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EPA

Project Summary

An Evaluation of Full-Scale Fabric Filters on Utility Boilers: SPS Harrington Station Unit 3

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The objective of this program was to evaluate and characterize the performance of full-scale fabric filter units installed on 100 MW or larger coal-fired power plants. This document reports results of total mass and fractional size particulate emission tests at Southwestern Public Service's Harrington Station Unit 3 from July 8 to July 11, 1981. Three outlet and one inlet mass and fractional size emission tests were performed. Due to the absence of inlet ports, inlet testing was done by bypassing the baghouse and testing at the outlet ports of the fabric filter. The fabric filter is a shake/deflate unit with 32 compartments. Each compartment has 204 bags, 30 ft 6 in.* long and 11.5 in. in diameter. Design air/cloth ratio is 2.8. Average outlet concentration was 0.007 lb/10^6 Btu. Inlet loading was 2.0 lb/10^6 Btu, giving a 99.65% collection efficiency. Particle sizing tests indicated that the mass geometric mean diameter for the three outlet tests ranged from 7.2 to 13 μm with an inlet mass diameter of 60 μm.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

*Readers more familiar with the metric system may use the conversion factors at the end of this Summary.

Introduction

EPA funded a program in 1980 to evaluate and characterize the performance of full-scale fabric filter units installed on 100 MW or larger coal-fired power plants. The program required particulate total mass and fractional size efficiency testing and collection of performance, operation, maintenance, and problem information. Southwestern Public Service's Harrington Station Unit 3 was selected as one of the sites to be tested.

Four outlet particulate total mass tests and one inlet particulate total mass test were performed. Run 1 was voided because an incorrect stack moisture content was assumed which resulted in the wrong size sampling nozzle being used. Runs 2, 3, and 5 (outlet tests) are considered valid. Run 4 was the inlet particulate test which was conducted by bypassing the baghouse and testing at the stack outlet ports. These data are summarized in Table 1.

Sampling was conducted at four ports spaced equidistant around a 20.8 ft diameter stack. Three traverse points were assigned to each port, resulting in a 12-point traverse particulate test.

Process and Control Device Description

SPS's Harrington Station Unit 3 consists of a tangentially fired, Combustion Engineering steam generator, capable of producing 2,682,393 lb steam/hr at

Table 1. *Data Summary*
(Southwestern Public Service, Harrington, Unit 3)

OUTLET EMISSION DATA — *July 8–11, 1981*

Run & Date	Particulate Emissions lb/10^6 Btu	lb/hr	gr/acf	MW Production % Opacity	Flow acfm dscfm	Temp. °F	Orsat CO_2 %	O_2 %	CO %	Baghouse Differential Pressure in. H_2O	Stack Gas Moisture, %
1 7/8/81	Void										
2 7/9/81	0.009	35.91	0.0024	340.5 5.5	1712460 944245	323.2	11.6	6.5	0.0	East BH: 6.98 West BH: 6.26	10.6
3 7/9/81	0.009	34.55	0.0022	349.7 5.5	1737950 911922	323.2	11.6	6.5	0.0	East BH: 8.1 West BH: 6.7	14.3
5 7/10/81	0.003	11.7	0.0008	349.4 5.6	1707690 938412	322.6	11.6	6.5	0.0	East BH: 7.1 West BH: 6.6	10.2

[a]INLET EMISSION DATA

Run & Date	Particulate Emissions lb/10^6 Btu	lb/hr	gr/acf	MW Production % Opacity	Flow acfm dscfm	Temp. °F	Orsat CO_2 %	O_2 %	CO %	Baghouse Differential Pressure in. H_2O	Stack Gas Moisture, %
4 7/9/81	2.0	7958.5	0.5167	349.3 98.1	1777280 947257	341.0	11.6	6.5	0.0	East BH: 5.4 West BH: 4.9	10.7

[a]Tests conducted by bypassing the baghouse.

2500 psig, 1005°F superheat, and 1005°F reheat.

Pulverized Western coal with average parameters of 8475 Btu/lb, 0.3% sulfur, and 5.5% ash is burned.

Particulate emissions are controlled by a Wheelabrator-Frye, Inc., baghouse designed to operate at a flue gas flow of 1,650,000 acfm at 313°F, with a minimum design efficiency of 98.6%. Design air/cloth ratio is 2.81 gross, 2.90 with one compartment down, and 3.0 with two compartments down.

There are two baghouse systems at Harrington Unit 3, east and west, each with its own operating control system and bypass dampers for start-up, emergency operation, and shutdown. This shake/deflate cleaning system consists of 6528 bags: 32 compartments with 204 bags per compartment.

Testing Methodology, Sampling Equipment, and Procedures

Particulate emission tests were conducted according to U.S. EPA Reference Method 5 procedures in conjunction with Methods 1, 2, 3, and 4. Each test included a 12-point traverse with a 10-minute sampling duration for each point.

Assembly and use of the impactor train followed state-of-the-art protocol and general Method 5 sampling train procedures. Special precaution was taken to avoid rough handling of loaded impactors, overloading of the impactor, and in the performance of hot leak tests.

The particulate sampling equipment used is referred to as the "EPA Method 5 Particulate Sampling Train," designed and developed by EPA.

The apparatus consisted of a stainless steel sampling nozzle, a Method 5 filter holder containing an 87 mm Schleicher and Scherell #1-HV high-purity glass filter, a series of four Greenburg-Smith impingers, a check valve, a leakless vacuum pump, a dry gas meter, and a calibrated orifice. The impingers and connecting tubes were made of Pyrex glass and were connected with glass ball-and-socket joints. The probe was Type 316 stainless steel.

Using the type "S" pitot tube, a velocity traverse was performed along each traverse axis during each particulate run. The velocity pressure at each sampling point was measured using an inclined manometer.

Prior to, and at the conclusion of, each run, the complete sampling train, including probe and nozzle, was leak-tested by plugging the nozzle with a rubber stopper and applying a vacuum of 15 in. Hg to the system.

At the completion of each test the sampling nozzle, the inside of the probe, the inside of the thimble holder, and the front-half of the glass fiber filter holder were washed with acetone. The washings were collected and stored.

Tests to determine carbon dioxide, oxygen, and carbon monoxide were conducted using an Orsat analysis according to EPA Method 3.

Discussion of Results

During this test series, there were no

deviations from normal operating conditions for Unit 3 that could be determined from the control room, baghouse control room data, or conferences with the boiler operators. Control room data monitored during the test period compared closely with previous data. Emission rates in pounds per million Btu were calculated using average F factors derived from coal analysis performed on SPS coal. Outlet particulate emissions at Harrington Unit 3 averaged 0.007 lb/10^6 Btu (27.39 lb/hr) for the three outlet tests. The single inlet emission test, performed by bypassing the baghouse, resulted in an emission rate of 2.0 lb/10^6 Btu (7958.5 lb/hr). Emission rates for outlet Runs 2 and 3 were very close: 0.009 lb/10^6 Btu (35.9 lb/hr), and 0.009 lb/10^6 Btu (34.6 lb/hr), respectively. Outlet Run 5 resulted in an unexpected low emission rate of 0.003 lb/10^6 Btu (11.7 lb/hr). The inlet run performed at the outlet stack ports also resulted in a lower emission rate than expected when compared to previous test results conducted at Unit 3.

Cascade impactor sampling was performed under the supervision of Research Triangle Institute, July 8 and 9, 1981. Three outlet and one inlet impactor tests were performed. Emission rates for the impactor and Method 5 tests are compared in Table 2.

After comparing previous ash analyses with the analysis made on the ash generated during this test series, it was concluded that little difference existed between the typical coal burned and the coal burned during this testing project. The coal burned at Southwestern Public Service Co. is a western coal, high in calcium and silica, mined from the Powder River Basin near Gillette, Wyoming.

Bag analyses were performed on four bags (two used and two new). The tests performed included permeability, tensile strength, MIT flex, and Mullen burst.

Overall, the bag analyses indicated a greater percentage loss of strength in terms of MIT flex, Mullen burst, and tensile strength than previous tests. The cleaning procedures differed between the two testing laboratories but, in general, indicated approximately the same permeability improvement after cleaning.

Table 2. *Grain Loading from Method 5 and Impactor Tests (SPS-Harrington Unit 3)*

July 8–11, 1981

Run & Date		Impactor Loading Rates gr/acf	Method 5 Particulate Loading gr/acf
Outlet 7/8/81	1	0.0004	VOID
Outlet 7/8/81	2	—	0.0024
Outlet 7/9/81	3	0.0007	0.0022
Outlet 7/10/81	5	0.0015	0.0008
[a]Inlet 7/9/81	4	1.06	0.5167

[a]Test performed by bypassing the baghouse.

Metric Conversions

This Summary includes certain nonmetric units for the reader's convenience. Those more familiar with the metric system may use the following conversion factors.

Nonmetric	Times	Yields Metric
Btu	1.055	kJ
°F	5/9 (°F−32)	°C
ft	30.48	cm
ft^3	28.32	1
gr	0.065	g
in.	2.54	cm
in.^{2}	6.45	cm^2
lb	0.454	kg

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***Dale L. Harmon** is the EPA Project Officer (see below).*
The complete report, entitled "An Evaluation of Full-scale Fabric Filters on Utility Boilers: SPS Harrington Station Unit 3," (Order No. PB 85-235 513/AS; Cost: $16.00, subject to change) will be available only from:
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Project Summary

Steam Stripping of Fixed-Bed Gasification Wastewaters

F. D. Skinner and B. J. Hayes

Laboratory- and bench-scale steam stripping tests were conducted using gas liquor from a fixed-bed coal gasifier at the Department of Energy's Morgantown Energy Technology Center. The gas liquor was pretreated by solvent extraction (for phenol removal) and filtered prior to stripping. This report presents the results of the wastewater stripping tests and provides engineering and environmental data for the design of steam strippers for fixed-bed gasification wastewaters. The laboratory tests were performed primarily to determine the effect of pH on contaminant removals. During the bench-scale tests, samples of influent, effluent, and overhead vapor and condensate were analyzed for a number of species of potential environmental concern (dissolved gases, sulfur and nitrogen species, trace metals, organics, and other water quality parameters). Mass transfer coefficients for ammonia, carbon dioxide, and hydrogen sulfide stripping were calculated.

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Introduction

The raw gas liquor resulting from fixed-bed coal gasification processes contains a number of contaminants, some of which are present in relatively high concentrations. These include tars and oils, dissolved organic (especially phenols), dissolved gases (e.g., NH_3, HCN, H_2S, CO_2), and both suspended and dissolved inorganics. Removal of these contaminants in a multiple step wastewater treatment system has been included in many proposed commercial coal gasification plant designs.

Steam stripping for the removal (and, in some cases, recovery) of dissolved ammonia and acid gases is a treatment process which is common to most of these designs. Capital and operating costs for steam stripping systems can account for a significant portion of the overall cost of wastewater treatment in coal gasification plants. There is a need, therefore, to develop design data that can be used to maximize the cost effectiveness of this process. In addition, the outlet streams need to be characterized to evaluate the effects of contaminants on downstream process performance.

This report presents the results of laboratory- and bench-scale stripping work, using wastewater obtained from a fixed-bed gasifier at the Department of Energy's Morgantown Energy Technology Center (DOE-METC).

Objectives and Approach

The principal objectives of the wastewater stripping study were:

- To provide data characterizing the various stripper outlet streams for species of environmental interest with respect to potential impacts on downstream process performance and environmental effects.
- To develop mass transfer data that could be used in the design of a steam stripper for wastewater from fixed-bed gasifiers following pretreatment by solvent extraction, filtration, and pH adjustment (if needed).

To meet these objectives, two series of tests were performed. First laboratory-scale screening tests were conducted to determine the effect of wastewater pH on the removal of dissolved ammonia, H_2S, CO_2, HCN, and the residual phenol remaining after pretreatment by solvent extraction using methyl isobutyl ketone (MIBK). These tests were conducted by heating a measured quantity of pH-adjusted wastewater to 95-100°C in a distillation flask. Gas (air or nitrogen) was sparged through the contents of the flask, and the ammonia concentration and pH of the wastewater were measured over a 270-minute period. After each run the contents of the flask were analyzed for pH, conductivity, total alkalinity, ammonia, cyanide (free and total), phenol, sulfide, sulfite, sulfate, and thiocyanate.

The results of the laboratory tests were used to determine the influent pH for the second series of tests, performed using a bench-scale steam stripping apparatus. The stripper was a 0.1 m (4 in.) diameter stainless steel column packed with 1.2 m (4 ft) of 0.6 mm (1/4-in.) ceramic Intalox saddles. Solvent-extracted wastewater was preheated to 90°C in an electric heater and pumped into the top of the column. Stripping steam entered below the packing and flowed countercurrent to the wastewater. Concentric tube heat exchangers were used to condense and cool the overhead vapor and to cool the stripped effluent. Samples were obtained periodically during each run of the various inlet and outlet streams for analysis of the environmental and performance parameters of interest. The principal independent variable during these tests was the steam to wastewater influent flow ratio.

Results and Conclusions

Laboratory-Scale Results

- Greater than 90% removals of dissolved ammonia and alkalinity (due to dissolved CO_2) were obtained by stripping the extracted METC wastewater at a pH of 8.6 (existing after solvent extraction) and higher. Ammonia removal increased from about 92% to over 99.9% as the initial wastewater pH was raised from 8.6 to 11.0. A decrease in CO_2 removal efficiency from over 99 to 96% was observed when increasing pH from 8.6 to 11.0.
- Dissolved H_2O removals decreased from 80 to 50% as the initial pH was increased from 8.6 to 11.0. Cyanide removals were between 10 and 20%; most of the cyanide content of this wastewater was present as fixed (and therefore non-strippable) cyanide at the pHs evaluated. It is likely that some of the free cyanide initially in the wastewater had been converted to fixed cyanide and/or thiocyanate, and the removal may be higher for "fresh" wastewater.
- Removal of the small amount of phenol (total) remaining in the extracted wastewater was found to be less than 20%. No clear trends were observed as the pH was increased. Technical questions remain regarding phenol stripping for unextracted wastewater or wastewater having phenol levels closer to those expected from commercial gasifier systems.
- Because of its buffering capacity (due to HCO_3/CO_3 alkalinity), the wastewater required a significant quantity of lime to raise its pH from 8.6 to 11.0. In order to go from pH 8.6 to 9.5, 470 milliequivalents (meq) of lime per liter was required: to go from pH 8.5 to 11, nearly 1200 meq of lime per liter was needed. The buffering capacity of the wastewater is readily reduced by steam stripping of the dissolved CO_2.
- Two-stage stripping would likely be required to remove all (or nearly all) of the dissolved ammonia and acid gas species (expecially H_2S and HCN) from this wastewater.
- Stripping the wastewater at a pH of 8.6 produced significant quantities of solids that collected on the surfaces of the equipment and led to plugging problems. Increasing the pH to 9.5 or higher by lime addition significantly reduced the plugging. The solids are likely ammonium salts, possibly ammonium carbonate or ammonium carbamate; however, the solids were not analyzed.

Bench-Scale Tests: Environmental

- Thiocyanate, sulfate, fluoride, and chloride are not removed by steam stripping. These contaminants will be found in the stripper effluent stream.
- Trace elements detected in stripper outlet streams appear to be largely system contaminants, possibly from the column, ceramic packing, and the lime added for pH adjustment. It appears that some of the volatile trace elements (e.g., arsenic, selenium, and antimony) are stripped to some extent. This has implications for the potential environmental impacts of the stripper overheads and effluent streams. For example, it may be possible to reduce the amounts of some toxic trace elements that might otherwise concentrate in brines produced by downstream evaporators; however, this potential was not investigated.
- Phenols were the major organic species found in the wastewater. 2, 4-dimethyl phenol was largely stripped and was found principally in the overhead condensate. Other phenols (e.g., phenol, cresol, and other xylenols) were only partially stripped and are found in both the effluent and overhead condensate.
- Hydrocarbon analyses of the overhead vapor were hampered by the relatively high concentration of residual methyl isobutyl ketone (MIBK) from the solvent extraction process. Toluene and xylene were not detected in any of the samples, and benzene was detected (at 1.1 ppmv) in only one set of the samples collected on charcoal. The residual solubility of MIBK in water is significant (reportedly about 2% by weight). Some other organics may be present in the MIBK layer produced as a result of condensing the stripper overhead stream. The solvent layer was not analyzed in this work.
- The presence of significant quantities of solvent vapor in the stripper overhead vapor stream has potential impacts on the downstream processes that may be used to remove H_2S and other acid gas species from this stream.The residual solvent concentration after extraction/inert gas stripping seen in this study is probably not representative of commercial operations. In a commercial extraction system, solvent recovery would be more efficient, not only to reduce the possibility of problems with downstream processes, but also to reduce solvent makeup requirements. However, more efficient solvent stripping would likely produce additional streams containing species stripped from the raffinate (including ammonia and hydrogen sulfide).
- Carbonyl sulfide was detected in all

Table 1. *Component Removal Summary for Bench-Scale Stripping Tests*[a]

Run Date	Steam/Influent kg/m^3	Influent pH	% Removal NH^3	CO_2	Sulfide	Total Cyanide	Total Phenols
9/25	133 ± 7	9.03 ± 0.05	83.6 ± 3.8	93.3 ± 0.5	30.9 ± 17.9	18.9 ± 4.2	−5.2 ± 5.4
9/27	298 ± 31	9.02 ± 0.15	94.3 ± 1.5	98.3 ± 0.6	17.7 ± 38.7	23.8 ± 13.6	44.9 ± 9.7
11/1	282 ± 44	9.14 ± 0.03	91.6 ± 4.5	98.6 ± 0.2	65.1 ± 9.1	59.7 ± 3.5	−72.8 ± 28.6
11/2	459 ± 49	9.17 ± 0.06	95.0 ± 1.7	99.0 ± 0.1	69.4 ± 16.6	16.6 ± 41.1	4.2 ± 31.8
11/5[b]	297 ± 34	8.45 ± 0.04	31.0 ± 25.6	81.6 ± 5.1	−7.6 ± 51.8	23.7 ± 21.0	46.7 ± 12.4

[a]*Values shown are mean ± sample standard deviation. All runs performed using 1.2 m (4 ft) of packing.*
[b]*11/5 run performed using effluent collected from previous stripping runs at similar steam/influent ratios.*

overhead vapor samples at concentrations of about 0.04 ppmv in the two-pass stripper run and from 1 to 5 ppmv in the single-pass runs. Carbon disulfide was the only other sulfur species detected (1 to 32 ppmv).

Bench-Scale Tests: Performance

- Contaminant removals consistent with the results of the laboratory-scale tests were found for ammonia, CO_2, and H_2S. Data scatter precluded the development of meaningful correlations for HCN and phenol (total) removal as a function of the steam to influent ratio. The component removals are summarized in Table 1.
- Contaminant removals were found to increase with increasing steam to wastewater ratio up to 250-300 kg steam/m^3 wastewater. Higher ratios produced no statistically significant improvement in contaminant removals. There would appear to be little incentive to operate at a steam to wastewater ratio higher than about 250 kg/m^3.
- Overall volumetric mass transfer coefficients (K_La) were calculated for steam stripping of NH_3, CO_2, and H_2S for the wastewater. For ammonia, K_La increased from 1.8 to 6.6 hr^{-1} as the liquid mass velocity increased from about 550 to 2000 kg/m^2hr. Over this same range K_La for CO_2 increased from 2.2 to 4.5 hr^{-1}. K_La for H_2S was found to be approximately constant at 0.6 hr^{-1} over this range of liquid flow rates.

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The complete report, entitled "Steam Stripping of Fixed-Bed Gasification Wastewaters," (Order No. PB 85-247 450; Cost: $16.95, subject to change) will be available only from:
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