DOE/MC/27364-93/C0185

The Midwest Power PCFB Demonstration Projects--AHLSTROM PYROFLOW First and Second Generation Pressurized Circulating Fluidized Bed (PCFB) Technology

Authors:
S. Ambrose
C.L. Green
R. Dryden
S.J. Provol

DOE/MC/27364--93/C0185

DE93 011583

Contractor:
Midwest Power
823 Walnut, PO Box 657
Des Moines, Iowa 50303

Contract Number:
DE-FC21-91MC27364

Conference Title:
American Power Conference

Conference Location:
Chicago, Illinois

Conference Dates:
April 13-15, 1993

Conference Sponsor:
Illinois Institute of Technology

DISCLAIMER

The Midwest Power PCFB Demonstration Projects AHLSTROM PYROFLOW® First and Second Generation Pressurized Circulating Fluidized Bed (PCFB) Technology

S. Ambrose	- Senior Mechanical Engineer, Midwest Power
Clifford L. Green	- Product Manager, Ahlstrom Pyropower Inc.
Richard Dryden	- Project Manager, Ahlstrom Pyropower Inc.
S. J. Provol	- Manager, New Product Development, Ahlstrom Pyropower Inc.

ABSTRACT

Midwest Power, Dairyland Power Cooperative, Pyropower Corporation (a subsidiary of Ahlstrom Pyropower Inc.), and Black & Veatch, have embarked on the demonstration of Clean Coal Technology (CCT) at Midwest Power's Des Moines Energy Center (DMEC), in Pleasant Hill, Iowa. The DMEC-1 PCFB Demonstration Project was selected by the U.S. Department of Energy for the demonstration of the First Generation Pressurized Circulating Fluidized Bed (PCFB) Technology. During Round 5 of the CCT Program, Midwest Power submitted a proposal for a second unit, to be known as DMEC-2. If selected by the DOE, the DMEC-2 unit will demonstrate Ahlstrom Pyropower's Second Generation (Advanced) PCFB technology which will incorporate a topping combustor fired on coal derived gas generated in a PCFB carbonizer, to raise the firing temperature of the gas turbine and the total net plant efficiency. The First Generation PCFB technology has the capability to achieve 40 - 42% efficiency, the Second Generation technology can obtain an efficiency in the range of 44 - 47% net.

This paper will provide a comparison of the commercial versions of the First and Second Generation PCFB systems, and the plans for demonstrating these systems for repowering and new plant installations during the late 1990's and into the next century. A discussion of the DMEC-1 and DMEC-2 projects and their key technical features will be provided together with a projection of the future markets for these advanced clean coal technologies.

INTRODUCTION

Midwest Power, a division of Midwest Power Systems, Inc., is the electric utility sponsoring both the DMEC-1 First Generation and the DMEC-2 Second Generation (Advanced) PCFB Demonstration Projects. The DMEC-1 project was selected by the U.S. Department of Energy (DOE) under Round 3 of the Clean Coal Technology (CCT) Program and is currently in preliminary design. The DMEC-2 Advanced PCFB Demonstration Project has been submitted to the DOE as an application for cooperative funding under Round 5 of the CCT Program. If selected by the DOE, the DMEC-2 project will be a sister unit to the DMEC-1 Project and will expand the application of PCFB technology. Both projects will be located at the Des Moines Energy Center Site located in Pleasant Hill, Iowa.

This paper will present an overview of the commercial versions of the First and Second Generation AHLSTROM PYROFLOW® PCFB Technologies. Following the overview, a brief description of the DMEC-1 and the proposed DMEC-2 projects will be presented. Finally, key market segments for First and Second Generation PCFB Technologies will be identified.

FIRST GENERATION PCFB TECHNOLOGY

A simplified process flow diagram of the First Generation PCFB Technology is presented in Figure 1. The inlet air is compressed in the compressor section of the gas turbine. The combustion air enters at the top of the pressure vessel and flows around the outside of the boiler to the bottom of the vessel. This air provides cooling of the vessel and its internal components. Combustion of the coal occurs in the combustor where most of the heat for the steam cycle is generated.

The air enters the boiler through a grid at the bottom of the boiler and through secondary air injection points above the grid. This division of primary and secondary air reduces NO_x, and is utilized to assist in plant load following. This approach is a significant advantage of the PCFB versus bubbling bed systems which cannot use primary and secondary air to reduce NO_x and which require a complex system of ash inventory control to start-up and follow load.

The boiler, designed by Pyropower, is a Pressurized Circulating Fluidized Bed boiler which incorporates the same principals used in atmospheric Circulating Fluidized Bed (CFB) technology.

Fuel and limestone are mixed with water and fed to the boiler as a paste. The fuel and sorbent paste are combined with the air in the boiler where combustion occurs at a temperature in the range of 1600-1650°F. As the coal is burned in the furnace, the SO_2 generated during combustion will be absorbed by limestone. The PCFB is projected to achieve 90 to 99% removal of SO_2 at Ca/S ratios in the range of 1.1 - 2.5.

Bed ash is removed from the bottom of the boiler, where it is cooled and depressurized in the ash removal system. The finer particles become entrained with the flue gas in the boiler and enter the hot cyclone. Here, the particles which contain unreacted material, are captured by the cyclone and returned to the boiler through the loop seal. The very finest particles, which are fully reacted, exit the cyclone with the hot gases.

The gas velocity in the boiler is about 15 feet/second at a pressure in the range of 150-250 psia. The pressure is dependent on the gas turbine incorporated into the cycle. Because of the continuous mixing throughout the boiler, and the thermal inertia of the solids in the hot loop, the gas temperature is constant from the bottom to the top of the boiler. The lower section of the boiler is refractory lined. Radiant heat transfer surfaces are located in the middle and upper sections of the boiler and none are located in the bottom. This arrangement greatly reduces the potential for erosion of heat transfer surfaces, provides improved flexibility during plant shut downs, and simplifies plant start-up and load following. This is a major advantage versus bubbling bed systems.

Heat generated from combustion in the boiler is transferred to the water walls and to the radiant superheater and reheat surfaces in the boiler, where steam is superheated and reheated to power the steam turbine. A special type of superheating surface, known as Double Omega surface, will be used to superheat and reheat steam in the boiler. This surface has been successfully demonstrated in many atmospheric Pyroflow boilers and in the Karhula PCFB testing facility. Natural circulation will cool the water walls even during a plant shut down condition. Other systems require forced circulation which increases station power consumption and increases risk during shut downs.

The flue gases leaving the hot cyclone pass through a ceramic barrier filter for particulate removal. The filter removes the fly ash from the flue gas to very low levels to meet requirements for operation of a conventional gas turbine and below current environmental standards. A particulate emission level under 0.01 lb/MMBtu is predicted. The filter operating temperature is in the range of 1600-1650°F. The solids are inert and safe for by-product use or disposal.

The clean flue gas from the filter is exhausted to the gas turbine where it is expanded to recover process mechanical energy and power. The resulting mechanical energy drives the compressor of the gas turbine and provides power output from the gas turbine's generator. Remaining useful heat is recovered from the gas turbine's exhaust for preheating feedwater and superheating steam. The heat transferred to steam and feedwater in the heat recovery section complements the heat absorbed in the boiler. The clean and cooled flue gases are emitted from the stack without further treatment.

SECOND GENERATION PCFB TECHNOLOGY

The Advanced PCFB Technology includes all the components of the First Generation PCFB Technology but also includes a carbonizer to provide synthetic gas to fire a topping combustor, and raise the gas turbine inlet temperature to a range of 2000-2500°F (depending on the capability of the gas turbine). This temperature is higher than the 1600-1650°F used in the First Generation PCFB Technology. For new greenfield plant installations, the higher turbine inlet temperature range of 2000-2500°F results in an additional enhancement to the efficiency of 15 to 20% versus the First Generation PCFB Technology and about 30% versus conventional coal fired Technologies.

A simplified process flow diagram of the Advanced PCFB Technology is presented in Figure 2. In the Advanced PCFB cycle, the air from the compressor is split by control valves and fed to the boiler, carbonizer, and the topping combustor.

The fuel and sorbent paste, and char from the carbonizer system, are combined with the air in the boiler where combustion occurs at temperatures in the range of 1600-1650°F. The boiler in the Advanced PCFB Technology operates the same as the boiler in the First Generation PCFB Technology and so can achieve 90 to 99% percent removal of SO_2.

Some of the heat in the flue gas leaving the combustors's hot cyclones is transferred convectively to reheat or superheat steam surface thus cooling the gas to 1100-1300 F. This relatively low and conservative operating temperature reduces filter size and materials requirements. The flue gas is then filtered at this lower temperature to remove fly ash particulates to very low levels to meet the requirements for operation of the gas turbine and to meet environmental standards. Once the particulates are removed from the flue gas, air from the gas turbine's compressor is added to the flue gas to raise the oxygen content of the gas. The mixed stream is used as the source of hot combustion air for the topping combustor. In the topping combustor, the clean synthetic gas, generated from the carbonizer, is burned with the hot combustion air to raise the inlet temperature to the gas turbine. This high turbine inlet temperature is the key aspect of the Advanced PCFB cycle efficiency increase.

The synthetic gas used for firing the topping combustor is generated in a carbonizer designed by Pyropower using the Ahlstrom pressurized CFB gasifier design. The carbonizer is comprised of a refractory lined pressurized CFB. This design has been developed and proven in a pilot plant and in four commercial atmospheric CFB gasifiers in operation in Europe and is similar to the design used in the BIOFLOW Pressurized CFB Gasification Demonstration Facility, designed by Ahlstrom. The BIOFLOW unit is located in Varnamo, Sweden and is scheduled for start-up in mid 1993.

Like the PCFB boiler, coal and limestone can be fed to the carbonizer by a paste feed system. Air from the gas turbine's compressor is increased in pressure by a booster compressor, and fed through the grid at the bottom of the carbonizer.

The air is fed in sub-stoichiometric quantities to maintain a temperature of about 1650°F in the carbonizer. This temperature, in the presence of limestone, is sufficient to cause effective cracking of tars. The limestone will effectively remove the sulfur compounds generated in the carbonizer. Sulfur, released during gasification, is absorbed by limestone. The high level of mixing and contacting in the carbonizer will promote the effectiveness of all of these processes. Combined with the capture of sulfur during combustion in the boiler, the Advanced PCFB plant can achieve 90 to 99% overall sulfur reduction.

As in the boiler, the carbonizer employs a hot cyclone which captures the solids entrained with the synthetic gas and returns them to the carbonizer for complete utilization. Char particles are collected in the bottom of the carbonizer and transferred to the boiler for complete utilization.

Hot 1650°F synthetic gas exits the carbonizer and is cooled to about 1100-1200°F in a synthetic gas cooler. Cooled gas then enters a synthetic gas ceramic filter. Like the filter used on the boiler flue gas, this low temperature reduces filter size and materials requirements. Any char collected by this filter will be transferred to the boiler for complete utilization.

Once cleaned, the synthetic gas is fired in the topping combustor with the hot combustion air. The gas from the topping combustor is exhausted to the gas turbine where it is expanded to recover process mechanical energy and power. The resulting mechanical energy drives the compressor of the gas turbine and provides power output from the gas turbine's generator. As in the First Generation PCFB Technology, the heat in the expanded gases is transferred to steam and feedwater in the heat recovery section. The flue gases are then emitted to the stack without further treatment.

FIRST GENERATION PCFB TECHNOLOGY DEMONSTRATION: DMEC - 1

The First Generation Pyroflow PCFB Technology will be demonstrated under Round 3 of the CCT Program. The project will include repowering an existing site using the existing steam turbine and generator, coal handling facilities, condensate and feedwater system. The project will incorporate the Pyroflow PCFB boiler, a ceramic barrier filter, and a conventional gas turbine operating at 1600 F.

The plant is designed to operate on a range of fuels including high sulfur bituminous coals such as Illinois No.6 and low sulfur sub-bituminous coals found in Wyoming.

The plant will generate approximately 85 MWe (gross), 65 MW from the steam turbine and 20 MW from the gas turbine when firing Illinois No. 6 coal. The plant will have the capability to achieve a plant heat rate improvement of 10 - 15 % versus what could be achieved if the plant was repowered with a conventional technology. It is important to note that the First Generation PCFB is capable of achieving a higher efficiency in new greenfield applications that are designed with a new steam turbine and modern plant auxiliaries.

Emissions of SO_2, NO_x, CO, and CO2 will be significantly lower than what could be achieved with conventional technology. Table 1 provides a summary of the predicted performance for DMEC-1. The performance is based on firing Illinois No. 6 coal.

Table 1
Predicted Plant Performance for DMEC-1

Steam Turbine, MWe	64.2
Gas Turbine, MWe	20.5
Total Gross Output, MWe	84.7
House Load, MWe	(4.2)
Net Power, MWe	80.5
Emissions - Proposed for Permit	
SO_2	0.53 lb/MMBtu
NO_x	0.30 lb/MMBtu
CO	0.15 lb/MMBtu
Particulate	0.01 lb/MMBtu
10-15% Heat Rate Improvement	

Table 2
Predicted Plant Performance for DMEC-2

Steam Turbine, MWe	94.0
Gas Turbine, MWe	46.0
Total Gross Output, MWe	140.0
House Load, MWe	(6.4)
Net Power, MWe	133.6
Emissions - Proposed for Permit	
SO_2	0.27 lb/MMBtu
NO_x	0.15 lb/MMBtu
CO	0.03 lb/MMBtu
Particulate	0.01 lb/MMBtu
About 20% Heat Rate Improvement	

SECOND GENERATION PCFB TECHNOLOGY DEMONSTRATION: DMEC - 2

Midwest Power is also the utility that is sponsoring the Second Generation Pyroflow PCFB Demonstration Project. The project has been submitted to DOE as an application for cooperative funding under Round 5 of the CCT Program. If selected, the DMEC-2 Demonstration Project will incorporate a Pyroflow PCFB boiler, a Pyroflow PCFB carbonizer, a topping combustor, and a gas turbine operating at over 2000 F°, to repower an existing reheat steam turbine.

Like DMEC-1, DMEC-2 is also designed to operate on high sulfur bituminous and low sulfur sub-bituminous coals. The plant will generate 140 MWe (gross), 94 MW from the steam turbine and 46 MW from the gas turbine when firing Illinois No. 6 coal. The plant will have the capability to achieve a plant heat rate improvement of about 20% versus what could be achieved if the plant was repowered with a conventional technology. For a new greenfield plant designed with a new steam turbine and modern plant auxiliaries, a higher efficiency can be achieved.

Emissions are predicted to be significantly lower than what could be achieved with conventional technology generating the same net plant output. Table 2 provides a summary of the expected performance for DMEC-2.

As can be seen in Table 2, the expected emissions from DMEC-2 are lower than what is predicted for DMEC-1. Pyropower believes that through optimization and experience gained during operation of DMEC-1 lower emissions values for DMEC-2 will be achieved. This philosophy is consistent with what has been experienced with Pyroflow atmospheric CFB boilers and pilot plant test results.

CONCEPTUAL DESIGN OF UTILITY SIZE UNITS

Pyropower is involved in the development of PCFB conceptual designs with plant capacities to 400 MWe (gross). These designs will include one PCFB boiler, one PCFB carbonizer and one gas turbine/compressor set. The designs are based on methodologies successfully adopted in developing utility size atmospheric Pyroflow units. Table 3 shows a development log of atmospheric and pressurized Pyroflow CFB units. From the table it can be seen that each stage of development is proceeded by using reliable scale-up factors for the atmospheric and pressurized CFB's as well as the PCFB carbonizer.

MARKET SEGMENTS FOR FIRST AND SECOND GENERATION PCFB TECHNOLOGY

As stated previously, the Second Generation PCFB technology compliments the First Generation by increasing the application of the PCFB technology. Both technologies can be used for repowering existing power plants and for new power plant installations. More specifically, the PCFB technology is targeted for the following market segments:

1. Repowering Market
    - Repowering coal fired power generating facilities that will be impacted by Phase 2 of the Clean Air Act.
    - Repowering aged coal fired power generating facilities for utilities that have a strong incentive to extend the life of a steam powered unit while reducing emissions, improving upon plant efficiency, and adding

incremental power output.

- Repowering gas and oil fired power generating facilities at sites that have existing coal handling capability.

- Repowering aged and inefficient coal fired boilers operating throughout the world.

2. New Power Station Market

- New utility and independent power stations that will be required as the need for new capacity continues.

- New central power stations in the Far East where plant emissions requirements are low and plant efficiency requirements are high because of high fuel prices.

SUMMARY

Midwest Power, Dairyland Power Cooperative, Pyropower Corporation, and Black & Veatch will demonstrate First Generation PCFB Technology. The project will be known as the DMEC-1 Project. Midwest Power has also submitted a proposal to the DOE under Round 5 of the Clean Coal Technology Program that will incorporate the Second Generation (Advanced) PCFB Technology. This project will known as the DMEC-2 Project. Both projects will be located at Midwest Power's Des Moines Energy Center site located in Pleasant Hill, Iowa. Both plants are predicted to show significant improvement in plant heat rate while producing very low emissions.

FIGURE 1 — FIRST GENERATION PCFB CYCLE

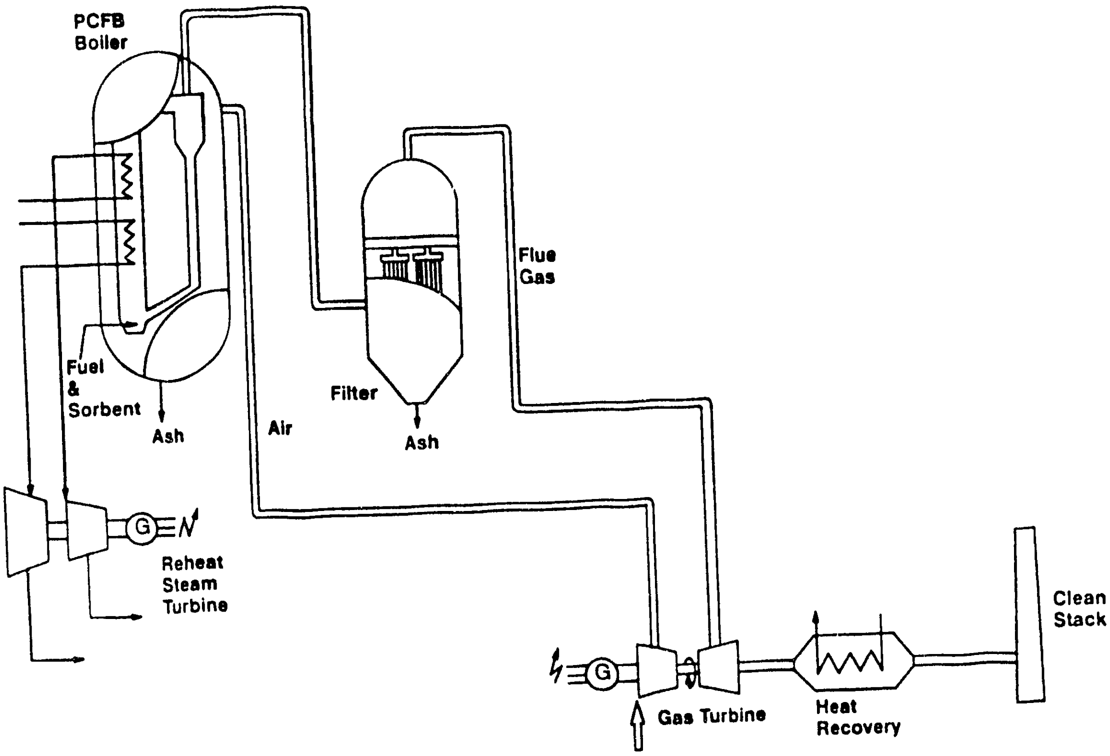

FIGURE 2 — ADVANCED PCFB CYCLE

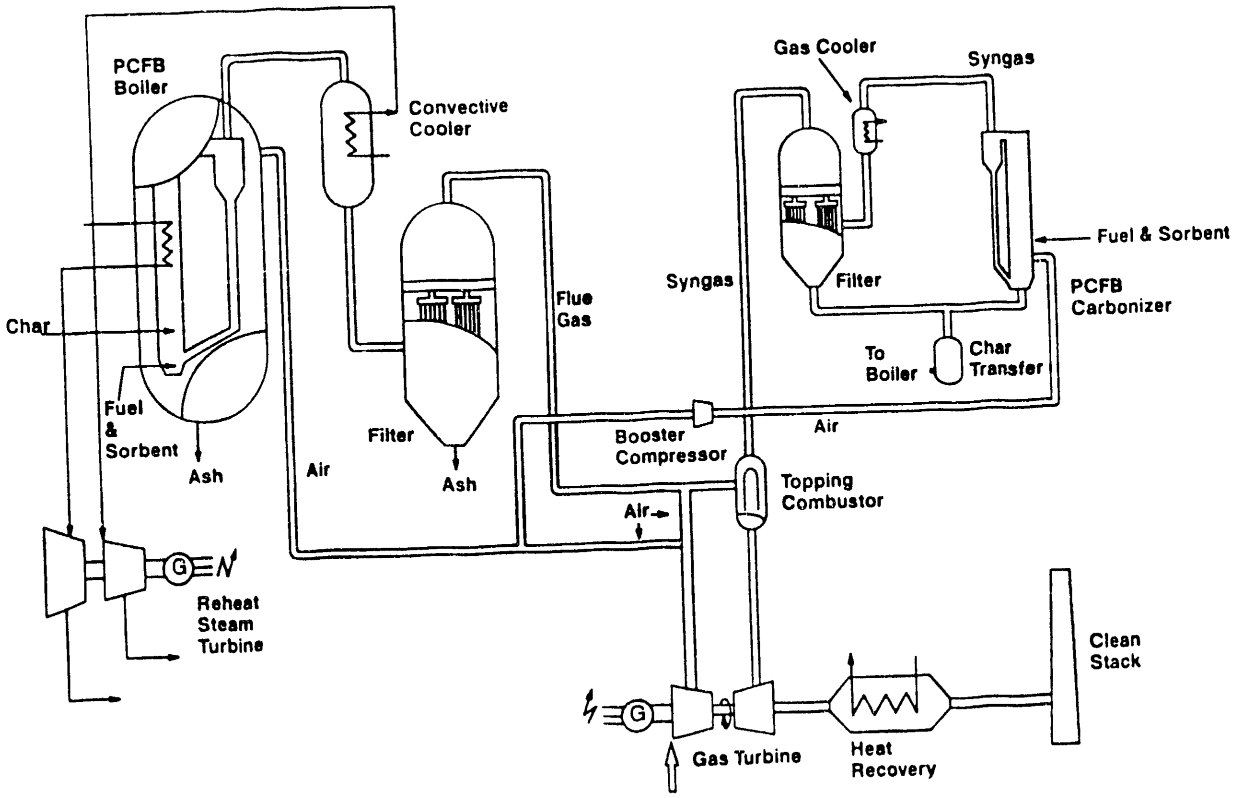

TABLE 3

Development Log of Atmospheric and Pressurized Pyroflow Units

	Atmosphric Units						Pressurized Units						
	Pilot Plant	Pihlava	Kauttua	Oriental Chemical Company	Colo–Ute Electric Assoc.	Nova Scotia Power Corp.	Karhula Testing Facility		DMEC–1 Demo. Unit	BIOFLOW Demo. Gasifier	DMEC–2 Demo. Unit		370 MWe Comm. Unit
							Boiler	Gasifier			Boiler	Gasifier	
Parameter													
Steam Conditions													
Pressure, psia	–	1230	1330	1600	1530	1870	–	–	1300	–	1800 / 350	–	2400 / 440
Temperature, F	–	970	930	970	1005	1005	–	–	955	–	1005 /1005	–	1005 /1005
Flow, klb/hr	Hot Water	45	200	264	930	1163	Hot Water	–	510	–	520 / 518	–	1712 /1623
Plant Output, MWe													
Steam Turbine	–	5	20	30	110	165	–	–	64.2	–	94	–	300
Gas Turbine	–	–	–	–	–	–	–	–	20.5	–	46	–	70
Total Equivelant Output	0.5	5	20	30	110	165	10 MWt	7 MWt	84.7	18	140	103	370
Boiler MW Scale Factor	1	10	4	1.5	3.7	1.5	1	–	16.1	–	1.5	–	3.2
Carbonizer MW Scale Factor	–	–	–	–	–	–	–	1	–	6.4	–	5.7	–
Year of Operation	1976	1979	1981	1984	1987	1993	1989	1994	1996	1993	1998	1998	–
Plant Type	PS	R. Cogen.	Cogen.	Cogen.	Utility	Utility	PS	PS	R. Utility	Cogen.	R. Utility	R. Utility	Utility

Key: PS = Pilot Scale; R. Cogen. = Retrofit Cogeneration; Cogen. = Cogeneration; R. Utility = Repowering Utility

DATE FILMED

6 / 23 / 93