Case Study: Pulse Jet Fabric Filter & Dry Sorbent Injection for Biomass Boiler Application

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Presented at
Power Plant Pollutant Control MEGA Symposium
August 19-21, 2014
Baltimore, MD, USA

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Paper # 95
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ABSTRACT

Andritz Inc. has recently supplied a biomass boiler, rated at 650,000 lb/hr, 975 °F and 1525 psig, and an air quality control system (AQCS) for a pulp and paper facility in the Eastern U.S. The AQCS train was subcontracted to Foster Wheeler (formerly known as Siemens Environmental Systems & Services and Wheelabrator) and includes a sodium bicarbonate injection system, powdered activated carbon injection system, and a long-bag intermediate pressure pulse jet fabric filter (PJFF) installed downstream of a bubbling fluidized bed (BFB) boiler.

This paper provides an overview and analysis of the AQCS design basis, emissions requirements, performance requirements, and field data from the first months of operation. The paper will provide a summary of the critical PJFF performance parameters, including: pulse cleaning system performance, differential pressure, and utility consumption.

INTRODUCTION

The main fuel for the bubbling fluidized bed (BFB) boiler is hogged woody biomass and other non-chemically treated wood and wood residue materials. The boiler is also capable to burn paper sludge, but no sludge has been used in the plant thus far. The boiler and steam turbine provide power for the pulp and paper facility. Refer to Table 1 below for basic unit information.

Table 1. Basic Unit Information.

Description	
Boiler	
Supplier	Andritz Inc.
Type	Bubbling Fluidized Bed (BFB)
Fuel	Woody Biomass
Main Steam Flow	

Mass Flow	650,000 lb/hr
Temperature	975 °F
Pressure	1,525 psig
Steam Turbine Generator	
Power Output	80 MWe

The schedule and timing of this particular project is significant in relation to the EPA Boiler MACT regulations.

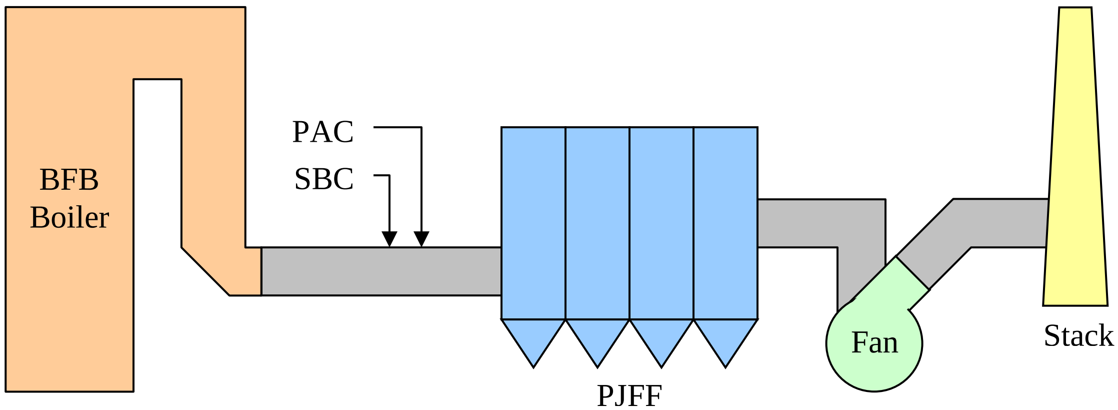
The air quality control system for the boiler was awarded to Foster Wheeler (formerly Siemens Environmental Systems & Services and Wheelabrator) in mid-2011 when the then-current version of the Boiler MACT required very low outlet emissions on new biomass fluidized bed boilers.[1] The AQCS for this project was designed to achieve the March 21, 2011 Boiler MACT emissions requirements for PM, HCl, Hg, and Dioxins/Furans (Table 2), as well as additional permit emissions requirements: PM_{10}, $PM_{2.5}$, Opacity, SO_2, HF, and H_2SO_4.

Table 2. Performance Requirements.

Primary "Back-End" Pollutants New—Biomass Fluidized Bed	**Boiler MACT March 21, 2011**	**Boiler MACT January 31, 2013**
Particulate Matter, Filterable (PM)	0.0011 lb/mmBtu	0.0098 lb/mmBtu
Hydrogen Chloride (HCl)	0.0022 lb/mmBtu	0.022 lb/mmBtu
Mercury (Hg)	3.5×10^{-6} lb/mmBtu	8.0×10^{-7} lb/mmBtu

Foster Wheeler designed an air quality control system that includes a sodium bicarbonate (SBC) injection system, powdered activated carbon (PAC) injection system, and a long-bag intermediate pressure pulse jet fabric filter (PJFF). The sorbents are injected immediately downstream of the air heater outlet and are dispersed by a venturi duct section upstream of the PJFF. The clean flue gas is ducted from the PJFF to a single centrifugal ID fan, then from the fan to the discharge stack. Refer to Figure 1.

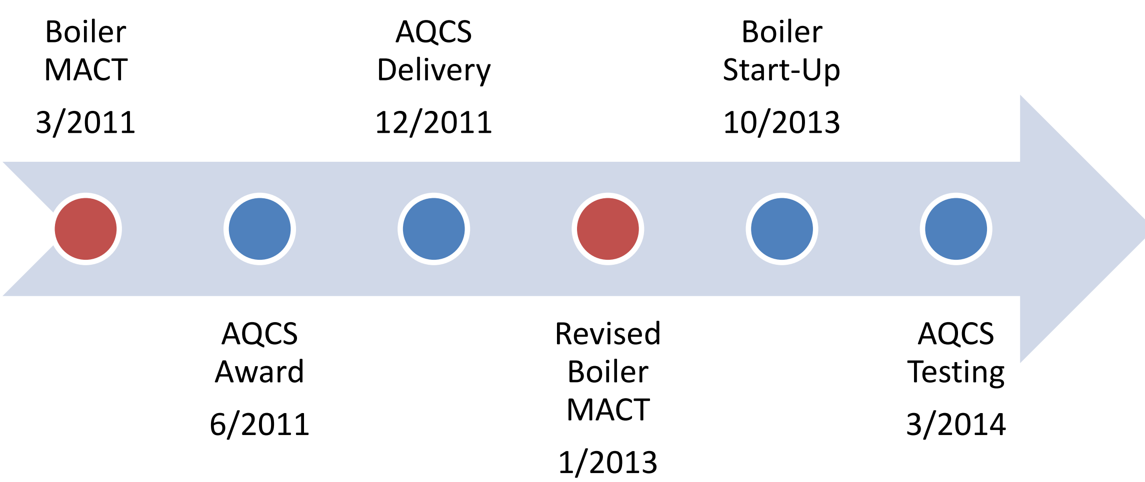
Figure 1. Flue Gas Train.



The PAC, SBC, and pulse jet fabric filter equipment was engineered and delivered by Foster Wheeler in approximately six (6) months. The contract required delivery of the AQCS equipment in December 2011. Field assembly was completed according to the project schedule in the Spring of 2013.

After the AQCS design and supply portion of the project was complete, the Boiler MACT was revised by the EPA in January 2013.[2] The initial boiler start-up occurred in October 2013 and performance testing occurred in March 2014. Refer to Figure 2 below.

Figure 2. Project Progression.



PROJECT APPROACH

The detailed design basis for the various boiler loads at the air heater outlet is shown below in Table 3.

Table 3. AQCS Design Basis.

	Normal	Low Ash	Max Volume	Max Ash
Boiler Heat Input				
mmBtu/hr	890	867	972	940
Flue Gas AH Out				
lb/hr	1,074,591	1,038,573	1,183,949	1,127,565
ACFM	402,100	374,723	448,702	428,146
Temperature (°F)	320	320	338	329
Pressure (in. w.g.)	-7.6	-6.6	-9.2	-8.5
Primary Pollutants				
SO_2 (lb/mmBTU)	0.042		0.225	
HCl (lb/mmBTU)	0.036		0.071	
H_2SO_4 (lb/mmBTU)	0.002		0.009	
Hg (lb/TBTU)	12.9		27.5	
Particulate				
lb/hr	10,259	2,436	3,183	18,216
lb/mmBTU	11.53	2.81	3.27	19.38
gr/acf	2.98	0.76	0.83	4.96

Foster Wheeler designed and supplied a modular pulse jet fabric filter in order to minimize the field labor and construction. The PJFF includes a total of eight (8) modules, and is capable of operating and meeting emissions requirements with one (1) module off-line for maintenance. Each module is fully shop-assembled with walls, hopper, roof, tubesheet, etc.

Due to the 10 meter (32 ft. 10 in.) long filter bag length utilized for this project, Foster Wheeler selected the intermediate pressure intermediate volume (IPIV) Jet VIP pulse cleaning system. The Jet VIP pulse cleaning system utilizes double diaphragm pulse valves, large capacity pulse air headers, and variable-hole manifold pipes for equal cleaning.

The Jet VIP pulse jet fabric filter also utilizes a split-gas vertical baffle in each module to lower the overall can velocity at the bottom of the filter bags. The vertical baffle also increases large particle drop-out prior to the filter bags. The low can velocity design allows the PJFF to clean on-line, reduces re-entrainment, reduces pulse cleaning, and extends bag life.

The detailed PJFF equipment sizing and selection is shown in Table 4 below.

Table 4. Pulse Jet Fabric Filter Equipment Sizing.

Description	
PJFF Arrangement	
No. of PJFF Casings	1
No. of Modules per Casing	8
Module Arrangement	Double Width
Bag Array (Per Module)	
Bag Quantity (Width Direction)	22
Bag Quantity (Depth Direction)	17
Bag Quantities	
No. of Bags per Module	374
No. of Bags Total	2,992
Bag Size	
Bag Diameter (Nominal)	5"
Bag Length	10 meters (32 ft. 10 in.)
Filter Material	PPS with ePTFE Membrane
Cloth Area	
Cloth Area per Module	16,058 ft^2
Cloth Area Total	128,464 ft^2

With the above PJFF selection, the resulting air-to-cloth ratios at the various load conditions are as follows in Table 5.

Table 5. Air-to-Cloth Ratios.

	Normal	Low Ash	Max Volume	Max Ash
ACFM	402,100	374,723	448,702	428,146
Air-to-Cloth Ratio				
All Modules On-Line (ft/min)	3.13	2.92	3.49	3.33
1 Module Off-Line (ft/min)	3.58	3.33	3.99	3.81

RESULTS AND DISCUSSION

The BFB boiler and air quality control system began initial operation in October 2013. The pulse jet fabric filter and sorbent injection systems were started-up per Foster Wheeler's recommended procedures and no major AQCS equipment malfunctions were experienced during this period. The PJFF filter bags were pre-coated with perlite.

During the initial start-up period, the PJFF pressure drop was very low and the pulse cleaning cycles were initiated by the built-in backup timer.

Actual Operating Conditions

Emission testing was conducted in March 2014, approximately five (5) months after the initial boiler start-up. During the first day of testing, three (3) PM test runs were conducted. The flue gas volumetric flow was measured at the discharge stack according to EPA Method 2 and corrected to the PJFF inlet conditions in Table 6. Flue gas temperature and pressure data at the PJFF inlet was recorded with installed instrumentation.

Table 6. Operating Conditions at PJFF Inlet.

	PM Run #1	PM Run #2	PM Run #3
Flue Gas Conditions			
Flue Gas Volume (ACFM)	410,327	400,303	402,713
Flue Gas Temperature (°F)	278	278	278
Flue Gas Static Pressure (in. w.g.)	-11.86	-11.69	-11.51
Air-to-Cloth Ratio			
Gross (ft/min)	3.19	3.12	3.13

Emissions Results

The AQCS system emissions met all required permit and Boiler MACT levels (Table 7, Figure 3, and Figure 4). The filterable particulate emissions did not measure below the previous 2011 Boiler MACT limit of 0.0011 lb/mmBtu, or approximately 1.5 mg/Nm^3 (dry). PM testing was conducted per EPA Method 5.

Table 7. Emissions Results.

Primary "Back-End" Pollutants New – Biomass Fluidized Bed	Boiler MACT March 21, 2011	Boiler MACT January 31, 2013	Test Results March 2014
Particulate Matter, Filterable (PM)	0.0011 lb/mmBtu	0.0098 lb/mmBtu	0.0024 lb/mmBtu
Hydrogen Chloride (HCl)	0.0022 lb/mmBtu	0.022 lb/mmBtu	0.0011 lb/mmBtu
Mercury (Hg)	3.5×10^{-6} lb/mmBtu	8.0×10^{-7} lb/mmBtu	1.64×10^{-8} lb/mmBtu

Figure 3. Particulate Matter & Hydrogen Chloride Results.

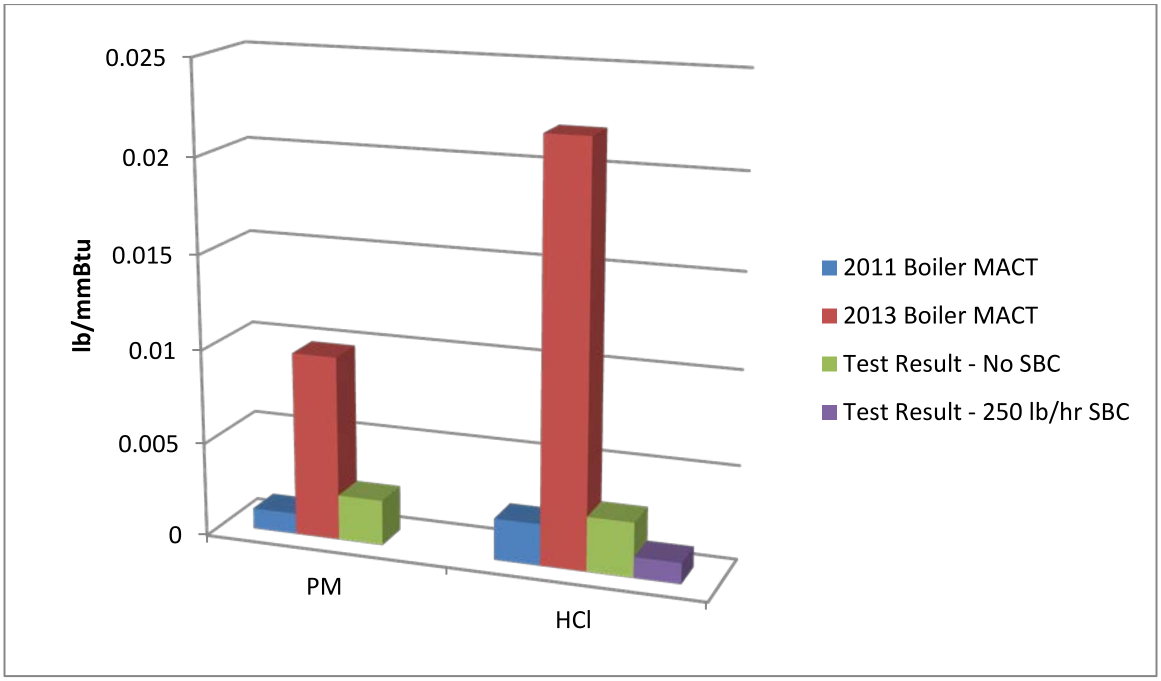
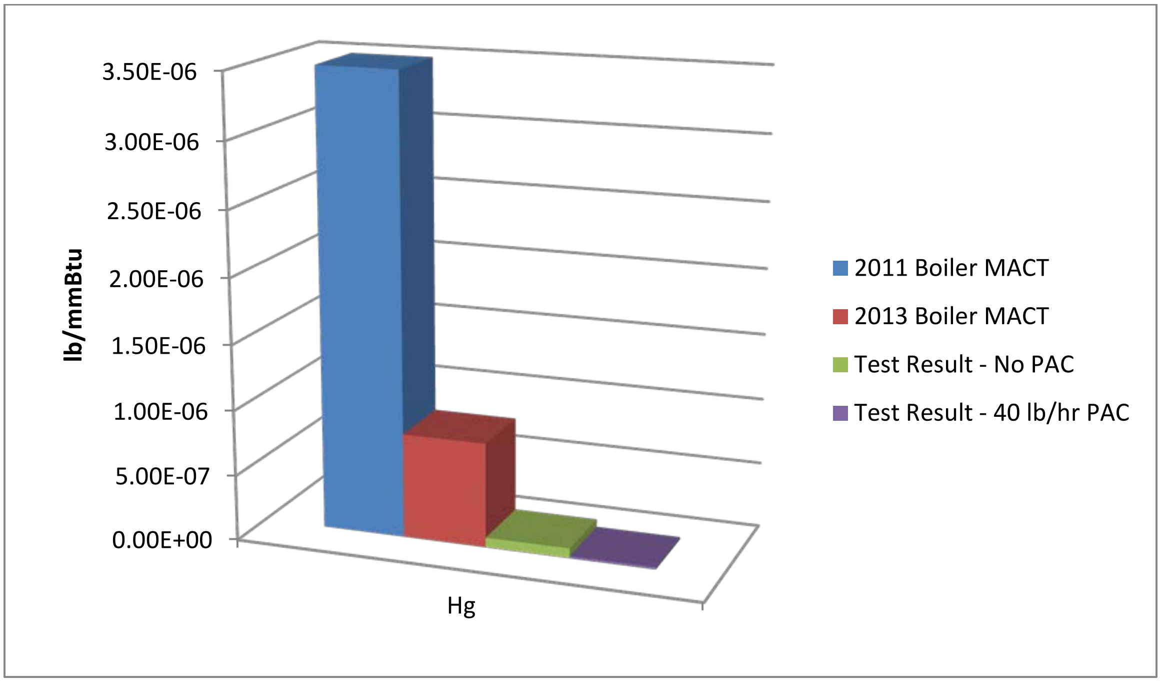


Figure 4. Mercury Results.



As shown in Table 8 below, the probe rinse portion of the filterable PM catch varied from 62% – 88% of the total catch. The amount of PM captured on the filter was very low, and in some cases approached the accuracy of the laboratory scale (0.0001 g). These results suggest that the majority of PM was not related to the process but instead due to measurement artifacts likely created in the test probe, due to the presence of NH_3 reacting with acid gases. For these reasons, Foster Wheeler suspects the actual PM emission rate is below the 2011 Boiler MACT emission rate of 0.0011 lb/mmBtu.

Table 8. Filterable PM Details.

Test Description	Run Time	Filter Catch	Probe Rinse	Total PM	lb / mmBtu
Preliminary Test: 12/12/2013	1 hour	0.0018 g 20%	0.0074 g 80%	0.0092 g 100%	0.0063
Preliminary Test: 01/07/2014	1 hour	0.0004 g 15%	0.0022 g 85%	0.0026 g 100%	0.0017
Preliminary Test: 02/19/2014	3 hours	0.0006 g 12%	0.0045 g 88%	0.0051 g 100%	0.0017
Performance Test: 03/26/2014	3 hours	0.0038 g 38%	0.0062 g 62%	0.0100 g 100%	0.0024

In order to accurately and reliably measure low level filterable PM emissions at the 2011 Boiler MACT level of 0.0011 lb/mmBtu (approximately 1.5 mg/Nm^3 (dry)), additional testing in accordance with EPA Method 5i[3] may be required:

- Improved sample handling procedures
- Light weight sample filter assembly
- Use of low residue grade acetone
- All glass, grease free, sample train components
- Paired sample trains for precision
- Increase sample catch, extend test duration

Because the subject boiler must only demonstrate 0.0098 lb/mmBtu with the revised Boiler MACT, testing per EPA Method 5i was not conducted for this project.

PJFF Differential Pressure

The flange-to-flange pulse jet fabric filter differential pressure and tubesheet differential pressure was measured and recorded concurrent with the particulate testing periods. The inlet and outlet plenum static pressure was measured by installed instrumentation and recorded in the DCS control system. The dP values reported in Table 9 are the time-averages for each PM test period.

Table 9. Flange-to-Flange Differential Pressure.

	PM Run #1	PM Run #2	PM Run #3
Inlet Static Pressure (in. w.g.)	-11.86	-11.69	-11.51
Outlet Static Pressure (in. w.g.)	-17.66	-17.48	-17.19
PJFF Differential Pressure (in. w.g.)	5.80	5.79	5.68

Based on Foster Wheeler experience and other industry resources, primary collectors in similar applications will operate between 5 – 8 in. w.g.

The tubesheet differential pressure for each module was measured by local Magnehelic gauges at 10-minute intervals and averaged over a 1-hour period. Table 10 below shows the time-averaged tubesheet differential pressure for each individual PJFF module.

Table 10. Tubesheet Differential Pressure.

PM Run #1				PM Run #2				PM Run #3		
Module 7 3.6”		Module 8 4.7”		Module 7 3.5”		Module 8 5.8”		Module 7 3.5”		Module 8 4.5”
Module 5 4.0”	PJFF Plenum	Module 6 4.8”		Module 5 4.0”	PJFF Plenum	Module 6 3.5”		Module 5 4.1”	PJFF Plenum	Module 6 3.5”
Module 3 4.0”		Module 4 3.5”		Module 3 3.9”		Module 4 3.5”		Module 3 4.0”		Module 4 3.5”
Module 1 5.8”		Module 2 3.9”		Module 1 4.3”		Module 2 4.0”		Module 1 4.9”		Module 2 4.3”
↑ Gas Flow Direction				↑ Gas Flow Direction				↑ Gas Flow Direction		

In Table 11 below, the “Mechanical dP” is calculated for the flange-to-flange PJFF. The “Mechanical dP” is the pressure loss associated with the PJFF plenums, damper openings, gas flow baffles, etc. Based on Foster Wheeler experience, the “Mechanical dP” for the Jet VIP pulse jet fabric filter varies from 1.5 – 2.5 in. w.g.

Table 11. Differential Pressure Summary.

	PM Run #1	PM Run #2	PM Run #3
PJFF Differential Pressure (in. w.g.)	5.80	5.79	5.68
Average Tubesheet dP (in. w.g.)	4.3	4.1	4.1
Mechanical dP, Calculated (in. w.g.)	1.5	1.7	1.6
dP Balance			
Tubesheet dP Standard Deviation	0.78	0.75	0.58

As shown in Table 11 above, the tubesheet differential pressure became noticeably better distributed by PM Run #3 with a standard deviation of 0.58 in. w.g. This improvement is attributable to a few isolated equipment issues that were causing certain modules to clean more than others during PM Run #1. The issues were diagnosed by Foster Wheeler and remedied at the end of PM Run #1. Refer to the Equipment Issues section below for additional details.

Pulse Cleaning System Performance

The pulse cleaning frequency was measured and recorded concurrent with the particulate testing periods. The PJFF was monitored from the penthouse enclosure and pulses were manually counted with a hand-held counter. Refer to Table 12.

Table 12. Pulse Cleaning Frequency.

	PM Run #1	PM Run #2	PM Run #3
No. of Pulses (1 hr)	179	134	137
Pulses / Bag / Day	24.4	18.3	18.7
Cleaning Cycle Duration	58.9 min	78.8 min	77.1 min

Based on Foster Wheeler experience and other industry resources, primary collectors in similar applications will clean between 6 – 48 p/b/d. The maximum recommended pulse cleaning frequency for acceptable bag life is 150 p/b/d.[4]

Similar to the tubesheet dP balance performance improvement that was witnessed from PM Run #1 to PM Run #3, the pulse cleaning frequency improved from approximately 24 p/b/d to 19 p/b/d by PM Run #3.

Utility & Sorbent Consumption

The instrument air consumption of the PJFF is calculated in Table 13 below based on the observed pulse cleaning frequency and the expected pulse valve performance.

Table 13. Instrument Air Consumption.

	PM Run #1	PM Run #2	PM Run #3
No. of Pulses (1 hr)	179	134	137
Pulse Volume (Assumed)	11.9 scf	11.9 scf	11.9 scf
Instrument Air Consumption (Average)	35.5 scfm	26.6 scfm	27.2 scfm

Sodium bicarbonate injection, powdered activated carbon injection, and acid gas and mercury testing occurred subsequent to the solid particulate testing period. The sorbents utilized during testing were: Solvay Chemicals SOLVAir® Select 300[1] and Cabot Norit DARCO® Hg-LH[2]. Various sorbent consumption rates and the corresponding acid gas and mercury emissions results are summarized in Table 14 and Table 15 below:

Table 14. Sodium Bicarbonate Consumption.

	Acid Gas Test #1	Acid Gas Test #2
Sorbent Injection Rates		
Sodium Bicarbonate Injection	0 lb/hr	250 lb/hr
Emission Results		
Hydrogen Chloride (HCl)	0.0029 lb/mmBtu	0.0011 lb/mmBtu
Sulfuric Acid (H_2SO_4)	8.59×10^{-5} lb/mmBtu	6.38×10^{-5} lb/mmbtu

[1] SOLVAir® is a registered trademark of Solvay Chemicals, Inc.
[2] DARCO® is a registered trademark of Cabot Corporation

Table 15. Powdered Activated Carbon Consumption.

	Mercury Test #1	**Mercury Test #2**
Sorbent Injection Rates		
Powdered Activated Carbon Injection	0 lb/hr 0 lb/mmACF	40 lb/hr 1.7 lb/mmACF
Emission Results		
Mercury (Hg)	7.49×10^{-8} lb/mmBtu	1.64×10^{-8} lb/mmbtu

Equipment Issues

Immediately prior to PM Run #1, Foster Wheeler personnel observed a full cleaning cycle from the PJFF penthouse and noted equipment issues that were causing the cleaning system to operate incorrectly. The issues are noteworthy since they were not resolved until PM Run #2 and account for the dP and pulse cleaning performance differences previously mentioned.

In Module #2, one (1) of the pulse valve solenoids was disconnected from the valve. This issue prevented 17 bags from being cleaned in module #2. Maintenance personnel reconnected the solenoid to the valve.

In Module #4, the "Off-Time" setting on the pulse timer board was not adjusted properly. During the pulse cleaning sequence, module #4 was cleaning two (2) pulse valves during one (1) cleaning step instead of one (1) pulse valve as originally designed. Maintenance personnel adjusted the "Off-Time" setting on the pulse timer board.

In Module #6, a single loose wire connection in the pulse timer panel was preventing 16 out of 22 pulse valves from firing. This issue prevented 272 bags from being cleaned. Maintenance personnel reconnected the wire in the pulse timer panel.

In Module #8, the "Off-Time" setting on the pulse timer board was not adjusted properly. During the pulse cleaning sequence, module #8 was cleaning two (2) pulse valves during one (1) cleaning step instead of one (1) pulse valve as originally designed. Maintenance personnel adjusted the "Off-Time" setting on the pulse timer board.

SUMMARY

The air quality control system supplied by Foster Wheeler is performing very well for the application. The boiler and the AQCS system are meeting emissions compliance, and the main performance parameters are within Andritz and Foster Wheeler design expectations. Regarding the AQCS, the following can be stated:

- Emissions are controlled to all permit and MACT levels
- PJFF differential pressure is low to average
- PJFF pulse cleaning frequency is low to average
- Utility consumption is per Foster Wheeler design

This project has demonstrated that the current Boiler MACT emission requirements are attainable for this particular application with a well-designed boiler and air quality control system.

REFERENCES

1. National Emission Standards for Hazardous Air Pollutants for Major Sources: Industrial, Commercial, and Institutional Boilers and Process Heaters, 40 CFR Part 63 (2011)

2. National Emission Standards for Hazardous Air Pollutants for Major Sources: Industrial, Commercial, and Institutional Boilers and Process Heaters, 40 CFR Part 63 (2013)

3. Method 5I—Determination of Low Level Particulate Matter Emissions From Stationary Sources, 40 CFR Part 60 Appendix A

4. Greiner, G; *Fabric Filter – Baghouses II, Operation, Maintenance and Troubleshooting (A User's Manual)*; ETS, Inc.: Roanoke, VA, 1993

KEYWORDS

pulse jet fabric filter, baghouse, biomass, Boiler MACT