal gas are given in Table 4.3.2.2. The coal gas contains a significant amount of hydrogen (2.6% by weight), and it is assumed that this hydrogen comes from the addition of water to the gasification process. The remaining nitrogen in the engine bleed air is sent back to the turbocooler for component cooling. The composition of the nitrogen stream is shown in Table 4.3.2.3. The calculations assume standard (59F) dry air gas composition for the compressor bleed air stream.

The heating value of the Shell coal gas is 4,875 Btu/lb. This is significantly lower than the natural gas which typically is in the 20,000 Btu/lb range. For this design, the fuel gas flow rate

is increased to maintain T4 for the air flow available after extraction. Development tests of the premixer will have to include auto-ignition and flashback testing at the appropriate pressures to eliminate the risk posed by hydrogen (2.6% mass fraction) contained in the fuel.

TABLE 4.3.2.1

Input Composition Required By The Coal Gasification Process

Constituent	Mass Fractions %
H ₂ O	23.66
Coal	35.84
O ₂	28.38
N ₂	10.33
Ar	1.79

TABLE 4.3.2.2

Constituents of the Shell Coal Gas

Constituent	Mass Fractions %
Hydrogen	2.60
Carbon Monoxide	80.98
Carbon Dioxide	4.08
Methane	0.02
Hydrocarbons	0.00
Nitrogen	10.33
Argon	1.79
Water	0.19

TABLE 4.3.2.3

Composition of the Nitrogen Stream

Constituent	Composition %
O ₂	8.00
CO ₂	0.1
N ₂	91.9

4.3.2.2 Emissions

A study using a PSR/PFR model of the combustor shows that the CO emissions are higher than with natural gas. The CELESTE chemical kinetics program has been used for this study. This is to be expected, as the amount of CO₂ is higher by a factor of about 2.2 compared to natural gas-fueled combustor. Based on GE experience, CO emissions are generally lower than the equilibrium calculated at combustor exit condition, possibly due to CO oxidation downstream of the combustor. CO emissions calculated for the ATS combustor burning coal gas and natural gas fuel are shown in Figure 4.3.2.2.1. The CO estimates should be anchored with experimental data. NO_x emission calculations are not reported for the coal gas fired combustor due to a lack of knowledge of pressure effects on the nitrogen chemistry with coal gas fuel at the ATS pressures (>50 atm).

4.3.2.3 Combustor Sizing

The cooling air flow utilization for the baseline natural-gas fired design has been retained for this study. The physical dimensions of the combustor are listed in Table 4.3.2.3.1, and a cross-section is shown in Figure 4.3.2.3.1. The length of the combustor, dome plate thickness, the prediffuser and diffuser length remain unchanged from the original design. The dome reference velocity has also been retained from the baseline design study. The air flow distribution around the combustor is shown in Figure 4.3.2.3.2. This combustor does not appear to be significantly different from the baseline natural gas fired design. The biggest difference is in the fuel flow: the 6-fold increase in fuel flow will require a totally new premixer design. The increased fuel flow (in comparison to the natural gas) could significantly affect air flow splits at part power staged operation due to additional fuel mass flow rate in the premixers. This will increase flame temperatures in the fueled domes and decrease the combustor pressure drop. Air flow split variation related issues will have to be resolved by rig testing with coal gas.

Figure 4.3.2.2.1. CO Prediction at Combustor Exit

CELESTE based Predictions of the CO emissions at the exit plane of the combustor. The coal gas has about 2.2 times the CO₂ of the natural gas fired design in the combustor exhaust gases. Dissociation of the increased CO₂ leads to increased CO emissions.

Figure 4.3.2.3.1. Preliminary ATS Combustor Layout

Figure 4.3.2.3.2. ATS DLE Combustor Air Flow

TABLE 4.3.2.3.1**Major Radial Dimensions of the Combustor**

Inner Dome Design	Inches
Inner Liner Radius	12.5
Dome Outer Radius	15.83
Dome Height	2.9
Middle Dome Design	
Inner Radius of Middle Dome	16.21
Dome Outer Radius	19.51
Dome Height	3.30
Outer Dome Design	
Inner Radius of Outer Dome	19.86
Dome Outer Radius	23.075
Outer Liner Radius	23.45
Case Inner Radius	24.65

4.3.2.4 Premixers

The current DACRS III premixers will have to be developed further to improve the emissions performance of these devices. The higher pressures of the ATS cycle and the presence of significant quantities of hydrogen in the fuel reduce auto-ignition delays. Auto-ignition and flashback could become important design constraints.

4.3.2.5 Diffuser

The ATS combustor design uses a 5-in. long diffuser. In order to limit diffuser dump losses, significant development will have to be undertaken to design a low-loss, ultra short diffuser. Trades between diffuser losses and combustor/engine lengths will have to be made to optimize the design of the diffuser.

4.3.2.6 Combustor Acoustics and Operability

Lean premixed combustors have been shown to have increased dynamic pressures. The ATS combustor is also a lean premixed combustion system and will require on-engine development to ensure that dynamic pressures are within design limits. The low emissions combustor operates within a few percentage points of the lean blowout limit. The lean

blowout limit may be affected by the high CO content of the fuel, limiting the operating window of the combustor. The lean blowout limit will have to be established in 2 cup premixer development tests. The ATS combustor is designed to operate within a narrow flame temperature window with the use of air flow modulation. The transient dynamics of the turbocooler and the rest of the engine will have to be modeled in the design of the control system for the ATS engine.

One combustor could be designed to work with separate coal gas and natural gas premixer nozzles. However technical challenges in premixer performance, sealing, operability/staging effects, diffuser design and coal gas capability would have to be addressed in a follow-on program.

4.3.3 ENGINE COMPRESSOR BLEED SYSTEM & AIR CYCLE MACHINE

The GFATS system used compressor discharge air, which is cooled and pressurized, via an air cycle machine, to cool combustor and turbine components. For the CFATS cycle, the engine airflow bleed system has to be modified to accommodate the additional airflow needed for the coal gasification unit, and also the required additional air needed to power the air cycle machine in order to pressurize the resulting nitrogen, from the gasifier system, for reintroduction into the gas turbine engine. Table 4.3.3.1 shows the air cycle machine modifications needed when compared to the GFATS system.

TABLE 4.3.3.1

GFATS Modifications Required

	Coal Fueled System	Natural Gas Fueled System
Compressor Bleed Flow (Lbs/Sec)	101	59.3
Air Cycle Machine Compressor Flow (Lbs/Sec)	66.2	51.17
Air Cycle Machine Turbine Flow(Lbs/Sec)	12.4	7.13
Air Cycle Machine Weight(Lbs)	1045	495

4.4 MATERIAL SYSTEMS

The use of coal-derived gas fuel increases the concern for component corrosion due to contaminants such as vanadium, sodium, potassium, lead, calcium and magnesium. Also, concern is raised regarding erosion from airstream particles. Based on General Electric's experience, limits have been defined for the use of coal-derived fuels in gas turbine engines. It is expected that the Shell gasification system should meet those limits. Materials analysis of planned gas flowpath

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