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PIÑON PINE: AN ADVANCED IGCC DEMONSTRATION

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INTRODUCTION

The Piñon Pine Power Project is a second generation integrated gasification combined cycle (IGCC) power plant, located at Sierra Pacific Power Company's (SPPC) Tracy Station, 17 miles east of Reno, Nevada. The project is being partially funded under the Department of Energy's (DOE's) Clean Coal Technology Program (CCT). SPPC intends to operate the plant in base-load mode to supply approximately 100 megawatts electric (MWe) to the transmission grid. This plant will be the first full-scale integration of several advanced technologies: an air-blown KRW gasifier; full-stream hot gas desulfurization using a transport reactor system with a zinc-based sorbent; full-stream, high-temperature ceramic filters for particulate removal; the General Electric Model MS6001FA (6FA) Gas Turbine Engine/generator, and a 950 pound per square inch absolute (psia), 950° F steam turbine generator. This paper reviews the overall configuration and integration of the gasification and power islands components, which yield the plant's high efficiency. Current status of the project is addressed.

PROJECT OBJECTIVE

The project objectives are: to demonstrate air-blown, pressurized, fluidized-bed IGCC technology incorporating hot gas cleanup; to evaluate a low-British thermal unit gas combustion turbine; and to assess long-term reliability, availability, maintainability, and environmental performance at a scale sufficient to determine commercial potential.

BACKGROUND

The Piñon Pine Power Project was one of nine projects selected for funding in the Fourth Clean Coal Solicitation (CCT IV). CCT IV technologies were to be capable of retrofitting, repowering, or replacing existing facilities while achieving significant reductions in the emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) and/or providing for future energy needs in an environmentally acceptable manner. The Cooperative Agreement between SPPC and DOE was executed in August 1992. The scope of the project entails the design, construction, and operation of an air-blown KRW fluidized-bed coal gasifier IGCC demonstration project. Foster Wheeler USA Corporation is providing the engineering and construction management services. The M. W. Kellogg Company's (MWK) scope of work is to engineer, design, and purchase equipment for installation in the gasifier island.

The project integrates a number of technologies fostered by DOE, including: the KRW gasifier with in-bed desulfurization using a calcium carbonate based sorbent, external hot gas desulfurization using a zinc-based sorbent, and hot gas filtration for particulate removal.

The development of the KRW gasification technology was supported from 1972 until 1988 by DOE and its predecessor agencies. The design of the process development unit (PDU) was initiated in 1972 by Westinghouse Electric Corporation. Construction of the PDU at the Westinghouse Waltz Mill Facility was completed in 1975. Well over a decade of testing was performed at the 25-ton-per-day PDU to develop the KRW gasification technology. This testing included: air-blown and oxygen-blown operating modes, in-bed desulfurization using limestone and dolomite sorbents, use of ceramic (and sintered metal) filters for particulate removal, and external-bed desulfurization using zinc ferrite sorbents in a fixed bed reactor.

TECHNOLOGY--KEY FEATURES

The KRW process improves upon first generation IGCC technology in several aspects. The simplified IGCC system incorporates air-blown gasification with hot gas cleanup. By eliminating the oxygen plant and minimizing the need for gas cooling and wastewater processing, the capital cost is reduced and plant efficiency is improved. Key features of the KRW IGCC process are described below:

Air-Blown Gasification

About 15 to 20 percent of the gas turbine compressor air is extracted for use as oxidant in the gasifier. A booster air compressor increases the pressure of this extracted air to compensate for pressure losses through the gasifier and downstream hot gas cleanup systems and control valve. This eliminates the need for an air separation plant to supply the gasification oxidant. The air blown configuration is less complex and has lower capital cost.

The gasifier is designed to operate with a wide variety of coals. For each coal property, there is a wide range acceptable to the gasifier. This fuel flexibility is a major advantage of this process. During the operation of the process, the predominant fuel will be low sulfur coals from the Western United States., with high sulfur coals from eastern or midwestern areas being used for demonstration tests.

Addition of limestone (or dolomite) to the gasifier serves several purposes. Limestone captures a significant percentage of the sulfur released from the coal in the gasification process and improves bed fluidization by making the bed more dense. Also, testing at the PDU indicated that product gas heating value can be increased and that ammonia production in the gasifier can be reduced by limestone addition. Ammonia in the product gas stream is a contributor to NO_x generation in the gas turbine combustor.

Hot Gas Cleanup

Most major gasification plants have utilized cold, i.e., wet, cleanup processes. Hot gas cleanup filters the gas at high temperatures allowing the gas to maintain most of its sensible heat. This results in a higher plant efficiency and fewer equipment items since the waste water is not produced in the cleanup process.

Hot Gas Desulfurization

Sulfur, contained in the coal, is removed in two steps. Hydrogen sulfide produced in the reducing environment of the gasifier is captured by limestone, which is fed to the gasifier with the coal. Sulfur capture, as calcium sulfide (CaS), within the gasifier will be limited by chemical equilibrium to approximately 50 percent when the low-sulfur (less than 0.5 percent) Uinta basin bituminous coal is fed into the gasifier. During testing on higher sulfur eastern coals, sulfur capture should approach 90 percent. Sulfur, primarily in the form of hydrogen sulfide, not captured by the limestone or retained in the ash exits the gasifier in the product gas stream. This sulfur is captured by the zinc-based sorbent in the external hot gas desulfurization system.

Sulfation System

Coal ash with spent limestone (LASH) containing CaS and unconverted carbon is sent to the sulfation system. The sulfation system oxidizes the CaS into calcium sulfate, combusts unconverted carbon, and absorbs sulfur dioxide from the desulfurization system regeneration gas. Small amounts of transport and depressurization gas will also combust in the system. The heat generated is used to generate steam. The sulfated LASH will be suitable for landfill.

MAJOR DESIGN IMPROVEMENTS

Through the course of engineering and design, several significant process design improvements have been achieved. These improvements include: the use of the General Electric 6FA gas turbine and the use of a transport reactor desulfurization system with a zinc-based sorbent. The design effort and a rigorous value engineering program have resulted in numerous project improvements, such as the reduction in the maximum gasifier island structure height from 170 feet to 130 feet, with the majority of the structure topped off at 90 feet.

General Electric 6FA Gas Turbine

For IGCC systems the selection of the gas turbine establishes the design basis, therefore final gas turbine selection must be made early in the project. During the preliminary design phase of the project, the General Electric was selected to supply the 6FA gas turbine.

The 6FA is aerodynamically scaled from General Electric's 7FA and has many common features, including the 2,350°F firing temperature. The 6FA was offered at the introductory rating of 70.1 MWe for 60-hertz operation on natural gas. At this rating, firing natural gas, the 6FA is designed for 34 percent efficiency in simple-cycle operation and near 53 percent in combined-cycle operation depending on the steam cycle. In natural gas fired, combined-cycle applications, the total power output would be 100 - 110 MWe. In the Piñon Pine Project, the primary fuel will be the coal derived syngas produced by the KRW gasification system, with natural gas as a startup and backup fuel. For the project, the 6FA site-rating, at an elevation of 4,300 feet above sea level, is 61 MWe on syngas and 67 MWe on natural gas. This project will have one of the first production 6FA gas turbines and, certainly, the first in an IGCC application.

Because the 6FA is more efficient and has a larger output than the originally proposed gas turbine, significant performance improvements were achieved. These improvements are illustrated in Table 1. Of note, the overall net power increases by roughly 30 percent, while the coal feed rate is increased by only 10 percent. Other plant modifications play some role, but this improvement is primarily due to the use of the 6FA gas turbine. Although, the resulting increase in the overall plant size was responsible for some project cost growth, the incremental cost for the additional megawatts was very reasonable. Overall, the project is much improved and presents a better demonstration of the KRW IGCC technology because of this design modification.

TABLE 1, Performance Changes

IGCC Item and Units	Awarded	Current
Coal Feed Rate, TPD	800	880
GT Power, gross MWe	52.8	61.0
ST Power, gross MWe	28.5	46.2
Gross Power, MWe	81.3	107.2
Auxiliary Power, MWe	4.9	7.5
Net Plant Power, MWe	76.4	99.7
Net Heat Rate (HHV)	9082	8390
Efficiency (HHV) %	37.6	40.6

Transport Reactor Desulfurization System

Based on the experience at the Waltz Mill Facility, the initial process design included a fixed-bed hot gas desulfurization (HGD) system using zinc ferrite sorbent. After this project was selected by DOE, three zinc-based sorbents were tested at DOE's Morgantown Energy Technology Center for use in the fixed-bed application. In this testing, zinc ferrite and zinc titanate tended to decrepitate over extended multi-cycle testing, apparently due to the high sulfur loading on the sorbent innate in the fixed-bed system. The Z-Sorb sorbent, developed by Phillips Petroleum Company, showed no decrepitation, but tended to lose capacity when regenerated in the presence of steam.

With the use of a transport reactor system, both the high sorbent sulfur loading and the use of steam during regeneration can be avoided. MWK investigated this concept using the Z-sorb sorbent. In these proof-of-concept tests, there was no detectable sulfur escaping the transport absorber. The regenerator was operated with a limiting amount of oxidant, such that only partial regeneration is achieved, limiting the oxidation exotherm. After an additional series of tests, in MWK's Transport Reactor Test Unit and a detailed technical review of both the fixed-bed and transport systems, the decision was made to replace the fixed-bed HGD with a transport HGD in the Piñon Pine Project. MWK continues to work with both METC and the sorbent vendors to improve desulfurization sorbents and systems.

The use of the Transport HGD represents both a technical and a cost improvement over the fixed-bed HGD system. The fixed-bed system, using multiple vessels, is inherently a complex system requiring numerous large valves in a hot, dirty environment and somewhat complicated piping schemes. To minimize valve cycling, the fixed-bed vessels tend to be large and contain a large inventory of sorbent. Both the vessels and the sorbent inventory become major cost items. An additional concern is that under upset conditions, an entire bed of sorbent might be rendered useless. This also holds true during the sorbent regeneration cycle, where testing has shown difficulty in controlling temperature and maintaining a relatively flat temperature distribution across the bed.

The Transport HGD has no valves in the hot product gas stream and runs in continuous operation, eliminating concern over process upsets during bed switching in the batch mode fixed-bed system. The high riser velocity in the transport absorber maximizes throughput per cross-sectional area, resulting in a relatively small diameter vessel. Sorbent inventory in the absorber is also minimized, most residing in the standpipe at any given time. Regeneration is achieved using undiluted air in a small diameter vessel.

PLANT CONFIGURATION

The major process systems of the Piñon Pine Project facility are briefly described in this section. A block flow diagram is provided as Figure 1.

Crushed coal, ¼"x0, and limestone, 16x200 mesh, are pneumatically fed into the gasifier through the central feed tube. Additional air, extracted from the gas turbine compressor and further increased in pressure by the booster compressor, will be fed through the central tube. The two feeds merge to form a central jet where the coal will quickly devolatilize. The remaining char and limestone enter the bed. Combustion of char and gas occurring within the jet provides the heat necessary for the endothermic devolatilization, gasification, and desulfurization reaction. Extraction steam from the steam turbine is injected through the gasifier grid to aid in fluidization and drive the gasification reactions. LASH particles, which separate from the bed particles due to their higher density, are cooled and removed from the gasifier through the bottom annulus. The product gas, exiting the gasifier at nominally 295 psia and 1,800°F, contains a significant quantity of particulates, which are separated from the gas in the gasifier cyclone and returned to the gasifier.

Product gas from the gasifier cyclone is cooled to about 1,000°F in a series of two product gas coolers. The rejected heat generates steam which is combined with steam from the sulfator's heat recovery steam generator (HRSG). The quantity of particulates in the gas stream are further reduced in the desulfurizer feed cyclone.

Gas exiting this cyclone enters the transport desulfurizer, where sulfur compounds are removed by a zinc-based sorbent. Sulfur compounds in the gas are reduced to less than 20 parts per million by volume in the riser section of the desulfurizer. The desulfurizer cyclone separates the product gas from the entrained sorbent particles. The desulfurized gas leaving the cyclone is directed to the hot gas filter. The partially sulfided sorbent from the cyclone is returned to the riser via a standpipe and non-mechanical valve. A small stream of sulfided sorbent will be withdrawn from the standpipe and will flow to the transport regenerator. The sulfided sorbent will be regenerated by air as both the sorbent and the air flow up the regenerator riser. The regenerator cyclone separates the sorbent from the SO_2-rich regeneration gas. The regenerated sorbent is returned to the desulfurizer standpipe.

With the exception of a small amount of sulfur in the fuel gas to the turbine, all of the sulfur in the coal is disposed of in the sulfator system. The system combusts the residual char in the ash and fines collected from gasification, captures SO_2 from residual char and regenerator gas, and oxidizes the CaS to calcium sulfate. Steam generated in the sulfator HRSG, combined with steam from the product gas coolers is heated to 600°F in the superheater section of the sulfator HRSG prior to exporting to the gas turbine HRSG where it is combined with other steam prior to entering the superheater section of the gas turbine HRSG.

Desulfurized fuel gas from the desulfurizer section will contain a small quantity of particulates. This stream is passed through the hot gas filter, which essentially removes all remaining particulates from the gas. The hot gas filter will be a ceramic candle type, utilizing back pulse gas for cleaning. The clean fuel gas exits the filter and is sent to the gas turbine.

The General Electric 6FA gas turbine combusts the fuel gas to drive the turbine. The engines's output power shaft is reduced in rotative speed in a gearbox from the optimum efficiency value for a gas turbine of this size to 3,600 revolutions per minute. Mechanical power is then converted to electrical power in a once-through, air-cooled synchronous generator. The power shaft also drives the gas turbine compressor, which supplies air to the gasification island and to the gas turbine combustors. Exhaust gas flow at approximately 1,400,000 pounds per hour and 1,100°F are sent to the gas turbine HRSG. The HRSG produces steam at 1,006.7 psia and 59.1 psia. Steam generated in the HRSG at 1,006.7 psia and steam from the gasification island is combined, superheated, and sent to the steam turbine at 950 psia, 950°F for expansion. The 59.1 psia steam is superheated and sent at 55 psia, 360°F to the deaerator, with any excess steam sent to the steam turbine.

The steam turbine is a condensing type with extraction at 485 psia providing steam to the gasifier at 420 psia, 700°F. When low throttle steam rates cause the extraction pressure to fall below 420 psia, high pressure letdown is used to provide steam for injection into the gas turbine for NO_x control at 420 psia, 700°F. The stream turbine exhausts into a surface condenser, which condenses the steam at 2 inches of mercury pressure, based on normal load at 50°F ambient temperature. The steam turbine generator has a design output of 46.2 MWe.

PROJECT STATUS

A project schedule showing the project phases and significant milestones is provided as Figure 2. As shown, the Cooperative agreement was awarded in August, 1992. Since that time, the project has proceeded through the design phase and into construction, which started in February, 1995. Phase 3, Operation will begin in February, 1997 and continue for 42 months. Piñon Pine will continue to operate after the CCT operation phase is completed in August 2000.

A DOE review of the engineering and construction status was conducted in January, 1996. The review indicated that the project was complete to approximately these levels: 100 percent of design, 80-90 percent engineering, and 20 percent construction. The project is on schedule. At the time of the review, the following items of significance were observed:

- The gasification island structure was erected to the 90 feet above grade level. Major equipment items, including the gasifier and hot gas filter vessels, had been set in the structure as their support level was completed
- The foundation for the gas turbine was complete. The HRSG shell was erected in place.
- The steam turbine foundation was poured.
- The startup heater was in place.
- The foundation for the coal unloading hopper was partially complete, most other underground piping and systems, including the coal reclaiming and conveyor tunnel, are complete.

Significant other events prior to start of Phase 3 are as follows:

1/96	Product gas coolers shipped
2/96	Gas turbine shipped
3/96	Erection of gasification structure complete
3/96	Installation of steam turbine generator
8/96	First firing of gas turbine on natural gas
9/96	Mechanical completion of combined cycle and offsites
10/96	Mechanical completion of gasification island
11/96	First coal-fired operation

CONCLUSIONS

The Piñon Pine project will provide utilities and other power generators with design, construction, and operating data on which to base future decisions regarding new power generation options. The technology's advantages of modularity, rapid, and staged on-line generation capability, high efficiency, low environmental emissions, and reduced land and natural resource needs, enhance the potential for this technology to achieve wide acceptance in meeting future U.S. energy needs.