TECHNICAL REPORT

December 1, 1992 through February 28, 1993

Project Title: **BEHAVIOR OF SULFUR AND CHLORINE IN COAL
DURING COMBUSTION AND BOILER CORROSION**

DE-FC22-92PC92521

Principal Investigator: C.-L. Chou, Illinois State
Geological Survey (ISGS)

Other Investigators: K.C. Hackley, J. Cao, R.R. Frost,
and R.R. Ruch, ISGS; W.-P. Pan,
M.L. Upchurch, H.B. Cao, and D.
Shao, Western Kentucky University

Project Manager: K.K. Ho, Illinois Clean Coal
Institute

ABSTRACT

The goals of this project is to investigate the behavior of sulfur and chlorine during pyrolysis and combustion of Illinois coals, the chemistry of boiler deposits and the process of ash formation, and remedial measures to reduce the sulfur and chlorine compounds in combustion gases.

The chemistry of boiler deposits provides information about the behavior of sulfur, chlorine, and ash particles during coal combustion. We report results obtained during this quarter on mineralogical and chemical compositions of twelve samples of boiler deposits collected from superheater and reheater tubes of an Illinois power plant. Scanning electron microscopy shows microscopic calcium sulfate droplets on cenospheres. There is a considerable variation of chemical composition among the samples. While eight out of twelve samples consist predominantly of quartz, mullite, and glass; the remaining four contain an appreciable amount additional phases (calcium sulfate and alkali iron sulfate). The chlorine content in the samples is determined by neutron activation analysis. One sample contains 37 ppm chlorine, and the chlorine concentration is below the detection limit in other eleven samples (<15-45 ppm), indicating that most of the chlorine in feed coal is lost during combustion. In a separate set of experiments, the effects of composite gases containing HCl, SO₂, and HCl+SO₂ on six metals are determined. Chromium-nickel steel and alloy show higher resistance to corrosion than carbon-manganese steels and chromium-molybdenum steels when metal coupons are exposed to hot gases at 600°C for 24 hours.

MASTER

"U.S. DOE Patent Clearance is NOT required prior to the publication of this document."

12
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

EXECUTIVE SUMMARY

Bakker et al. (1990, presented at the American Power Conference, Chicago) listed five "factors that control the severity of superheater corrosion: 1. The amount of liquid sulfate on the tube, 2. The sulfur content of coal, 3. The chlorine content of coal, 4. The temperature of the superheater tube wall, 5. The chemical composition of the alloy." The chlorine content of coal is not the only factor that determines boiler corrosion. An important purpose of this project is to better understand how these factors are related to superheater corrosion and ash deposition in coal-fired power plants. During the first year of the project (1991-1992) we determined the gaseous species of sulfur and chlorine in combustion gases, and their release profiles.

The chemical and mineralogical compositions of deposits from superheater and reheater in utility boilers are important because corrosion losses of metal tubes may be related to the amounts of the alkali sulfate and in boiler tube deposits. Furthermore, the chlorine content in boiler deposits provides information about the behavior of chlorine in the boiler.

During the past quarter, six boiler deposits from superheater and reheater tubes in a utility boiler have been examined. Each deposit is separated into inner and outer portions and analyzed for mineralogical composition by X-ray diffraction, microstructure by scanning electron microscopy, and major, minor, and trace elements by X-ray fluorescence spectrometry and neutron activation analysis. There is considerable variation of chemistry among the twelve samples. Eight out of twelve samples consist mostly of quartz, mullite, and glass; the remaining four contain an appreciable amount of alkali sulfate and calcium sulfate, indicating chemical fractionation of ash and volatiles during coal combustion in the boiler. The chlorine content in the samples are very low. Apparently most of the chlorine is lost during coal combustion because of its high volatility. This is one argument against the hypothesis that chlorine takes part in corrosion of the high-temperature portion of a boiler.

Laboratory experiments are conducted to investigate the effects of HCl, SO₂, and HCl+SO₂ on metals of different compositions. The initial results confirm that chromium-nickel steel and alloy are much more resistant to corrosion than carbon-manganese steels and chromium-molybdenum steels. More experiments on the chemistry of boiler deposits and behavior of steel coupons exposed to composite gases will be continued to gain further insights.

OBJECTIVES

The purpose of the project is to study the behavior of sulfur and chlorine during pyrolysis/gas combustion, mineralogical and chemical compositions of boiler deposits, the effect of HCl and SO₂ in combustion gases on boiler metals, and remedial measures to reduce the HCl concentration in boiler gases. The specific goals of the project are to:

- Identify gaseous sulfur and chlorine species evolved from coal under various pyrolysis and combustion conditions.
- Determine sulfur and chlorine species during coal combustion in oxidizing and reducing atmospheres.
- Determine the mineralogical and chemical compositions of superheater and reheater deposits and investigate ash deposition processes.
- Characterize the effect of HCl and SO₂ gases on metals of different composition.
- Develop remedial methods for reducing HCl in the combustion gases.

INTRODUCTION AND BACKGROUND

The superheater tube corrosion is related to the amount of alkali sulfates in the tube deposits (Bakker et al., 1990). A knowledge of the chemistry of the deposits and the process of deposit formation provides information about the behavior of inorganic constituents during coal combustion in a boiler, as well as the role of alkalis, sulfur, and chlorine in boiler corrosion and fouling. We report herein new results on a suite of superheater and reheater deposits from a power plant.

To determine the effect of HCl and SO₂ in combustion gases on metals of different composition, we have conducted a set of tests to determine corrosion losses of a suite of six metals when they are exposed to composite gases containing HCl, SO₂, or HCl+SO₂ at 600°C for 24 hours.

EXPERIMENTAL PROCEDURES

Boiler deposits

Six samples of boiler deposits were collected from the final superheater and reheater areas of the Wood River Unit 5 boiler, Illinois Power Company. Samples 1, 2, 3, 5, and 6

(sample numbers WR5-1, -2, -3, -5, and -6) are from the superheater area, and sample 4 (WR5-4) from the reheater area. Wood River Unit No. 5 is equipped with a Combustion Engineering tangential-fired, pulverized coal boiler operating at 1,050°F main steam temperature and 1000°F reheat steam temperature. A diagram of the boiler with sample locations is included in a previous report (Figure 1 of Chou et al., 1992). Each of the six samples was examined in the laboratory and separated into inner (comparatively close to the tube surface) and outer portions, with the exception of sample WR5-4. The inner portion is generally loosely aggregated, often friable, whereas the outer layer is relatively compact and firm. Sample WR5-4 consists of a compact piece of brownish and reddish portions. The brown and red portions were separated for analysis. The samples were examined under scanning electron microscope, and were pulverized for X-ray diffraction analysis for mineralogical composition and X-ray fluorescence spectrometry and neutron activation analysis for chemical compositions. The sample numbers and analysis numbers (C#) are listed below:

WR5-1a (C32825) Outer portion
WR5-1b (C32826) Inner portion

WR5-2a (C32827) Outer
WR5-2b (C32828) Inner

WR5-3a (C32829) Outer
WR5-3b (C32830) Inner

WR5-4a (C32831) Outer brown
WR5-4b (C32832) Outer red

WR5-5a (C32833) Outer
WR5-5b (C32834) Inner

WR5-6a (C32835) Outer
WR5-6b (C32836) Inner

Effect of HCl, SO₂ and HCl+SO₂ in composite gases on metals

The purpose of this study is to define a set of parameters that outline corrosion effects on metals under simulated low-temperature conditions. The metal samples are handled in two ways; one, they are left unprotected to the flue gas stream and the other, they are protected with a corrosion resistant epoxy which is a common practice in industry.

Three variables are considered: (1) HCl concentration, (2) length of exposure time, (3) temperature under isothermal conditions. Using data obtained under the three conditions, boiler construction materials (characteristics of metals) can

be evaluated for its resistance and stability.

The experiments will generate four categories of data: (1) weight gain or loss as a measure of corrosion, (2) the created surface depth caused by the HCl gas concentration, (3) an optimum measure of the corrosion rate as it pertains to a specific metal substituent, and (4) determining the relationship for a particular metal between the rate of corrosion and HCl concentration.

Evaluation of corrosion for any metal is dependent on the length of a particular experimental run. To keep the number of runs reasonably small, the increments of time chosen is to be 100 hours up to a total of 400 hours. Also, the experiments will be run at three different temperatures (100°C, 200°C, and 600°C). The temperature of 600°C is chosen as an extreme value for comparison since it simulates a common superheater temperature. The 100°C temperature is chosen to determine the interaction of water, as it condenses or evaporates, with metals on the corrosion rate. Therefore, for the 100°C run, water vapor will be introduced to the samples by passing nitrogen gas through a water bath then to the furnace setup.

The rate of corrosion is evaluated by weight gain or loss per unit of time. We expect that there will be a weight gain initially from the oxidation of the metal coupons, changing to a weight loss from the deterioration of the metal by corrosion.

A preliminary test of the flow rate is done before a major set of runs is completed. Specifically six samples (one of each metal) will be used to evaluate the outlined 15 mL/min flow rate against a 50 mL/ml flow rate. The tests are conducted at 600°C for 24 hours. Every eight hours the samples will be weighed for their respective weight gain or loss depending on the length of time. From this, the proper flow rate for best results will be chosen and the rest of the experiment will be completed with this flow rate. The furnace design is shown in a previous report (Figure 2 of Chou et al., 1992).

RESULTS AND DISCUSSION

Boiler deposits

The SEM photomicrographs of superheater deposit WR5-1a (outer, C32825) and WR5-1b (inner, C32826) are shown in Figures 1a,b. The inner portion of the deposit (Fig. 1a) consists of relatively large (compared to outer portion of the deposit) thin-walled hollow spheres (cenospheres) and flakes. Note an impact damaged cenosphere in the upper left of the figure. The

surface of the cenosphere is covered with calcium sulfate droplets. In contrast to the inner portion, the outer portion of the slag consists of spheres of much smaller particle size. The particles are apparently agglutinated together when the particles are partially molten. Energy-dispersive spectrometric (EDX) analysis shows abundant Si, Al, and O contents, as well as minor amounts of Na, Mg, S, K, Ca, Ti, and Fe. The EDX spectrum of the small droplets on the cenosphere shows abundant Ca, S, and O, indicating these are calcium sulfate.

The samples WR5-1a and WR5-1b were analyzed by X-ray diffraction. The mineralogical composition of the two samples is similar, and these superheater deposits are composed mainly of quartz (SiO_2) and mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$), and glass (Figure 2).

The chemical compositions determined by X-ray fluorescence and neutron activation analysis are listed in Table 1. The major constituents in the deposits ($>0.5\%$) are SiO_2 , Al_2O_3 , Fe_2O_3 , CaO , MgO , K_2O , Na_2O , TiO_2 , P_2O_5 , and SO_3 . The Al_2O_3 content is fairly uniform in mostly samples from 22.5% - 24.5%, except sample WR5-6a with 20.11% Al_2O_3 and WR5-4b with 10.84% Al_2O_3 . Sample WR5-6a has high Fe_2O_3 , CaO , Na_2O , and SO_3 , indicating possible occurrence of alkali iron sulfate and calcium sulfate; sample WR5-4b has high CaO and SO_3 contents.

Eight out of twelve samples have a SiO_2 content between 57% and 62%; the remaining four samples (WR5-6a,b and WR5-4a,b) have a lower SiO_2 content (30.4% - 51.4%). Samples WR5-6a,b are high in Fe_2O_3 , SO_3 and alkalis. Samples WR5-4a,b are brown and red portions from the same piece of deposit. The brown sample WR5-4a is relatively high in CaO , MgO , Na_2O , TiO_2 , P_2O_5 , SO_3 , and a high loss of ignition (volatile component). The red sample WR5-4b is rather unique in having low Al_2O_3 (10.8%) and K_2O , but high in CaO (20.0%), MgO , Na_2O , and SO_3 (about 21%), indicating an appreciable amount of hydrated calcium sulfate.

The chlorine content in the samples is very low. One sample (WR5-2b) contains 37 ppm chlorine. The others have a chlorine content below the detection limit (between 15 and 45 ppm). It appears that chlorine was lost during coal combustion. The chlorine in Illinois coal occurs as chloride ions adsorbed on the organic matter (Chou, 1992) and is highly volatile. Most of the sodium is not associated with chlorine and is largely retained in ash deposits.

Table 1. Chemical compositions of ash deposits from superheater and reheater of a boiler determined by XRF and NAA (for Na and Cl only) (on dry basis except H₂O)

Superheater deposits						
	WR5-1a (C32825)	WR5-1b (C32826)	WR5-2a (C32827)	WR5-2b (C32828)	WR5-3a (C32829)	WR5-3b (C32830)
<i>Major and minor constituents (in %)</i>						
SiO ₂	60.36	62.08	58.49	59.64	57.89	60.75
Al ₂ O ₃	22.94	22.46	23.51	23.37	23.50	22.47
Fe ₂ O ₃	3.48	2.77	3.45	4.02	3.42	2.89
CaO	4.90	4.53	5.07	4.04	5.71	4.61
MgO	1.67	1.56	1.76	1.46	1.92	1.58
K ₂ O	1.16	1.11	1.21	1.33	1.13	1.10
Na ₂ O (XRF)	1.18	1.26	1.24	1.15	1.27	1.24
(INAA)	1.18	1.21	1.18	1.13	1.21	1.23
TiO ₂	0.79	0.71	0.86	0.90	0.87	0.74
P ₂ O ₅	0.72	0.46	0.90	0.61	0.99	0.65
MnO	0.02	0.01	0.01	0.02	0.02	0.01
SrO	0.20	0.19	0.22	0.17	0.24	0.20
BaO	0.39	0.37	0.42	0.35	0.45	0.40
SO ₃	0.57	0.55	0.56	0.56	0.37	0.55
LOI*	1.26	1.49	1.75	1.92	1.59	2.33
Total**	99.64	99.55	99.45	99.54	99.37	99.52
H ₂ O	0.02	0.03	0.04	0.06	0.04	0.03

*At 1000°C

**XRF Na₂O value used

Table 1, continued

Superheater deposits						
	WR5-1a (C32825)	WR5-1b (C32826)	WR5-2a (C32827)	WR5-2b (C32828)	WR5-3a (C32829)	WR5-3b (C32830)
<i>Trace elements (in ppm)</i>						
Cl (INAA) <15	<15	<15	<15	37	<15	<30
V	87	70	101	116	103	73
Cr	100	33	149	93	141	40
Co	31	28	32	36	29	26
Ni	41	26	45	53	41	27
Cu	65	36	83	72	80	42
Zn	124	36	186	129	195	48
Rb	42	37	46	53	42	37
Zr	364	350	370	349	386	357
Nb	21	19	26	23	26	20
Mo	2	2	4	4	4	3
Cd	nd	nd	1	nd	nd	nd
Sn	1	1	3	1	4	1
Pb	60	43	95	80	109	51

nd: not detected.

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.

Table 1, continued

	Superheater deposits				Reheater deposits	
	WR5-5a (C32833)	WR5-5b (C32834)	WR5-6a (C32835)	WR5-6b (C32836)	WR5-4a (C32831)	WR5-4b (C32832)
<i>Major and minor constituents (in %)</i>						
SiO ₂	58.97	60.24	39.96	45.43	51.42	30.40
Al ₂ O ₃	23.40	23.04	20.11	23.03	24.53	10.84
Fe ₂ O ₃	3.34	3.11	11.28	12.10	3.84	4.99
CaO	5.37	4.61	9.00	3.55	6.58	20.04
MgO	1.84	1.60	1.96	0.94	2.12	3.79
K ₂ O	1.13	1.12	1.84	1.68	1.13	0.43
Na ₂ O (XRF)	1.24	1.28	1.66	1.44	1.59	1.66
(INAA)	1.26	1.24	1.53	1.24	1.53	1.57
TiO ₂	0.84	0.78	1.33	1.40	1.01	0.96
P ₂ O ₅	0.90	0.71	0.61	0.40	1.55	0.45
MnO	0.02	0.01	0.05	0.03	0.01	0.02
SrO	0.23	0.20	0.14	0.07	0.27	0.23
BaO	0.43	0.39	0.18	0.06	0.51	0.45
SO ₃	0.35	0.60	6.99	3.22	1.23	20.95
LOI*	1.42	1.79	4.42	6.17	3.58	4.43
Total**	99.48	99.48	99.53	99.52	99.37	99.64
H ₂ O	0.01	0.06	0.21	0.29	0.29	1.31

Table 1, continued

	Superheater deposits				Reheater deposits	
	WR5-5a (C32833)	WR5-5b (C32834)	WR5-6a (C32835)	WR5-6b (C32836)	WR5-4a (C32831)	WR5-4b (C32832)
<i>Trace elements (in ppm)</i>						
Cl (INAA)	<25	<40	<35	<45	<30	<45
V	87	78	308	292	129	140
Cr	101	41	783	335	155	136
Co	29	29	101	77	38	44
Ni	39	32	307	234	49	59
Cu	68	45	261	226	108	145
Zn	156	56	1425	943	243	364
Rb	40	39	108	105	43	23
Zr	373	360	291	260	369	260
Nb	24	22	33	32	33	18
Mo	4	2	13	12	8	16
Cd	nd	nd	7	5	2	11
Sn	1	2	11	6	7	nd
Pb	80	54	195	332	154	69

Effects of HCl, SO₂, and HCl+SO₂ in composite gases on metals

Six metals listed below were selected for tests:

<u>AISI ID</u>	<u>Composition</u>
C1010	8-13% C, 0.3-0.6% Mn
C1018	15-20% C, 0.6-0.9% Mn
F11	1.25% Cr, 0.5% Mo, LC
F22	2.25% Cr, 1% Mo, LC
310SS	25% Cr, 21% Ni
Alloy 800	21% Cr, 31% Ni

Test runs using gas flow rates of 50 mL/min and 15 mL/min. The metal samples were cut into 1 cm² size coupons. A set of preliminary runs was conducted to compare the rate of corrosion at two flow rates: 15 mL/min and 50 mL/min. The experimental runs were performed at 600°C for 24 hours and a measurement was taken every eight hours. The weight loss versus time for each of the six metals was plotted. The rate of weight loss which is determined by the slope of the weight change versus time. In all cases, except metal F11 for which only negligible weight loss was observed, the rate of weight loss is similar for the flow rate of 15 mL/min and 50 mL/min. Figures 3a,b show the weight change for metal C1010 and metal F22. Thus, use of a flow rate of 15 mL/min does not make significant difference from 50 mL/min in corrosion rate of metal coupons. A flow rate of 25 mL/min is used for subsequent experiments for smooth control of the apparatus and relatively lower amount of gases used than a flow rate of 50 mL/min.

Effects of HCl and SO₂ on metals. A set of preliminary experiments was conducted to observe the corrosion effects of high concentrations of HCl and SO₂ on metals. Three 24 hour runs at a gas flow rate of 25 mL/min at 600°C were completed. The percentages of gases used are listed in Table 2.

Table 2. Gas composition used in the laboratory tests to determine the effect of HCl, SO₂, and HCl+SO₂ on metals.

Test run	%HCl	%SO ₂	%O ₂	%N ₂
1	4.5	0.0	4.0	91.5
2	0.0	4.5	4.0	91.5
3	4.5	4.5	4.0	87.0

The concentrations of HCl and SO₂ in the composite gases were made high so that the effects of these gases on the metals can be observed within a reasonable period of time.

The first run was conducted to determine the effect of HCl in a gas mixture of oxygen and nitrogen on metals (Figure 4a-f). Four metals of C-Mn steels and Cr-Mo steels (C1010, C1018, F11, F22) show that there is an initial increase in weight due to oxidation of the metal, and then the weight decreases due to corrosion. Sample F11 has a slight weight increase in the final stage. In contrast, chromium-nickel alloy and steel (Alloy 800 and 310SS) show a weight increase in the first eight hours, then a minor weight change.

The second run was conducted to determine the effect of SO₂ (Figure 5a-f). Metal C1018 shows continuous small weight increase (Figure 5b) whereas metal samples (C1010, F11, and F22) show a continuous weight decrease throughout the run. Chromium-nickel steel and alloy (310SS and Alloy 800) show a small weight change, indicating their strong resistance to corrosion by SO₂.

The third run is to determine the effect of combined HCl and SO₂ gases (Figure 6a-f). The results are similar to, although the weight losses are lower than, that of HCl. Four metal samples (C1010, C1018, F11 and F22) show weight loss. The chromium-nickel steel and alloy (310SS and Alloy 800) show slight weight gain.

The net weight change (in mg/g) of each metal is listed in Table 3. It appears that HCl gas causes the greatest weight change among the three kinds of gas mixtures, the next is HCl+SO₂ in which the weight change is slightly lower, and the SO₂ gas causes the least weight change. Among the metals tested, the chromium-nickel steel and alloy show slight weight gain, no weight loss; apparently these metals are only

slightly oxidized, no significant corrosion occurred under the experimental conditions.

It is of interest to note the results reported by Bakker et al. (1990) on a laboratory study of superheater corrosion. They found that in a totally synthesized environment between 600°C and 750°C the chromium content of the alloy largely determines its resistance to superheater corrosion. Our results are consistent with that of Bakker et al.

Laboratory simulation can not duplicate exact boiler conditions. For example, our laboratory tests do not involve ash deposition. However, the results show that using an improved corrosion resistant material may be a possible measure to reduce corrosion damage to boiler tubes.

Table 3. Net weight change (in mg/g) after a metal was exposed to a composite gas at 600°C for 24 hours.

Metal	HCl	SO ₂	HCl+SO ₂
C1010	-62.6	-20.9	-52.1
C1018	-23.8	+3.4	-23.5
T-11	-63.7	-27.3	-45.5
T-22	-66.4	-2.1	-57.8
310 SS	+7.6	0	+1.8
Alloy 800	+4.1	+0.27	+0.45

CONCLUSIONS AND RECOMMENDATIONS

In a continued effort to better understand the behavior of sulfur and chlorine during combustion, a set of twelve samples of superheater and reheater deposits of an Illinois power plant has been studied for their mineralogical and chemical compositions. Considerable variation in mineralogy and chemistry has been observed among the samples. Whereas most samples are composed of quartz, mullite, and glass, some samples contain an appreciable amount of calcium sulfate and alkali sulfates. The chlorine content of these samples is very low. The chlorine in Illinois coal occurs mostly as chloride ions adsorbed on the organic matter, it may be lost during combustion due to high volatility. A more detailed study of these samples and other samples will be conducted to gain further insights into the behavior of inorganic constituents

in a boiler.

A set of experiments is completed to determine the behavior of six metal coupons exposed to composite gases containing HCl, SO₂, or HCl+SO₂ at 600°C for 24 hours. The results show that chromium-nickel steel and alloy have much higher resistance to corrosion by composite gases than carbon-manganese steels and chromium-molybdenum steels. While the laboratory tests using composite gases can not have conditions identical to boilers, these results, nevertheless, point out that materials of improved corrosion resistance may be used for superheater construction in coal-fired boilers.

REFERENCES

- Bakker W.T., Blough J.L., Wolowodiuk W., and Kihara S. (1990) Materials for future fossil fuel fired steam generators. Proceedings of the American Power Conference, Chicago, p. 1-9.
- Chou C.-L. (1991) Distribution and forms of chlorine in Illinois Basin coals. In Chlorine in Coal (edited by J. Stringer and D.D. Banerjee), Coal Science and Technology 17, p. 11-29. Elsevier.
- Chou C.-L., Hackley K.C., Cao J., Ruch R.R., Pan W.-P., and Shao D. (1992) Behavior of sulfur and chlorine in coal during combustion and boiler corrosion. Technical Report, September 1 through November 30, 1992, to Illinois Clean Coal Institute, Carterville, IL, 16 p.

Figure 1a. SEM photomicrograph of cenospheres with calcium sulfate droplets on their surface. sample WR5-1a.

Figure 1b. SEM photomicrograph of outer portion of a superheater deposit, sample WR5-1b.

Figure 2. X-ray diffraction patterns of two boiler deposit samples WR5-1a and WR5-1b, showing peaks of quartz and mullite.

Figure 3a. Weight change versus time for carbon-manganese steel C1010 using two flowrates of 15 mL/min and 50 mL/min.

Figure 3b. Weight change versus time for chromium-molybdenum steel F22 using two flowrates of 15 mL/min and 50 mL/min.

Figure 4. Weight change versus time for metal coupons exposed to a composite gas containing HCl at 600°C. (a) C-Mn steel C1010, (b) C-Mn steel C1018, (c) Cr-Mo steel F11, (d) Cr-Mo steel F22, (e) Cr-Ni steel 310SS, and (f) Cr-Ni Alloy 800.

Figure 5. Weight change versus time for metal coupons exposed to a composite gas containing SO_2 at 600°C . (a) C-Mn steel C1010, (b) C-Mn steel C1018, (c) Cr-Mo steel F11, (d) Cr-Mo steel F22, (e) Cr-Ni steel 310SS, and (f) Cr-Ni Alloy 800.

Figure 6. Weight change versus time for metal coupons exposed to a composite gas containing HCl and SO₂ at 600°C. (a) C-Mn steel C1010, (b) C-Mn steel C1018, (c) Cr-Mo steel F11, (d) Cr-Mo steel F22, (e) Cr-Ni steel 310SS, and (f) Cr-Ni Alloy 800.

PROJECT MANAGEMENT REPORT
September 1, 1992 through February 28, 1993

Project Title: **BEHAVIOR OF SULFUR AND CHLORINE IN COAL
DURING COMBUSTION AND BOILER CORROSION**

Principal Investigator: C.-L. Chou, Illinois State
Geological Survey (ISGS)

Other Investigators: K.C. Hackley, J. Cao, R.R. Frost,
and R.R. Ruch, ISGS; W.-P. Pan,
M.L. Upchurch, H.B. Cao, and D.
Shao, Western Kentucky University

Project Manager: K.K. Ho, Illinois Clean Coal
Institute

COMMENTS

The project has proceeded well. The expenditures are in
line with the projected amounts.

COSTS BY QUARTER

Behavior of Sulfur and Chlorine in Coal During Combustion
and Boiler Corrosion

Months and Quarters

O = Projected Expenditures -----

■ = Actual Expenditures _____

Total CRSC Award \$ 66,047

Schedule of major milestones

September 1, 1992 - August 31, 1993

Milestones:

- A. Employ research assistants
- B. Subcontract WKU
- C. Request and receive samples from utility boilers
- D. Analyze boiler deposits and conduct boiler corrosion studies (Task 3, ISGS)
- E. Perform laboratory corrosion experiments with simulated combustion gases (Task 4, WKU)
- F. Perform combustion tests with TGA and DTA systems with FTIR spectroscopy (Task 5, WKU)
- G. Perform combustion tests for coal with additives with temperature-programmed pyrolysis coupled with quadrupole gas analysis and assess remedial measures (Task 6, ISGS)
- H. Prepare and submit technical reports
- I. Prepare and submit project management reports

END

DATE
FILMED
6/11/93