**SUPERCLEAN COAL-WATER SLURRY COMBUSTION
TESTING IN AN OIL-FIRED BOILER**

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Semiannual Technical Progress Report
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1.0 INTRODUCTION

The Pennsylvania State University is conducting a superclean coal-water slurry (SCCWS) program for the United States Department of Energy (DOE) and the Commonwealth of Pennsylvania with the objective of determining the capability of effectively firing SCCWS in an industrial boiler designed for oil. Penn State has entered into a cooperative agreement with DOE to determine if SCCWS (a fuel containing coal with 3.0 wt.% ash and 0.9 wt.% sulfur) can effectively be burned in an oil-designed industrial boiler without adverse impact on boiler rating, maintainability, reliability, and availability. The project will provide information on the design of new systems specifically configured to fire these clean coal-based fuels. The project consists of four phases: (1) design, permitting, and test planning, (2) construction and start up, (3) demonstration and evaluation (1,000-hour demonstration), and (4) program expansion (additional 1,000 hours of testing). The boiler testing will determine if the SCCWS combustion characteristics, heat release rate, fouling and slagging behavior, corrosion and erosion limits, and fuel transport, storage, and handling characteristics can be accommodated in an oil-designed boiler system. In addition, the proof-of-concept demonstration will generate data to determine how the properties of SCCWS and its parent coal affect boiler performance. Economic factors associated with retrofitting and operating boilers will be identified to assess the viability of future oil-to-coal retrofits.

The project consists of four phases as previously mentioned. Following is an outline of the project tasks that comprise the four phases:

Phase I: Design, Permitting, and Test Planning

Task 1. Design

Task 2. Permitting

Task 3. Test Planning

Phase II: Construction and Start Up

Task 1. Host Site Readiness/Boiler Retrofit

Task 2. SCCWS Preparation

Task 3. Performance Prediction

Task 4. Shakedown Testing

Phase III: Demonstration and Evaluation

Task 1. Test Burn

Subtask 1.a. SCCWS combustion performance

Subtask 1.b. Slagging/fouling propensity; corrosion characteristics

Subtask 1.c. Erosion characteristics

Subtask 1.d. Fuel transport, storage, and handling characteristics

Task 2. Evaluate Retrofit Economics

Task 3. Project Report

Phase IV: Advanced System Tests

Task 1. Burner/Superheater Procurement/Installation

Task 2. SCCWS Preparation Facility

Task 3. Flue Gas Treatment System

Task 4. 1,000-Hour Test

Task 5. Final Report

Penn State began a coal-water fuel (CWF) research and development program in 1984 with the ultimate goal of facilitating the replacement of petroleum-based fuels with coal-based fuels in oil-fired (designed) boilers. The Pennsylvania legislature appropriated funds in 1984 for the construction of a demonstration CWF boiler with a capacity of approximately 15,000 lbs steam/h on the main campus of Penn State at University Park. The project goal was to conduct a demonstration of the use of CWF, derived from Pennsylvania coal, in an environmentally acceptable manner, while evaluating the effects on boiler performance of long-term firing with CWF. From a commercialization viewpoint, the motivation for the project was to demonstrate the technical feasibility of retrofitting existing oil-fired units to burn CWF, particularly in the commercial and light-industrial sectors. Funding each year since 1984 has allowed for fuel procurement and the installation of a nominally rated 1,000 lb steam/h (maximum firing rate of 2 million Btu/h) Cleaver-Brooks A-frame watertube boiler [1] to investigate: the effect of boiler operating parameters on combustion performance [2]; automation of the firing of slurry fuels, particularly with respect to start up and shutdown procedures but also for optimizing boiler performance [3]; testing candidate CWFs; and [4] providing the necessary research support and training prior to start up of the demonstration unit. The SCCWS demonstration program is being conducted on the 15,000 lb steam/h demonstration boiler.

The objective of the program will be accomplished by installing a natural gas/oil-fired package boiler and generating baseline data firing natural gas. This is followed by system shakedown with SCCWS and the beginning of the first 1,000 hours of testing using the burner/atomizer system provided with the boiler. The first 1,000-hour demonstration will consist of boiler optimization testing and the combustion performance will be evaluated using SCCWS preheat, varying atomizing air pressure (up to 200 psig as compared to the 100 psig boiler manufacturer design pressure), and using steam as the atomizing medium. If the combustion performance is not acceptable based on combustion efficiency and the level of gas support necessary for flame stability, then low-cost modifications will be implemented such as building a quarl and testing alternate atomizers. If acceptable combustion performance is not obtained with these modifications, then the first demonstration will be terminated and the burner system replaced with one of proven coal design. In addition to the advanced burner system, a superheater tube and

advanced flue gas cleanup system will be installed and the second 1,000-hour demonstration will be conducted.

Accomplishments this period are presented in Sections 2.0, 3.0, 4.0, 5.0, and 6.0 for Phases I, II, III, IV, and miscellaneous activities, respectively. Section 7.0 outlines the activities planned for the next semiannual period. References are contained in Section 8.0 and acknowledgments are given in Section 9.0. The status of the project schedule is given in Figures 1 through 6, with a description of the milestones contained in Table 1.

2.0 PHASE I: DESIGN, PERMITTING, AND TEST PLANNING

Phase I has been completed with the exception of identifying operating procedures (a portion of Task 3). This portion of Task 3 is an on-going effort with operating procedures continually updated. Upon the conclusion of the program, an operating manual will be prepared which will be the compilation of procedures developed during the execution of the program.

2.1 Task 3. Identifying Operating Procedures

Operating procedures for various system components are being prepared for inclusion into an operating manual. Procedures were documented this reporting period for SCCWS storage and handling.

2.1.1 SCCWS Storage and Handling

Storage

The standard operating procedure for mixing the SCCWS in the 16,000-gallon storage tank involves operating the low-speed mixer for 30-45 minutes per shift (typically there are two shifts per day). Figure 7 is an isometric drawing of the boiler system (not to scale). Each shift then transfers the quantity of SCCWS that will be required for testing during that shift from the storage tank to the 2,000-gallon day tank. After transfer to the day tank, the SCCWS is mixed for 15 minutes and sampled for the determination of the solids loading.

Handling

Figure 8 is a plan view of the boiler system depicting the location of the SCCWS transfer station, day tank, SCCWS preheater, boiler, and SCCWS piping system. Figures 9-12 are schematic diagrams of the SCCWS transfer pump and header system, day tank (side view), storage tank (plan view), and outside boiler room wall (facing the SCCWS transfer station), respectively, with each valve numbered. Table 2 lists the valve positioning for each SCCWS handling function.

3.0 PHASE II: CONSTRUCTION AND START UP

The facility construction task, Task 1 Host Site Readiness/Boiler Retrofit, was completed last reporting period. Details of the boiler and auxiliary equipment have been given elsewhere [4,5].

In addition, a boiler performance model was developed (Task 3 Performance Prediction) by Burns and Roe Services Corporation last reporting period. Although Task 3 is completed, the model will be compared with data generated during the demonstrations.

Work continued on Tasks 2 and 4 and the results are discussed in the following sections.

3.1 Task 2. SCCWS Preparation

This section summarizes the activities to clean and prepare SCCWS during this reporting period. Details of the coal company, coal cleaning facility, and SCCWS preparation have been previously reported [6].

Slurry Procurement

Approximately 220 tons of SCCWS was prepared by Kennedy Van Saun (KVS) and transported to Penn State. Table 3 summarizes the proximate analyses that were performed on selected production runs.

Tables 4 to 14 summarize the KVS quality assurance production records. The coal-water formulation was modified to improve slurry stability. This was done by using a pH modifier (ammonium hydroxide) and increasing the solids loading of the slurry in order to manipulate the particle size distribution (increasing the fines) of the coal suspension. Dr. Ed McHale, of Science Applications International Corporation, assisted in the reformulation process. Tables 4 to 10 summarize the slurry production prior to the reformulation process. Tables 11 and 12 summarize the slurry production with ammonium hydroxide added for pH modification (June). Tables 13 and 14 summarize the slurry production using a pH modifier and increasing the solids loading (July). The slurry prepared during the production run of July 13 to 14 had excellent stability (< 1 % settling in 21 days).

The use of pH modifiers with the A-23M dispersant is well known. Addition rates for the ammonium hydroxide were adjusted to the targeted pH (pH 9.1 to 9.4). The importance of an optimum coal particle size distribution (PSD) is also well documented [7]. Optimum PSD's are typically achieved using a two stage grinding circuit in which a portion of the stage one grinding product is diverted to the stage two grinding circuit and the products from both stages are blended downstream. The KVS coal-water slurry circuit, however, is only a single stage grinding circuit. In order to achieve a broader PSD with the KVS single stage, the solids loading was increased to approximately 66 to 67 wt. %. By increasing the solids loading, and holding the dispersant concentration relatively constant, the viscosity of the slurry in the mill increases and particle-particle attrition occurs at an accelerated rate. With increased particle-particle attrition, the generation of additional coal fines occurs. Table 15 summarizes the changes in PSD and viscosity by increasing solids.

3.2 Task 4. Shakedown Testing

3.2.1 Equipment Shakedown

The final equipment components were checked this reporting period. The SCCWS preheater and automatic control system for firing SCCWS are now operational. This completes Task 4.

4.0 PHASE III: DEMONSTRATION AND EVALUATION

4.1. Task 1. Test Burn

4.1.1 Subtask 1a. SCCWS Combustion Performance

Approximately 335 hours of testing have been completed, of which ~243 hours were accumulated this reporting period. Table 16 lists the hours accumulated to date. Testing through January 1992 was summarized in the previous semiannual report [8]. A summary of the testing performed this reporting period is presented in the following subsections.

March/April 1992

Testing was conducted in March and April using various nozzle combinations. The atomizer and components are manufactured by Faber Burner Company, a wholly-owned subsidiary of Tampella Power Corporation. A schematic diagram of the Faber oil gun provided with the 15,000 lb steam/h package boiler is shown in Figure 13. The end of the gun contains a plug and cap combination, one of which is illustrated in Figure 14. This particular combination is the extra-high capacity (XHC) plug and cap. Faber produces plugs and caps with various capacities and spray angles. Table 17 lists the sizes of the air and slurry openings of the different plugs and caps.

Testing was conducted in March in order that the contractor could demonstrate that the SCCWS preheater was operational using the extra high capacity plug and high capacity nozzle with a 65° spray angle. Detailed heat and mass balances were not conducted because the system conditions were varied often.

In April, testing was conducted using nozzle/plug combinations that produced the best flame appearance during the March testing. The results from the April testing is summarized in Table 18. In April, ~53 hours of testing was conducted of which ~36 hours have detailed heat and energy balances. Tests 1-3 were conducted with a modified XHC (MXHC) plug and a XHC75° cap. Penn State modified the XHC plug by drilling the 1/8" air openings to 3/32". Test 4 was performed using the MXHC plug and HC65° cap. SCCWS instability was experienced in April and settling occurred. Test 1 was conducted with SCCWS containing 58% solids whereas Tests 2-4 were conducted with SCCWS containing 52% solids.

May 1992

In May, the boiler was operated for the contractor to verify that the automatic control system for firing SCCWS was working correctly. The system is working; however, it is operated

manually because the combustion performance is not satisfactory and optimization testing is on-going.

Approximately 50 hours were accumulated firing SCCWS in May as part of the control system verification and for testing. Because of extreme SCCWS instability, data were not collected for detailed heat and mass balances.

June 1992

In June, ~47 hours were accumulated firing SCCWS. Of these 47 hours, detailed heat and mass balances were made for ~36 hours. The testing was conducted to evaluate the effect of SCCWS temperature on combustion performance. Table 19 summarizes the results of the June Testing. Difficulties with SCCWS stability were still being experienced in June and testing was conducted with the solids content varying from 57 to 51 wt. %. Testing was conducted using various plug/cap combinations.

In summary, the latter tests were conducted with lower solids concentration due to SCCWS instability. This, in combination with the oil-designed burner, resulted in gas support being necessary to maintain a stable flame. Coal carbon conversion ranging from 84 to 93% was achieved with 23 to 36% gas support. In addition, the tests conducted with SCCWS preheat exhibited slightly better carbon burnout.

The last equipment item, the SCCWS preheater, was also tested in June and is now operational. Minor modifications to the preheater condensate pump were necessary in order for the preheater to work properly. The condensate pump transfers condensed steam (steam is used as the medium to heat SCCWS) to the deaerator tank.

July 1992

In July, ~58 hours firing SCCWS were accumulated. Tables 20 and 21 summarize the results from the July testing. The specific objectives of the tests were:

- Test 1 -- Evaluate the effect of SCCWS preheat on combustion performance using the MXHC plug and MHC75° cap;
- Test 2 -- Test the reformulated SCCWS using the MXHC plug and XHC75° cap;
- Tests 3 & 4 -- Evaluate the effect of SCCWS temperature on combustion performance using the reformulated SCCWS and the MXHC plug and MHC75° cap;
- Tests 5 & 6 -- Evaluate the effect of SCCWS temperature while operating the boiler under positive pressure (+1.0" W.C.) using the MXHC plug and MHC75° cap;
- Tests 7 & 8 -- Repeat Tests 5 & 6 except that the HC65° cap was used;
- Test 9 -- Test the effect of smaller atomizer nozzle openings on combustion performance using the MXHC plug and a 70° cap with an internal cone tip and capacity of 175 gallon/minute

- Test 10 -- Evaluate the effect of lower gas support and SCCWS preheat on combustion performance using the MXHC plug and HC65° cap; and
- Test 11 -- Evaluate the effect of SCCWS temperature while operating the boiler under positive pressure on combustion performance using the MXHC plug and HC65° cap.

The tests conducted in July, except for Test 1 which was a carryover from the June testing, were performed with the reformulated SCCWS and contained 62-65% solids. All the tests, except Test 10, were conducted with ~30% gas support. Coal carbon conversion was consistently near 90% regardless of the operating conditions. The major conclusion of the July testing is that the oil-designed burner system provided with the boiler does not perform adequately in that SCCWS can not be burned without gas support even with the use of SCCWS preheat.

August 1992

Three tests were conducted in August using steam as the atomizing medium and are summarized in Table 22. Steam at ~113 psig was used with 30% gas support resulting in ~90% coal carbon conversion. The steam was removed directly from the steam drum, which was operated at ~250 psig, and it was found that if atomizing steam pressure was greater than ~140 psig plugging of the nozzle occurred. Future testing, identified in Section 7.0, will be directed towards techniques to improve carbon conversion and decrease the level of gas support.

4.1.2 Subtask 1b. Slagging/Fouling Propensity: Corrosion

Characteristics

Bench-Scale Testing

Bench-scale testing on corrosion was completed this reporting period. The objective was to study the corrosion behavior of a group of selected alloys in a simulated fireside environment. Test coupons of five alloys were exposed to two types of ashes generated by combustion of SCCWS. A laboratory simulation of a fireside environment in a coal-fired boiler was achieved by passing a synthetic flue gas through a retort containing the test coupons for fixed time periods at a set of selected temperatures. The coupons, after removal from the furnace, were examined for corrosion losses employing several techniques. Following is a summary of the conclusions from the bench-scale testing. A detailed synopsis will be presented in the project report that will be prepared upon the completion of the first demonstration test.

The five alloys selected for the study were austenitic stainless steels of Types 304, 316, 321, 347, and high-nickel 800H. The composition of the alloys is given in Table 23. The alloys were tested in two series of testing. In Test Series I, the effects of two ashes on the alloys were studied by submerging test coupons in the ash and exposing them at 1,000°C for a test period of 48 hours in an inert atmosphere. In Test Series II, the alloy coupons were precoated with ash and exposed to a flue gas atmosphere for a test period of 48 hours, at different temperatures. Table 24 contains the composition of the ashes. Ash A was a low-carbon (27 wt.%) ash recovered from the

combustion of SCCWS in the research boiler. Ash B was a high-carbon (57 wt.%) ash recovered from the demonstration boiler.

Scanning electron micrographs of the test coupon surfaces after removal from the furnace revealed the morphology of the corroded surfaces. Micrographs of the coupon surfaces after removal from the furnace after descaling (described previously [8]) for each alloy at each test condition were taken. These micrographs revealed the nature of ash activity on the coupon surfaces. In all of the tests the ash had formed adherent scales of deposits to varying extents. The coupons exposed to ash A revealed a thick layer of what appeared to be residual slag covering the exposed surface. The coupons exposed to ash B revealed thin scales of fused ash sticking to the exposed surface.

Unburned carbon particles were visible at high magnifications for coupons exposed to both ashes. The morphology of the fused deposits on some of the coupons, particularly Type 316 stainless steel, clearly revealed glassy phases which looked like globules. The ash particles which had formed bonded deposits on the coupon surfaces all had rounded edges and there was inter-particle fusion visible. This clearly suggests that these ash phases had been in the liquid phase.

Optical micrographs of transverse sections of the coupons, after removal from the furnace, revealed the presence of an adherent layer of deposit on the surface. Also, general attack of the metal, presence of pitting, and penetration of corrosion products were revealed. With the help of the SEM micrographs and the optical micrograph, it was possible to make some conclusions on the corrosion behavior of the alloys chosen. In the Test Series I testing, the common observation was that the ash sticking to the coupon surfaces appeared to be particles of fused silica. Type 316 stainless steel appeared to have undergone the maximum corrosion attack from ash A at all the test temperatures in Test Series II. It was possible to grade the alloys in order of increasing corrosion resistance towards ash A. The alloys placed in order of increasing corrosion resistance were Types 316, 304 347, 321, and 800H for Test Series II testing with ash A. For Test Series II tests with ash B, the grain boundary attack and pitting was more pronounced. The alloys placed in the order of increasing corrosion resistance were Types 304, 3476, 316, 321 and 800H.

The weight loss data gave a quantitative measure of corrosion losses of each alloy at the various test conditions. Test Series I tests with ash A resulted in Type 347 stainless steel undergoing the maximum losses. All the alloys were attacked in the range of 2-5 mg/cm² average weight loss. Type 347 showed an average weight loss of 28.34 mg/cm². Test Series II tests with ash B again showed that Type 347 stainless steel was heavily attacked in terms of weight loss (11.36 mg/cm²). The other alloys showed lower weight losses compared to Type 347. In the Test Series II tests, it was clear that all the alloys were attacked more heavily by ash A than ash B. A weight loss of 1 mg/cm² was assumed to be equivalent to a surface recession of 1.25×10^{-3} mm and by linear extrapolation, the corrosion (penetration) rate in mm/year, assuming 8,000 hours of

operation annually, was obtained by multiplying the corrosion loss (mg/cm^2) by 0.1. This method for converting corrosion loss in mg/cm^2 to corrosion (penetration) rate in mm/year is reported in work by EPRI. Figures 15 and 16 show plots summarizing the corrosion rates of each of the alloys with respect to temperature and ash type. The relative corrosion resistance of the alloys towards the two ashes was different, suggesting that the carbon and CaO content of the ashes played a major role in determining the behavior of the ash to the particular alloy. The microanalysis of the test coupons from tests with ashes A and B at 800°C revealed the general nature of corrosion products that had formed. The quantitative data revealed the absence of sulfur in the deposit formed on coupon surfaces at 800°C . The corrosion products appeared to be composed mainly of oxides of iron and chromium.

Figure 17 shows a column plot comparing the data of Kihara et al [9] for pulverized coal combustion and the experimental data obtained from the present study for a test temperature of 600°C and ash A. It can be seen that the corrosion rates for the four alloys are significantly higher for pulverized coal combustion as compared to SCCWS combustion. At 700°C , the corrosion rates of these alloys in pulverized coal systems is in the range of 20-30 mm/year according to test data of Kihara et al., which is extremely high when compared to experimental results from the present study. Figure 18 shows a comparison between the results of Menzo and Rahoi [10] and the results from the present study for test temperatures of 600 and 700°C and ash A in the form of a column plot. When compared to Menzo and Rahoi's data, the experimental data exhibits significantly greater corrosion.

4.1.3 Subtask 1c. Erosion Characteristics

Erosion tests have been conducted in the demonstration boiler when cofiring SCCWS with natural gas. The technique developed in this program has been described in previous reports [4,6] and a recent publication [11]. The objective of the recent work is to obtain further information on the transition from erosion of metal, oxide, and deposits, to deposition of ash, accompanying the formation of metal oxide. This information is necessary in order to refine the erosion model previously developed [4]. The objective of this subtask is to construct a model that predicts erosion, using an accelerated technique, as a function of metal oxidation, particle properties and velocity, gas composition and temperature, and deposition. The model will then be used to extrapolate erosion for the less severe conditions experienced by the demonstration boiler.

Experimental

The measurements reported here were made in the convective section of the boiler. At the location of the erosion probe, the gas temperature was 850 K (1070°F) and particle concentration was $2.7 \text{ g}/\text{m}^3$ (calculated). The compositions of the fuel and flue gas are given in Table 25.

The carbon steel specimens were prepared per the procedure described previously [11]. The parameters which were varied during the tests were metal temperature and jet gas oxygen content,

while the initial jet gas velocity remained at 200 m/s. Each sample was exposed to the effects of the high velocity jet, flue gas, and entrained particles for 2 hours. The conditions at which measurements were made are given in Table 26.

Results and Discussion

The shapes of the surfaces of the carbon steel samples, after exposure to different combinations of jet gas and metal temperature, are shown in Figures 19a to 19i. Each of these figures show a profile of the surface in the region 5 mm from the jet axis. Scanning electron micrographs of the samples, looking down onto the surfaces, are shown in Figures 20a to 20i. The scale in the photographs is the same as that in the profiles.

When the metal temperature was 450 K, the effect of changing the jet gas from nitrogen, to air, to oxygen is shown in Figures 19a, 19b, and 19c. The profile, in all three cases, showed a crater having its maximum depth approximately 1.5 mm from the axis of the jet. Measurement of the depth in the profile indicates an erosion rate of $0.6 \mu\text{m}/\text{hour}$ (Table 26). The scanning electron micrograph in Figure 20a, shows that ash deposit was responsible for the peaks appearing at 0.5 mm from the jet axis. Static electricity on the polished metal surface was suspected to contribute to the deposition. For the cases shown in Figures 20b and 20c, the effect of static electricity might be missing due to the presence of oxidation under air and oxygen jets. The oxidation rate at 450 K is extremely low, the clear specimen surface in Figure 20c implies minimum interaction between metal surface and fine ash particles.

The profiles in Figure 19d, 19e and 19g were dominated by erosion, which produced a large crater at the jet axis extending up to 5 mm on either side. The erosion rate, measured from the deepest position of the profiles, is 1.0 to $1.7 \mu\text{m}/\text{hour}$ (Table 26). Micrographs of the craters are shown in Figures 20d, 20e, and 20g. A thin oxide layer remained at the surface at the rim of craters in Figures 20d and 20g, which had been scored by particles. In the central region, it appears that the oxide was continuously removed from the metal surface as it formed. Therefore, the erosion rate was greatest, in agreement with the prediction from an erosion model [8].

When the rate of formation of metal oxide was increased by increasing metal temperature and/or the oxygen content of the jet gas, the effect is shown in the profiles of Figures 19f, 19h and 19i. Both crater and peak appear on all three profiles. Even the depth of the crater and the height of peak have approximately the same value, corresponding to erosion and deposition rates of $0.6 \mu\text{m}/\text{hour}$ (Table 26). The micrographs in Figures 20f, 20h, and 20i show the ash deposit in the central region, where there was enough oxide on the sample surface with which to form a bond with incoming sticky ash particles. The ash particles attached to the oxidized surfaces provided some protection against erosion, so erosion would have been attacking the deposit, rather than the tube material. This could also result in an impression that metal oxide was more resistant to erosion than the metal.

4.1.4 Subtask 1d. Fuel Transport, Storage, and Handling Characteristics

SCCWS instability was experienced with slurry produced during March through June. This was a combination of slurry formulation, quality control during SCCWS production, and SCCWS production equipment problems. Each of these factors was addressed and SCCWS produced in July for the July and August testing was very stable.

There were several instances at KVS where mistakes occurred during production which resulted in atypical slurry settling. This included the use of oxidized coal and widely varying additive feed rates. This was remedied by improving quality control at KVS. Penn State set up a quality control laboratory which was manned 24 hours/day and viscosity, particle size distribution, and solids content were monitored.

Equipment problems were encountered on two occasions at KVS during slurry production. The ball mill motor and a moyno pump failed which resulted in premature termination of slurry production, thus affecting slurry characteristics, including stability.

SCCWS instability due to the formulation was addressed. SCCWS reformulation was discussed in Section 3.1.

5.0 ADVANCED SYSTEM TESTS

5.1 Task 1. Procure and Install Burner and Superheater

Requests for proposals to provide an advanced burner system were submitted to several boiler manufacturers and engineering firms in July. A boiler data sheet and a full set of drawings were provided to each potential vendor along with the following burner specifications:

- >98% carbon conversion;
- >3:1 burner turndown;
- >10,000 hour atomizer tip life;
- excess air < 30%;
- combustion air preheat <400°F with no support fuel;
- burner pressure drop <8 in. W.C.;
- maximum droplet diameter and droplet volumetric median diameter of 300 and 80 μm , respectively;
- air/steam as the atomizing medium;
- NO_x emissions of <475 ppmv;
- air/fuel ratio <0.15; and
- dual fuel capability (coal-water slurry and natural gas).

Several proposals were received and are currently under review with DOE prior to selection.

5.2 Task 2. Construction of a SCCWS Preparation Facility

A facility will be constructed at Penn State that will be used to produce SCCWS and dry micronized coal. Three programs, one of which is the SCCWS project, are being integrated in order to efficiently utilize DOE funding. Preliminary engineering drawings have been prepared and are currently being finalized. The plans are continuously being revised; therefore, plans have not

been included in the report. Upon design finalization, construction will begin. Figures depicting process flowsheets, equipment, and site drawings will be submitted in the next semiannual report after the design has been finalized.

5.3 Task 3. Install an Advanced Flue Gas Treatment System

Task 5 was initiated this reporting period. Contact has been made between Penn State and two potential suppliers of an advanced flue gas treatment system. Work is very preliminary and will increase, in conjunction with DOE, during the next reporting period.

6.0 MISCELLANEOUS ACTIVITIES

The 17th International Conference on Coal and Slurry Technologies which was held in Clearwater, Florida from April 28 to May 1, 1992, was attended. Three papers and one poster presentation were prepared. Authors and titles are:

- Bruce G. Miller and Alan W. Scaroni, "Penn State's Superclean Coal-Water Slurry Demonstration Program;"
- Peter M. Walsh, Jiangyang Xie, John T. Elston, Bruce G. Miller, and Alan W. Scaroni, "Erosion of a Tube by a High Velocity Jet in the Presence of Ash from Coal-Water Slurry Combustion;"
- Jiangyang Xie, Peter M. Walsh, Alan W. Scaroni, and Bruce G. Miller, "Erosion of Metal at High Temperature In Oxidizing Atmosphere (poster presentation);" and
- Massood Ramezan, John Lagomarsino, Sarma V. Pisupati, Bruce G. Miller, and Alan W. Scaroni, "Performance Predictions of a Multifuel Industrial-Type Boiler."

An open house was held May 22, 1992 to dedicate the coal-water fuel demonstration facility. Guests representing federal and state agencies, industry, and academia were in attendance.

A paper was prepared and a project summary presented at the 8th Annual Coal Preparation, Utilization, and Environmental Control Contractors Conference in Pittsburgh, Pennsylvania held July 27-30, 1992. The authors and title of the paper are:

- Bruce G. Miller and Alan W. Scaroni, "Superclean Coal-Water Slurry Combustion Testing in an Oil-Fired Boiler."

7.0 NEXT SEMIANNUAL PERIOD ACTIVITIES

During the next reporting period, a quarl will be installed in the boiler to stabilize the flame. In addition to testing the quarl, Tecogen's variable spray angle external-mix atomizer and higher pressure (200 psig) atomizing air will be tested.

Work will continue in assembling the operating procedures. The procedures for calibrating and using the continuous flue gas analyzers and monitoring the boiler feedwater chemistry are currently being prepared and will be completed next reporting period.

8.0 REFERENCES

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- Sarma V. Pisupati - Research Associate
- Ronald S. Wasco - Wage Payroll Assistant
- Ronald T. Wincek - Research Assistant

FIGURE 1. 1989 Milestone Schedule (First 1,000-h Demonstration)

FIGURE 2. 1990 Milestone Schedule (First 1,000-h Demonstration)

FIGURE 3. Phase I and II 1991 Milestone Schedule (First 1,000-h Demonstration)

Figure 4. Phase III 1991 and 1992 Milestone Schedule (First 1,000-h Demonstration)

Figure 5. Phase III 1992 and 1993 Milestone Schedule (First 1,000-h Demonstration)

Figure 6. Phase IV Milestone Schedule

TABLE 1
MILESTONE DESCRIPTION

<u>Milestone</u>	<u>Description</u>	<u>Planned Completion Date</u>	<u>Actual Completion Date</u>
Phase I			
Task 1, No. 1	Identify equipment and diagnostic instrumentation	09/15/89	09/15/89
Task 2, No. 1	Review present permit	09/15/89	09/15/89
Task 3, No. 1	Develop SCCWS specifications, identify operating procedures, prepare detailed test plan	10/15/89	
Phase II			
Task 1, No. 1	Building/boiler construction and installation let for bids	10/18/89	10/18/89
Task 1, No. 2	Building/boiler construction and installation awarded	12/31/89	03/23/90
Task 1, No. 3	Prepare site, install boiler and auxiliary equipment	04/01/91	01/31/92
Task 2, No. 1	Identify coal for SCCWS preparation	09/30/90	09/30/90
Task 2, No. 2	Prepare SCCWS for demonstration	04/01/91	
Task 3, No. 1	Predict boiler performance	06/15/91	02/01/92
Task 4, No. 1	Shakedown boiler and auxiliary equipment	04/31/91	06/30/92
Task 4, No. 2	Generate baseline data on gas	05/31/91	09/30/91
Phase III			
Task 1, No. 1	Perform demonstration		
Subtask 1a, No. 1	300-hour demonstration milestone	07/30/92	07/31/92
Subtask 1a, No. 2	500-hour demonstration milestone	10/31/92	
Subtask 1a, No. 3	Redefine SCCWS specifications	01/15/93	
Subtask 1b, No. 1	Develop deposition and corrosion test plan	10/15/89	10/15/89
Subtask 1b, No. 2	Design suction pyrometer	06/01/90	08/01/90
Subtask 1b, No. 3	Construct suction pyrometer	10/01/90	10/01/90
Subtask 1b, No. 4	Deposition characterization equipment design and specification	01/01/91	02/15/91
Subtask 1b, No. 5	Acquisition of baseline data for spectroscopic analysis of deposits; acquisition of baseline data for corrosion of tubes by ash components	08/31/91	08/15/92
Subtask 1b, No. 6	Accelerated corrosion testing; coupon testing in boiler	10/31/92	
Subtask 1b, No. 7	On-line deposition analysis	12/31/92	
Subtask 1b, No. 8	Complete deposition testing (auxiliary spectroscopic testing); complete corrosion modeling; complete deposition modeling	01/15/93	
Subtask 1c, No. 1	Develop erosion test plan	10/15/89	10/15/89
Subtask 1c, No. 2	Complete research boiler erosion evaluation	08/01/90	08/01/90
Subtask 1c, No. 3	Full-scale erosion technique decision	10/01/90	10/01/90
Subtask 1c, No. 4	Design probe for full-scale erosion study	01/01/91	02/15/91
Subtask 1c, No. 5	Construct erosion probe	05/01/91	10/15/91
Subtask 1c, No. 6	Complete erosion modeling	01/15/93	
Subtask 1d, No. 1	Identify viscometer	10/15/89	10/15/89
Subtask 1d, No. 2	Complete preliminary viscosity and stability tests	08/15/90	09/15/90
Subtask 1d, No. 3	Complete viscosity and stability tests	11/30/92	
Task 2, No. 1	Complete economic evaluation	01/15/93	
Task 3, No. 1	Complete project report	03/01/93	

Table 1 (Cont.)
Milestone Description

<u>Milestone</u>	<u>Description</u>	<u>Planned Completion Date</u>	<u>Actual Completion Date</u>
Phase IV			
Task 1, No. 1	Procure and install burner and superheater	07/01/93	
Task 2, No. 1	Complete construction of SCCWS preparation facility	03/01/93	
Task 3, No. 1	Install flue gas treatment system	07/01/93	
Task 4, No. 1	Complete 1,000-hr test	08/31/94	
Task 5, No. 1	Complete final report	03/01/95

Figure 7. Penn State's SCCWS-Fired Boiler System

Figure 8. Piping Configuration for SCCWS and Water

- A) SLURRY TO THE 16000 GALLON STORAGE TANK
- B) EXTRA PORT FOR RECIRCULATING THE TANKER
- C) PORT FOR HOOKING UP THE TANKER
- D) SLURRY INLET TO THE PUMP FROM THE 16000 GALLON TANK
- E) SLURRY INLET TO THE DAY TANK FROM THE PUMP
- F) SLURRY PURGE LINE TO THE TRENCH (PRESENTLY NOT USED)
- G) AUTOMATIC WATER PURGE CONTROLLED FROM THE CTRL PANEL

Figure 9. Schematic of Transfer Pump and Header Depicting Valve Location

Figure 10. Side View of 2,000-Gallon Day Tank

Figure 11. Plan View of 16,000-Gallon SCCWS Storage Tank

Figure 12. Outside View of East Wall of Boiler Room
Showing the Location of the Water Valve

Table 2. Valve Configurations for Pumping SCCWS and Purging Lines

SLURRY PUMPING VALVE CONFIGURATIONS

Pumping Description	1	2	3	4	5	6	7	9	10	11	12	13	14	15	16	17	18
Pumping from tanker to 16,000 gallon tank				0			0		0					*	*	*	
Fill day tank from tanker	0						0									0	
Fill day tank from 16,000 gallon tank	0					0						0				0	
Fill tanker from 16,000 gallon tank					0	0						0					
Recirculate the 16,000 gallon tank				0		0			0			0					

* Indicates automatic actuated valves

SLURRY PURGING VALVE CONFIGURATIONS

Pumping Description	1	2	3	4	5	6	7	9	10	11	12	13	14	15	16	17	18
Purge 16,000 gallon tank exit to day tank	0					0					0					0	0
Purge 16,000 gallon tank entrance to day tank	0					0				0						0	0
Auto purge from pump to burner								0		0							0

* Indicates automatic actuated valves

During auto purge the burner must be on line

Table 3. Proximate Analysis of SCCWS Samples^a.

Date	Tanker Id#	Volatile Matter	Fixed Carbon	Ash
03/24/92	D-518	33.80	61.92	4.28
03/24/92	D-608	35.39	60.50	4.11
06/16/92	D-607	36.26	60.22	3.52
06/23/92	D-607	35.91	60.43	3.66
06/23/92	D-608	36.16	60.26	3.58
07/13/92	D-607	35.64	60.74	3.62

^aDry basis

Table 4. KVS Coal-Water Slurry Fuel Production Run for March 18, 1992

Time	Solids Loading (wt. %)	Particle Size Distribution		Viscosity (cp)	pH	Ball Mill Operating Conditions		
		-50 mesh	-200 mesh			Dry Coal	A-23M	4800C
1500	60.23	99.75	83.86	712	5.93	2088	0.94	0.03
1600	59.92	99.66	82.58	724	6.15	2287	0.95	0.04
1700	60.05	99.74	83.67	536	6.25	2230	0.88	0.04
1800	60.06	99.76	83.95	1392	6.19	2459	1.15	0.40
1900	60.76	99.58	82.67	1044	6.24	2244	1.55	0.05
2000	60.46	99.53	84.55	940	6.23	2332	1.62	0.05
2100	60.37	99.65	85.78	860	6.19	2275	1.15	0.04
2200						2275	0.96	0.04
2300	61.45	99.63	83.39	988	6.04	2389	0.83	0.04
2400	62.32	99.60	85.19	1240	5.97	2399	0.82	0.04

Comments: All of the data summarized above has been supplied by KVS.

- a) Solids loading were determined using a Harry W. Dietart Company moisture teller.
- b) Particle size distributions were determined by wet sieving.
- c) Viscosities were determined using a Brookfield "RVT" viscometer (spindle #5 at 100 rpm after 3 minutes)
- d) pH measurements using an Orion pH meter.
- e) Ball mill conditions
 - Dry coal feed rate expressed in lbs/hr
 - Dispersant (A-23M) and stabilizer (Flocon 4800 C) concentrations expressed as wt. % active solids/dry coal basis

Table 5. KVS Coal-Water Slurry Fuel Production Run for March 19, 1992

Time	Solids Loading (wt. %)	Particle Size Distribution		Viscosity (cp)	pH	Ball Mill		
						Dry Coal	A-23M	4800C
0100	63.15	99.54	83.23	1356	5.84	2220	0.87	0.05
0200	63.39	99.46	84.55	1436	5.86	2400	0.81	0.04
0300	63.59	99.63	84.00	1436	5.81	2280	1.05	0.04
0400	62.43	99.62	85.25	1164	5.95	2280	0.92	0.05
0500	61.73	99.66	84.23	988	5.92	2280	1.02	0.05
0600	60.96	99.65	86.46	936	5.99	2100	1.22	0.05
0700	60.10	99.69	86.21	784	6.15	2145	1.20	0.05
0800	59.21	99.73	85.22	688	6.16	2430	1.08	0.04
0900	58.52	99.71	84.48	660	6.05	2400	1.00	0.04
1000						2430	0.93	0.04
1100	57.39	99.67	86.05	580	6.36	2530	1.09	0.04
1200	56.40	99.67	85.10	500	6.55	2625	1.00	0.04
1300	57.19	99.74	83.03	556	6.50	2430	1.03	0.04

Comments: All of the data summarized above has been supplied by KVS.

- a) Solids loading were determined using a Harry W. Dietart Company moisture teller.
- b) Particle size distributions were determined by wet sieving.
- c) Viscosities were determined using a Brookfield "RVT" viscometer (spindle #5 at 100 rpm after 3 minutes)
- d) pH measurements using an Orion pH meter.
- e) Ball mill conditions
 - Dry coal feed rate expressed in lbs/hr
 - Dispersant (A-23M) and stabilizer (Flocon 4800 C) concentrations expressed as wt. % active solids/dry coal basis

Table 6. KVS Coal-Water Slurry Fuel Production Run for April 8, 1992

Time	Solids Loading (wt. %)	Particle Size Distribution		Viscosity (cp)	pH	Ball Mill		
		-50 mesh	-200 mesh			Dry Coal	A-23M	4800C
1600						2241	1.55	0.09
1700						2323	1.14	0.03
1800	55.94	99.59	85.34	460	6.58	2186	1.10	0.02
1900	56.92	99.69	83.33	540	6.55	2350	0.88	0.05
2000	59.15	99.56	84.18	716	6.58	2241	0.92	0.04
2100	60.09	99.59	81.78	788	6.59	2241		0.04

Comments: All of the data summarized above has been supplied by KVS.

- a) Solids loading were determined using a Harry W. Dietart Company moisture teller.
- b) Particle size distributions were determined by wet sieving.
- c) Viscosities were determined using a Brookfield "RVT" viscometer (spindle #5 at 100 rpm after 3 minutes)
- d) pH measurements using an Orion pH meter.
- e) Ball mill conditions
 - Dry coal feed rate expressed in lbs/hr
 - Dispersant (A-23M) and stabilizer (Flocon 4800 C) concentrations expressed as wt.% active solids/dry coal basis

Table 7. KVS Coal-Water Slurry Fuel Production Run for May 4, 1992

Time	Solids Loading (wt. %)	Particle Size Distribution		Viscosity (cp)	pH	Ball Mill Operating Conditions		
		-50 mesh	-200 mesh			Dry Coal	A-23M	4800C
1600	60.67	99.52	81.92	520	6.56	2141	0.76	0.07
1700	60.96	99.53	82.31	1412	6.97	2225	0.78	0.03
1800	59.37	99.46	83.01	596	7.38	2085	1.10	0.02
1900	58.38	99.58	82.83	480	7.44	2115	0.87	0.02
2000	58.01	99.76	81.79	424	6.74	2030	0.76	0.02
2100	57.69	99.67	83.00	464	6.97	2143	0.91	0.04
2200	57.44	99.78	83.54	520	7.06	2143	0.91	0.04
2300	57.65	99.73	82.28	560	7.10	2270	1.24	0.04
2400	57.70	99.72	82.74	544	7.18	2326	1.63	0.04

Comments: All of the data summarized above has been supplied by KVS.

- a) Solids loading were determined using a Harry W. Dietart Company moisture teller.
- b) Particle size distributions were determined by wet sieving.
- c) Viscosities were determined using a Brookfield "RVT" viscometer (spindle #5 at 100 rpm after 3 minutes)
- d) pH measurements using an Orion pH meter.
- e) Ball mill conditions
 - Dry coal feed rate expressed in lbs/hr
 - Dispersant (A-23M) and stabilizer (Flocon 4800 C) concentrations expressed as wt. % active solids/dry coal basis

Table 8. KVS Coal-Water Slurry Fuel Production Run for May 5, 1992

Time	Solids Loading (wt. %)	Particle Size Distribution		Viscosity (cp)	pH	Ball Mill		
						Dry Coal	A-23M	4800C
0100	57.12	99.65	84.02	1567	7.11	2228	1.36	0.04
0200	58.04	99.66	82.24	628	6.97	2143	1.31	0.05
0300	58.06	99.75	83.27	624	6.86	2312	1.13	0.03
0400	59.28	99.57	84.20	808	6.71	2312	1.04	0.04
0500	59.71	99.57	81.49	984	6.65	2355	1.01	0.04
0600	59.66	99.65	81.08	1156	6.75	2242	1.07	0.05
0700	59.99	99.36	81.84	980	6.88	2341	0.98	0.04
0800						2256	1.05	0.04
0900	59.08	99.65	81.94	688	6.82	2312	0.94	0.04
1000	58.65	99.68	82.55	716	6.62	2059	1.11	0.04
1100	57.08	99.59	83.60	496	6.60	2312	1.08	0.05
1200	57.34	99.71	84.07	388	6.72	2425	1.05	0.02
1300	57.24	99.64	82.52	308	6.71	2383	1.09	0.00
1400	57.55	99.68	81.84	456	6.88	2228	1.08	0.04
1500	57.55	99.68	83.73	1176	6.93	2226	1.02	0.16
1600	58.08	99.55	82.06	1056	6.98	2226	0.98	0.08
1700	58.21	99.64	84.20	792	7.21	2226	0.93	0.04
1800	58.91	99.68	82.90	768	7.37	2172	0.80	0.04
1900	59.48	99.50	83.19	924	7.37	2277	1.00	0.04
2000	59.97	99.56	82.46	940	7.29	2100	1.34	0.04

Comments: All of the data summarized above has been supplied by KVS.

- a) Solids loading were determined using a Harry W. Dietart Company moisture teller.
- b) Particle size distributions were determined by wet sieving.
- c) Viscosities were determined using a Brookfield "RVT" viscometer (spindle #5 at 100 rpm after 3 minutes)
- d) pH measurements using an Orion pH meter.
- e) Ball mill conditions

Dry coal feed rate expressed in lbs/hr

Dispersant (A-23M) and stabilizer (Flocon 4800 C) concentrations expressed as wt.% active solids/dry coal basis

Table 9. KVS Coal-Water Slurry Fuel Production Run for May 11, 1992

Time	Solids Loading (wt. %)	Particle Size Distribution		Viscosity (cp)	pH	Ball Mill		
		-50 mesh	-200 mesh			Dry Coal	A-23M	4800C
1100	58.65	99.55	83.93	660	7.64	2266	0.69	0.04
1200	59.13	99.70	81.73	644	7.37	2237	0.58	0.04
1300	59.24	99.25	83.85	608	7.34	2272	0.72	0.03
1400	59.30	99.58	84.23	588	7.27	2272	0.76	0.04
1500	59.24	99.55	81.82	640	7.27	2328	0.70	0.04
1600	59.82	99.52	80.88	780	7.23	2188	0.81	0.05
1700	60.27	99.62	82.21	784	7.23	2200	0.74	0.04
1800	60.08	99.66	81.58	680	7.13	2284	0.83	0.03
1900	60.03	99.66	82.32	696	7.16	2228	0.83	0.04
2000	60.14	99.66	82.35	684	7.09	2326	0.81	0.04

Comments: All of the data summarized above has been supplied by KVS.

- a) Solids loading were determined using a Harry W. Dietart Company moisture teller.
- b) Particle size distributions were determined by wet sieving.
- c) Viscosities were determined using a Brookfield "RVT" viscometer (spindle #5 at 100 rpm after 3 minutes)
- d) pH measurements using an Orion pH meter.
- e) Ball mill conditions
 - Dry coal feed rate expressed in lbs/hr
 - Dispersant (A-23M) and stabilizer (Flocon 4800 C) concentrations expressed as wt. % active solids/dry coal basis

Table 10. KVS Coal-Water Slurry Fuel Production Run for May 19, 1992

Time	Solids Loading (wt. %)	Particle Size Distribution		Viscosity (cp)	pH	Ball Mill		
						Dry Coal	A-23M	4800C
1100	57.31	99.60	82.13	356	7.03	2186	0.80	0.05
1200	58.74	99.65	81.23	756	7.00	2256	0.82	0.04
1300	58.15	99.60	81.36	624	7.07	2249	0.77	0.04
1400	58.51	99.70	81.49	612	7.05	2305	0.92	0.03
1500	58.54	99.60	79.72	648	7.00	2241	0.71	0.04
1600	58.91	99.66	84.27	632	6.99	2325	0.81	0.04
1700	59.30	99.75	81.78	700	6.96	2311	0.66	0.04
1800	59.32	99.66	82.40	724	6.97	2255	0.84	0.04
1900	59.26	99.71	82.01	704	6.97	2116	0.87	0.04

Comments: All of the data summarized above has been supplied by KVS.

- a) Solids loading were determined using a Harry W. Dietart Company moisture teller.
- b) Particle size distributions were determined by wet sieving.
- c) Viscosities were determined using a Brookfield "RVT" viscometer (spindle #5 at 100 rpm after 3 minutes)
- d) pH measurements using an Orion pH meter.
- e) Ball mill conditions
 - Dry coal feed rate expressed in lbs/hr
 - Dispersant (A-23M) and stabilizer (Flocon 4800 C) concentrations expressed as wt.% active solids/dry coal basis

Table 11. KVS Coal-Water Slurry Fuel Production Run for June 16, 1992

Time	Solids Loading (wt. %)	Particle Size Distribution		Viscosity (cp)	pH	Ball Mill Operating Conditions		
		-50 mesh	-200 mesh			Dry Coal	A-23M	4800C
1200	60.44	99.58	81.69	60.44	8.64	2164	0.25	0.03
1300	60.47	99.49	81.94	60.47	8.32	2164	0.31	0.03
1400	60.03	99.40	79.81	60.03	8.36	2437	0.58	0.03
1500	59.32	99.47	82.48	59.32	8.31	2337	0.56	0.03
1600	59.60	99.63	82.65	59.60	8.56	2280	0.62	0.03
1700	59.47	99.62	82.21	59.47	8.54	2408	0.54	0.03
1800	59.90	99.67	82.34	59.90	8.58	2252	0.58	0.03
1900	59.59	99.67	82.56	59.59	8.57	2138	0.61	0.03
2000	59.44	99.61	81.66	59.44	8.67	2294	0.61	0.03
2100	62.31	99.59	81.62	62.31	8.71	2180	0.65	0.03

Comments: All of the data summarized above has been supplied by KVS.

- a) Solids loading were determined using a Harry W. Dietart Company moisture teller.
- b) Particle size distributions were determined by wet sieving.
- c) Viscosities were determined using a Brookfield "RVT" viscometer (spindle #5 at 100 rpm after 3 minutes)
- d) pH measurements using an Orion pH meter.
- e) Ball mill conditions
 - Dry coal feed rate expressed in lbs/hr
 - Dispersant (A-23M) and stabilizer (Flocon 4800 C) concentrations expressed as wt. % active solids/dry coal basis

Table 12. KVS Coal-Water Slurry Fuel Production Run for June 23, 1992

Time	Solids Loading (wt. %)	Particle Size Distribution		Viscosity (cp)	pH	Ball Mill Operating Conditions		
		-50 mesh	-200 mesh			Dry Coal	A-23M	4800C
1100	58.10	99.46	82.58	304	9.10	2228	0.68	0.01
1200	58.09	99.32	82.16	356	9.10	2130	0.69	0.04
1300	58.07	99.61	82.53	404	9.09	2214	0.64	0.04
1400	58.07	99.53	82.90	396	9.08	2289	0.62	0.03
1500	58.29	99.46	82.71	424	9.07	2176	0.55	0.02
1600	59.86	99.66	84.64	484	9.03	2247	0.63	0.04
1700	59.94	99.67	83.22	488	9.12	2247	0.63	0.03
1800	59.17	99.61	83.30	464	9.13	2289	0.62	0.03
1900	59.12	99.49	74.65	560	9.18	2289	0.57	0.03
2000	59.79	99.51	84.11	524	9.20	2190	0.59	0.03
2100	60.12	99.68	81.37	504	9.19	2289	0.62	0.03
2200	59.35	99.62	83.25	522	9.19	2233	0.68	0.03
2300	58.67	99.63	80.49	480	9.22	2233	0.58	0.03

Comments: All of the data summarized above has been supplied by KVS.

- a) Solids loading were determined using a Harry W. Dietart Company moisture teller.
- b) Particle size distributions were determined by wet sieving.
- c) Viscosities were determined using a Brookfield "RVT" viscometer (spindle #5 at 100 rpm after 3 minutes)
- d) pH measurements using an Orion pH meter.
- e) Ball mill conditions

Dry coal feed rate expressed in lbs/hr

Dispersant (A-23M) and stabilizer (Flocon 4800 C) concentrations expressed as wt. % active solids/dry coal basis

Table 13. KVS Coal-Water Slurry Fuel Production Run for July 13, 1992

Time	Solids Loading (wt. %)	Particle Size Distribution		Viscosity (cp)	pH	Ball Mill Operating Conditions		
		-50 mesh	-200 mesh			Dry Coal	A-23M	4800C
1700	66.55	98.67	74.66	1960	9.01	2270	0.54	0.03
1800	67.17	97.90	75.86	1592	9.05	2205	0.72	0.01
1900	66.84	97.49	74.92	1104	9.04	2071	0.53	0.03
2000	66.69	98.25	72.71	1304	9.03	2140	0.71	0.03
2100	66.62	98.16	73.68	1824	9.04	2210	0.69	0.03
2200	66.39	97.99	78.45	1652	9.05	2256	0.63	0.03
2300	67.03	98.29	70.93	1428	9.04	2270	0.57	0.03
2400	67.11	97.86	71.53	1432	9.01	2284	0.52	0.03

Comments: All of the data summarized above has been supplied by KVS.

- a) Solids loading were determined using a Harry W. Dietart Company moisture teller.
- b) Particle size distributions were determined by wet sieving.
- c) Viscosities were determined using a Brookfield "RVT" viscometer (spindle #5 at 100 rpm after 3 minutes)
- d) pH measurements using an Orion pH meter.
- e) Ball mill conditions

Dry coal feed rate expressed in lbs/hr

Dispersant (A-23M) and stabilizer (Flocon 4800 C) concentrations expressed as wt. % active solids/dry coal basis

Table 14. KVS Coal-Water Slurry Fuel Production Run for July 14, 1992

Time	Solids Loading (wt. %)	Particle Size Distribution -50 mesh	Particle Size Distribution -200 mesh	Viscosity (cp)	pH	Ball Mill Operating Conditions		
						Dry Coal	A-23M	4800C
0100	66.92	97.83	71.63	1168	8.99	2355	0.64	0.03
0200	66.91	97.80	72.28	948	9.03	2200	0.69	0.03
0300	66.69	97.87	74.50	728	9.01	2171	0.60	0.03
0400	68.83	97.66	76.70	732	9.00	2157	0.70	0.03
0500	66.58	97.67	71.83	784	9.01	2242	0.63	0.03
0600	66.91	98.02	72.45	756	9.00	2115	0.82	0.03
0700	66.32	98.32	73.01	748	9.05	2157	0.65	0.03
0800	66.76	98.11	74.03	748	9.05	2220	0.68	0.03
0900	66.81	98.36	73.46	680	9.04	2332	0.70	0.02
1000	66.44	98.08	77.51	692	8.96	2053	0.58	0.03
1100	67.73	98.95	78.96	696	8.95	2290	0.66	0.02
1200	65.88	98.51	76.67	788	9.03	2151	0.60	0.03
1300	68.35	98.72	75.57	836	9.03	2290	0.62	0.03
1400	67.04	98.14	76.13	872	9.03	2308	0.66	0.03
1500	66.25	99.07	75.19	776	8.99	2225	0.53	0.03
1600	64.86	98.73	79.29	704	9.07	2267	0.65	0.02
1700	64.49	98.86	78.06	704	9.05	2183	0.60	0.04
1800	64.63	98.90	77.76	828	9.01	2211	0.62	0.03
1900	65.54	98.70	76.37	864	8.94	2197	0.57	0.03
2000	65.61	98.53	74.07	984	8.94	2267	0.59	0.03
2100	65.94	98.36	74.28	992	8.93	2141	0.47	0.03
2200	66.10	98.09	73.87	1000	8.87	2183	0.72	0.02
2300	67.34	98.23	74.15	1016	8.89	2253	0.67	0.03
2400	66.38	97.77	71.47	1088	8.92	2225	0.66	0.03

Comments: All of the data summarized above has been supplied by KVS.

- a) Solids loading were determined using a Harry W. Dietart Company moisture teller.
- b) Particle size distributions were determined by wet sieving.
- c) Viscosities were determined using a Brookfield "RV" viscometer (spindle #5 at 100 rpm after 3 minutes)
- d) pH measurements using an Orion pH meter.
- e) Ball mill conditions

Dry coal feed rate expressed in lbs/hr

Dispersant (A-23M) and stabilizer (Flocon 4800 C) concentrations expressed as wt.% active solids/dry coal basis

Table 15. SCCWS Comparison for Different Milling Conditions.

	06/13/92 (Tanker 607)	07/13/92 (1815 sample)
Solid's Loading (wt. %) ^a	58.39	66.18
Viscosity (cp @ 100 sec -1) ^b	454	1250
Approximate Dispersant Concentration (A-23M) ^c	1.00	0.70
pH ^d	ND ^e	8.85
Particle Size Distribution ^f		
Top Size	162.0	162.2
D (v, 0.9)	77.8	91.4
D (v, 0.5)	23.0	17.9
D (v, 0.1)	3.8	1.8

^aSolids loading was determined using a CEM Microwave Moisture Analyzer.

^bViscosity was determined using a Bohlin Rotational Viscometer.

^cDispersant concentration was approximated from the KVS production records.

^dpH measurement was conducted using an Orion pH meter.

^eNot determined.

^fParticle size measurement was conducted using a Malvern 2600C Droplet and Particle Size Analyzer

Table 16. Cumulative Hours Firing SCCWS (First 1,000-Hour Demonstration)

<u>Date</u>	<u>Hours</u>	<u>Cumulative Hours</u>	<u>Comments</u>
1991-September	5.0	5.0	Shakedown testing; conduct gas-fired baseline testing
October	61.5	66.5	Continue SCCWS shakedown; conduct SCCWS continuous testing
November	0	66.5	Repair baghouse
December	0	66.5	Awaiting contractor to complete performance testing
1992-January	26.0	92.5	Performance testing
February	0	92.5	KVS shut down
March	21.0	113.5	Testing various nozzle combinations
April	52.5	166.0	Testing various nozzle combinations
May	50.0	216.0	Problems with slurry stability; various solids concentrations
June	46.5	262.5	Testing SCCWS preheat; low solids concentration
July	57.5	320.0	Testing SCCWS preheat; high solids concentration
August	15.0	335.0	Testing SCCWS preheat; high solids concentration

Figure 13. Schematic Diagram of Faber Oil Gun

Figure 14. Schematic Diagram of Faber XHC Plug and Cap

Table 17. Hole Diameters of Faber Plugs and Caps

Swirl Plug Opening Diameters (175 gal/h):

Slurry Openings	1/16"
Axial Air Openings	7/64"
Tangential Air Openings	1/8"

Standard Plug Opening Diameters:High Capacity (HC)

Axial Slurry Opening	3/32"
Radial Air Opening	7/64"

Medium High Capacity (MHC)

Axial Slurry Opening	1/16"
Radial Air Opening	3/32"

Extra High Capacity (XHC)

Axial Slurry Opening	7/64"
Radial Air Opening	1/8"

Standard Cap Opening Diameters:

Extra High Capacity	5/32"
High Capacity	9/64"
Medium High Capacity	1/8"

Table 18. Summary of April Testing

Test Number	1	2	3	4
Length of SCCWS Firing (hours)	11.0	10.0	8.0	6.5
Firing Rate (MM Btu/h)				
Natural Gas	7.5	5.8	4.5	3.4
SCCWS	7.5	12.2	13.5	14.6
Total	15.0	18.0	18.0	18.0
Gas Support (%)	50.0	32.0	25.0	19.0
Air Preheater Temperatures (°F)				
Combustion Air Inlet	114	122	119	116
Combustion Air Outlet	352	363	367	375
Flue Gas Inlet	547	558	558	570
Flue Gas Outlet	334	355	353	364
Combustion Air Temperature (°F) ^a	340	352	355	363
Steam Flow (lb/h)	12,239	13,703	13,040	12,642
Boiler Efficiency (%)	77.4	74.9	72.4	66.5
Carbon Conversion (%) ^b	91.6	89.9	86.7	86.4
Atomizing Air Pressure (psig)	97	97	98	99
SCCWS Temperature (°F)	62	63	66	74
Baghouse				
Pressure Drop (inches water column)	0.87	1.15	0.93	0.98
Inlet Temperature (°F)	328	350	348	355
Outlet Temperature (°F)	303	319	322	327
Flue Gas Composition (dry basis)				
O ₂ (%)	6.7	4.8	3.8	3.5
CO (ppm)	175	186	228	155
CO ₂ (%)	10.4	12.8	14.3	14.6
SO ₂ (ppm)	220	388	503	481
NO _x (ppm)	359	392	347	415

^aMeasured at windbox, after in-duct auxiliary gas burner; in-duct burner was not operated during April testing

^bCarbon conversion of SCCWS; 100% combustion efficiency assumed with natural gas

Table 19. Summary of June Testing^a

Test Number	1	2	3	4	5
Length of SCCWS Firing (hours)	8	8	4.5	3.5	10.5
Firing Rate (MM Btu/h)					
Natural Gas	5.7	4.4	4.4	4.4	6.5
SCCWS	12.6	14.9	12.6	12.6	11.7
Total	18.3	19.3	17.0	17.0	18.2
Gas Support (%)	31.0	22.9	26.0	26.0	35.6
Air Preheater Temperatures (°F)					
Combustion Air Inlet	81	82	83	83	91
Combustion Air Outlet	352	355	354	366	365
Flue Gas Inlet	561	556	561	590	570
Flue Gas Outlet	345	341	348	365	357
Combustion Air Temperature (°F) ^b	358	343	342	352	350
Steam Flow (lb/h)	11,019	9,634	9,608	9,589	9,603
Boiler Efficiency (%)	N.D. ^c	72.5	75.3	77.4	78.0
Carbon Conversion (%) ^d					
Total	92.5	86.5	90.6	93.8	94.7
Coal	90.3	84.0	88.5	92.5	92.9
Atomizing Air Pressure (psig)	90	96	95	97	98
SCCWS Temperature (°F)	85	90	181	202	158
SCCWS Solids Loading (wt. %)	55.5	57.0	52.0	52.0	51.2
Baghouse					
Inlet Temperature (°F)	333	329	322	351	344
Outlet Temperature (°F)	306	307	335	309	318
Flue Gas Composition (dry basis)					
O ₂ (%)	3.6	3.6	3.9	4.6	3.3
CO (ppm)	N.M. ^e	310	206	214	186
CO ₂ (%)	N.M.	14.2	13.7	13.3	13.6
SO ₂ (ppm)	N.M.	N.M.	N.M.	N.M.	N.M.
NO _x (ppm)	N.M.	689	295	555	N.M.

^aThe following nozzle combinations were used: Tests 1, 2, and 5 - MXHC plug, XHC75° cap; Test 4 - MXHC plug, XHC65° cap; and Test 3 - swirler plug (no cap)

^bMeasured at windbox, after in-duct auxiliary gas burner; in-duct burner was not operated during testing

^cNot determined

^dTotal carbon conversion includes contribution from natural gas

^eNot measured

Table 20. Summary of July Testing^a

Test Number	1	2	3	4	5	6
Length of SCCWS Firing (hours)	6	3	6	6	4.5	6
Firing Rate (MM Btu/h)						
Natural Gas	5.8	5.6	5.9	6.0	6.2	6.2
SCCWS	12.9	13.3	13.0	13.0	12.9	13.1
Total	18.7	18.9	18.9	19.0	19.1	19.3
Gas Support (%)	30.9	29.8	31.1	31.4	32.4	32.0
Air Preheater Temperatures (°F)						
Combustion Air Inlet	96	90	81	80	80	83
Combustion Air Outlet	362	368	343	348	346	351
Flue Gas Inlet	557	587	549	557	560	562
Flue Gas Outlet	350	361	341	345	346	347
Combustion Air Temperature (°F) ^b	347	405	387	390	390	391
Steam Flow (lb/h)	9,571	13,867	14,447	15,000	14,016	12,215
Boiler Efficiency (%)	77.3	77.0	76.6	77.5	78.6	77.6
Carbon Conversion (%) ^c						
Total	94.0	90.7	91.0	92.1	92.9	92.3
Coal	91.8	87.4	87.7	89.1	90.1	89.3
Atomizing Air Pressure (psig)	96	95	94	94	95	93
SCCWS Temperature (°F)	183	147	80	153	162	95
SCCWS Solids Loading (wt. %)	51.3	64.6	61.8	62.7	60.4	61.7
Baghouse						
Inlet Temperature (°F)	338	348	329	334	332	334
Outlet Temperature (°F)	311	320	306	308	307	310
Flue Gas Composition (dry basis)						
O ₂ (%)	4.6	3.7	3.3	3.3	3.7	3.7
CO (ppm)	175	159	201	223	175	212
CO ₂ (%)	12.7	13.6	13.7	13.6	13.5	13.6
SO ₂ (ppm)	459	N.M. ^d	495	544	N.M.	N.M.
NO _x (ppm)	578	N.M.	534	588	N.M.	N.M.

^aThe following nozzle combinations were used: Tests 1, 3, 4, 5, and 6 - MXHC plug, MHC75° cap; Test 2 - MXHC plug, HC75° cap

^bMeasured at windbox, after in-duct auxiliary gas burner; in-duct burner was not operated during April testing

^cTotal carbon conversion includes contribution from natural gas

^dNot measured

Table 21. Summary of July Testing (cont.)^a

Test Number	7	8	9	10	11
Length of SCCWS Firing (hours)	5	5.5	4	6.5	5
Firing Rate (MM Btu/h)					
Natural Gas	5.8	5.8	5.9	4.5	5.8
SCCWS	12.4	13.0	12.7	15.1	12.9
Total	18.2	18.8	18.6	19.6	18.7
Gas Support (%)	31.9	30.7	31.7	23.2	31.1
Air Preheater Temperatures (°F)					
Combustion Air Inlet	78	76	84	88	90
Combustion Air Outlet	343	348	352	357	355
Flue Gas Inlet	552	564	562	562	554
Flue Gas Outlet	341	346	348	334	345
Combustion Air Temperature (°F) ^b	385	389	392	395	394
Steam Flow (lb/h)	13,867	N.M. ^c	N.M.	N.M.	11,030
Boiler Efficiency (%)	79.5	77.5	78.8	77.1	77.9
Carbon Conversion (%) ^d					
Total	94.0	92.2	93.5	90.6	92.3
Coal	91.7	89.4	91.0	88.4	89.4
Atomizing Air Pressure (psig)	95	92	95	92	100
SCCWS Temperature (°F)	156	91	144	135	141
SCCWS Solids Loading (wt. %)	61.5	61.2	61.8	61.8	60.0
Baghouse					
Inlet Temperature (°F)	329	334	335	338	333
Outlet Temperature (°F)	303	306	309	310	308
Flue Gas Composition (dry basis)					
O ₂ (%)	3.6	3.8	4.1	3.6	3.6
CO (ppm)	160	193	198	225	192
CO ₂ (%)	13.7	13.5	13.4	14.2	13.7
SO ₂ (ppm)	N.M.	460	N.M.	305	593
NO _x (ppm)	N.M.	N.M.	585	549	644

^aThe following nozzle combinations were used: Tests 7, 8, 10, and 11 - MXHC plug, HC65° cap; Test 9 - MXHC plug, 70° internal tip cap

^bMeasured at windbox, after in-duct auxiliary gas burner; in-duct burner was not operated during testing

^cNot measured

^dTotal carbon conversion includes contribution from natural gas

Table 22. Summary of August Testing^a

Test Number	1	2	3
Length of SCCWS Firing (hours)	4.5	4.5	6
Firing Rate (MM Btu/h)			
Natural Gas	5.9	5.9	5.9
SCCWS	12.3	13.0	13.3
Total	18.2	18.9	19.2
Gas Support (%)	32.4	31.1	30.6
Air Preheater Temperatures (°F)			
Combustion Air Inlet	84	82	83
Combustion Air Outlet	353	354	361
Flue Gas Inlet	564	563	579
Flue Gas Outlet	349	350	359
Combustion Air Temperature (°F) ^b	395	395	467
Steam Flow (lb/h)	11,030	13,337	11,746
Boiler Efficiency (%)	76.2	78.1	78.3
Carbon Conversion (%) ^c			
Total	91.8	92.8	92.8
Coal	88.7	90.1	90.2
Atomizing Steam Pressure (psig)	113	115	113
SCCWS Temperature (°F)	88	140	139
SCCWS Solids Loading (wt. %)	62.3	59.0	60.5
Baghouse			
Inlet Temperature (°F)	338	337	348
Outlet Temperature (°F)	314	316	324
Flue Gas Composition (dry basis)			
O ₂ (%)	4.3	3.3	3.8
CO (ppm)	188	180	184
CO ₂ (%)	13.0	13.8	13.5
SO ₂ (ppm)	348	N.M. ^d	371
NO _x (ppm)	502	N.M.	587

^aThe MXHC plug and HC65° cap were used for the August testing

^bMeasured at windbox, after in-duct auxiliary gas burner; in-duct burner was not operated during testing

^cTotal carbon conversion includes contribution from natural gas

^dNot measured

Table 23. Composition of Alloys Tested (wt. %)

<u>Constituent</u>	<u>Alloy</u>				
	<u>304</u>	<u>316</u>	<u>321</u>	<u>347</u>	<u>800H</u>
C	.055	.017	.047	0.44	0.08
Mn	1.71	1.71	1.18	1.49	0.98
P	0.022	0.023	0.025	0.021	--
S	0.025	0.007	0.012	0.012	<0.001
Si	0.55	0.38	--	0.64	0.15
Cr	18.34	17.22	17.46	17.30	19.62
Ni	8.40	12.90	10.25	9.36	31.65
Mo	0.11	2.56	0.22	0.20	--
Cu	0.08	--	0.46	0.23	0.38
Co	0.16	--	0.10	0.11	--
Ti	--	--	0.57	--	0.54
N	--	--	0.018	--	--
Al	--	--	--	--	0.32
Cb	--	--	--	0.69	--
Ta	--	--	--	0.02	--
Fe	balance	balance	balance	balance	46.28

Table 24. Chemical Analysis of Ash A and B

<u>Compound</u>	<u>Ash A (wt. %)</u>	<u>Ash B (wt %)</u>
SiO ₂	35.36	15.65
Al ₂ O ₃	26.05	9.19
Fe ₂ O ₃	6.80	4.94
TiO ₂	0.73	0.40
MgO	0.46	0.54
CaO	1.86	7.52
P ₂ O ₅	0.19	<0.28
Na ₂ O	0.44	0.23
K ₂ O	0.86	0.59
SO ₃	---	3.29

Figure 15. Comparison rate of alloys expressed in mm / year. Test condition: Alloys precoated with ash A and exposed to synthetic flue gas for 48 hours

Figure 16. Comparison rate of alloys expressed in mm / year. Test condition: Alloys precoated with ash B and exposed to synthetic flue gas for 48 hours

Figure 17. Comparison of experimental data with test data of Kihara et al.

Figure 18. Comparison of experimental data with test data of Menzo and Rahoi

Table 25. Composition of Fuel and Flue Gas

Fuel	Flue Gas	
CH ₄	14.41 wt %	13.57 vol %
H ₂ O	35.95 "	14.31 ^a "
C	39.63 "	3.74 "
H	2.72 "	68.26 ^a "
S	0.44 "	432 vol ppm
N	0.77 "	570 "
O	4.44 "	189 "
Ash	1.64 "	

^a Calculated.

Table 26. Experimental Conditions and Summary of Results

Jet Velocity [m/s (ft/s)]	Metal Temperature [K (°F)]	Jet Oxygen Content [vol % O ₂ in N ₂]	Erosion Rate [μm/hour]	Deposition Rate [μm/hour]
200 (656)	450 (350)	~0	0.6	0.6
200 (656)	450 (350)	21	0.6	-
200 (656)	450 (350)	100	0.6	-
200 (656)	550 (530)	~0	1.4	-
200 (656)	550 (530)	21	1.0	-
200 (656)	550 (530)	100	0.6	0.6
200 (656)	650 (710)	~0	1.7	-
200 (656)	650 (710)	21	0.6	0.6
200 (656)	650 (710)	100	0.6	0.6

Figure 19. Profiles of the surfaces of test coupons after 2 hours of exposure to the high velocity jet, entrained flue gas, and fly ash, under different conditions of gas composition and metal temperature. The conditions are indicated at the upper left in each figure. The effects of changes in the jet gas are shown by the vertical column of figures, and changes in metal temperature by the horizontal column.

Figure 20. Electron micrographs of the samples, viewed from above, showing the effects of jet oxygen content and metal temperature on the state of the surface. The axis of the jet intersects the surface approximately at the center of the region shown. The conditions and a scale bar are at the bottom of each figure.

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