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Direct Coal-Fired Gas Turbines for Combined Cycle Plants

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1.4 Direct Coal-Fired Gas Turbines for Combined Cycle Plants

CONTRACT INFORMATION

Contract Number	DE-AC21-86MC23165
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Contractor Project Manager	John Rothrock
Principal Investigators	Richard Wenglarz, Peter Hart, Hukam Mongia
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Period of Performance	July 1986 to July 1993

OBJECTIVES

The overall goal of this program is to develop and demonstrate the technological bases for economically attractive, commercial, coal-fueled gas turbine systems. Objectives to accomplish this goal include:

- identify candidate technical approaches to meet the challenges of using coal as a turbine fuel.
- screen the candidate technical approaches by testing their relative performance and evaluating their effects on the economic attractiveness of commercial coal-fueled systems.
- demonstrate the most promising technologies and associated components in proof-of-concept system tests leading up to commercialization.

BACKGROUND INFORMATION

Coal is an abundant domestic fuel source and has been evaluated as a turbine fuel in two major programs that started in the late 1940s in the U.S. (Smith et al., 1966) and later in Australia (Interdepartment Gas Turbine Steering Committee, 1973). Although these projects were only partially successful, later advancements in coal technologies stimulated a renewed interest (Pitrolo, 1983; Stettler et al., 1983) in coal as a potential source of fuel for commercial gas turbines.

The Allison Gas Turbine Division of General Motors Corporation tested a rich-quench-lean (RQL), low nitrogen oxide (NOx) combustor in a NASA program which started in the late 1970s. The U.S. Department of Energy (DOE) continued

this program with coal-derived fuels (including coal water fuels [CWF]) in tests that extended into the early 1980s. A DOE/Allison Component Screening Program was initiated in 1984. The RQL combustor was modified for improved combustion efficiency using CWF, and deposition, erosion, corrosion (DEC) tests were conducted with specimens exposed at turbine flow-path conditions. Allison and other turbine manufacturers were awarded Advanced Coal-Fueled Gas Turbine Systems Programs in mid-1986. This report describes efforts in the Allison program.

PROJECT DESCRIPTION

Coal-Fuel Turbine Technology Development

The Allison RQL combustor tested in the earlier programs was of metallic construction and used air quench. In this program, the combustion approach was changed to a refractory lined design with water quench to improve NO_x performance and increase the combustor durability. This bench-scale combustor (about 1/10 flow rate of a combustor sized for the Allison 501K turbine) was tested for combustion and emissions (NO_x and CO) performance with several CWF.

Based on experience from the bench-scale combustor, a full 501K turbine scale combustor facility was developed. This combustor was also tested with CWF for combustion and emissions performance. An Allison 501K turbine was then operated for about four hours using the full-scale combustor and a subbituminous CWF. Ash from the products from the combustor rich zone was removed upstream of the turbine using two parallel cyclone separators.

During most of the program, a number of organizations had been developing CWF; however, in recent years most suppliers have terminated their CWF efforts. Low cost commercial CWF for turbines are no longer expected to be available in the foreseeable future. Consequently, efforts were directed to preparing the two Allison facilities (bench-scale and full-scale) for operation with fine powder coal.

Subscale dry coal feed tests have started. A bench-scale (25 candle) hot gas filter vessel has been installed for the purpose of tests following combustion/emissions verification with powder coal. Two DEC test sections have been installed downstream of the combustor for the purpose of exposing specimens at conditions of two turbine rows. Improved combustor refractories have been installed along with a slipstream to evaluate Zn titanate sulfur control.

Work has started to install in the full-scale facility the refurbished 501K turbine, a dry coal feed system, and the combustor with improved refractories. A preliminary design effort has been initiated for a hot gas filter for the engine facility.

Commercial System Definition and Assessments

Two types of commercial direct coal-fired plants have been defined and analyzed:

- cogeneration plants based on the Allison 501K turbine
- combined cycle plants based on large utility turbines

Performance, costs and economics have been assessed for several variations of these systems.

A reference cogeneration system that has been evaluated uses a hot gas filter to control particulate emission and protect the turbine flow path from particulate effects (deposition and erosion). Alternate cogeneration systems have also been evaluated. These alternate systems use cyclone separators and various other measures to protect the environment and turbine from particulate. Systems and cost analyses have also been conducted for several direct coal-fueled turbine combined cycle (CFTCC) plants based on turbines ranging in size from about 50MW to over 100MW.

RESULTS

Results of program technical evaluations have been reported previously (Santanam, et al., 1990; Wilkes, et al., 1992) along with systems analyses results for the baseline cogeneration system (Merrion, 1991; Wenglarz, 1992) and alternate cogeneration systems (Wenglarz, 1991). This paper summarizes results of systems evaluations for CFTCC plants.

CFTCC Power Plants

CFTCC Schematic. The CFTCC system is illustrated by the simplified schematic diagram shown in Figure 1. The system consists of two major blocks, the coal combustion/emissions control block and the power generation block. The power generation block is a combined cycle (gas turbine and steam turbine cycle) system and uses equipment designed to operate with conventional turbine fuels (e.g., natural gas). The coal combustion and emissions control block converts the conventionally-fueled

combined cycle plant to operation with coal. As will be discussed later, the coal combustion equipment uses gas turbine technology rather than process plant technology and provides compactness and cost advantages over other coal utilization systems.

Referring to Figure 1, a portion of the gas turbine compressor discharge air is directed to the combustion/emissions control block where it is reacted with coal. Coal contaminants (e.g., sulfur and ash particulate) are removed from the combustion product stream before final combustion and expansion in the turbine. Quench water and heat extraction are used in the combustion/emissions control block to lower the temperature of the combustion products to a suitable level (1340°F) for removal of coal contaminants and emissions control. The heat extracted in the combustion/emissions control block is used in the steam equipment of the combined cycle power generation block to produce power.

Combustion/Emissions Control Block. NO_x is controlled in the combustion/emissions block by RQL combustion of coal. The rich zone of the combustor operates under fuel rich conditions, which inhibits the formation of NO_x from fuel bound nitrogen found in the coal. The quench and final lean combustion zones involve relatively low reaction temperatures that minimize the formation of thermal NO_x from dissociation of molecular nitrogen found in air. Tests with the RQL coal combustor sized to the Allison Model 501K industrial gas turbine have demonstrated simultaneous control of NO_x and CO emissions to less than 25 ppmv (at 15% O₂)

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Figure 1. Simplified Block Diagram of CST Demonstration Project

with prospects for lower levels with further optimization of the local stoichiometry.

Sulfur oxide (SO_x) is controlled in the combustion/emission block by a zinc titanate sulfur scrubber. Tests indicate that this control method should ultimately be capable of reducing SO_x emissions by over 99%.

Particulates are controlled in two stages by a cyclone separator followed by a hot

gas ceramic barrier filter. A number of high temperature filter tests have reduced gas stream particle carryover to under 10 ppmw.

Applications

The CFTCC technology can be utilized for new power plants or for re-powering of existing natural gas-fired, combined cycle power plants. Depending on the gas tur-

bine used, this technology can provide coal-fueled power blocks with electrical outputs from about 85 MWe (e.g., for the GE MS6000 turbine) to over 350 MWe (e.g., for the Westinghouse 501F turbine) and even higher outputs for future advanced turbines. Figure 2 illustrates the layout for a 100 MWe plant based on the Westinghouse 251 turbine.

CFTCC Advantages

The combustion/emissions control island of the CFTCC plant produces cleaned coal combustion gases for expansion in the gas turbine. The gases are cleaned to protect the turbine from flow-path degeneration due to coal contaminants and to reduce environmental emissions to comparable or lower levels than alternate clean coal power plant technologies.

Most of these alternate clean coal technologies have been developed by organizations that design process plants. As a result, incorporation of these coal technologies with a combined cycle power generation system requires integration of turbine equipment with a process plant. An advantage of the CFTCC system over other clean coal technologies using gas turbines results from the CFTCC system having been designed as an adaptation to coal of a natural gas-fired combined cycle plant. Gas turbines are built for compactness and simplicity. The RQL combustor is designed using gas turbine combustion technology rather than process plant reactor technology used in other pressurized coal systems. The result is simpler and more compact combustion equipment than for alternate technologies. The natural effect is lower cost and improved reliability.

To illustrate the difference in technology, the residence time in the rich zone of the RQL system is typically only about 20% to 30% of that for many entrained coal gasifiers that have the shortest residence times of the alternate coal technologies. This results in a more compact system. Combustion in the RQL system is achieved with air, thereby not requiring the complexity and the high cost of the oxygen plant needed for many coal gasification systems. No equipment is necessary in the RQL combustion system to capture and recycle combustion product fines while such equipment is usually needed for efficient coal consumption in advanced pressurized systems.

In addition to new power generation plants, CFTCC technology will provide relatively compact and gas turbine compatible coal combustion/emissions control islands that can adapt existing natural gas-fired combined cycle plants to coal when gas prices rise to the point where conversion is economically attractive. Because of the simplicity, compactness, and compatibility of the RQL combustion/emission control island compared to other coal technologies, it could be a primary candidate for such conversions.

351 MWe CFTCC Plant

Plant Description. The following describes the performance of a 351 MWe CFTCC plant that utilizes the Westinghouse 501F turbine and a 2400 psig/1000°F/1000°F/2.5 in. Hg steam cycle. The plant produces 351 MWe output using 112.9 tons/hour of an eastern bituminous coal containing 2.5% sulfur and 16.4% ash. A salable by-product of the plant is elemental sulfur. About 2.7 tons/hour of sulfur is

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Figure 2. 100 MWe Demonstration Plant Layout

extracted from the coal combustion stream using the zinc titanate sulfur capture system.

Emissions. Table I shows lower NO_x and SO₂ and particulate emissions for the CFTCC system than for an existing 300 MWe coal boiler plant without provisions for SO_x and NO_x control. The CFTCC emissions are also substantially lower than the Federal New Source Performance Standards (NSPS) shown in Table I.

Efficiency. Table II shows the efficiency of the 351MWe CFTCC plant and the efficiency of the 300 MWe pulverized coal boiler plant. The CFTCC plant efficiency is over seven percentage points higher than

that for the existing conventional power plant.

Costs. As discussed earlier, the CFTCC system design approach adapts a conventional combined cycle plant design to operation with coal by using the RQL combustion/emissions control island. The distinction of equipment between combined cycle equipment and coal combustion/emissions control equipment allows identification of the incremental capital costs per kilowatt for the CFTCC plant compared to a combined cycle plant that uses conventional fuels. Cost evaluations have indicated an incremental cost of about \$480/kW for the coal combustion/emissions control equipment.

Table I. Comparison of Air Emissions of 300 MWe Coal Boiler Plant with the CFTCC Plant

<u>Emission specie</u> <u>(HHV basis)</u>	<u>PC boiler</u> <u>plant</u>	<u>CFTCC</u> <u>plant</u>	<u>NSPS</u>
NO ₂ , lb/MMBtu	1.24	0.113	0.5
SO ₂ , lb/MMBtu	3.96	0.101	1.20
Particulates, lb/MMBtu	0.10	0.013	0.03

Table II. Power Plant Efficiencies

<u>System</u>	<u>Heat rate</u> <u>Btu/kW-hr</u> <u>HHV basis</u>	<u>HHV</u> <u>efficiency--%</u>
351 MWe CFTCC plant	7785	43.8
300 MWe PC boiler plant	9493	36.0

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