Pulse Combustor CRADA PC91-001 Final Report

August 31, 1992

U.S. Department of Energy
Pittsburgh Energy Technology Center
626 Cochran Mills Road
Pittsburgh, PA 15236

and
BO Technical Developments Ltd.
7087 McPherson Avenue
Burnaby, BC V5J 4N4
Canada

RECEIVED

FFR 26 1999

OSTI

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

PULSE COMBUSTOR CRADA WITH BO TECHNICAL DEVELOPMENTS LTD.

FINAL REPORT

Pittsburgh Energy Technology Center

Coal Combustion Division

INTRODUCTION

As outlined in the Cooperative Research and Development Agreement (CRADA) between BO Technical Developments, Ltd. (BO Tech) and the Pittsburgh Energy Technology Center (PETC) Coal Combustion Division, a BO Tech designed pulse-blade combustor was studied at PETC. Phase 1 involved limited tests of a single-blade pulsed-combustor module to evaluate the suitability of a gas-designed unit for firing coal for use in residential, commercial, or industrial sectors.

During the course of the project, three different pulsed blade burners were designed and fabricated by BO Tech and subsequently delivered to PETC for evaluation. These units were designed to allow modification of the furnace dimensions, which would give PETC a means to take simple steps to improve coal firing performance if required. No major furnace design changes were to be included as part of the phase 1 activities.

DESIGN SUMMARY

1. The theory of Mr. John D. Chato's unique harmonic tuning technology has been proven accurate in as much as it relates to emissions.

Tests with the 3 inch blade, conducted by Mr. Tim McIlvried at the DOE, have demonstrated the lowest emissions were achieved at the setting Mr. Chato's theory predicted and that in fact, only slight deviations from the recommended setting produced a sharp rise in carbon monoxide emissions.

2. Mr. Chato has recently informed us that a scaled-up model, with an output of 600 to 800 thousand Btu, has been successfully fired on natural gas at the Toronto laboratory. The design, because of its simplicity, appears to be easily scaled. If this proves to be the case, the problems of carbon burnout may well be answered by having both a larger charge per hertz (increased turbulence) and a longer residence time as a result of a lower operating frequency.

3. It must be noted that the focus of this investigation was to assess the basic design relative to its potential to burn coal. Therefore, the decoupler work (control of sound levels) and efficiency for the three inch diameter model were considered to be of secondary aspects and were not addressed by the DOE or by Mr. Chato. However Mr. Chato has since reported a 61 dB reading at a distance of 1 meter from the exhaust of the low pressure steam boiler in Toronto, Ontario, Canada.

RESULTS

The first unit delivered to PETC consisted of a one-inch water-cooled blade and was rated at approximately 10,000 Btu/hr. Fuel was supplied through a single, adjustable-height fuel-injection needle. A decoupling chamber was connected to the exhaust of the combustor to act as a muffler and reduce the noise level. A series of gas-firing tests, using bottled methane as the fuel, were

performed to determine base-line performance. NO_x , CO, and O_2 concentrations in the flue gas were continuously monitored by on-line gas analyzers (Thermo Electron Model 10 NO_x analyzer, Beckman Industrial Model 868 CO analyzer, Beckman Industrial Model 755A O_2 analyzer). Cooling-water flow rate was measured with a rotameter, while the cooling-water inlet and outlet temperatures and flue-gas temperature were measured with thermocouples. Originally, a venturi meter was installed in the flue-gas line to measure the flue-gas flow rate. However, the pressure drop across the venturi adversely affected furnace operation (i.e. the furnace did not pulsate properly when subjected to a back pressure), so it was removed.

The furnace was easily ignited using a spark plug, which was turned off after ignition occurred. Self-sustained combustion, with self-aspiration of the combustion air, was then achieved. Additional air could be added directly to the combustion chamber, from a pressurized-air line, to increase the air-to-fuel ratio.

Figure 1 shows the effect of firing rate on CO emissions. In general, there was a strong decrease in CO emissions with increased firing rate. For the "self-aspirating" cases, all of the combustion air was drawn in with the fuel through the intake tubes by the pulsating action of the furnace. The O_2 concentration in the flue gas was between 0.3 and 0.5% (<2% excess air) while operating in this mode. In the "forced-air" mode, additional combustion air was added from a pressurized-air line. This brought

the O₂ concentration in the flue gas up to -1.6% (8% excess air) while substantially reducing the CO emissions. NO_x emissions (Figure 2) were fairly constant over the entire range of firing rates and independent of excess-air level. Noise levels were measured during these tests and were found to be about 90 Db at approximately 1 ft from the furnace.

CO emissions for the 1 inch blade burner were higher than anticipated, possibly due to the relatively cold wall temperatures and high surface-to-volume ratio for this blade size. It is also possible that "dead zones" in the corners of the rectangular combustion chamber may have contributed to CO emissions. It was believed that a larger unit might produce lower CO emissions while also providing a larger combustion volume for the coal-firing phase of the cooperative program. Therefore, a second unit, composed of a 3 inch blade and rated at approximately 30,000 Btu/hr, was constructed and sent to PETC. Fuel was supplied from two adjustable-height fuel-injection needles and introduced into the furnace, along with the combustion air, through two cylindrical-intake tubes (one tube below each fuel injection needle). The new intake tubes had a design similar to a trombone slide. This allowed the length of the intake tube to be changed on-line during testing, thus permitting fine tuning of the combustor (matching the harmonics of the intake tubes with those of the combustor). This unit was also equipped with a decoupling chamber to reduce noise emissions. A series of gas-firing tests were performed on this second unit to determine NO_x and CO emissions. Additional

combustion air was added to the furnace during this series of tests, from a pressurized-air line, to bring the O_2 concentration in the flue gas up to around 2% (10% excess air). Results are shown in Figures 3 and 4 for CO and NO_x , respectively. CO emissions for the 3 inch blade combustor ranged between ~50 and 60 ppm when normalized to 3% O_2 . Normalized NO_x emissions were around 16 ppm. The optimum length for the intake tubes was found to be 2.1 inches, which was, incidently, the original design length calculated for these tubes.

It was believed that "dead zones" in the corners of the combustion chamber might contribute to the higher than expected CO emissions. Therefore, rounded inserts were placed in the corners of the combustion chamber to provide more of an oval cross section. It was hoped that this would reduce the level of CO emissions. The lower line in Figure 3 shows the CO emissions after the inserts were installed. Operating conditions used during these tests were essentially the same as those used in previous tests without the inserts. CO emissions were reduced to about 20 ppm at the lowest firing rate (26,500 Btu/hr) and essentially zero at the highest firing rate (30,500 Btu/hr). (It should be noted that the CO analyzer had a range of 0 to 2000 ppm with an error of 1% of scale). NO_x emissions (Figure 4) with the inserts in place were slightly higher than with the rectangular cross section.

The 3 inch unit was further modified so that the gas diffusers could be raised or lowered during testing. The diffuser distance

from the intake tubes could be varied between 0.25 and 0.75 inches. Figures 5 and 6 show the effect of diffuser distance on CO and NO_x emissions, respectively, at a constant firing rate of 26,500 Btu/hr (fuel pressure of 10 psig). At the optimum diffuser distance of between 0.55 and 0.65, normalized CO emissions were approximately 30 ppm and normalized NO_x emissions were about 20 ppm. An interesting phenomena observed during these tests was that the furnace operated much more quietly as the diffuser was moved closer to the intake tubes.

Low Methane Gas Pressure Tests

The tests described above were operated at gas pressures of 10 psig or greater. Since residential delivery gas pressure is approximately 2.5 inches of water, modified gas intake systems were designed. One intake system had a metal diffuser while the other did not. Methane was introduced into the combustor through a center tube that fed two hollow disks. Gas escaped through holes in the sides of the hollow discs. The discs were designed to aid in the mixing of the air and methane. Combustion was sustained with both systems as long as air pressure was maintained at 10 psig or greater. NO_x and CO readings were approximately 35 ppm and 4500 ppm, respectively, for the intake system with the metal diffuser. Tests conducted with the system without a diffuser yielded similar CO and NO_x readings of approximately 46 ppm. No attempt was made to improve the operation of the combustor. These tests indicate that a pulse combustor can operate with gas pressures of 2-3 inches of water, however, air pressures must be maintained at 10 psig or

greater.

Coal Firing Tests

For the coal-firing tests, the combustor configuration was initially set up at the optimum conditions determined for gas firing. Coal was fed from a vibrating coal feeder into a venturi and pneumatically transported to the combustor through 1/8 inch-diameter teflon tubing. Upper Elkhorn #3 coal and West Star coal were used. Analyses of these coals are given in Table 1. Two different grinds of an Upper Elkhorn #3 seam coal were tested: 100% through 200 mesh and 100% through 325 mesh. The coarser-grind coal was used initially because it tended to flow more easily than did the finer coal during preliminary tests with the vibrating coal feeder. Four different coal-injector locations were tried (see Figure 7A - 7D). Initial tests were conducted with ~50% gas co-firing. A fine-mesh screen was installed in the exhaust line of the combustor to capture flyash. The combustor could only be operated for short periods of time (~15 minutes) while firing coal with the screen in place. The increased pressure drop caused by the buildup of flyash on the screen interfered with the natural aspiration of the furnace and caused a flameout to occur.

CO emissions ranged between 300 and 450 ppm while NO_x emissions ranged between 100 and 150 ppm (both CO and NO_x are corrected to 3% O₂) under these conditions. The actual O₂ concentration in the exhaust was about 1.5%. Carbon burnout varied between 58-64%. The best results were obtained with the finer coal and the injector design shown in Figure 7D. This geometry was used for all

subsequent tests. Self-sustained coal flames, i.e. without gas support, were not achieved with any of the firing geometries. To improve carbon conversion, the combustor volume was enlarged by increasing the distance between the plates by 1/4 inch and then, by adding an aluminum plate to the top of the blade which extended its length by 1/2 inch. This modification increased the combustion chamber volume by about 37% with a corresponding increase in residence time. A second series of coal-firing tests were conducted with this new configuration, while reducing the thermal input from gas co-firing to about 10% of the total. Normalized CO emissions were ~690 ppm and NO_x emissions were ~220 ppm with actual O₂ concentration in the flue gas of ~2.5%. The higher CO emissions were likely the result of the increased coal firing and reduced gas support. However, carbon conversion increased to 74%. An effort was made to eliminate gas support, however, a flameout occurred every time the gas pressure was reduced below 1 psig (5% of the total thermal input). Self-sustained coal combustion (i.e., without gas support) was not achieved in the pulsed-blade combustor.

BO Tech subsequently designed and fabricated a diffuser specifically for coal firing. The diffuser was designed to enhance gas-coal mixing and increase coal residence time. West Star bituminous coal, which had been pulverized to less than 200 mesh (mean size of 33 microns), was used for these tests. Table 2 summarizes the test parameters. The unit was ignited and allowed to warm up on methane. The unit was operated with and without

transport air so that the effect of the transport air on emissions was gauged. As coal was introduced to the unit, the O_2 content in the flue gas decreased while CO and NO_x emissions increased. Two ash samples were collected as indicated in the table. The unit was shutdown during sample collection. Next, the maximum coal flow rate was set and the methane flow rate was gradually decreased. O_2 and CO content of the flue gas increased while NO_x reading decreased. When the methane thermal input fell below 7900 BTU/HR, combustion was not sustained. Other diffusers were tried but results were not better than those reported. Carbon content of the ash samples were 67% and 69% respectively, indicating very little fuel burnout.

CONCLUSIONS AND RECOMMENDATIONS

- o Both furnaces were easily ignited and able to maintain self-sustained combustion with methane over the load range tested. Steady-state conditions were reached within ~5 minutes of ignition.
- o The decoupling chamber reduced the noise level to 80-90 Db. However, this may still be high for residential use. If the commercial unit is encased in a metal shell, this may reduce the noise to an acceptable level.
- o Normalized CO emissions were between 0-20 ppm when gas was fired in the 30,000 Btu/hr furnace with rounded corners and air assist. Normalized NO_x emissions were between 20-25 ppm.

Efforts should be directed towards increasing the quantity of excess air that the furnace aspirates so that additional air is not required to lower the CO emissions.

- o Flue-gas temperatures in the experimental unit were between 400-600°F. Additional heat-transfer surface in a commercial unit would increase overall efficiency.
- o Normalized CO emissions were ~690 ppm for 90% coal/10% gas tests, while NO_x emissions were ~220 ppm. Self-sustained coal firing without gas support was not achieved during the phase 1 testing of the pulsed-blade combustor. Additional furnace modifications beyond simple combustion chamber enlargements appear necessary to increase carbon conversion and eliminate the need for gas support. These could include refractory lining in the upper portion of the furnace and/or a pulsed-coal feed system which would feed coal in phase with the furnace pulsations.

Table 1. As-received analyses of coals used in the pulse combustion tests.

Analysis	Upper Elkhorn #3	West Star
Moisture	1.37	1.57
Ash	5.65	13.48
Hydrogen	5.06	4.74
Carbon	80.69	71.62
Nitrogen	1.51	1.23
Sulfur	0.71	1.36
Oxygen (diff)	5.01	7.57

Table 2. Results of the West Star coal combustion tests.

Thermal Input (BTU/hr)		Transport Air	Emissions		
Coal	Methane	(SCFH)	O ₂	CO	NO _x
			(%)	(ppm)	(ppm)
0	11750	0	7.1	160	14
0	11750	10	8.8	200	10
1460*	11750	10	8.4	600	20
4130*	11750	10	8.0	1300	46
4130	11000	10	8.0	1120	50
4130	9540	10	9.5	1600	31
4130	7900	10	10.7	2500	22

* Ash was collected from unit after these tests

Figure 1. CO Emissions versus Firing Rate for 1-Inch Blade Burner

Figure 2. NO_x Emissions versus Firing Rate for 1-Inch Blade Burner

Figure 3. CO Emissions versus Firing Rate for 3-Inch Blade Burner

Figure 4. NO_x Emissions versus Firing Rate for 3-Inch Blade Burner

Figure 5. CO Emissions versus Diffuser Distance for 3-Inch Blade Burner

Figure 6. NO_x Emissions versus Diffuser Distance for 3-Inch Blade Burner

(A)

(B)

(C)

(D)

Figure 7. Various Coal Injector Positions Tested.