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PROOF OF CONCEPT TESTING OF AN INTEGRATED DRY INJECTION SYSTEM FOR SO_x/NO_x CONTROL

Quarterly Technical Progress Report
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Prepared by
D. J. Helfritch and S. J. Bortz,
Research-Cottrell Environmental Services & Technology

and

R. Beittel, Riley Stoker Corp.

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9/30/90

300 tons of program goal were delivered in July. Analysis of this coal is attached.

The entire system was operated under shakedown conditions on 9/26/90 and 9/27/90. SO_2 removal was approximately 80%, with Ca/S - 2.1 - 2.4 aNd Na_2/S = 0.3 - 0.5. It is expected that these results will improve when the injector positions are optimized and when the optimum injection temperature is determined.

A detailed discussion of the performance of the subsystems is given below.

1) Sorbent Storage/Feeding Systems

Silo Loading: Modification of the initial silo loading procedure was needed in order to decrease the time needed to fill the calcium storage silo. The NY blower (AF#7, see Attachment A for equipment locations) operating at 27" W.C. vacuum pressure and using a 3" line allowed the unloading of sorbent at a rate equal to only about one shipping container (7 tons) every three days. Switching to the Hoffman blower (as much as 80" vacuum pressure using a 4" line) cut that period to approximately one day.

The silo bin vent baghouse was braced using angle iron to withstand the higher vacuum pressures of the larger Hoffman blower. Using a bypass valve, vacuum pressures no higher than 2 psig (56" WC) were maintained to further protect the baghouse. At this pressure, a venturi measurement indicated a flow rate of approximately 700 cfm.

Up to this point, approximately two shipping containers (14 tons) of sorbent have been moved to the storage silo. The silo is filled very near to capacity. The possibility of maintaining a moisture free nitrogen atmosphere to protect the sorbent within the silo was investigated, but proved to be too expensive and impractical when attempted.

Calcium Feeder Refilling: The rate at which the gravimetric calcium hydroxide feeder refilled depended on the amount of material in the storage silo located immediately above it. With little material in the silo, the feeder greatly overshot its high level refill cutoff value. This value needed to be kept below 100 lbs in order to insure the feeder would not exceed its maximum capacity of 220 lbs when refilling. Methods of limiting the travel of the refill butterfly valve were investigated but not implemented due to the slow rate of refill when the silo was fuller.

With a full silo, the feeder usually exceeded 60 seconds in refill mode, triggering a time limit warning. Refill continued at a slow but acceptable rate with regular activation of the storage silo bin shaker. A bin shaker activation button was installed near the feeder control in order to facilitate refill. In addition, a new automatic timer was installed to produce periodic bin vibration at specified time intervals. The timer automatically resets after each refill in order not to activate the vibrator during refills which occur quickly (such as discussed above).

Acceptable refill was achieved throughout initial testing. Months of settling of the sorbent currently in the silo during the shutdown period may make refill difficult upon start-up. At that time steps would need to be taken to reaerate or, if it proves unusable, dispose of sorbent currently in the silo.

Calcium Feeder Setup/Calibration: Acceptable calcium hydroxide feedrates were obtained by changing the feeder feedscrew. With the original screw (2-1/4" Half Pitch, No Center Rod), maximum feedrate was 420 lbs/hr at 104 RPM. Adjusting motor voltage to 90V (nominal) resulted in increased RPM but flow rates were still inadequate. Changing to a 2-1/4" full pitch NCR screw allowed for flowrates up to 762 lbs/hr. An extra 2-1/4" full pitch NCR screw suitable for use with either the calcium or sodium feeder was also ordered. Flow rates can be further increased by adjusting motor voltage to a maximum of 110% of nominal voltage (99V). This should not be necessary at Ca/S =< 3.

Calibration and zeroing of gravimetric feeder was done on two occasions. Using the feeder's "learn" function provided accurate feedrate calibration. Subsequent checks resulted in no need for recalibration. The feeder provided acceptably steady feedrates during initial testing but operators must be careful not to upset its gravimetric readings during operation.

Calcium Transport/Injection System: All initial testing was done using Type 1 injectors (2 vertical pipes, each with 3/4" holes facing downstream). Air flow was measured using an orifice plate. With no solids loading in the line, total flow measured 345 scfm. Measured flowrates dropped to 325 scfm after starting sorbent at 8 lbs/min (Ca/S approximately 3). Flowrates dropped further to 315 scfm after 20 minutes of continuous operation but seemed to hold steady thereafter. The flowrate maintained itself at 310 scfm or more during subsequent operation.

Care was taken to clear the calcium hydroxide sorbent line after each operation by continuing to operate the calcium blower (AF#4) for 15 minutes after shutdown. Calcium buildup inside the line may prove to be a problem during repeated testing. The recommended minimum continuous flowrate through blower AF#4 is 320 scfm giving an additional reason to monitor whether flow drops significantly below this rate. Some initial buildup was observed inside the unions above the vertical injection pipes and in the flexible hose leading to these unions. Sand was fed through the system in order to clean the system for the present shutdown period. All significant buildup above the vertical pipes was removed.

All 8 injection holes were observed during operation. The flow of sorbent was well defined and steady near the injection point. An even fog was observed at ports 2-4' downstream, suggesting good mixing within the duct.

One pluggage occurred when the calcium transport line rotary valve (RV#6) was accidentally overloaded. An access point for a compressed air lance was added to the transport line to address this problem should it reoccur. In addition, AF#7 was connected so that it can be used to capture fugitive dust emissions from the feeder. Both packing glands on RV#6 were connected to higher pressured air from the blower to purge parts during operation.

Sodium Injection System: Sodium bicarbonate injection during initial testing was accomplished by placing a 2" horizontal pipe with four 11/16" holes in the gas stream. The sodium transport air blower (AF#5) generated 70" W.C. (110 cfm airflow from the fan performance curve). A new, larger capacity screw (2.25" 1/2 pitch NCR) was installed in order to meet capacity requirements. With the new screw, feedrates from the volumetric feeder were found to be nearly linear with feedrate dial setting throughout the range necessary for testing. The maximum feedrate was 450 lbs/hr.

After adjustment, the 2" Fox eductor used to pull the sorbent into the pneumatic line handled all flowrates necessary for testing. Rat holing in the sodium feeder storage bin became a problem during initial testing. As sodium bicarbonate in the bottom of the bin was discharged, the remaining material formed a bridge which would span the undulating section of the feeder walls. Because several hours of testing were possible without this problem developing, the bridge was collapsed manually during initial testing. In the future, it may be necessary to install a timed vibrator or pulse jet to automatically steady discharge.

2) Controls

Automatic Flow Control: A total of 5 automatic controllers were programmed and used during initial testing. All operating parameters were set and recorded during system shakedown. Tuning of the two controllers used in maintaining flows through the baghouse and ESP (FV#6 AND FV#7) was accomplished using the "Reaction Curve" method. Using this method, typical responses in flow rate to changes in valve position were measured and used to calculate appropriate controller PID values.

PID values for the three controllers used in maintaining heat exchanger exit temperatures were found using the controller autotune function. Once typical flows and temperatures were established, autotune was used to automatically gauge response and calculate appropriate tuning constants.

With the current programming, the automatic controllers provided good control of system flow rate and temperatures during initial testing. The two pressure transmitters and five actuators used in flow control were calibrated and adjusted as necessary. The thermocouple used in controlling FV#4 needed to be switched from TK#5 to TK#6 due to stratified flow exiting the air heater section. Since minimal heat loss occurs immediately downstream of the air heater, TK#6 is an acceptable indicator of the air heater exit temperature.

Venturi Calibration: A pitot traverse of both the baghouse and ESP venturi meter inlets was done in order to check their accuracy in measuring flow. Eight point traverses at perpendicular angles (16 points each venturi), were conducted on each for three flow conditions. Calculated flows from the pitot traverse were within 1% or 3% of those calculated based on venturi pressure differential for the ESP or baghouse respectively (See Attachment B). The three tests averaged to within one percent for both venturi meters. Based on these results, no adjustments were made in the method of calculating flow rate.

System Chart Recorder: A total of 27 input channels are wired into and recorded by the chart recorder (See Attachment C). These include thermocouples, pressure transmitters, the calcium hydroxide feeder feedrate, and gas concentration readings from both the CBTF and from RCEST analyzers. All signals were cross checked and/or calibrated as needed prior to testing. Numerical values are printed every fifteen minutes and can be checked at any time during operation. Several key channels are trended continuously by the recorder in one of ten specified colors. A detailed relatively easy to read record of system temperatures, flowrates, and gas analysis is produced.

Thirteen additional channels are calculated by the recorder using the input channels and equations programmed into the recorder during setup. The values of these channels are also logged every fifteen minutes and selected ones are trended continuously.

Calculated channels contain the venturi flow calculations and corrections of gas concentration values to 3% oxygen. Both pressure at the venturi meters and water vapor content are treated as constants in calculations. Values for these variables must be reprogrammed into the recorder as conditions change. This process can be done during operation.

ESP Humidification System: At 0.68 gallons per minute of humidification water flow, a temperature drop of 74°F was recorded at the ESP inlet (TK#12). This was reasonably close to the 100°F temperature drop expected for these conditions.

Water flowrate was initially controlled manually to avoid flooding the humidification chamber. Automatic control should be used to maintain flowrate when the ESP inlet is near setpoint temperature. The flow regulator was set to maintain 60 psi of air pressure behind the water injection nozzle during operation (maximum rotameter rating = 75 psi). Controller air was regulated to 20 psi. The resulting 77 scfm of airflow provides for adequate humidification capacity under all expected conditions.

3) Burner/CBTF

CBTF/Burner Operation: Maintaining constant coal feed and air flow rates at 50 million Btu/Hr heating in the furnace was sometimes difficult due to the higher nominal capacities of the equipment. Test conditions were reasonably steady during three days of initial testing and should not prove a problem during subsequent tests. SO_2 readings averaged approximately 2500 ppm (adjusted to three percent oxygen) and varied by less than 100 ppm 90+% of the time. Oxygen readings of flue gas exiting the CBTF averaged approximately 4.5% and varied +/- one percent.

NO_x output from the furnace averaged 220 ppm (corrected to three percent oxygen) and varied by less than 20 ppm 90+% of the time. Available time allowed for only limited attempts to minimize NO_x. Initial tests were run with a 25% register position and 50% shroud position. Adjustments in these settings also helped correct early problems with burner flame outs.

Cooling Water Sprays: Two adjustments were needed in the CBTF cooling water sprays in order to accommodate the test loop. Decreased temperature readings at TK#1, the thermocouple furthest upstream, when sprays were turned on suggested that water was entering through the test loop intake. Two cooling water spray leaks which sprayed into the loop were fixed in order to correct this. In addition, one of six spray nozzles near the test loop exit needed to be removed to stop water from dripping towards the test loop ID fan.

4) Heat Exchangers

Performance: Heat exchanger performance limited the gas flowrate through the test loop during initial testing. With no sorbent flow, the heat exchangers could maintain the design temperatures of 1000°F at the economizer section inlet, 700°F at the economizer section outlet, and 300°F at the air heater outlet only for flows of 7800 scfm or less. With typical sorbent feedrates, this flowrate had to be dropped to 6500 scfm or less to maintain the same temperatures. The later case represents approximately 65% of design flow.

The most limiting heat exchangers were the second and third tube banks (the simulated economizer section). The temperature setpoint at TK#4 was only maintained for the previously mentioned conditions with FV#2 and FV#3 100% opened. Under the same conditions, temperatures were maintained with FV#1 85% open for the first tube bank. Though this is less limiting, it is expected that modifications will have to be made if this heat exchanger is to meet design conditions. The simulated air heater heat exchanger had no problem maintaining temperature and should need no modifications to handle design flow.

5) Other Components

System Blowers: Maintaining adequate airflow through the test loop was easily accomplished with the new NY Blower ID fan (AF#1). The design airflow rate of approximately 10 KSCFM is well within capacity. During shakedown, the following flows were measured with the given damper positions:

Total	Baghouse Loop		ESP Loop		Fan
KSCFM	% Open	KSCFM	% Open	KSCFM	Amps
6.7	22	5.9	0	0.8	75
10.1	22	5.9	50	4.2	90
13.2	22	5.9	63	7.3	100
19.7	45	12.7	63	7.0	127

Current flow through the test loop ID fan was well below the fan's full load amperage (FLA = 164). A high limit of 70% open was programmed into the controllers for both the Baghouse and ESP loop damper (FV#6 and FV#7) in order to avoid exceeding full load amperage. Even with this precaution, operators should avoid opening both dampers fully at the same time.

A maximum current flow of 35 amps was measured for the air heater cooling fan (AF#3), well under its full load rating of 47 amps. Pressure readings taken at the other heat exchanger fan (AF#2) indicate no problem with exceeding amperage. Minimum damper positions of 20% for the two controllers associated with AF#2 (FV#1 and FV#3) and 5% for the air heater damper control (FV#4) were programmed in order to prevent mechanical binding of the dampers and to maintain a minimum amount of airflow over the heat exchanger tubes.

Test Loop Leakage: Leaks discovered in the test loop during shakedown were patched using silicone. One leak was discovered in the metal ESP casing and was repaired. Oxygen readings from the EST oxygen analyzer and taken at the first and last sample points (SP#1 and SP#3) during initial testing indicate the introduction of approximately 14% outside air. About five percent of the added air would be due to air for sorbent transport.

Refractory Curing: Approximately 15 hours of operation over a four day period were dedicated to the curing of test loop refractory. During the time, temperatures were raised slowly in order to avoid cracking or other damage to the refractory while moisture was being removed. No additional curing of refractory will be necessary before future testing.

Solids Removal System: Under design conditions, typically 1300 lbs/hr of solid waste is expelled from the one baghouse and the four ESP discharges. Because of the reduced flow rates during initial testing, total solids flow probably never exceeded 900 lbs/hr. The capacity of the system proved adequate under these conditions. No problems with plugging or ash build up occurred.

A cover was designed and built to allow dust collector discharge and containment of solids in the BFI waste container. Fugitive dust emissions were not a problem during initial testing. Under design conditions, a 20 yard BFI container will be filled every one to two days.

One bag needed replacement in the system collector. This was due to damage done to the bag when the collector was welded in place and should not be an ongoing problem within the system. An additional fan (AF#8) was added during initial tests to maintain the collector at slightly negative pressures. The additional airflow should also insure adequate system capacity under heavier solids loading.

The solids removal system was run for several hours after the recent shutdown in order to clean out the test loop as much as possible. During this process, higher than normal flowrates were alternately maintained through the ESP and baghouse in order to maximize the amount of material removed.

6) Sorbent Injection Tests

As part of the system shakedown, sorbent was injected during full system operation (ie, hot testing) on two days. The results are shown on the attached table, and identified by calendar day.

Wulfrasorp calcium hydroxide was injected at flue gas temperatures of 1000-1050 F, and at Ca/S ranging from 2 to 2.5. Sulfur dioxide removal ranged from 55-66%, with a range of utilization of 15-31%. The shakedown tests utilized Type 1 injectors (two vertical pipes spanning the duct, each with az series of 3/4" holes facing downstream). There was no clear effect of temperature over the limited 50 F range of injection temperature variation. Electrical characteristics of the ESP were severely degraded compared to flyash-only operation. During the second day's run, the ESP portion of the flue gas was humidified to lower the gas temperature to about 210 F over the ESP (compared to 260-294 F without humidification). The calculated increment in flue gas moisture was 0.044 mol H_2O/mol dry FG. Electrical operation of the ESP improved significantly. No opacity or loading measurements were attempted.

Sodium bicarbonate was injected at about 330 F during the first hot shakedown run. There was no humidification. The nominal Na/(2s+N) ratio at the injection point was 0.7; considering sulfur only, the nominal Na2/S ratio was 0.77. The SO_2 removal was 58%, for an apparent utilization 75% based on sulfur-only stoichiometry. NO decreased only about 6%, with a corresponding increase in NO_2, and no net NO_x removal. There was an anomaly in the gas analysis in that prior to starting sodium injection (but during calcium injection), the SO_2 (corrected to 3% O_2) was slightly higher at the ESP exit than at the air heater exit. A transient due to calcium feeder refill during the transition between sample points accounts for part, but not all, of this difference. The test was too limited in duration to track down this problem.

Sodium injection during the second run resulted in less sulfur capture at a higher stoichiometry, nominally 53% removal at 1.2 Na/(2S+N). NO reduction was 21%, and there was an apparent decrease in NO_2 for a net NO_x reduction of 23%. The injection temperature was slightly lower than in the previous test, but the flue gas downstream was cooled by humidification to about 210 F.

A review of the operating log indicates that the sodium feeder was mistakenly refilled with sodium sesquicarbonate between the two tests reported above. Thus, the second test probably utilized a mixture of the two sorbents. In addition, since these were shakedown tests aimed primarily at equipment checkout, and were limited in length, feed rate calibrations and gas analysis cross checks were not performed. Therefore, the results should not be taken as definitive, but only as preliminary indication of reasonable system performance.

7) Electrostatic Precipitator

The electrostatic precipitator was on line and operating during the two days of shakedown. Particle sampling was not attempted during this time, but the electrical characteristics were carefully monitored. It was possible to observe the precipitator behavior under several different inlet conditions.

Attachment D shows the current voltage characteristics of the second field of the precipitator while operating with no sorbent injection (ash only, inlet T = 275 F), with hydrate and bicarb injection (inlet T = 290 F), and with sorbent injection plus humidification cooling (inlet T = 210 F). In all cases the precipitator was operated at an SCA of 200.

It can be seen that the addition of the sorbents to the ash caused the current to sharply rise and limited the achievable voltage to under 35 KV, a clear indication of back corona. The application of gas cooling to 210 deg F through humidification resulted in more normal lower current and higher voltage, the anticipated response.

RILEY

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FUELS LABORATORY

TEST REPORT

Laboratory No. 41,363 Sample of Coal Date Rec'd 7/31/91

Received From Riley Research PSCF Worcester Ma

Sample Data Coal Sample - Marion Mine Coal at National Coal Yard 7/31/91

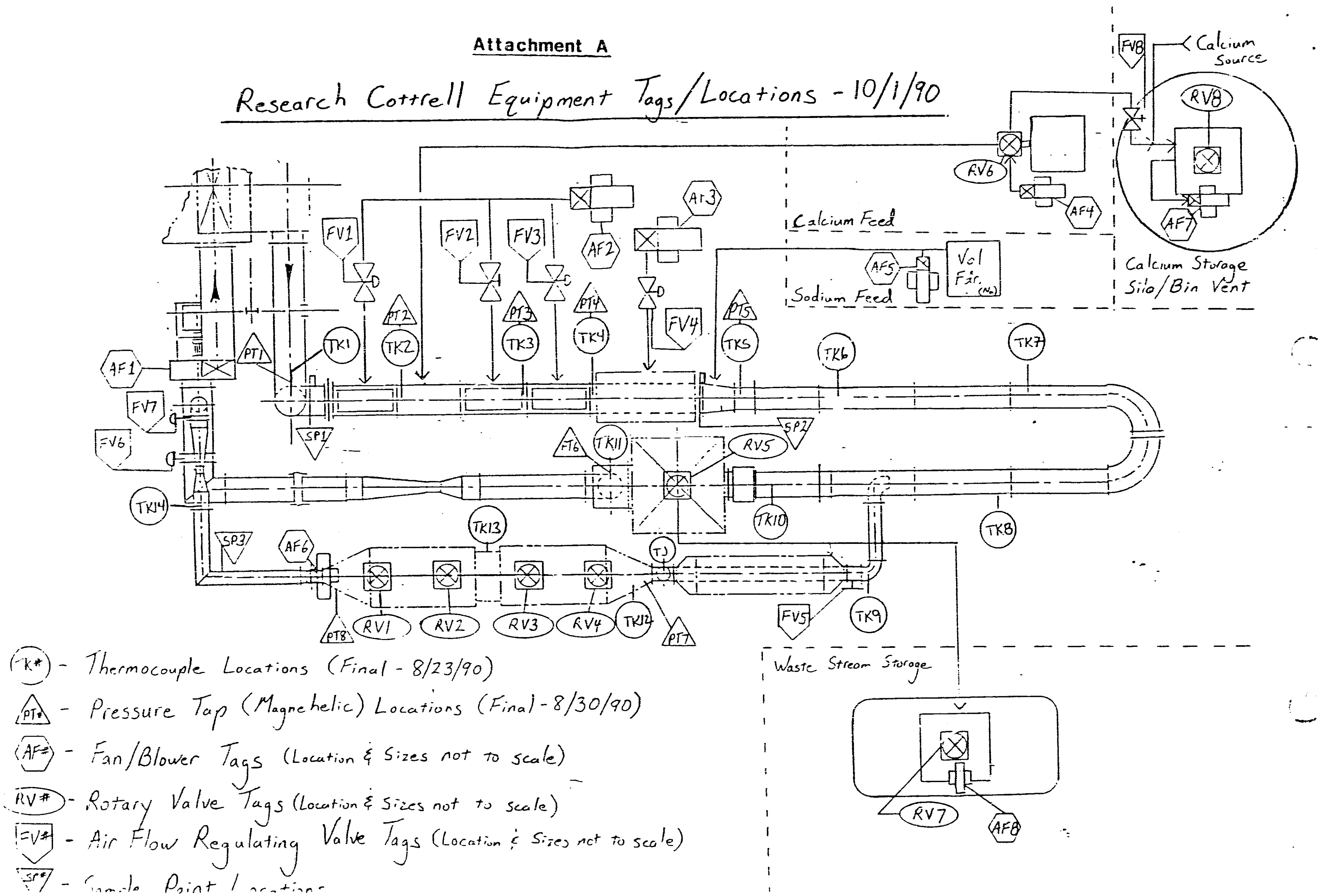
Contract No. 641-90856-1000 Field Sample By Sass

Air Drying Loss 4.1 %

Proximate Analysis	As Rec'd	Dry	Ultimate Analysis	As Rec'd	Dry
Moisture	8.8 %	------	Moisture	%	------
Volatile	32.8 %	36.0 %	Carbon	%	%
Ash	13.3 %	14.6 %	Hydrogen	%	%
Fixed Carbon	45.1 %	49.4 %	Nitrogen	%	1.44 %
	100.0 %	100.0 %	Oxygen	%	%
British Thermal Units	11,272	12,360	Sulfur	3.0 %	3.3 %
Fusibility of Ash Oxid Red			Ash	%	14.6 %
Initial Deformation		F		100.0 %	100.0 %
Softening (H=W) (H=½W)		F	Free Swelling Index		
Fluid		F	Grindability Index		

Attachment A

Research Cottrell Equipment Tags/Locations - 10/1/90



TK# - Thermocouple Locations (Final - 8/23/90)

PT# - Pressure Tap (Magnehelic) Locations (Final - 8/30/90)

AF# - Fan/Blower Tags (Location & Sizes not to scale)

RV# - Rotary Valve Tags (Location & Sizes not to scale)

FV# - Air Flow Regulating Valve Tags (Location & Sizes not to scale)

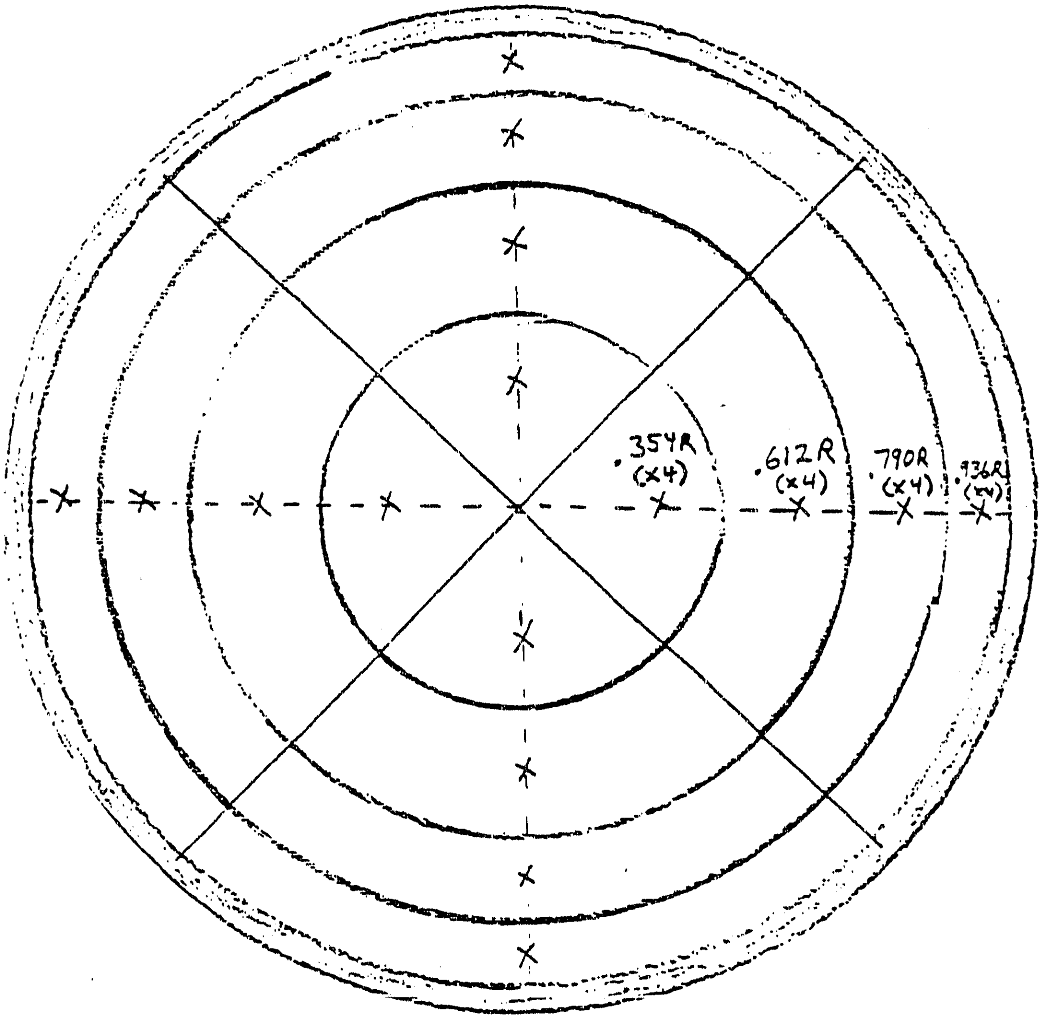
SP# - Sample Point Locations

Attachment B

Venturi Calibration

	Test #	Venturi ΔP (" WC)	Pitot Velocity (ft/sec)	Venturi Velocity (ft/sec)	Vel_p/Vel_v
ESP	1	23.1	96.38	96.6	0.998
	2	12.6	71.96	71.3	1.009
	3	0.65	16.39	16.4	0.999
Baghouse	1	31.0	69.98	67.8	1.032
	2	16.0	47.86	48.8	0.981
	3	4.5	25.31	26.0	0.973

Sample Point Locations

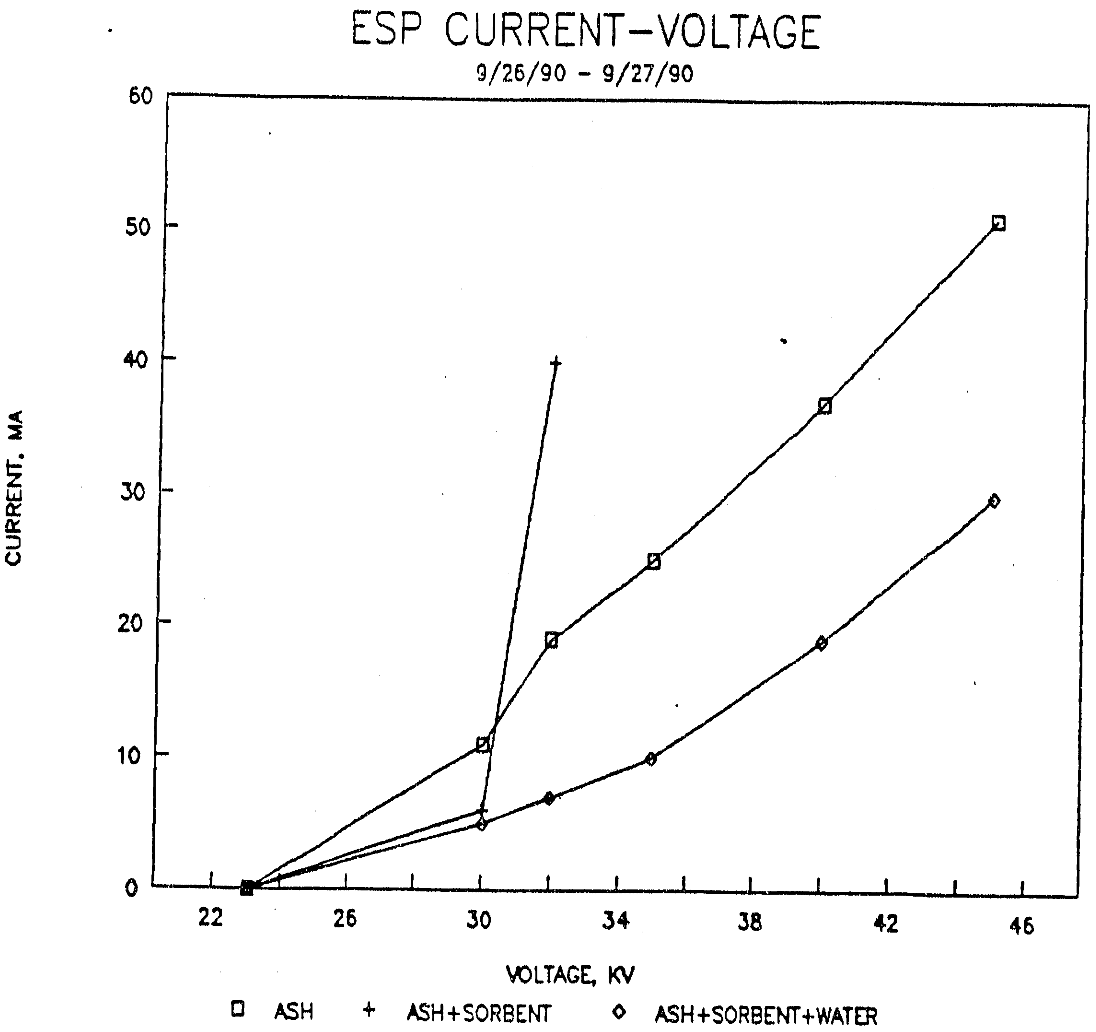


Attachment C

Research Cottrell Chart Recorder Channel Assignments
Ver. 1.9 9/28/90

Ch#	Description	Signal	Trend Color-Zn#	Range
1	TK1-Furnace Outlet	TC-K	Purple-Z1	0-2000 F
2	TK2-Sorb Inj Pt	TC-K	Red-Z1	0-2000 F
3	TK3-Inter Econ	TC-K	-	
4	TK4-Econ Out	TC-K	Orange-Z1	0-2000 F
5	TK5-Air Htr Out	TC-K	-	0-2000 F
6	TK6-Air Htr Cntrl	TC-K	Brown-Z1	0-2000 F
7	TK7-100'Duct	TC-K	-	
8	TK8-100'Duct	TC-K	-	
9	TK9-Humid Cham In	TC-K	-	
10	TK10-Baghouse In	TC-K	-	
11	TK11-Baghouse Out	TC-K	-	
12	TK12-ESP In	TC-K	Yel-Green-Z1	0-2000 F
13	TK13-Inter ESP	TC-K	-	
14	TK14-ESP Out	TC-K	Blue-Z1	0-2000 F
15	DP1-BH Venturi DP	1-5V	-	
16	DP2-ESP Venturi DP	1-5V	-	
17	Ca(OH)2 Feedrate	1-5V	Red-Z2	0-1000 #/hr
18				
19				
20				
21	CBTF CO2	0-1V	-	0-25%
22	CBTF O2	0-1V	Blue-Z2	0-10%
23	CBTF NOx	0-1V	-	0-1000 ppm
24	CBTF SO2	0-1V	-	0-10000 ppm
25	CBTF CO	0-1V	-	0-500 ppm
26	KVB O2	0-1V	-	0-25%
27	KVB NO	0-1V	-	0-1000 ppm
28	KVB NOx	0-1V	-	0-1000 ppm
29	KVB SO2	0-1V	-	0-5000 ppm
30	KVB CO	0-1V	-	0-1000 ppm
31	ESP Flow Calc	Calc	-	
32	ESP Flow Result	Calc	-	Actual SCFM
33	BH Flow Calc	Calc	-	
34	BH Flow Result	Calc	-	Actual SCFM
35	KVB NO @ 3%	Calc	Brown-Z2	0-1000 ppm
36	KVB NO2 @ 3%	Calc	Black-Z2	0-1000 ppm
37	KVB SO2 @ 3%	Calc	Navy-Z2	0-5000 ppm
38	KVB CO @ 3%	Calc	Yel-Green-Z2	0-1000 ppm
39	CBTF NOx @ 3%	Calc	Red-Purple-Z2	0-1000 ppm
40	CBTF SO2 @ 3%	Calc	Orange-Z2	0-5000 ppm
41	CBTF CO @ 3%	Calc	Purple-Z2	0-1000 ppm
42	Total Flow	Calc	Black-Z1	0-10000 SCFM
43	KVB O2	Calc	Green-Z2	0-10%

ATTACHMENT D



DATE
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9/01/92