CONF-960426--8

DOE/MC/21023-96/C0687

Increased Efficiency of Topping Cycle PCFB Power Plants

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Contract Number:

DE-AC21-86MC21023

Conference Title:

American Power Conference

Conference Location:

Chicago, Illinois

Conference Dates:

April 9-11, 1996

Conference Sponsor:

Illinois Institute of Technology

Contracting Officer Representative (COR):

Don Bonk, C04

DISCLAIMER

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INTRODUCTION

Pressurized circulating fluidized bed (PCFB) power plants offer the power industry significantly increased efficiencies with reduced costs of electricity and lower emissions. When topping combustion is incorporated in the plant, these advantages are enhanced. Figure 1 is a simplified process block diagram of a coal-fired, topping cycle PCFB plant.

In the plant, coal is fed to a pressurized carbonizer that produces a low-Btu fuel gas and char. After passing through a cyclone and ceramic barrier filter to remove gas-entrained particulates and a packed bed of emathelite pellets to remove alkali vapors, the fuel gas is burned in a topping combustor to produce the energy required to drive a gas turbine. The gas turbine drives a generator and a compressor that feeds air to the carbonizer, a PCFB combustor, and a fluidized bed heat exchanger (FBHE). The carbonizer char is burned in the PCFB and the exhaust gas passes through its own cyclone, ceramic barrier filter, and alkali getter and supports combustion of the fuel gas in the topping combustor. Steam generated in a heat-recovery steam generator (HRSG) downstream of the gas turbine and in the FBHE associated with the PCFB drives the steam turbine generator that furnishes the balance of electric power delivered by the plant.

The low-Btu gas is produced in the carbonizer by pyrolysis/mild devolatilization of coal in a fluidized bed reactor. Because this unit operates at temperatures much lower than gasifiers currently under development, it also produces a char residue. Left untreated, the fuel gas will contain hydrogen sulfide and sulfur-containing tar/light oil vapors; therefore, lime-based sorbents are injected into the carbonizer to catalytically enhance tar cracking and to capture sulfur as calcium sulfide. Sulfur is captured in situ, and the raw fuel gas is fired hot. Thus, the expensive, complex, fuel gas heat exchangers and chemical or sulfur-capturing bed cleanup systems that are typical of coal gasification combined-cycle plants are eliminated.

The char and calcium sulfide produced in the carbonizer and contained in the fuel gas as elutriated particles are captured by high-temperature filters, rendering the fuel gas essentially particulate free and able to meet New Source Performance Standards (NSPS). The captured particulate and carbonizer bed drains, are collected in a central hopper and injected into the PCFB through a nitrogen-aerated nonmechanical valve. The excess air in the combustor transforms the calcium sulfide to sulfate, allowing its disposal with the normal PCFB spent sorbent.

In the PCFB, the burning char heats the combustion air-flue gas to 1600°F; any surplus heat is transferred to the FBHE by the recirculation of solids (sorbent and coal fly ash) between the units. Controlled recirculation is accomplished with cyclone separators and nonmechanical valves. The FBHE contains tube surfaces that cool the circulating solids. Because of the low fluidizing velocity in the FBHE ($\leq$½ ft/s), the risk of tube erosion is virtually eliminated.

The exhaust gases leaving the carbonizer and the PCFB contain sorbent and fly ash particles -- both of which can erode and foul downstream equipment. A hot gas cleanup (HGCU) system, consisting of ceramic barrier candle filters preceded by cyclone separators, cleans the gases before they enter the fuel gas topping combustor and the gas turbine, thus preventing erosion and fouling. Ceramic cross-flow filters, screenless granular-bed filters and others are candidate alternatives for the candle filters, should their performance and economics be found superior. All these devices are currently under development for non-topping PCFB combustion plants. They should also be applicable to the topping cycle plant.

The topping combustor, which consists of metallic-wall multiannular swirl burners (MASBs), will be provided in two external combustion assemblies (topping combustors) on opposite sides of the gas turbine. Each MASB contains a series of swirlers that aerodynamically create fuel-rich, quick-quench and fuel-lean zones to minimize NO_x formation during the topping combustion process. The swirlers also provide a thick layer of air at the wall boundary to control the temperature of the metallic walls.

A team of companies -- led by Foster Wheeler Development Corporation (FWDC) with Foster Wheeler Energy Corporation and Foster Wheeler USA, Parsons Power/Gilbert-Commonwealth, Institute of Gas Technology, Westinghouse Power Generation Business Unit (PGBU) and Westinghouse Science & Technology Center -- is working on a DOE funded three-phase program to develop the technology for this new type of plant. A conceptual design of a 3-percent-sulfur Pittsburgh No. 8 coal-fired, topping cycle PCFB plant with a conventional 2400 psig/1000°F/1000°F/2-½ in. Hg steam cycle was prepared, and its economics were determined in Phase 1 (Ref. 1). We estimated that, when operating with a 14-atm/1600°F carbonizer, the plant efficiency would be 44.9 percent (based on the higher heating value of the coal) and its cost of electricity would be 21.8 percent lower than that of a conventional pulverized coal-fired plant. Tests conducted in our Phase 2 pilot-scale carbonizer yielded performance superior to that previously estimated. As a result, we now expect a more energetic fuel gas and a plant efficiency of 46.2 percent with a 1600°F carbonizer (Ref. 2).

PROJECT DESCRIPTION

The first phase of the DOE program has already been completed and it was aimed at plant conceptualization, optimization, and identification of plant R&D needs. The second phase, involving laboratory-scale tests of the key plant components, is near completion.

In Phase 2, the key components of this new type of plant were tested separately to ascertain their individual performance characteristics. The Phase 2 tests involved testing (1) a 10-in.-diameter carbonizer with a cyclone and ceramic barrier filter, (2) an 8-in.-diameter PCFB with a cyclone and ceramic barrier filter and (3) 12-in., 14-in. and 18-in. diameter MASBs. The first two test programs were conducted by FWDC at its John Blizard Research Center in Livingston, New Jersey. A total of 37 carbonizer test points with three coals, one petroleum coke, and two sorbents were completed; a total of 23 test points with four coals, one petroleum coke, 3 carbonizer char residues, and two sorbents were similarly completed in the PCFB. The test programs were conducted at 10 to 14 atmospheres pressure and were highly successful. Test reports have been released to the NTIS for publication. The MASB tests were conducted at the University of Tennessee Space Institute at Tullahoma, Tennessee, under the direction of Westinghouse PGBU. The development effort has culminated in the successful testing of a full scale 18 in. diameter MASB. Although a final report has not yet been issued (two additional tests are planned), test results have been published (Ref.3,4,5).

In Phase 3, a carbonizer and PCFB with their respective cyclones and ceramic candle filters have been interconnected and operated successfully as an integrated subsystem in Livingston.

Improved Carbonizer Performance

Based on the success of our Phase 2 pilot plant test program, we now expect the commercial plant carbonizer to perform better than our Phase 1 estimate. Compared with that estimate, the fuel gas energy content is 10 percent higher (140 vs. 127 Btu/sft^3) and emissions will be lower. At the same 1.75 calcium to sulfur molar feed ratio, the carbonizer sulfur capture efficiency will be 6 points higher (94 vs. 88 percent) and the fuel gas ammonia content 21 percent lower (0.23 vs. 0.29 weight percent).

Westinghouse PGBU computer codes predict an optimum firing temperature of 2425°F for the updated carbonizer fuel gas. This firing temperature or topping combustor outlet temperature provides a turbine inlet temperature (inlet to first rotating stage) of approximately 2300°F. Figure 2 presents an updated heat and material balance for the Phase 1 commercial plant. The plant utilizes two carbonizer - PCFB - gas turbine modules and one steam tubine to produce a net power output of 538 MWe. The plant operates with an efficiency of 46.2 percent (7385 Btu/kWh) based on the coal higher heating value. This efficiency is 1.3 points higher than our Phase 1 estimate and reflects a higher gas turbine to steam turbine power split (50/50 vs. 45/55). With the carbonizer and PCFB operating at 94 and 97 percent sulfur capture efficiency respectively, the plant overall sulfur capture efficiency will be 94.6 percent. Although, only one module is shown in Fig. 2, the flow rates given are for a two module plant.

Further Efficiency Increases

A 1600°F operating temperature was selected for the Phase 1 carbonizer because it was the minimum temperature that enabled the plant to reach a 45 percent efficiency goal; higher temperatures were not investigated as they would involve increased extrapolation risks. Our pilot plant tests, however, have generated extensive test data and demonstated successful carbonizer operation, at temperatures as high as 1815°F with highly caking Pittsburgh No. 8 coal. Increasing the carbonizer temperature increases the amount of coal energy transferred to the fuel gas and conversely decreases the amount of energy left in the char-sorbent residue transferred to the PCFB. As a result, less coal needs to be carbonized and with less char residue transferring to the PCFB, coal must be added to the PCFB to maintain its prior heat release.

The gas turbine leg of the plant is more efficient than the steam turbine portion of the plant. As a result, the gas turbine to steam turbine power split is an indicator of the plant efficiency. With coal being added to the PCFB we now have the ability to reduce the PCFB heat release and hence heat input into the steam cycle; this reduces the steam turbine power output, results in a higher gas turbine to steam turbine power split, and increases the plant efficiency. In Table 1, the key features of the 1600°F carbonizer plant shown in Figure 2 are compared with a similar plant, but one operating with a 1700°F carbonizer and with the above described reduced coal flow to the PCFB. By purposely reducing the size of the steam cycle (282.2 vs. 204.5 MWe), the gas turbine to steam turbine power split increases from 50/50 to 57/43 and the plant efficiency increases from 46.2 to 46.5 percent.

In the above comparison, both plants utilize two 2300°F gas turbines and one 2400 psig/1000°F/1000°F/2½ in. Hg. steam turbine. If the operating temperatures and pressures of either these machines are increased, even higher plant efficiencies (greater than 46.5 percent) can be achieved. As a result, we see the PCFB topping cycle as a leading contender for both repowering and new coal fired capacity additions. As a further step in the development of this new technology, a 3½ MWe gas turbine is being integrated with a Foster Wheeler carbonizer - PCFB - FBHE subsystem and a

Westinghouse MASB for testing at Southern Company Services Power Systems Development Facility at Wilsonville, Alabama. Testing is expected to start the third quarter of 1996 and continue through 1997. We look forward to the startup and successful operation of the Wilsonville plant, the next step in the development of the PCFB topping cycle.

REFERENCES

1. A. Robertson, et al. 1988. Second-Generation PFB Combustion Plant Performance and Economics. *1988 EPRI Seminar on Fluidized-Bed Combustion Technology for Utility Applications*. Palo Alto, CA.

2. A. Robertson, et al. 1993. Second-Generation PFBC Systems Research and Development -- Phase 2, Best Efficiency Approach in Light of Current Data. *Proceedings of the Coal-Fired Power Systems 93 -- Advances in IGCC and PFBC Review Meeting*, Don Bonk (ed.), DOE/METC 93/6131.

3. W. Domeracki, et al. 1994. Development of Topping Combustor for Advanced Concept Pressurized Fluidized Bed Combustion. *Proceedings of the Coal-Fired Power Systems 94*, M. McDaniel. R. Staubly and V. Venkataraman, (ed.), DOE/METC 94/1008.

4. W. Domeracki, et al. 1993. Second-Generation PFBC Systems Research and Development. *Proceedings of the Coal-Fired Power Systems 93*, Don Bonk (ed.), DOE/METC 93/6131.

5. W. Domeracki, et al. 1992. Second-Generation PFBC Systems Research and Development. *Proceedings of the Ninth Annual Coal-Fueled Heat Engines, Advanced Pressurized Fluidized Combustion and Gas Stream Cleanup Systems Contractors Review Meeting*, DOE/METC 93/6129.

Table 1

Comparison of Topping Cycle PCFB Plants

Carbonizer Temperature, °F	1600	1700
Carbonizer Coal Flow, 10^3 lb/h	306.5	258.6
PCFB Coal Flow, 10^3 lb/h	0	24.8
Main Steam Flow, 10^3 lb/h	1624.9	1182.4
Steam Turbine Power, MWe	282.2	204.5
Gas Turbine Power, MWe	278.2	272.2
Net Plant Power, MWe	538.2	458.3
Plant Efficiency, % (HHV)	46.2	46.5

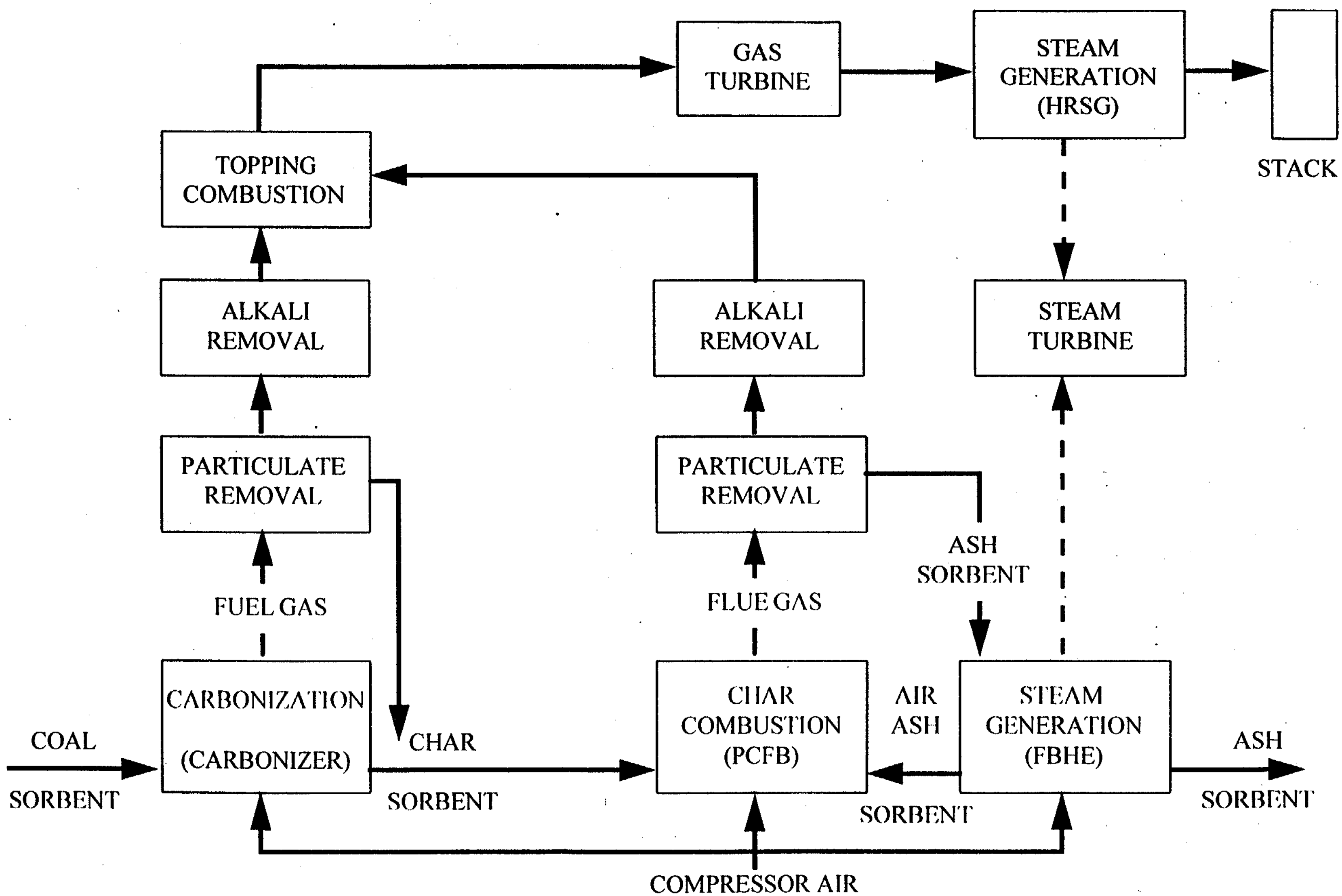

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Figure 1
Simplified Process Block Diagram -- Topping Cycle PCFB Combustion Plant

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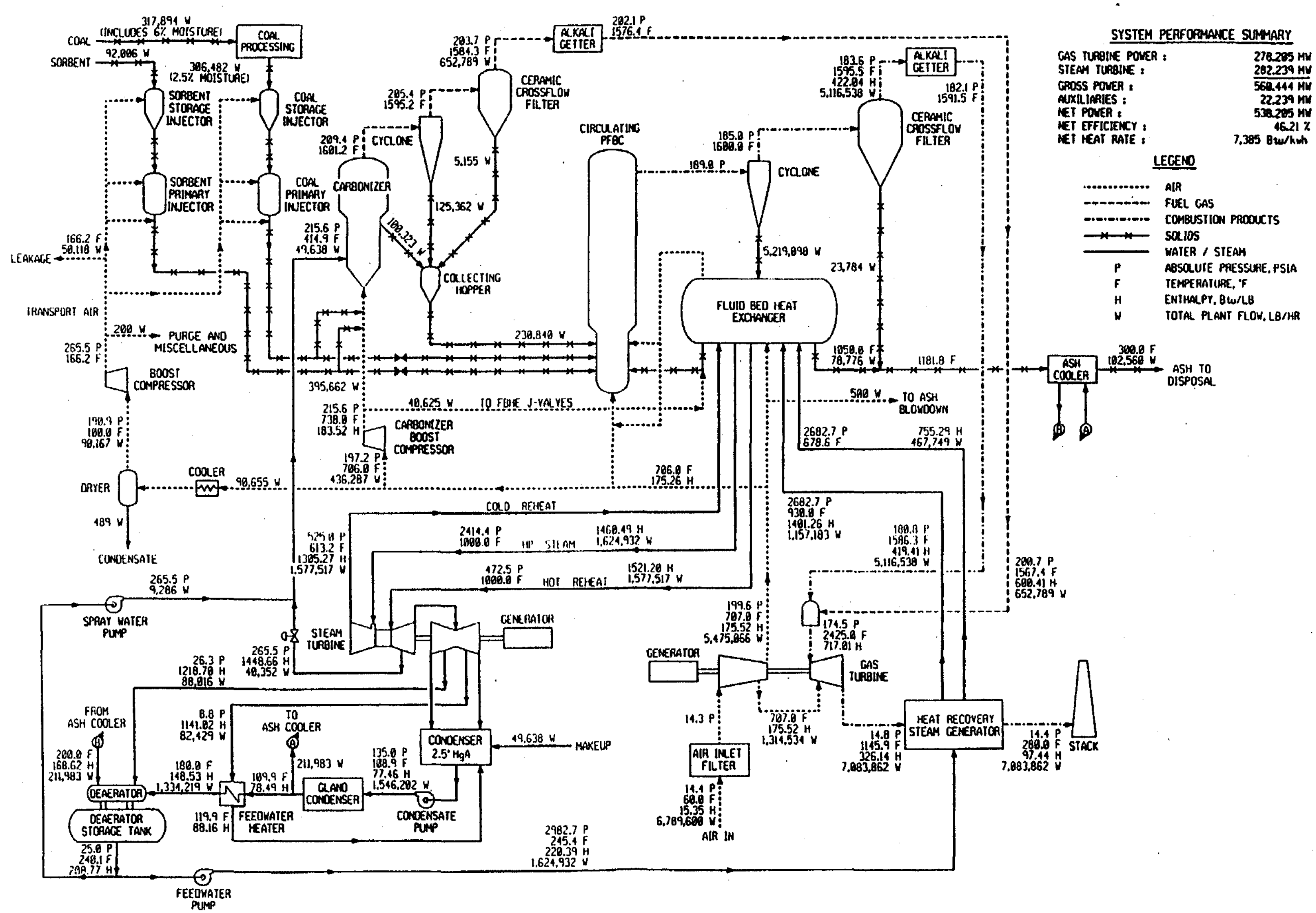

Figure 2

Phase 2 Topping Cycle PCFB Commercial Plant Update (46.2% BEP)

14-atm/1600°F Carbonizer

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