SIXTH INTERNATIONAL SYMPOSIUM

ON

COAL SLURRY COMBUSTION

Hyatt Orlando, Kissimmee, Florida

June 25-27, 1984

WELCOMING ADDRESS
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ANNOUNCEMENTS
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PROCEEDINGS OVERVIEW
(Gray Pages Divide Sessions)

I Pilot Testing
II Commercial and Industrial Applications
III Combustion Technology
IV Slurry Rheology and Characterization
V Commercialization and Economics
VI Additive Considerations
VII Demonstration Projects
VIII Fuel Clean-up (Beneficiation)
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XII Equipment

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On behalf of the United States Department of Energy, allow me to wish you all a warm welcome to Orlando, Florida, and the Sixth International Symposium on Coal Slurry Combustion and Technology.

The progress we have seen in coal slurry combustion, particularly in the past year, is most promising. Not only are the industrial and electric utility sectors showing increasing interest in this technology, but new and existing companies are displaying their creativity by expanding the market potential for this kind of energy source. Because of these efforts, the Department of Energy is proud and eager to assist you in pioneering coal slurry combustion technology by sponsoring this symposium.

We feel confident that the technical program for this year's symposium is both an accurate reflection of the state-of-the-art and a working blueprint for the future. However, the benefits we hope to realize will be determined by our active participation in these sessions. Your enthusiam, opinions, and technical contributions have made this annual symposium a success, and we look forward to this same kind of interaction in the days ahead.

Sincerely,

Sun W. Chun, Director
Pittsburgh Energy Technology Center
U. S. Department of Energy

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Session I

PILOT TESTING

Monday, June 25, 1984

Chairman: Howard Feibus
Office of Coal Utilization Systems, DOE

COMBUSTION OF COAL-METHANOL-WATER MIXTURES IN A 700-HP WATERTUBE BOILER

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ABSTRACT

The use of coal-methanol-water (CMW) mixtures as substitute fuels has been evaluated in the Pittsburgh Energy Technology Center's 700-hp watertube boiler designed for oil firing. Tests were conducted with mixtures prepared with a high volatile A bituminous coal and a high volatile C bituminous coal to determine the minimum level of methanol required in the fuel mixture to maintain a stable flame without preheated combustion air. Tests were also carried out using preheat temperatures typical of utility boiler conditions.

With CMW mixtures containing 60 percent hvAb coal, the minimum level of methanol required without using preheated combustion air was determined to be about 16 percent. The carbon conversion and boiler efficiencies at full load for mixtures containing 0 percent to 39 percent methanol were in the ranges of 92 percent to 98 percent and 72 percent to 81 percent, respectively, when the combustion air temperature varied from ambient temperature to 500°F.

With CMW mixtures containing hvCb coal, no more than 51 percent coal could be added because of the formation of high viscosity mixtures, resulting in high fuel-pump pressures and nozzle-plugging problems. A series of combustion tests with mixtures containing 51 percent coal showed that mixtures containing 23 percent or less methanol required preheating of the combustion air to be fired successfully. For mixtures containing 12 percent to 45 percent methanol, the carbon conversion efficiencies at full load were all $\geq$99.4 percent, and the boiler efficiencies were in the range of 76 percent to 81 percent when the combustion air temperature was varied from ambient temperature to 500°F.

INTRODUCTION

Coal-methanol-water mixture (CMW) combustion tests have been conducted at the Pittsburgh Energy Technology Center (PETC) to determine the maximum level of water that can be tolerated in the fuel mixture while still maintaining a stable flame using ambient-temperature or minimally preheated combustion air and also using an air-preheat temperature typical of utility boiler conditions.

Results of combustion tests conducted with CMW mixtures in an oil-designed 100-hp firetube boiler at PETC have been reported previously.[1] More recently, CMW tests were conducted at PETC in an oil-designed, 700-hp watertube boiler. The 100-hp boiler has a design heat liberation rate of 184,000 Btu/hr/cu ft, while the 700-hp boiler has a design heat liberation rate of 47,000 Btu/hr/cu ft. A high-volatile A bituminous (hvAb) coal and a high-volatile C bituminous (hvCb) coal were used in the tests.

COMBUSTION TEST FACILITY

The Combustion Test Facility, as arranged for firing CMW mixtures, is shown in Figure 1. The test unit is a Nebraska 700-hp, "D" type watertube, packaged industrial boiler originally designed for No. 6 oil firing. The boiler generates about 24,000 lb of steam at full load. Figure 2 is a sectional plan view through the firebox and convective section of the boiler. Flue gas cleanup devices include a dry sorbent injection system for SO_2 removal and a baghouse for particulate control. Modest retrofitting to the fuel feed system included a feed tank mixer, a recirculation pump and loop, a variable-speed feed pump, and nonclogging fuel-metering capabilities. Preheated combustion air is provided by an external source because the boiler was not equipped with an air preheater. Extensive instrumentation and a computer-controlled data acquisition system provide considerable experimental data for detailed analysis and evaluation of the tests.

Figure 3 is a cross-sectional view of the burner/air register used for test firing. The air register depicted is a Coen single-air-zone register provided with the boiler. One of two modifications made to the air register was a diameter change of the sheet metal shroud, which increased the secondary air linear velocities at the exit throat of the register. The other simple change was the insertion of a center air tube to establish a stable flame front. The center tube had a fixed air spinner, and both the center-tube air feed and the secondary air feed had independent flow control systems. This allowed considerable flexibility of burner operating capabilities.

The burner nozzle (Figure 4) used in carrying out all CMW mixture tests is only slightly different from the originally supplied oil-designed, inside-mix, steam-atomized burner nozzle. The changes are the following: (1) enlargement of the nozzle hole cross-sectional area, (2) installation of tungsten carbide sleeves to reduce erosion, (3) reduction of the burner spray angle, (4) utilization of air atomization, and (5) enlargement of fuel gap width in the mixer to reduce fuel pressure (at Section A-A, Figure 4).

COMBUSTION TEST PROCEDURES

Preparation of CMW mixtures was accomplished by first charging the 2500-gallon mix tank with a measured quantity of methanol and/or water. Pulverized coal (particle size-consist of ≈90 percent minus 200 mesh; top particle size of 140 mesh) was subsequently added to the liquid constituents of the CMW mixture until the desired coal loading was attained. Mixture concentration and viscosity were periodically determined to assure that mixture specifications were met.

Prior to each combustion test, the furnace ash was removed and the firebox was thoroughly cleaned. Firing of the boiler with No. 6 fuel oil at full-load conditions was initiated about 12-15 hours before a test with a CMW mixture. This was done to allow the boiler to heat up thoroughly and reach steady-state conditions. The heat transfer surface in the convective bank of the boiler was cleaned during this period by activating the soot blower several times. The soot blower was not used during a test to avoid interference with data acquisition. The boiler was switched to natural gas at one-third load immediately prior to a CMW test. Preheated combustion air flow and temperature were then established. The CMW mixture combustion was initiated with a natural gas support flame, and the load was slowly brought up by increasing the CMW mixture flow rate to a point where the natural gas support flame could be extinguished. The CMW mixture flow rate was further increased until reaching the proper firing rate, and the excess air level was adjusted to the specified condition.

Atomizing air flow and pressure, secondary air swirl, center-tube air to secondary air ratio, and the burner nozzle position were adjusted to obtain the best flame pattern (short bushy flame) without impingement on the quarl or furnace walls. The boiler was operated at steady-state conditions for about one hour before acquisition of any test data. Instrumentation was calibrated during the steady-state operation period before the test. Each test lasted two to three hours.

After completion of a test, the boiler was switched back to natural gas, and the load brought down with minimal disturbance to the furnace ash accumulation. The furnace was allowed to cool and then was opened for inspection. Furnace deposits were collected, weighed, and analyzed.

COAL-METHANOL-WATER MIXTURE PROPERTIES

A Pittsburgh seam hvAb coal and an Alberta (Canada) hvCb coal were used to prepare the CMW mixtures. Typical analyses of these two coals are given in Table 1. Both coals were pulverized to a particle size-consist of about 90 percent minus 200 mesh.

Earlier viscosity measurements of CMW mixtures containing 60 percent Pittsburgh hvAb coal indicate that there is a viscosity maximum at a methanol/water ratio of about 40/60 in the liquid phase and that the viscosity of the coal-methanol mixture is somewhat lower than that of the coal-water mixture.[2] The addition of small amounts of Lomar D (a surfactant) slightly reduced the viscosity of the CMW mixtures. The CMW mixtures prepared for the test program contained ≈60 percent coal and 0.24 percent to 0.53 percent Lomar D (except for the coal-methanol mixtures). The viscosities ranged from 325 to 693 cP at 100 sec^{-1} shear rate and at room temperature.

The CMW mixtures prepared with hvCb coal also displayed a similar viscosity maximum in the plot of slurry viscosity vs. percent methanol in the liquid, as illustrated in Figure 5. With the CMW mixtures containing hvCb coal, no more than 51 percent coal could be added because the formation of high-viscosity mixtures resulted in high fuel-pump pressures and nozzle-plugging problems. The addition of Lomar D to these CMW mixtures did not have a beneficial effect in reducing the viscosity. The hvCb CMW mixtures used in the test program contained about 51 percent coal and had viscosities in the range of 295 to 826 cP at 100 sec^{-1} shear rate and room temperature.

COMBUSTION TEST RESULTS

Combustion tests were conducted at full boiler load (24,000 lb/hr steam output) and with combustion air at temperatures ranging from ambient to 500°F. The minimum levels of methanol required in the hvAb and hvCb CMW mixtures to maintain stable combustion at full load without preheated combustion air were determined. In addition, minimum preheat requirements at half-boiler load were determined for hvAb CMW mixtures containing varying levels of methanol.

Pittsburgh hvAb Coal

Table 2 shows analyses of CMW mixtures prepared with ≈60 percent Pittsburgh hvAb coal and various levels of methanol and water. As the methanol content in the fuel increased from 0 percent to 38.9 percent, the heating value of the fuel increased from 7,729 Btu/lb to 11,695 Btu/lb.

TABLE 1. Analysis of Coals

	Pittsburgh hvAb	Alberta hvCb
Proximate Analysis (%) - As-Fired		
Moisture	1.73	8.99
Volatile Matter	35.86	33.68
Fixed Carbon	51.68	43.88
Ash	10.73	13.45
Ultimate Analysis (%) - Moisture-Free		
Hydrogen	5.27	5.54
Carbon	73.32	64.90
Nitrogen	1.55	1.51
Sulfur	1.75	0.39
Oxygen (ind.)	7.19	12.88
Ash	10.92	14.78
Heating Value (Btu/lb) - Moisture-Free	13,102	11,278
Ash Fusion Temperatures (^{o}F)		
Initial Deformation Temperature	2,460	2,320
Softening Temperature	2,540	2,390
Fluid Temperature	2,620	2,530

Boiler operating conditions and performance are shown in Table 3. Both carbon conversion and boiler efficiencies increased with increasing methanol content in the CMW mixtures when operating at full load using combustion air preheated to ≈500^{o}F, and excess air levels of 9 percent to 11 percent. This trend is presented in Figure 6.

Tests 4-11 of Table 3 show the results obtained at full and half loads using ambient-temperature combustion air or minimally preheated combustion air to sustain a stable flame. At full-boiler load, the minimum level of methanol required without using preheated combustion air was determined to be 40 percent in the liquid phase; this corresponds to an overall composition of 60 percent coal, 24 percent water, and 16 percent methanol (Test No. 5). At half-boiler load, however, the same CMW mixture containing 16 percent methanol required a minimum combustion air temperature of 389^{o}F to burn successfully. As the methanol content in the CMW mixture was increased for the half-load tests, the required preheating of the combustion air was decreased.

As methanol content in the CMW mixtures increases, water content decreases, but hydrogen content increases slightly (Table 2). It is expected that the heat consumed in evaporating water would decrease but the heat lost in formation of moisture from burning hydrogen in the fuel would increase. With methanol content in CMW mixtures varying from 0 to 38.9 percent and with 500^{o}F combustion air, heat loss due to water content decreased from 6.15 percent to 0.08 percent, while heat loss due to hydrogen content increased from 4.13 percent to 7.12 percent (see Table 3, Tests 1-3). For full-load tests, actual heat losses due to water content and hydrogen content in fuel, expressed as the percentage of total thermal input, are plotted in Figure 7. Apparently, with the displacement of water by methanol, the reduction in heat loss due to water content in the fuel is more than enough to offset the increase in heat loss due to H_2O formation from methanol.

Table 4 shows flue gas analysis and particulate emissions obtained during the combustion tests. Particulate emissions during full-load tests using 500^{o}F combustion air decreased with the increase of methanol content (see Figure 8). This was probably due to the increase in carbon burnout, which reduced the carbon content of the particulates.

Alberta hvCb Coal

Tests with CMW mixtures prepared from about 51 percent Alberta hvCb coal were conducted at full load using 500^{o}F and ambient-temperature or minimally preheated combustion air. The methanol concentrations of the mixtures varied from 12.4 percent to 44.6 percent, and the heating values from 6,881 Btu/lb to 10,326 Btu/lb. Analyses of these mixtures are shown in Table 5.

Boiler operating conditions and performance are given in Table 6. The boiler efficiency increased from 77.1 percent to 81.2 percent with increasing methanol content, but the carbon conversion efficiencies were

TABLE 2. Analyses of Coal-Methanol-Water Mixtures Prepared with Pittsburgh hvAb Coal

Test	1	2	3	4	5	6	7	8	9	10	11
Fuel Composition (%)											
Coal (Moisture-Free)	59.60	59.80	60.30	59.70	59.90	59.90	61.30	61.30	59.80	60.30	60.30
Methanol	0.00	23.75	38.90	11.96	15.78	15.78	19.34	19.34	23.75	23.81	38.90
Water	39.90	16.21	0.80	27.83	23.83	23.83	19.06	19.06	16.21	15.36	0.80
Lomar D	0.50	0.24	0.00	0.51	0.49	0.49	0.30	0.30	0.24	0.53	0.00
Coal Size Consist (% minus 200 mesh)	90	89	93	94	91	91	91	91	89	94	93
Ultimate Analysis (%)											
Hydrogen	7.6	8.0	8.2	7.8	7.8	7.8	7.8	7.8	8.0	7.9	8.2
Carbon	43.2	52.9	58.8	48.5	50.1	50.1	52.3	52.3	52.9	53.4	58.8
Nitrogen	0.8	0.9	0.9	0.9	0.9	0.9	1.0	1.0	0.9	0.9	0.9
Sulfur	1.5	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Oxygen	39.7	30.6	24.5	35.0	33.4	33.4	31.0	31.0	30.6	29.9	24.5
Ash	7.2	6.6	6.6	6.7	6.7	6.7	6.8	6.8	6.6	6.8	6.6
Heating Value (Btu/lb)	7,729	10,171	11,695	9,031	9,427	9,427	9,943	9,943	10,171	10,268	11,695
Viscosity (cp @ 100 sec^{-1})	NA	502	325	513	531	531	693	693	502	560	325

TABLE 3. Operating Conditions and Boiler Performance for Coal-Methanol-Water Mixture Tests With Pittsburgh hvAb Coal

Test Number	1	2	3	4	5	6	7	8	9	10	11
Methanol/Water Ratio	0/39.9	23.75/ 16.21	38.9/ 0.80	11.96/ 27.83	15.78/ 23.83	15.78/ 23.83	19.34/ 19.06	19.34/ 19.06	23.75/ 16.21	23.81/ 15.36	38.9/ 0.80
Load	Full	Full	Full	Full	Full	Half	Full	Half	Full	Half	Full
Flue Gas O_2 (%)	2.5	2.4	2.0	2.5	2.4	3.4	3.1	3.7	2.9	3.1	2.3
Excess Air (%)	9	11	9	9	7	17	10	20	12	15	6
Steam Flow (lb/hr)	23,980	23,840	23,840	24,020	23,230	12,600	23,860	12,080	23,910	12,170	24,200
Fuel Flow (lb/hr)	3,697	2,750	2,210	3,336	3,384	1,598	3,385	1,380	3,159	1,416	2,594
Thermal Input (MBtu/hr)	31.06	30.23	27.63	31.15	32.26	16.05	33.65	14.39	32.25	15.28	30.52
Combustion Air Temperature (°F)	493	497	509	223*	119**	389*	102**	346*	72**	299*	91**
Total Air Flow (lb/hr)	24,810	22,310	20,510	24,610	25,750	13,290	27,160	12,090	25,890	12,340	23,820
Atomizing Air Flow (lb/hr)	1,129	1,373	1,338	1,330	1,241	1,045	1,317	809	1,364	948	1,342
Atomizing Air Pressure at Burner (psig)	95	129	126	133	121	130	128	130	130	130	128
Fuel Pressure at Nozzle (psig)	89.1	101.9	85.2	132.8	103.8	66	103.1	50.1	108.1	60.8	89.3
Center-Tube Air Flow (lb/hr)	4,677	5,165	4,704	5,904	6,080	3,838	5,939	2,885	6,078	4,434	5,798
Average Flue Gas Temperature (°F)	554	522	520	598	525	454	598	466	572	470	521
Carbon Conversion Efficiency (%)	95.5	97.3	97.9	94.2	93.5	97.4	91.8	97.2	94.8	97.3	93.4
Boiler Efficiency (%) (Heat Loss Method)	75.0	80.0	81.2	73.5	74.8	79.2	72.0	78.8	75.2	79.5	77.0
Heat Loss Due to H_2O in Fuel (%)	6.15	1.85	0.08	3.86	3.13	2.89	2.45	2.22	2.03	1.75	0.09
Heat Loss from Burning H (%)	4.13	6.26	7.12	5.78	6.07	5.60	6.53	5.91	6.89	6.32	7.67

*Minimum combustion air preheat based on stable combustion and carbon monoxide emissions $\leq$ 400 ppm.
**Ambient-temperature air.

TABLE 4. Flue Gas Emissions in Coal-Methanol-Water Mixture Tests With Pittsburgh hvAb Coal

Test Number	1	2	3	4	5	6	7	8	9	10	11
Flue Gas Analysis											
O_2 (%)	2.5	2.4	2.0	2.5	2.4	3.4	3.1	3.7	2.9	3.1	2.3
CO_2 (%)	15.3	14.5	14.9	14.8	14.8	14.1	13.8	13.2	13.9	14.3	15.1
CO (ppm)	86	58	122	142	374	100	448	122	151	107	181
SO_2 (ppm)	1,981	1,218	1,032	1,500	1,424	1,288	1,328	1,176	1,196	1,164	1,131
(lb/MBtu)	3.69	2.23	1.81	2.73	2.53	2.52	2.47	2.42	2.22	2.18	1.86
NO_x (ppm)	452	355	401	393	340	360	298	403	340	543	424
(lb/MBtu)	0.61	0.47	0.50	0.51	0.43	0.51	0.40	0.60	0.45	0.73	0.50
THC* (ppm)	9	<1	<1	1.3	1.7	1.1	2.4	2.1	1.1	1.3	0.7
Opacity (%)	N.A.	53.3	53.6	56	6	56	62	50	55	54	60
Particulate Emissions, Uncontrolled (lb/hr)	249	153	134	266	253	76	338	69	227	66	262
(lb/MBtu)	8.0	5.1	4.8	8.5	7.8	4.7	10.0	4.8	7.0	4.3	8.6
Analysis (%)											
Carbon	N.A.	24.96	19.47	34.86	43.01	26.68	41.85	27.36	37.29	29.90	37.85
Sulfur	N.A.	0.38	N.A.	0.52	0.51	N.A.	0.63	0.20	0.48	N.A.	0.45

*Total hydrocarbons.