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Pilot Plant Becomes Demonstration Plant Design

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DISCLAIMER

2.2 Pilot Plant Becomes Demonstration Plant Design

CONTRACT INFORMATION:

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Period of Performance:	November, 1990 through January, 1996

OBJECTIVES - PHASE 3

The three major objectives of Phase 3 are: ▪ Test a 1.2-MWe equivalent carbonizer and Circulating Pressurized Fluidized Bed Combustor (CPFBC) with their associated ceramic candle filters as an integrated subsystem. ▪ Evaluate the effect of coal-water paste feed on carbonizer performance. ▪ Revise the commercial plant performance and economic predictions where necessary.

BACKGROUND INFORMATION

Advanced or second-generation pressurized fluidized bed combustion plants (APFBC) that generate electricity offer utilities the potential for significantly increased efficiencies with reduced costs of electricity and lower emissions while burning the nation's abundant supply of high-sulfur coal. Figure 1 is a simplified process block diagram of a second-generation PFB combustion 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 CPFBC, and a fluidized bed heat exchanger (FBHE). The carbonizer char is burned in the CPFBC with high excess air. The vitiated air from the CPFBC 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 CPFBC 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 part of the coal gasification combined-cycle plants now being developed 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 material, with carbonizer bed drains, is collected in a central hopper and injected into the CPFBC through a nitrogen-aerated nonmechanical valve. The high excess air in the combustor transforms the calcium sulfide to sulfate, allowing its disposal with the normal CPFBC spent sorbent.

In the CPFBC, the burning char heats the high-excess-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 (≤½ ft/s), the risk of tube erosion is virtually eliminated.

The exhaust gases leaving the carbonizer and the CPFBC contain sorbent and fly ash particles—both of which can erode and foul downtream equipment. A hot gas cleanup (HGCU) system, consisting of ceramic barrier filters preceded by cyclone separators, cleans the gases to <20 ppm solids loading 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 first-generation PFB combustion plants. They should also be applicable to the second-generation 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, Gilbert/Commonwealth, Inc., Institute of Gas Technology, Westinghouse Power Generation Business Unit (PGBU) and Science & Technology Center (STC)—has embarked upon 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 second-generation PFB plant with a conventional 2400 psig/1000°F/1000°F/2-½ in. Hg steam cycle was prepared, and its economics were determined [1]. In 1987 we estimated that, when operated 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 estimated in 1987. As a result, we now expect a more energetic fuel gas and a plant efficiency of 46.2 percent with a 1600 °F carbonizer [2].

PROJECT DESCRIPTION

The second-generation PFB combustion plant development effort is divided into three phases, the first of which has already been completed and documented in a series of reports available through the National Technical Information Service.

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

The R&D needs of this new type plant were presented in the Phase 1 Task 2 Report issued under this contract [3]; an integrated program plan for meeting these needs was presented in the Task 3 Report [4].

The move to commercialization of this new type of plant involves the five steps shown in Figure 2. Starting from the left and moving to the right, each succeeding step involves increased integration of components and increased plant size/complexity. In the first step—Phase 2 of our DOE contract—the key components of this new type of plant were tested separately to ascertain their individual performance characteristics. These Phase 2 tests involved testing (1) a 10-in.-diameter carbonizer (Figure 3) with a cyclone and ceramic barrier filter, (2) an 8-in.-diameter CPFBC (Figure 4) with a cyclone and ceramic barrier filter and (3) 12-in., 14-in. and 18-in.-(Figure 5) diameter MASBs. The first two test programs were conducted by FWDC at its John Blizard Research Center in Livingston, New Jersey. These programs were successful and 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. Although a final report has not yet been issued (two additional tests are planned), test results have been presented at previous meetings [5][6][7].

In the second step to commercialization—Phase 3 of our DOE contract—a carbonizer and CPFBC with their respective cyclones and ceramic candle filters are being interconnected and operated as an integrated subsystem. The FWDC PFB pilot plant in Livingston, New Jersey was expanded in 1994 to permit this integrated operation. The new and previously tested units are compared in Figures 3 and 4. The new CPFBC is 13 inches in diameter by 38.3 feet tall and operates at a 2 1/2 times higher throughput than the previous Phase 2 unit. The new carbonizer is actually the previous unit lengthened by a 5-foot-tall spool piece that allows operation with a commercial-scale, 24-foot-deep bed height. The hot shakedown of the expanded/integrated carbonizer-CPFBC pilot plant is underway.

In step three of Figure 2, an MASB and a gas turbine will be integrated with a carbonizer and CPFBC. This will be the first either has operated with carbonizer fuel gas as all previous MASB tests utilized gas mixtures synthesized to the composition predicted by FWDC for a commercial plant. This integration will occur at the Southern Company Services Power Systems Development Facility (PSDF) at Wilsonville, Alabama. This facility is being funded by the US DOE, the Electric Power Research Institute, and Industry for advanced coal-based power system R&D.

The APFBC process will be tested at the PSDF and a process flow diagram is presented in Figure 6. The plant will incorporate a 37-inch-ID CPFBC, an FBHE with two tube-bundle-containing fluidized beds, cyclones and ceramic candle filters, an 18-inch MASB, and a ≈3-MWe gas turbine. For cost savings a steam turbine will not be provided and the FBHE heat absorption will be exhausted to atmosphere via cooling towers. The 18-in. MASB will combust ≈1700°F carbonizer fuel gas to raise the ≈1600°F CPFBC flue gas/vitiated air to 2300°F. The gas turbine, being a relatively small unit, operates with a 1975°F turbine inlet temperature. Compressor discharge air will be injected into the 2300°F MASB exhaust to cool it to 1975°F, thereby allowing commercial plant MASB operation to be demonstrated.

The PSDF will be operated with Illinois No. 6 bituminous and Eagle Butte subbituminous coals. Limestone from Longview, Alabama will be injected into the APFBC fluidized beds to capture sulfur in situ. Each of these feedstocks has already been successfully tested in the Livingston Phase 2 carbonizer and CPFBC pilot plants. Based on these tests the 1700°F Wilsonville carbonizer is expected to produce a fuel gas with a 124-Btu/SCF heating value when operating with Illinois No. 6 coal. A gas yield of 3.2 lb/lb of coal is expected and the limestone sulfur capture efficiency is projected to be 94 percent at a calcium to sulfur molar feed ration of 1.75. The detailed performance of the carbonizer is presented in Figure 7. The char-sorbent residue from the carbonizer will be transferred to and burned in the CPFBC. Livingston pilot plant test data shown in Figures 8 and 9 indicate the CPFBC will operate with at least a 99-percent combustion and a 97-percent sulfur capture efficiency, respectively. The Phase 2 CPFBC was operated with a 12 ft/s gas velocity, and the effectiveness of staged combustion for controlling NO_X emissions was investigated. Because of the low height of the unit (28.5 feet) the gas residence time in the oxidizing zone was less than 1 1/2 seconds. The Phase 3 CPFBC is 38.3 feet tall and, with its higher oxidizing zone residence time, we anticipate NO_X emissions will be substantially less than the levels shown in Figure 10.

The Wilsonville APTBC will be commissioned in stages. Beginning in early 1996 the plant will be operated as a first generation PFB (no carbonizer or topping combustion) with coal being fired in the CPFBC. Then when the topping combustor is delivered in second quarter 1996 integrated carbonizer-CPFBC operation will begin. With proposed feedstocks and operating conditions having already been tested in Phase 2 and with Wilsonville personnel having witnessed Phase 2 testing and Phase 3 integrated carbonizer-CPFBC pilot plant commissioning runs, we anticipate a successful two-year test program.

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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. A. Robertson, et al. 1989. Second-Generation Pressurized Fluidized Bed Combustion Plant: Research and Development Needs. Foster Wheeler Development Corporation, Livingston, NJ. Phase 1 Task 2 Report FWC/FWDC-TR-89/06 to the U.S. DOE under Contract DE-AC21-86MC21023.

4. A. Robertson, et al. 1989. Second-Generation Pressurized Fluidized Bed Combustion Plant Integrated R&D Program Plan. Foster Wheeler Development Corporation, Livingston, NJ. Phase 1 Task 3 Report FWC/FWDC TR-89/08 to the U.S. DOE under contract DE-AC21-86M21023.

5. 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.

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

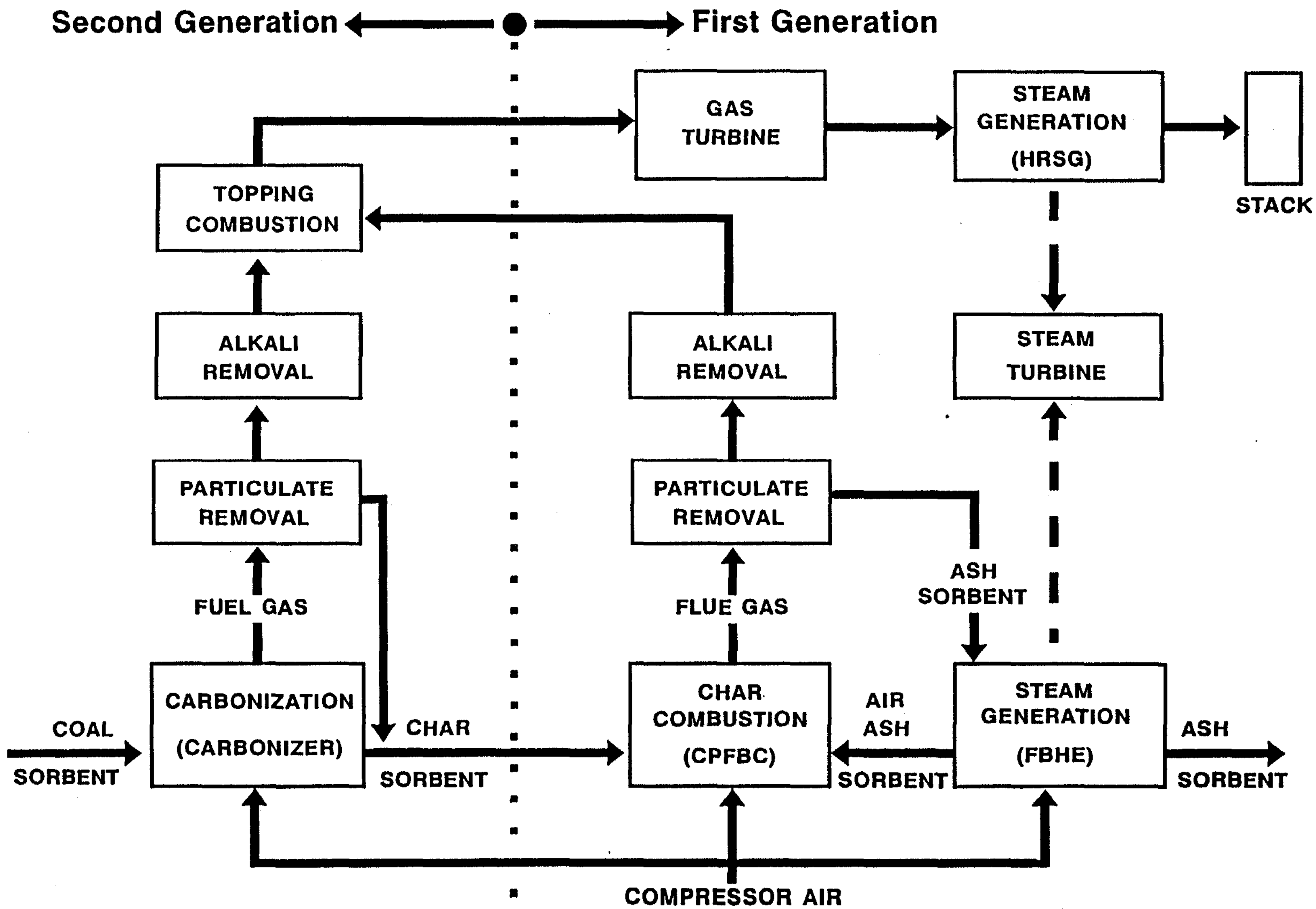


Figure 1. Simplified Process Block Diagram—Second-generation PFB Combustion Plant

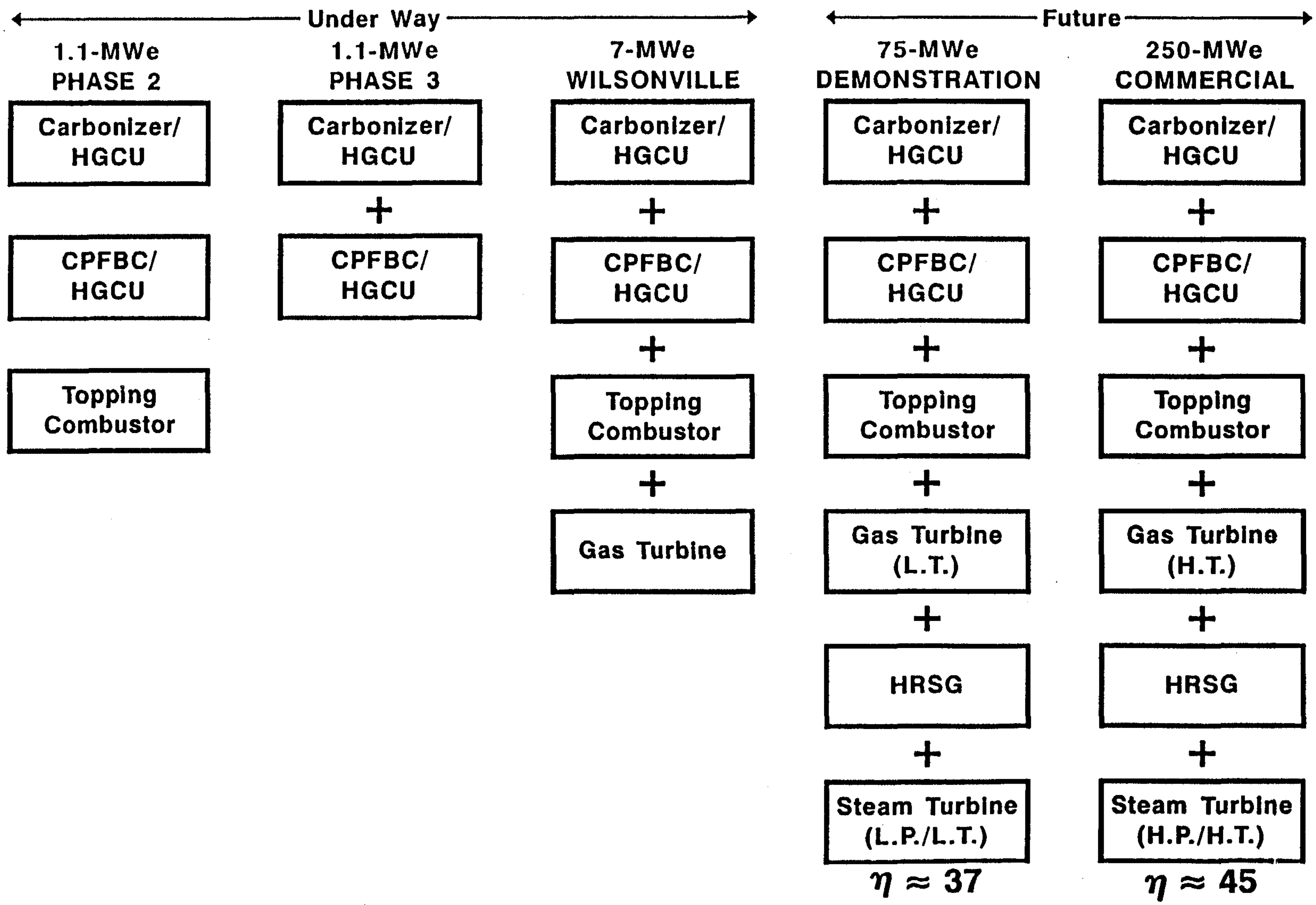


Figure 2. Second-generation PFB Plant Development Plan

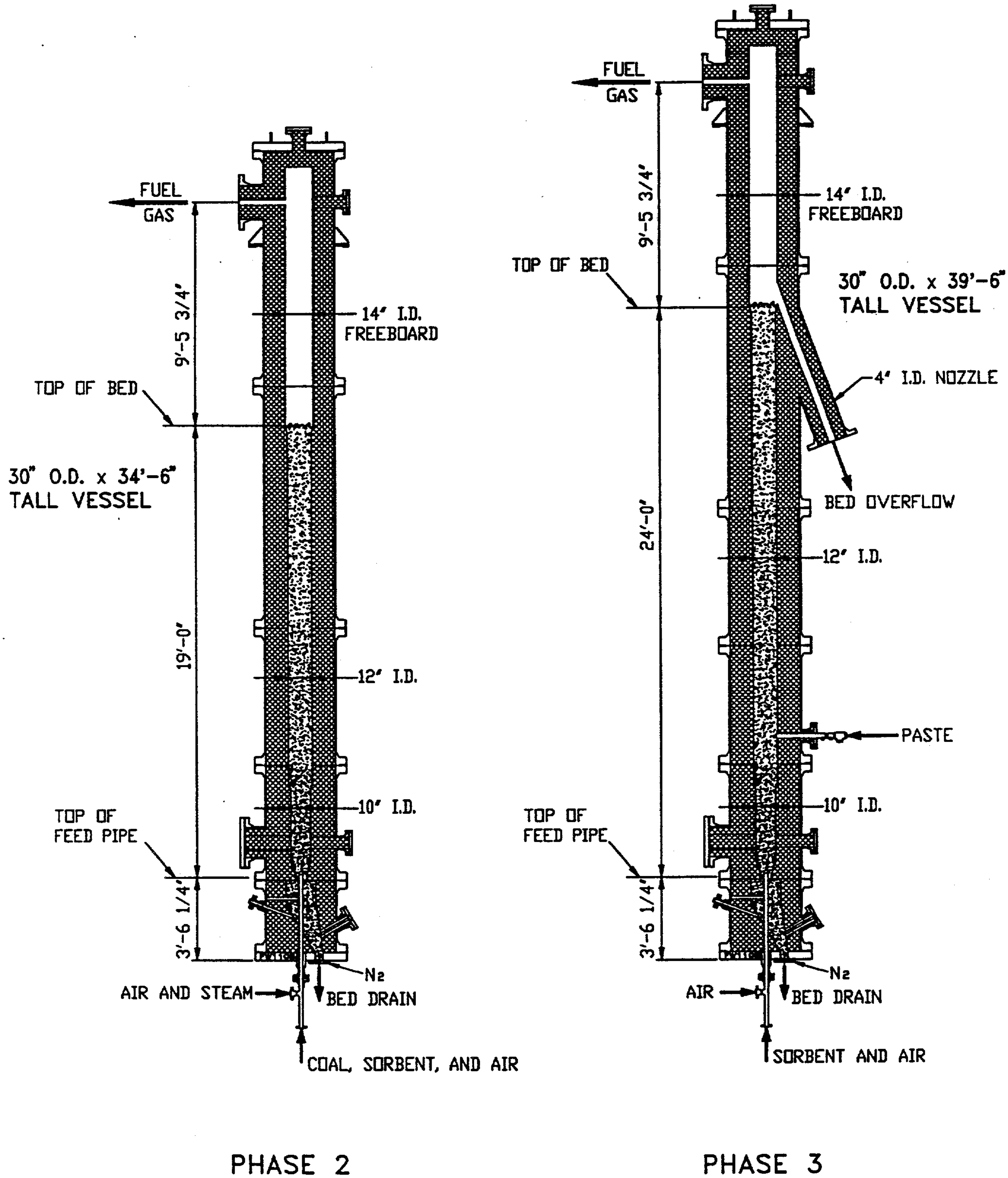


Figure 3. Carbonizer Comparison

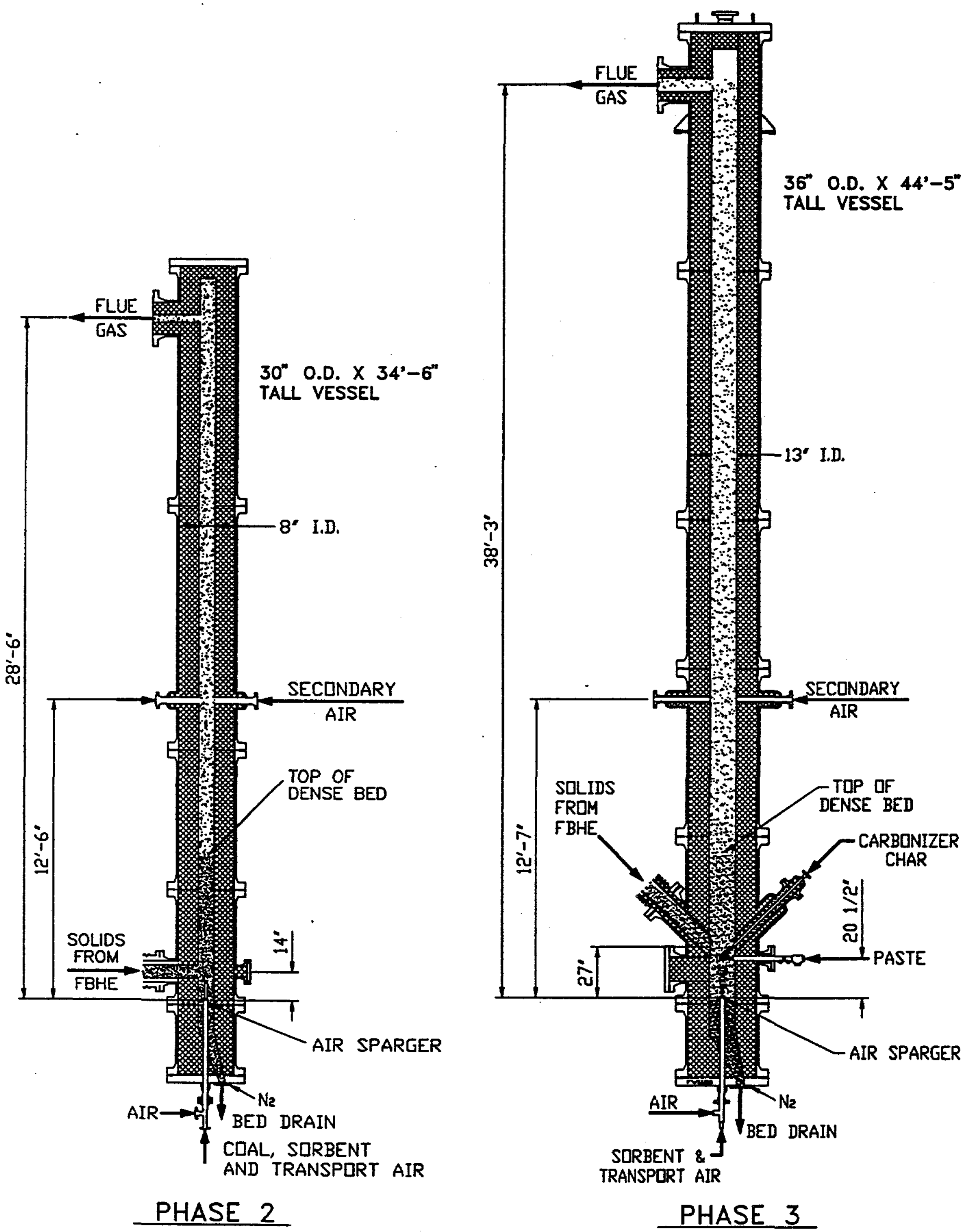


Figure 4. CPFBC Comparison

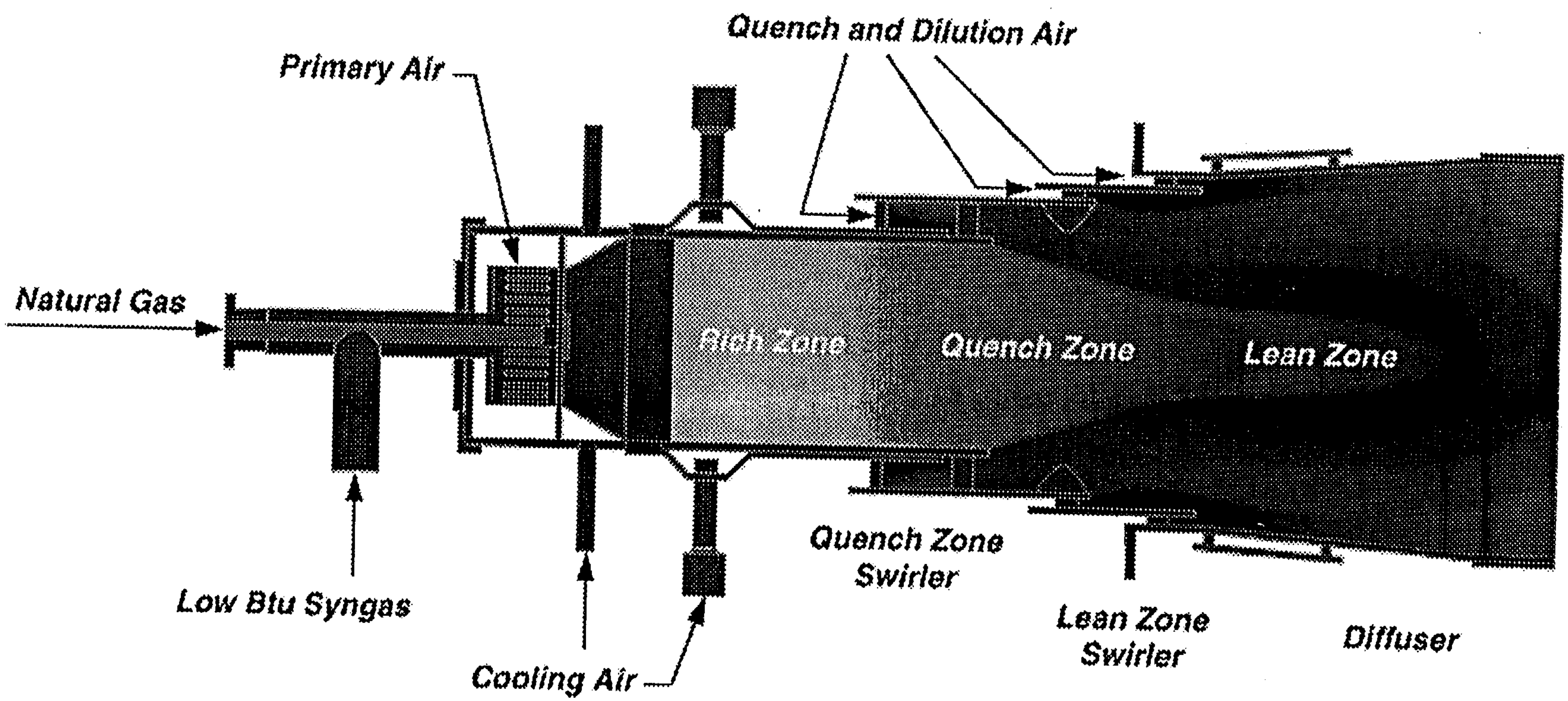


Figure 5. 18-inch-diameter Westinghouse MASB Test Unit

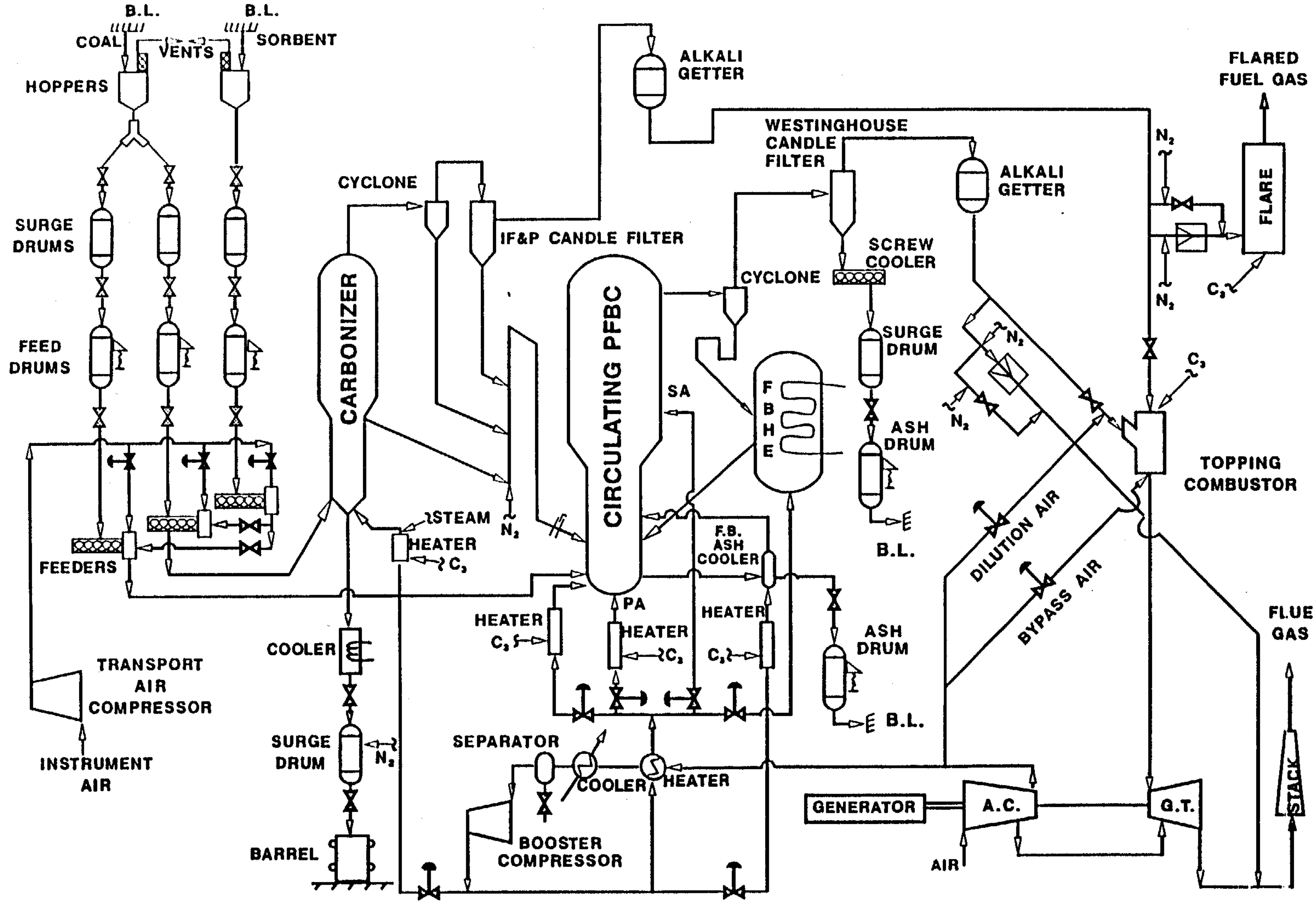
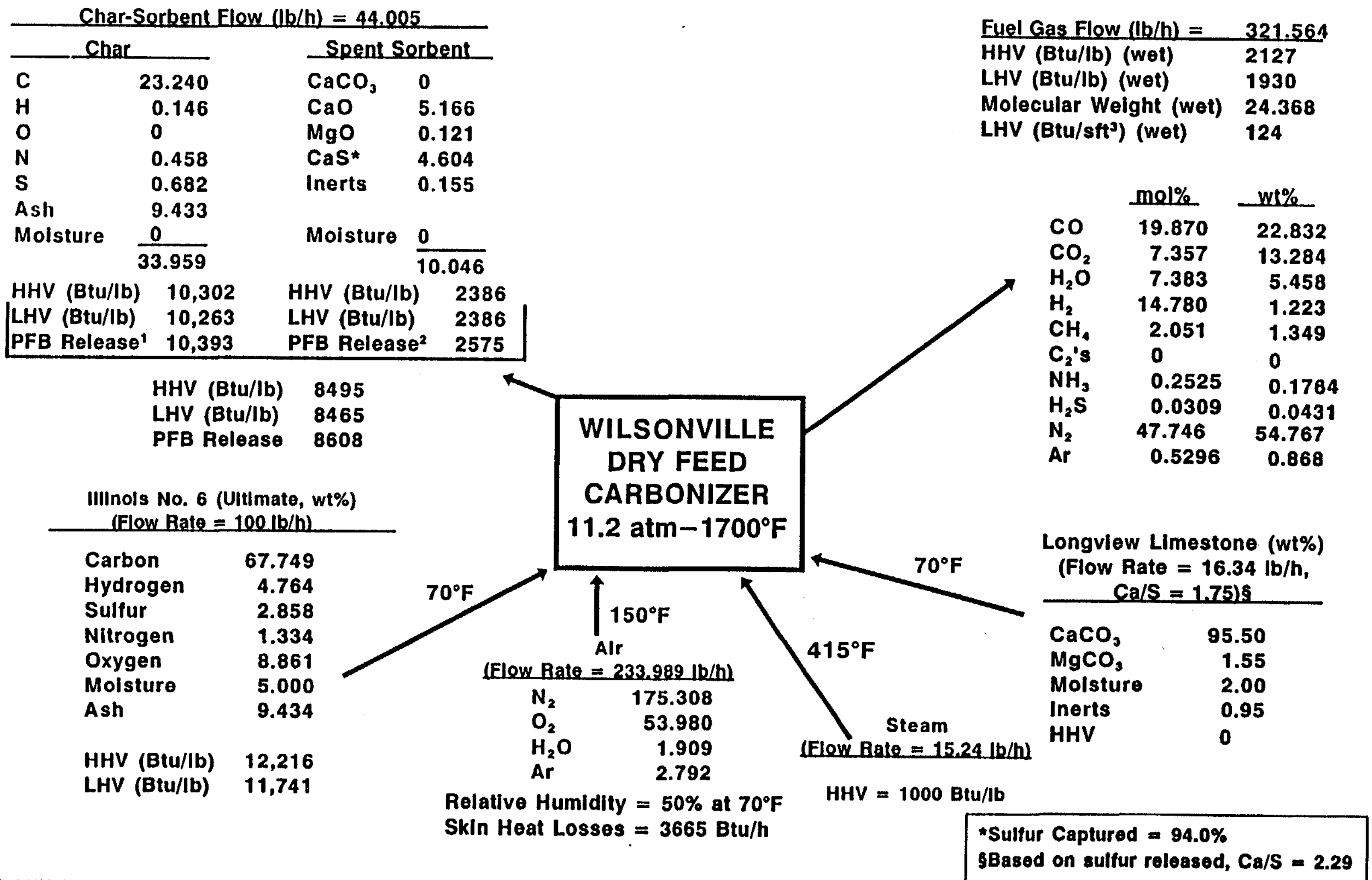


Figure 6. Wilsonville APFBC PFD



[1] LHV (10,263) + $CaO + \frac{1}{2}O_2 + SO_2 \rightarrow CaSO_4$ (207,710 Btu/lb mole SO_2)

[2] $CaS + 2O_2 \rightarrow CaSO_4$(404,350 Btu/lb mole CaS) - $CaCO_3 \rightarrow CaO + CO_2$ (-72,240 Btu/lb mole $CaCO_3$)

Figure 7. Wilsonville 1700°F Carbonizer Performance with Illinois No. 6 Coal

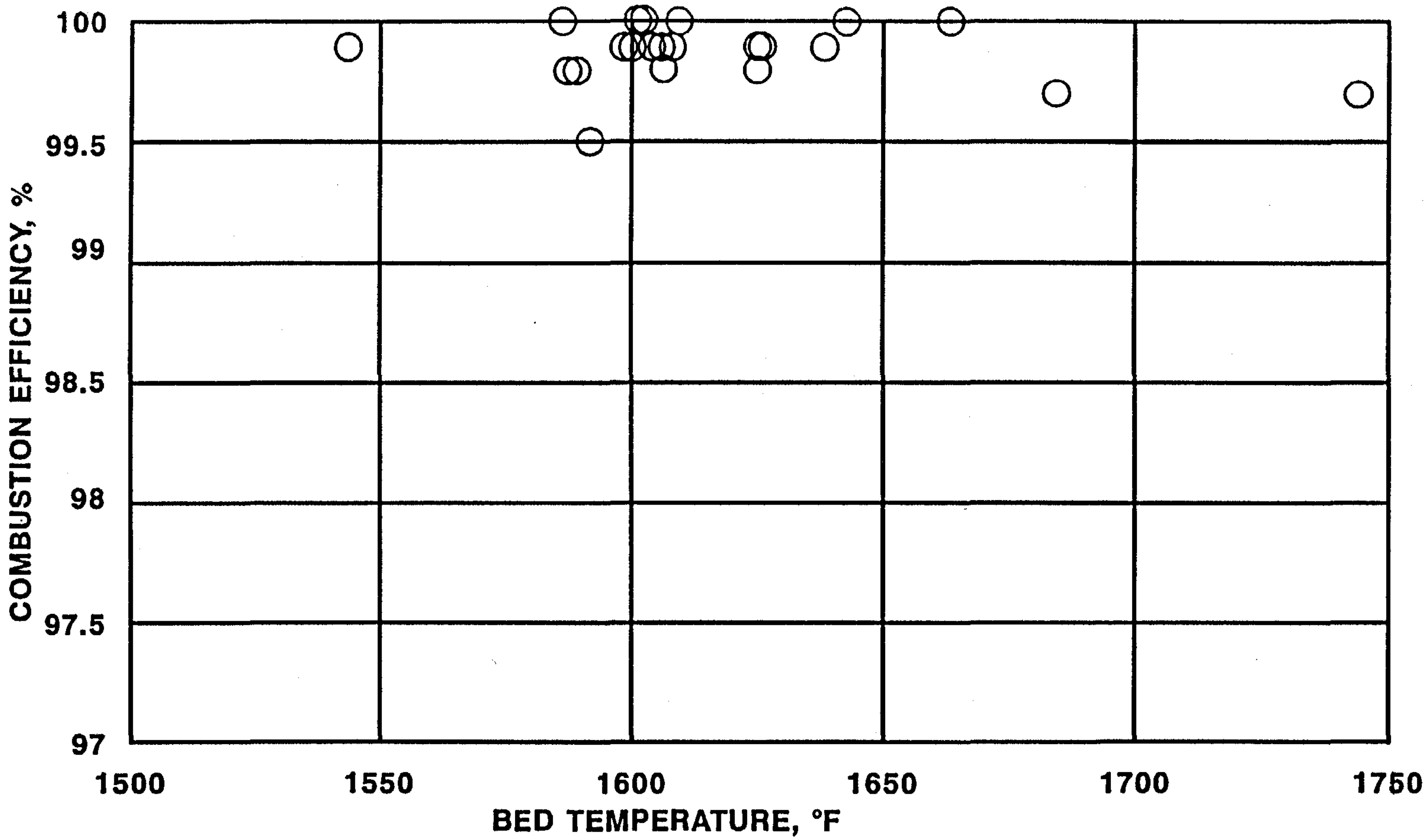


Figure 8. Phase 2 CPFBC Combustion Efficiencies

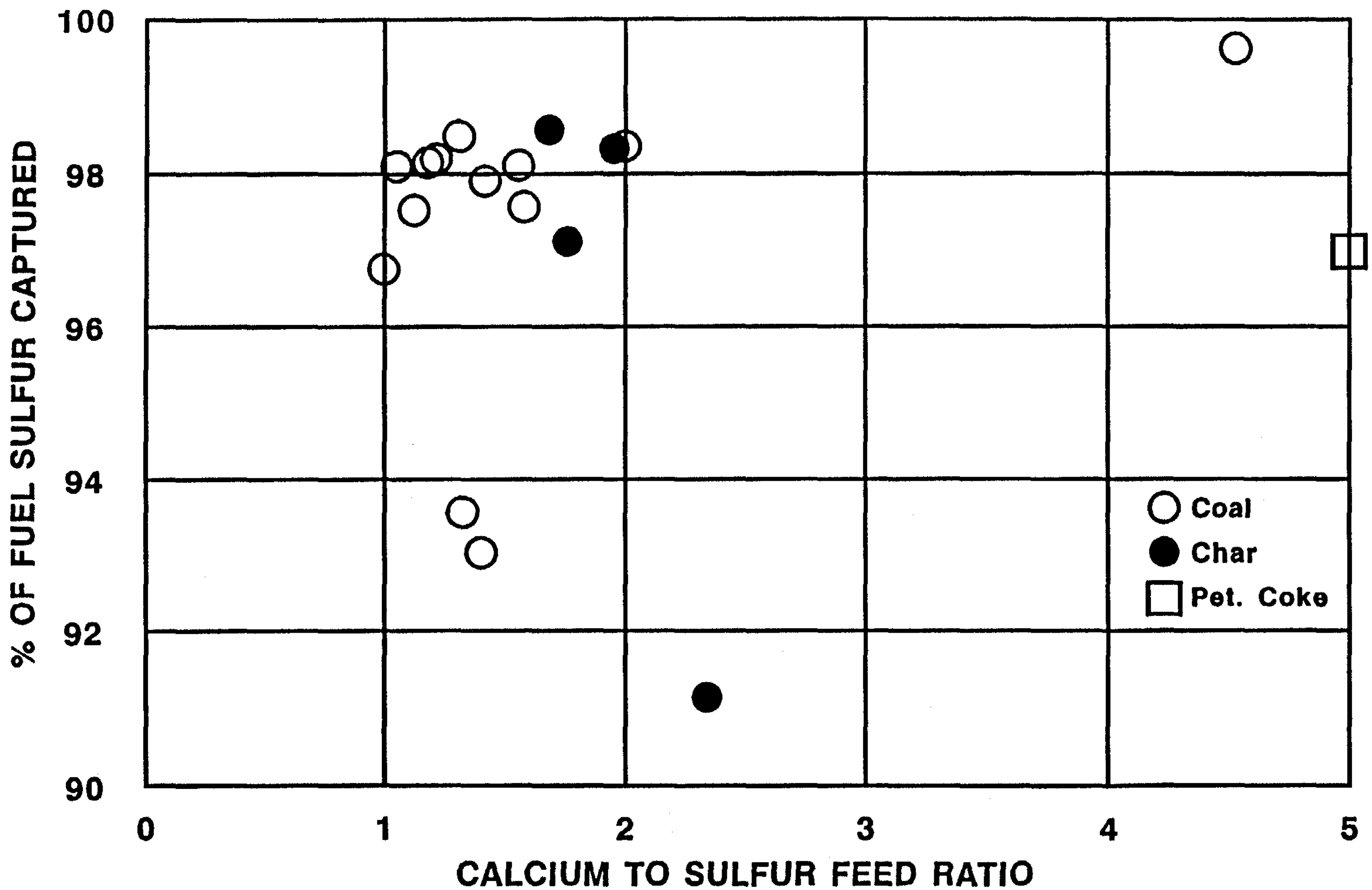


Figure 9. Phase 2 CPFBC Sulfur Capture Efficiencies

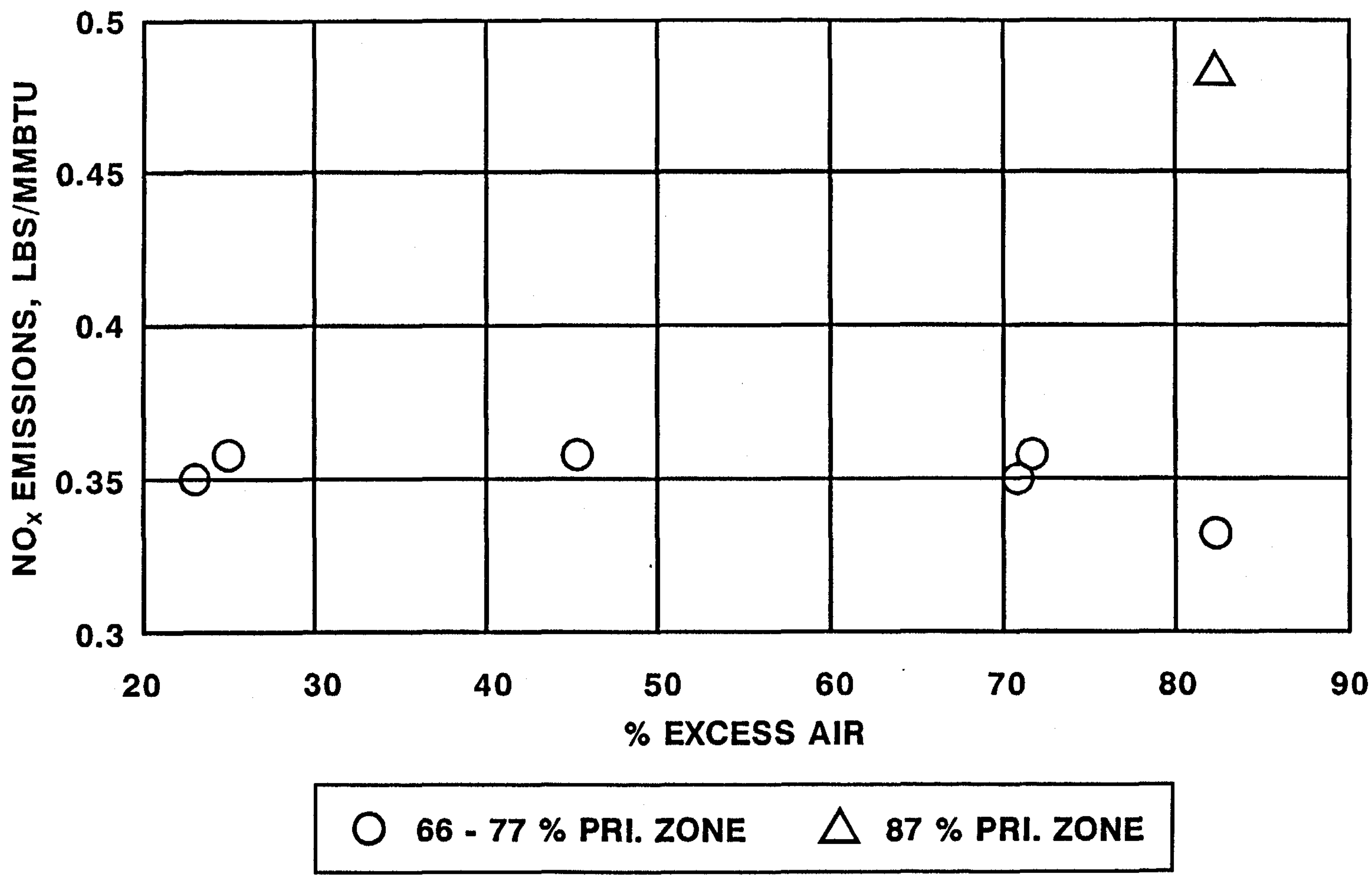


Figure 10. Phase 2 CPFBC NO_x Levels