Status of the Lakeland McIntosh Unit 4 Advanced Circulating Fluidized Bed Combined Cycle Demonstration Project

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ABSTRACT

In December 1997, the City of Lakeland, Florida, signed a Cooperative Agreement with the U.S. Department of Energy (DOE) that will facilitate the demonstration of the Advanced Circulating Fluidized-Bed Combined Cycle technology being developed by Foster Wheeler. The project will be conducted under the DOE Clean Coal Technology Program at the City of Lakeland's McIntosh Power Station in Lakeland, Florida. In August 1998, Lakeland authorized Foster Wheeler to begin the preliminary engineering and permitting support of the demonstration plant.

The Lakeland McIntosh Unit 4 Project is a nominal 240 MWe combined cycle plant that integrates the partial gasification of coal with pressurized circulating fluidized bed (PCFB) combustion. The partial gasification process produces a low Btu syngas and a coal char residue. The latter is burned in a PCFB boiler producing steam for a steam turbine and hot vitiated air/flue gas for a high efficiency gas turbine. The syngas, in turn, is burned in the gas turbine topping combustor

(topping combustion) to heat the vitiated air to over 2300EF for expansion through the turbine.

The plant is designed to burn both low and high sulfur coal and incorporates a Siemens V64.3 gas turbine with a 2400 psig/1000EF/1000EF steam turbine. This paper describes the demonstration plant and identifies its design status.

INTRODUCTION

The City of Lakeland operates two power stations totaling approximately 820 MWe of generating capacity of which about 80% is wholly owned by Lakeland Electric Utilities. The McIntosh Station on the North side of Lake Parker is the larger of the two with approximately 590 MWe of generating capacity; the smaller Larsen Station on the South side of the lake has about 230 MWe of generating capacity.

The City of Lakeland has experienced and is forecasting steady load growth within its system of approximately 15 MWe per year; this will result in a capacity shortfall of approximately 60 MWe by the year 2000. In addition, Lakeland expects to retire 70 MWe of inefficient generating capacity. Faced with this load growth and anticipated retirement of older units, Lakeland plans to add approximately 200-250 MWe of new generating capacity.

To help meet their new power generation requirement, Lakeland plans to build a nominal 240 MWe plant utilizing Foster Wheeler's Advanced Circulating Fluidized Bed Combined Cycle (ACFBCC) technology. The plant integrates the partial gasification of coal with pressurized circulating fluidized bed (PCFB) combustion. The partial gasification process produces a low Btu syngas and a coal char residue. The latter is burned in a PCFB boiler to produce steam for a steam turbine and hot vitiated air/flue gas for a gas turbine. The syngas in turn is burned in the gas turbine (topping combustion) to heat the vitiated air to over 2300EF.

The McIntosh Unit 4 PCFB plant will be constructed on undeveloped land located adjacent to the existing McIntosh Unit 3. The plant will be designed to burn a range of coals including both the current Eastern Kentucky coal burned in the conventional pulverized coal fired Unit 3 as well as lower priced, high ash, high sulfur coals that are available on the open market. Limestone will be procured from Florida sources while the ash will be disposed in landfill or marketed.

The plant will be funded in part through the U.S. Department of Energy (DOE) Clean Coal Technology (CCT) Program. The DOE funding results from a combination of two previous Clean Coal awards: the DMEC-1 PCFB Repowering Project selected under Round III and the Four Rivers Energy Modernization Project (FREMP) selected under Round V. The DMEC-1 project was intended to demonstrate non-topping PCFB technology (gas turbine temperature is essentially the same as the PCFB temperature), while the FREMP project was planned to demonstrate Topped PCFB technology (gas turbine inlet temperature is markedly higher than the PCFB temperature).

PROCESS DESCRIPTION

A non-topped PCFB plant is a combined cycle power generation system employing gas and steam turbines and combusting solid fossil fuel in a PCFB boiler. Tubes contained in the PCFB generate, superheat, and reheat steam for use with the most advanced steam turbines (Rankine cycle) and the hot, pressurized combustion flue gas/vitiated air emanating from the PCFB in turn can drive a gas turbine (Brayton cycle) for additional power generation. A non-topped PCFB plant can achieve thermal efficiencies in excess of 40 percent (HHV) and have a levelized busbar cost of electricity below any competing coal technology. In addition to the economic benefits, the built-in feature of environ-mental control (SO_2 and NO_X) in the combustion process eliminates the need for any external gas clean up such as scrubbers. A PCFB can also burn a much wider range of coals than a pulverized-coal-fired boiler. PCFB combined-cycle power plants offer real economic incentives for low cost electric power generation in an environmentally acceptable manner, while burning a wide range of low cost, abundant coals.

Figure 1 represents a simplified schematic of Foster Wheeler’s Non-Topped PCFB

Combined Cycle. Combustion and fluidizing air is supplied from the compressor section of the gas turbine to the PCFB combustor located inside a pressure vessel. Coal and sorbent (usually limestone) are mixed with water into a paste which is pumped into the combustion chamber using reciprocating pumps commonly used in the concrete industry. The same type of pumps have been successfully proven in a number of pressurized fluidized bed combustion plants and facilities around the world. The limestone sorbent captures sulfur in situ as sulfur dioxide, and nitrogen oxides are controlled by temperature and pressure.

Combustion takes place in the fluidized bed combustor at a temperature of approximately 1550 - 1600^{o}F and, depending on the gas turbine used, typically 10 to 16 atmospheres. Particulate matter entrained in the flue gas exiting the combustor is removed using cyclones and ceramic barrier filters, such as a Siemens Westinghouse ceramic candle type Hot Gas Particulate Filter System (HGPFS), located between the PCFB and gas turbine. The high temperature, high pressure HGPFS is similar to that tested for 6000 hours at the American Electric Power PFBC Demonstration facility (Tidd) in Brilliant, Ohio [1]. Modules of this type of filter system have also undergone extensive testing at Foster Wheeler's PFB pilot plants in Livingston, New Jersey, and in Karhula, Finland [2] [3], and in the Wilsonville Power Systems Development Facility operated by Southern Company Services for the DOE [4]. In addition to protecting the gas turbine from erosion, the HGPFS eliminates the need for any particulate removal at the stack thereby eliminating the need for a back-end electrostatic precipitator (ESP) or baghouse.

The hot gas cleaned by the filter system expands through the gas turbine, exhausts to a heat recovery unit, and vents to a stack. The heat recovered from both the combustor and the heat recovery unit is used to generate, superheat and reheat steam for use in the steam turbine. Approximately 15 to 25% of the total power produced is generated in the gas turbine, and the balance is generated in the steam turbine.

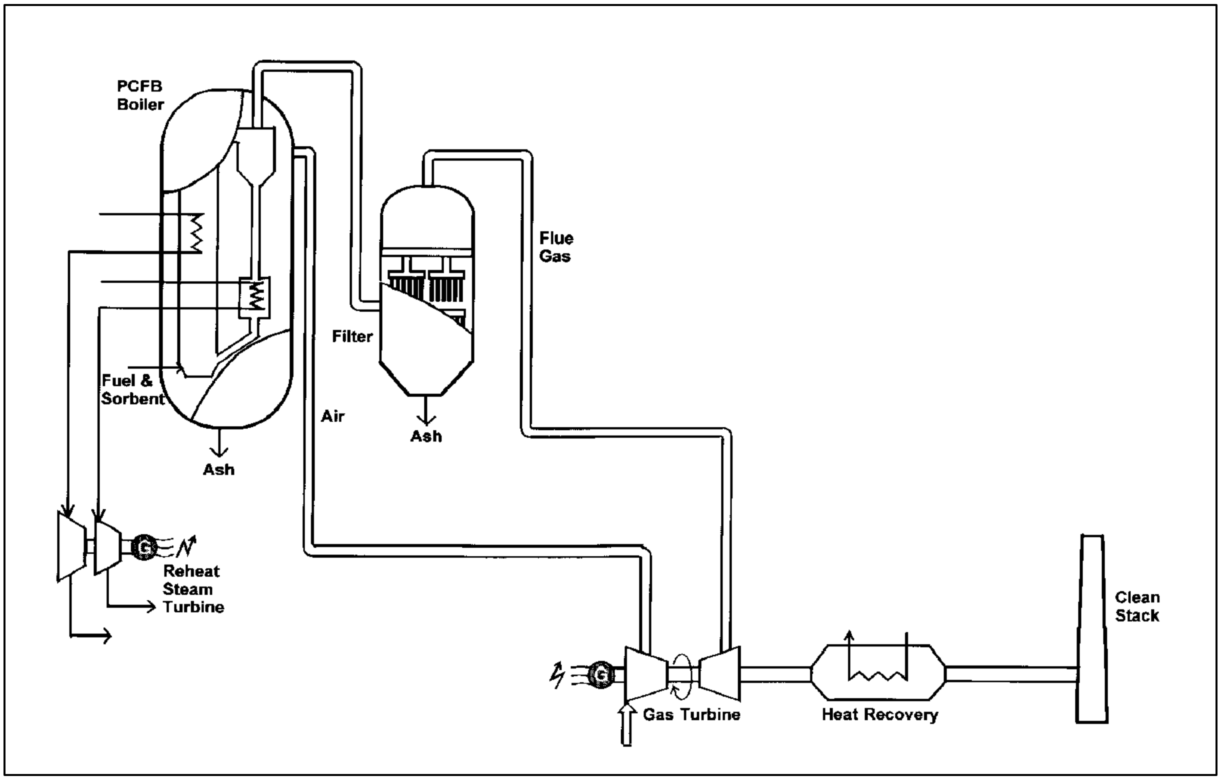

Figure 1 Foster Wheeler Non-Topped PCFB Cycle

Figure 2 shows a simplified schematic of Foster Wheeler's Topped PCFB/Advanced Circulating Fluidized Bed Combined Cycle Plant. ACFBCC technology integrates a carbonizer island and gas turbine topping combustor in the PCFB cycle. The additional components allow the firing temperature of the gas turbine to be increased to state-of-the-art levels; this is achieved by the combustion of a coal derived, low-Btu syngas produced in the carbonizer and fired in the gas turbine topping combustor. As a result, the gas turbine power output increases relative to the steam turbine, thereby increasing the plant efficiency to levels greater than 46 percent.

The carbonizer is an air-blown jetting, fluidized bed operating at 1600°F to 1800°F. Dried coal and sorbent are fed to the carbonizer using a conventional pneumatic transport system employing lock hoppers. The coal is devolatilized and partially gasified in the carbonizer to produce a low-Btu syngas and a solid residue (called char); the latter is removed from the carbonizer and transferred to the PCFB for combustion. The limestone sorbent captures sulfur as calcium sulfide and also acts as a stabilizer to prevent bed agglomeration. The particulate matter entrained in the syngas (char plus sorbent) is removed using a cyclone and Siemens Westinghouse HGPFS similar to that used for the PCFB. This collected material, together with the main char flow from the carbonizer, is transferred hot to the PCFB to complete combustion and sulfur removal. The hot, clean syngas is fired in the topping combustor to raise the PCFB flue gas/ vitiated air temperature to the firing temperature of the gas turbine.

The ACFBCC Plant is essentially built around the gas turbine. Selection of the latter sets the plant operating pressure and air flow rate. With the air rate established, the next question is how much coal should be burned. In order to achieve the desired gas turbine firing temperature, a minimum amount of syngas must be produced which equates to a minimum amount of coal to the carbonizer and a minimal amount of char to the PCFB. Under this condition the gas turbine is fully powered, the steam turbine power is at a minimum (gas turbine to steam turbine power ratio is about one to one), the plant excess air is very high and the plant efficiency is maximized (efficiency can be greater than 46 percent). If the customer desires more power, rather than opting for a larger gas turbine, the char flow to the PCFB can be supplemented with direct coal feed. Increasing the direct coal feed increases the steam turbine output, and in the extreme the steam turbine power can be almost tripled. Although the plant efficiency decreases, the increased power is relatively inexpensive. In addition, the carbonizer char transferring to the PCFB and syngas and flue gas proceeding to the gas turbine topping combustor can be cooled with boiler feed water. Gas cooling extends candle filter life, minimizes ash bridging potential in the filters, reduces gas turbine hot corrosion risks (alkali vapors condense on the particulate being removed by the filters), and eases material selections for valves, piping, etc. The ACFBCC Plant can be designed to operate, depending on the utility's preference, at either extreme (peak efficiency vs. maximum power output) or any point in between.

The ACFBCC Plant with its large gas turbine output is envisioned for larger size plants (250 to 500 MWe) whereas the Non-Topped PCFB with its smaller gas turbine is ideal for smaller size plants (100 to 400 MWe) as well as repowerings.

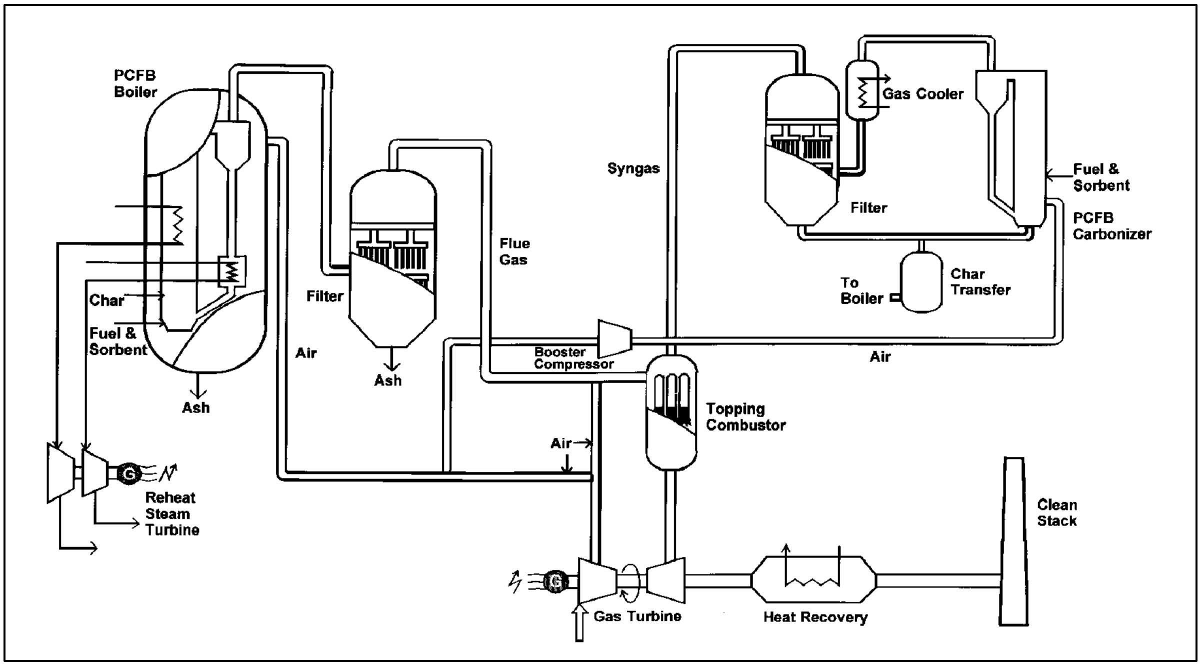

Figure 2 Foster Wheeler Advanced Circulating Fluidized Bed Combined Cycle Plant

LAKELAND PLANT DESCRIPTION

Foster Wheeler has previously presented [5] performance data for the demonstration plant that showed a 189 MWe net power output with 42.8 percent efficiency (coal higher heating value basis). This efficiency is less than the cycle's full potential because a medium rather than a large size gas turbine is being used. The plant design at that point in time incorporated a 401F gas turbine; this was an 87 MWe gas turbine being developed by Westinghouse. In August 1998, Siemens AG purchased the Westinghouse Power Generation Division of CBS, and it has been decided to replace the 401F with the 60 MWe Siemens V64.3 gas turbine. Although the latter is well proven (over 30 in operation), it is a smaller machine furnishing less air and less power. To offset the lower gas turbine power output (. 30 MWe) and provide Lakeland with the additional power it desires, the steam turbine is being increased in size to 200 MWe. The PCFB, however, cannot furnish the additional steam required by the enlarged steam turbine because there is not enough air to support additional direct coal feed; instead, we will burn carbonizer char and coal in the gas turbine heat recovery steam generator to generate the additional steam. With the steam turbine to gas turbine power ratio increased to approximately three to one, the plant has become a maximum power output rather than a peak efficiency plant. As of the writing of this paper (January 1999) performance data for the V64.3 modified to operate with Westinghouse Multi Annular Swirl Burners had not yet been finalized. Our preliminary calculations, however, indicate the plant will have a net output of 238 MWe with an efficiency greater than 40 percent (HHV basis), and it will demonstrate the key features of our ACFBCC technology.

PROJECT SCHEDULE

In August 1998 the City of Lakeland authorized Foster Wheeler to proceed with the preliminary engineering and permitting support of the plant once certified gas turbine performance data becomes available. In the meantime, Lakeland is in the process of initiating permitting and licensing activities that are now expected to take two years.

The project schedule is shown in Figure 3. The design of the facility (Phase 1) will coincide with and continue until the permitting process is completed. Thereafter, Phase 2 will begin with the general release for fabrication and construction, and last for 30 months to mechanical completion. Phase 3 will begin with the start up of the first (non-topping PCFB) demonstration. After up to 12 months of operation and testing, the gas turbine topping combustor will begin operation with natural gas. A similar 12 month test period is envisioned after which the carbonizer leg of the plant will be activated and the second (topping PCFB) demonstration begun. Topping PCFB operation and testing will continue for two years, after which the plant will be released to Lakeland for commercial operation.

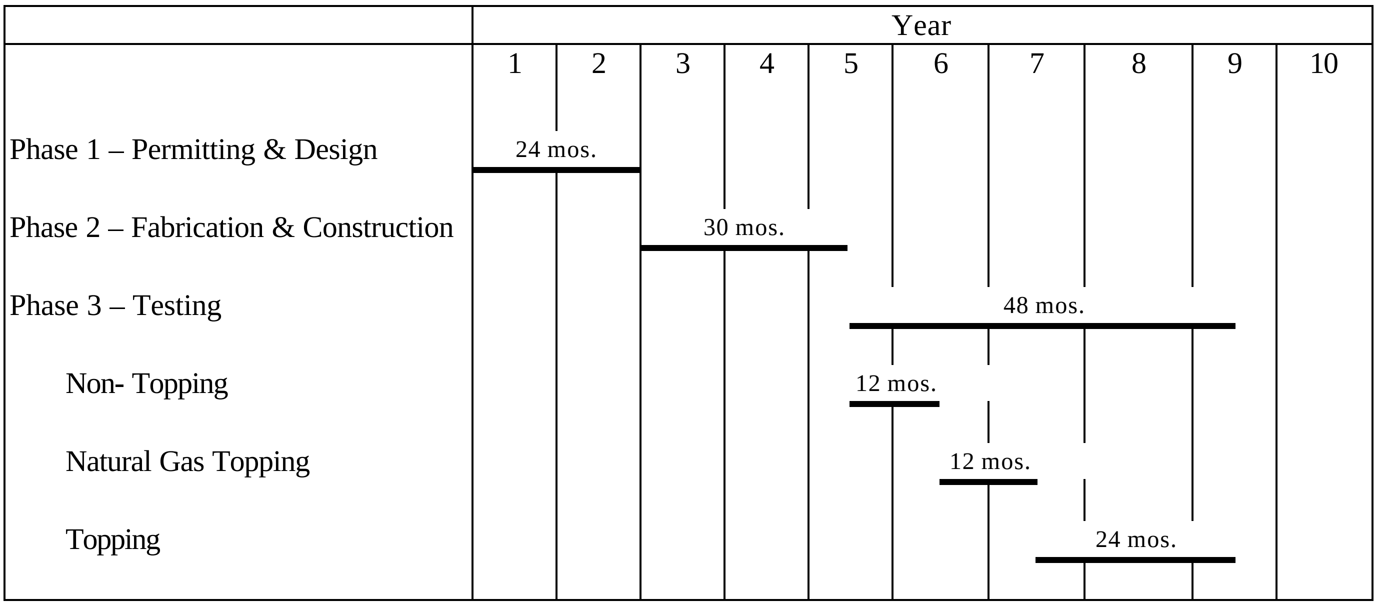

Figure 3 Lakeland Demonstration Plant Project Schedule

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