Burner Test Report

WOOD Foster Wheeler Energy Ltd.

for

BOC/Hunstman

in

Teeside, United Kingdom

P.O. No.: 20105669

Witness Test Date:
September 23rd, 2020

Equipment Tested:
CUBLF-6W-PSA

CallidusTechnologies, LLC
7130 South Lewis, Suite 500
Tulsa, OK 74136-5488
Phone (918) 496-7599

Project: B-9050770

Revision 0

Oct 1st, 2020

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This burner witness test was conducted at the UOP Callidus Manufacturing and Testing Facility located at
2499 Highway 16
Beggs, OK 74421-9581
(918) 267-4920

ATTENDEES DURING TESTING

Peter Holsgrove	WOOD
Richard Spires	WOOD
Shyam Pillalamarri	WOOD
James Percy	Linde/BOC

CALLIDUS TEST FACILITY PERSONNEL

Name	Title
James Dickson	Test Engineer
Teresa Thomas	Project Manager

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I. BURNER TEST

A. INSTALLATION

The burner was installed in Test Furnace #3, mounted in the center of the furnace against the firing wall (opposite the tube wall). (Information about Test Furnace #3 can be found in Appendix C)

B. EXECUTIVE SUMMARY

The burner for this project was originally designed and optimized to meet guarantee criteria in accordance with Callidus burner project B-9011196. The burner tested was a field burner delivered from the customer site. No changes to the burner design were made to affect performance.

The purpose of this project was to demonstrate the effects on emissions using a fuel with less inert CO2 in PSA fuel than was used in the original performance test. The agreed to test points performed can be found in the test procedure located in Appendix A. A complete set of all burner parameters captured during testing can be found in Appendix B

C. CONCLUSION

The burner was tested across various site conditions on forced air preheat. The final burner configuration ran stable across all operating points and was optimized to meet all design criteria.

Test point 1 was performed as specified. During testing, it was clarified that emissions for this point could not clearly be compared to the original burner test. The overall heat release for this point is comparable to that of the minimum heat release of the original test. Typically, during burner performance tests, minimum heat release points are performed with air settings remaining set at normal heat release conditions to give a worst-case condition for stability. Because of this, high excess O2 along with a cold firebox provide and a diluted NOx sample and is not corrected for in calculation. Thus, no point from the original test can easily be compared for test point 1.

Test point 2 was performed as indicated and did show a marginal increase in NOx (44.22 mg/Nm^2 corrected to specified site conditions) emissions compared to that of the original fuel (as expected) but did not exceed the guarantee of 146 mg/Nm^3.

A third test point was requested during testing to demonstrate the effect of higher excess O2 on NOx emissions. Firing rates remained unchanged from test point 2, but draft was increased to bring excess oxygen to approximately 4%. NOx emissions did increase at this point (as expected) to 53.35 mg/Nm^3 (corrected to same site conditions as test point 2) but again, did not exceed the original emissions guarantee.

Noise data was taken at both test points 1 and 2. Both test points measured below the guarantee of 80 dBa. Background noise was not measured nor removed from noise reading due to raw noise readings being below that of the guarantee.

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II. Appendix

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A. Test Procedure

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BURNER TEST PROCEDURE

Rev 1

7130 S. Lewis
Tulsa, OK 74136
Telefax (918) 496-7597
Telephone (918) 496-7599

Project Engineer	Teresa Thomas
Test Engineer	James Dickson, Godfrey Wanyama
Date Prepared	September 21, 2020
Test Date	September 24, 2020

Cust.	**WOOD Foster Wheeler Energy Limited**	**Burner**	**CUBLF-6W-PSA**	**Dwg:**	**B-9011196 - 301**	**Cap. Curve:**	**B-9011196 - 181 / 182**
PO no.	**20105669**	**Job no.**	**B-9050770**	**User:**	**BOC / Huntsman**	**Site:**	**Teeside, UK**

Performance Guarantees To Be Demonstrated

Original Guarantees: NOx: 73 ppm(vd) at 1020°C BWT CO: 100 ppm(vd) Noise: 80 dBA @ 1 meter

Emissions Recording Correction Basis: For Test Point 1, correct emissions to BWT of 890°C and 3% dry O2; For Test Point 2, correct emissions to BWT of 1020°C and 3% dry O2

Data to be recorded at test:

X	Gas Pressure	X	Amb Air Temp	X	DP Across Burner	X	Barometric Press	X	CO	X	Box Temp	X	Heat Release
X	Gas Temp	X	Comb Air Temp	X	Air Register Pos'n	X	Flame Dimensions	X	NOx	X	O2%		

Fuel	(VOL %)	Aux Fuel (NG)	PSA-30% HMU	PSA-86% HMU				
Gas		**A**	**B**	**C**				
Nat Gas		**100**	**12**	**13**				
C3H8		**0**	**0**	**0**				
H2		**0**	**65**	**50**				
CO2		**0**	**23**	**37**				
MJ/kg	**LHV**	**47.49**	**19.06**	**11.78**				
	SG	**0.619**	**0.470**	**0.680**				
	Wobbe	**50.4**	**18.4**	**13.6**				
Target	**Wobbe**	**50.4**	**18.4**	**13.5**				

Aux Fuel Site Temperature: 100°C
Aux Fuel Site Pressure Available: 200 kPa(g)
PSA Site Fuel Temperature: 25°C
PSA Site Fuel Pressure Available: 15 kPa(g)
Site Elevation: 0 m (Coastal/Sea Level) Site Relative Humidity: 90%

Test Point	Aux Heat Release MW	PSA Heat Release MW	PSA Fuel	Comb. Air Temp.	O2 vol% dry	ΔP mm H2O	Comments
TP1	0.338	0.351	B	130°C	8.0%	TBD	HMU Operation at 30% capacity; Record Noise; Emissions Corrections as stated above
TP2	0.292	1.191	C	350°C	1.9%	TBD	HMU Operation at 86% capacity; Record Noise; Emissions Corrections as stated above

Site Fuel Details

Fuel (Vol%)	Aux	PSA 30	PSA 86		Fuel	Units	Aux	PSA 30	PSA 86
CH4	85.37%	16.56%	16.54%		LHV	MJ/kg	46.20	18.03	11.26
C2H6	8.31%				HHV	MJ/kg	51.11	20.44	12.60
C3H8	2.42%				SG		0.656	0.544	0.779
C4H10	0.60%				MW		18.93	15.70	22.47
C5H12	0.16%				Wobbe		50.4	18.4	13.5
CO		8.66%	12.94%						
CO2	2.06%	20.66%	34.40%						
N2	1.07%	1.00%	0.74%						
H2		52.02%	34.58%						
H2O		1.10%	0.80%						
TOTAL	100%	100%	100%						

NOTES:

1) Beggs Natural Gas composition: 89% CH4, 8% C2H6, 1% C3H8, 2% N2

Reviewed/Approved _____ **Date** _____ **Witnessed/Approved** _____ **Date** _____

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B. Test Data

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Client	**WOOD FOSTER WHEELER**	**Work Order**	**B-9011196**
Date	**9/24/2020**	**Furnace #**	**F3**
Burner Description	**CUBLF-6W-PSA**		

Variable Name	Units								
Test Point #		1	2	3					
Time		10:09 AM	11:33 AM	12:09 PM					
Fuel Gas Composition									
Total Burner Heat Release	MW	0.64	1.48	1.49					
Fuel Gas 1 Name		B	C	C					
Heating Release - LHV	MW	0.35	1.19	1.19					
Heating Value	kj/Nm^3	10931	9710	9738					
Specific Gravity		0.471	0.684	0.681					
CO	%	0.00%	0.00%	0.00%					
NG	%	12.04%	12.96%	12.97%					
H2	%	65.00%	49.80%	50.05%					
C3H8	%	0.00%	0.00%	0.00%					
CO2	%	22.97%	37.24%	36.98%					
Fuel Gas 2 Name		A	A	A					
Heating Release - LHV	MW	0.29	0.29	0.29					
Heating Value	kj/Nm^3	35692	35692	35692					
Specific Gravity		0.622	0.622	0.622					
CO	%	0.00%	0.00%	0.00%					
NG	%	100.00%	100.00%	100.00%					
H2	%	0.00%	0.00%	0.00%					
C3H8	%	0.00%	0.00%	0.00%					
CO2	%	0.00%	0.00%	0.00%					
Pressure									
Fuel Gas 1 Tip Pressure	kPag	0.124	1.293	1.293					
Fuel Gas 1 Tip Pressure @ 77°F	kPag	0.128	1.260	1.225					
Fuel Gas 2 Tip Pressure	kPag	3.566	4.441	4.598					
Fuel Gas 2 Tip Pressure @ 212°F	kPag	4.610	5.751	6.014					
Airside Pressure Drop	mm W.C.	3.2	8.4	10.4					
Airside Pressure Drop Corrected to Site Conditions	mm W.C.	3.2	8.5	10.3					
Damper Position		WO	WO	WO					
Temperature									
Ambient Air Temperature	C	26.6	27.9	30.9					
Combustion Air Temperature	C	125.0	342.0	354.2					
Upper Furnace Temperature	C	734.1	1041.9	1026.2					
Floor Temperature	C	653.6	1000.0	974.1					
Fuel Gas 1 Temperature	C	16.4	32.9	41.7					
Fuel Gas 2 Temperature	C	15.5	14.9	12.1					
Emissions									
Actual O2 % (Dry)		8.05	2.01	3.92					
Raw NOx	PPMV	18.38	23.33	25.19					
NOx @ *** BWT	PPMV	28.65	22.37	24.94					
NOx @ 3% O2	PPMV	25.54	22.11	26.54					
NOx @ 3% O2 & *** BWT	PPMV	39.83	21.20	26.28					
NOx @ 3% O2 & *** BWT & *** CAT	PPMV	40.03	21.57	26.03					
NOx (HHV) @ *** BWT	mg/Nm^3	81.64	43.46	53.88					
NOx (HHV) @ *** BWT & *** CAT	mg/Nm^3	82.06	44.22	53.35					
Raw CO	PPMV	0.00	0.00	0.00					
CO Corrected to 3% O2	PPMV	0.00	0.00	0.00					
Flame Dimensions									
Flame Height	m.	1.2192	1.524	1.524					
Flame Width	m.	0.4572	0.4572	0.4572					
Notes		Emission Corrections: BWT: 890°C CAT: 130°C	Emission Corrections: BWT: 1020°C CAT: 350°C	Emission Corrections: BWT: 1020°C CAT: 350°C					
Damper Position are listed in number of notches from full open *** BWT and CAT temperature correction is specified below each test point									

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Client	**WOOD FOSTER WHEELER**	**Work Order**	**B-9011196**
Date	**9/24/2020**	**Furnace #**	**F3**
Burner Description	**CUBLF-6W-PSA**		

Variable Name	Units								
Test Point #		1	2	3					
Time		10:09 AM	11:33 AM	12:09 PM					
Fuel Gas Composition									
Total Burner Heat Release	MMBtu/hr	2.20	5.06	5.08					
Fuel Gas 1 Name		B	C	C					
Heating Release - LHV	MMBtu/hr	1.20	4.06	4.07					
Heating Value	Btu/SCF	293.4	260.6	261.4					
Specific Gravity		0.471	0.684	0.681					
CO	%	0.00%	0.00%	0.00%					
NG	%	12.04%	12.96%	12.97%					
H2	%	65.00%	49.80%	50.05%					
C3H8	%	0.00%	0.00%	0.00%					
CO2	%	22.97%	37.24%	36.98%					
Fuel Gas 2 Name		A	A	A					
Heating Release - LHV	MMBtu/hr	1.00	1.00	1.00					
Heating Value	Btu/SCF	958.0	958.0	958.0					
Specific Gravity		0.622	0.622	0.622					
CO	%	0.00%	0.00%	0.00%					
NG	%	100.00%	100.00%	100.00%					
H2	%	0.00%	0.00%	0.00%					
C3H8	%	0.00%	0.00%	0.00%					
CO2	%	0.00%	0.00%	0.00%					
Pressure									
Fuel Gas 1 Tip Pressure	Psig	0.018	0.2	0.2					
Fuel Gas 1 Tip Pressure @ 77°F	Psig	0.019	0.2	0.2					
Fuel Gas 2 Tip Pressure	Psig	0.5	0.6	0.7					
Fuel Gas 2 Tip Pressure @ 212°F	Psig	0.7	0.8	0.9					
Airside Pressure Drop	in. W.C.	0.13	0.33	0.41					
Airside Pressure Drop Corrected to Site Conditions	in. W.C.	0.13	0.34	0.41					
Damper Position		WO	WO	WO					
Temperature									
Ambient Air Temperature	F	79.9	82.3	87.7					
Combustion Air Temperature	F	257.0	647.6	669.6					
Upper Furnace Temperature	F	1353.4	1907.4	1879.2					
Floor Temperature	F	1208.5	1832.0	1785.4					
Fuel Gas 1 Temperature	F	61.6	91.1	107.1					
Fuel Gas 2 Temperature	F	59.8	58.9	53.9					
Emissions									
Actual O2 % (Dry)		8.05	2.01	3.92					
Raw NOx	PPMV	18.38	23.33	25.19					
NOx @ *** BWT	PPMV	28.65	22.37	24.94					
NOx @ 3% O2	PPMV	25.54	22.11	26.54					
NOx @ 3% O2 & *** BWT	PPMV	39.83	21.20	26.28					
NOx @ 3% O2 & *** BWT & *** CAT	PPMV	40.03	21.57	26.03					
NOx (HHV) @ *** BWT	lb/MMBtu	0.0600	0.0230	0.0384					
NOx (HHV) @ *** BWT & *** CAT	lb/MMBtu	0.0603	0.0234	0.0380					
Raw CO	PPMV	0.00	0.00	0.00					
CO Corrected to 3% O2	PPMV	0.00	0.00	0.00					
Flame Dimensions									
Flame Height	ft.	4	5	5					
Flame Width	ft.	1.5	1.5	1.5					
Notes		Emission Corrections: BWT: 1634°F CAT: 266°F	Emission Corrections: BWT: 1868°F CAT: 662°F	Emission Corrections: BWT: 1868°F CAT: 662°F					
Damper Position are listed in number of notches from full open *** BWT and CAT temperature correction is specified below each test point									

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C. Noise Data

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Client: **WOOD Foster Wheeler**

Date: 9/23/2020

Burner Type: **CUBLF-6W-PSA**

Job Number: **B-9050770**

Tested by: James Dickson

Time:	10:09 AM	Time:	11:33 AM
Test Pt:	TP1	Test Pt:	TP2
Fuel:	A/B	Fuel:	A/C

A	Fuel Blend %
N.G.	100

Scale / Frequency			Scale / Frequency		
A Scale	77.4	dBa	A Scale	78.8	dBa
31.5	36.5	dB	31.5	36.4	dB
63	44.2	dB	63	45.6	dB
125	49.3	dB	125	49.9	dB
250	54.3	dB	250	56.5	dB
500	60.1	dB	500	59.7	dB
1000	62.3	dB	1000	63.5	dB
2000	66.7	dB	2000	67.6	dB
4000	76.3	dB	4000	77.9	dB
8000	65.3	dB	8000	66.1	dB
16000	57.9	dB	16000	57.8	dB

B	Fuel Blend %
N.G.	12
H2	65
CO2	23

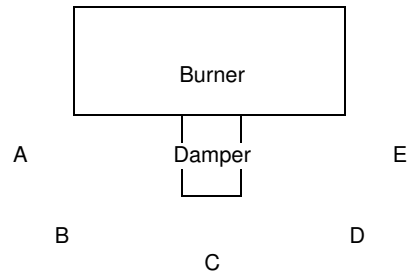
C	Fuel Blend %
N.G.	13
H2	50
CO2	37

Meter: Quest Technologies, SoundPro SE/DL

Notes:

Muffle Type: **None, Flat, Shoebox, Snorkel**

Distance From Burner Opening: 3 Feet



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D. Test Equipment

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A. Test System Configuration

The general layout for any test includes test fuel gas storage, test fuel gas blending station, a furnace, a cooling water circulation system, and a flue gas sample system.

Test Fuel gas is blended to adequately simulate site fuel gas by metering and measuring each component gas, mixing in a fuel header and delivering to the test burner. Each test fuel gas is calculated to simulate as best as possible the site fuel gas using wobbe number, heating value, and specific gravity. The burner is mounted in the most appropriate test furnace as close to the field mounting configuration as possible with regards to overall burner duty or combined burner duty. Water is circulated through process tubes in the furnace to remove heat. The temperature of the furnace is controlled as close to the design temperature as possible through insulation of the cooling tubes.

Various pressure, temperature, and differential pressure transmitters are placed in this system for measurement of all critical parameters. A vacuum pump draws a sample of the flue gas at the exit of the radiant section and delivers the sample to gas analyzers located in the Central Control Room (CCR.)

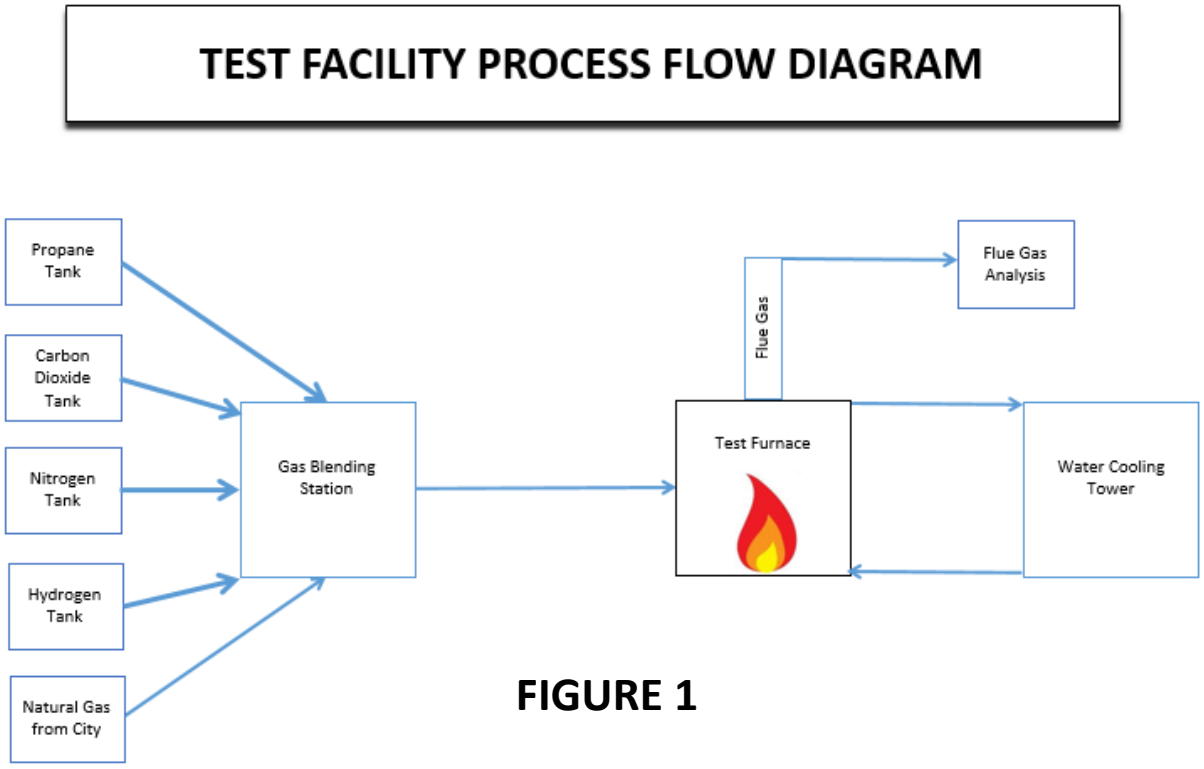


FIGURE 1

B. Test Furnace

Furnace 3: The test furnace itself is rectangular in section, measuring 6 ft. each side with an overall height of 22.5 ft. inside. Test burner is mounted in the center of the floor of the furnace firing upwards. The furnace is equipped with a 2' I.D. stack with an overall height of 50 ft. above the floor. Cooling tubes are located adjacent to one wall to simulate process tubes in a fired heater. Refractory covers the interior surfaces. Ceramic fiber is used on the walls and castable refractory covers the floor, roof, and stack. A draft connection is located at the floor and in the combustion air duct (if present for forced air applications). A temperature connection is provided at the top of the radiant section.

A suction pyrometer is located near the exit of the radiant section. A Flue Gas Sample Port is located just after the exit of the radiant section. Note: there is no convection section on this furnace. The draft across the burner is measured via a differential pressure. The downstream pressure tap is located at the roof of the furnace. The upstream pressure tap is located either, in the ducting upstream of the burner for forced draft applications, or is open to atmosphere in natural draft applications. See FIGURE 2 for Furnace Layout

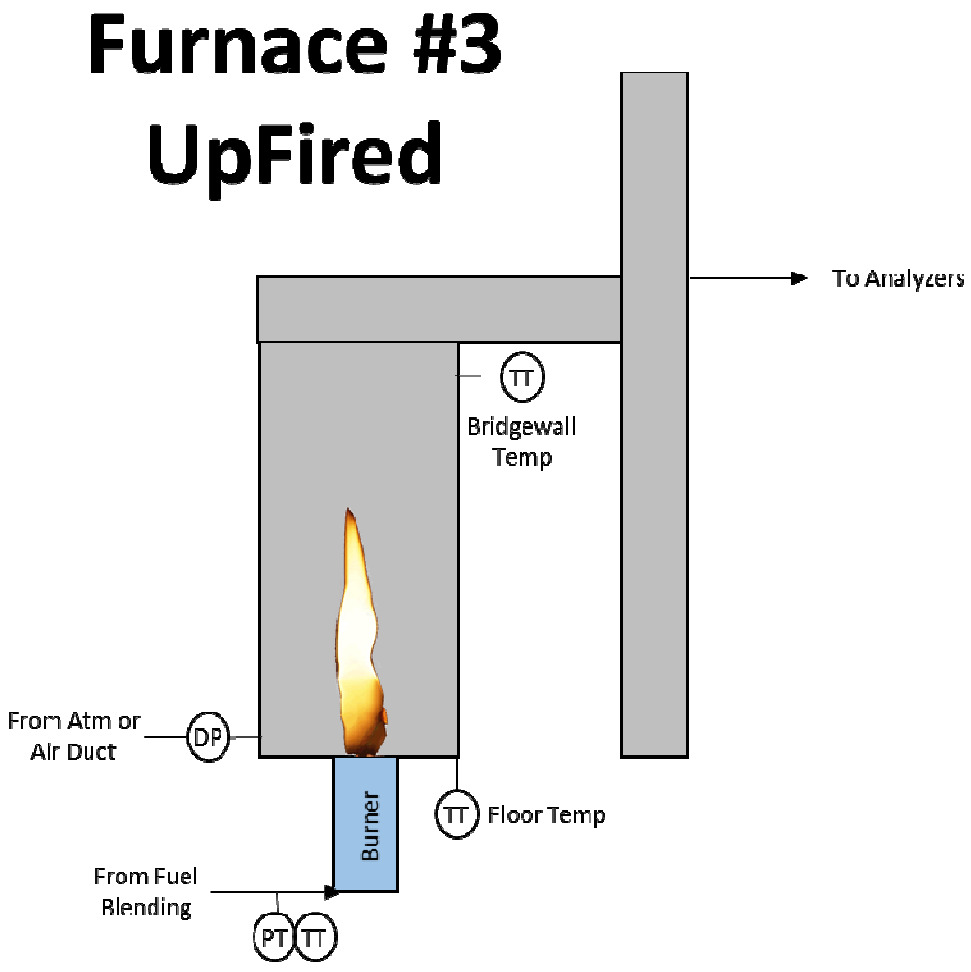


FIGURE 2

C. Instrumentation

Each component of the test fuel is controlled by automated flow control valves and measured by the use of an individual orifice run, which conforms to American Gas Association (AGA) specifications. Orifice plates are selected to provide accurate ranges of flow. Fuel temperature, orifice differential pressure and operating pressures are transmitted to the Honeywell Distributed Control System (DCS) which calculates individual component flow rate, specific gravity, and heating value. These values are totaled up and recorded to define the overall characteristics of the Test Fuel Blend. **See FIGURE 3**

A Suction Pyrometer, mounted at the end of the radiant section, measures the temperature of the radiant section / bridgewall temperature. Honeywell Wireless pressure, differential pressure, and temperature transmitters monitor furnace draft across the burner, fuel pressure, fuel temperature, and furnace temperature, all of which are transmitted wirelessly to the DCS. **Reference FIGURE 2**

Flame dimensions are ascertained visually and recorded manually unless otherwise stated.

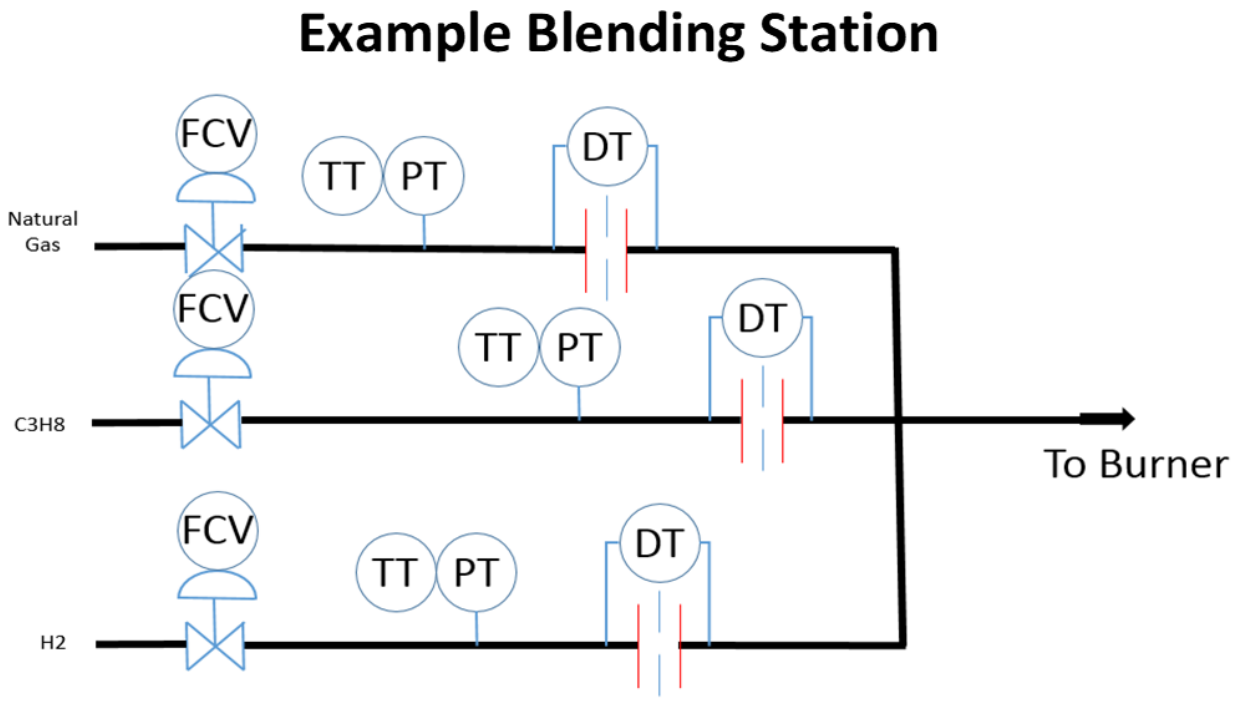


FIGURE 3

D. Flue Gas Sampling

Flue gas samples are drawn from the end of the radiant section through a heated stainless steel line by the use of a Vacuum Diaphragm Pump. Water is removed from the sample gas via a Thermoelectric Gas Cooler of make and model common in refinery CEMS, then delivered to analyzers for analysis.

NO_X content is measured using Chemlumonescence detection. Excess Oxygen content is measured using Paramagnetic detection. Carbon Monoxide content is measured using Infrared detection. All of the instruments are calibrated using certified zero and span gases in the operating range of the test facility. Calibration of the meters are done before and after each test, and at any time that there is questionable data. **See FIGURE 4**

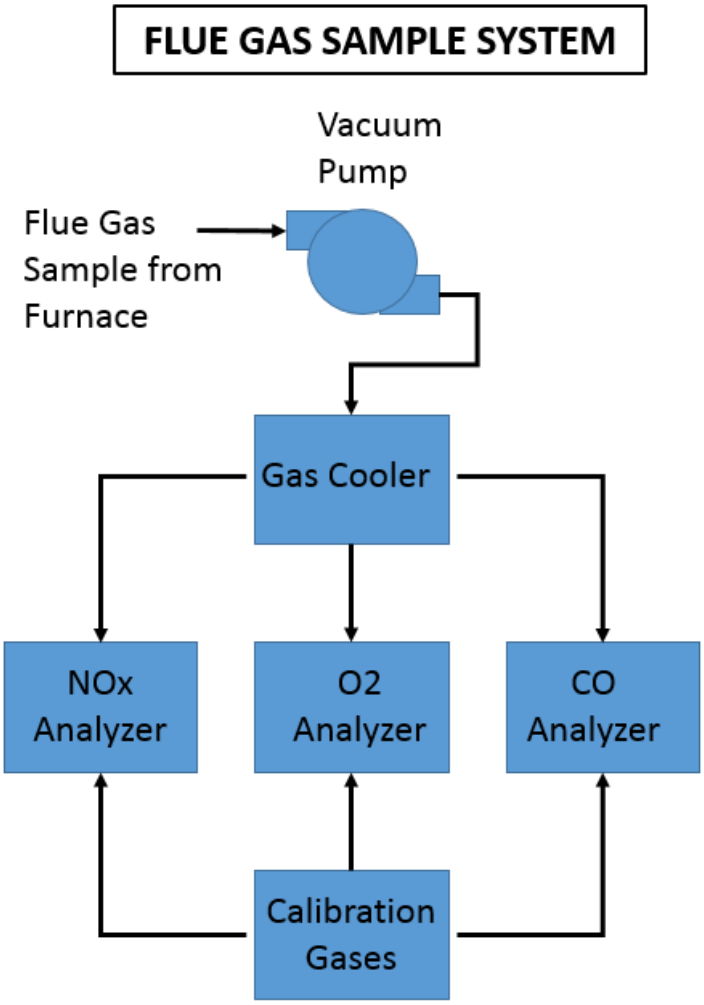


FIGURE 4

E. Data Acquisition and Reduction

All field instruments and flue gas analyzers transmit to a Honeywell Distributed Control System. These process variable signals are converted from analog to digital then to engineering units in the DCS. All flow calculations are also made by the DCS. The converted and calculated process variables then populate a spreadsheet specifically designed to calculate critical values that cannot be measured directly, such as Fuel Heating Value, Specific Gravity, percentage (%) of total flow for each fuel, etc.

The spreadsheet also calculates corrected values for NO_x and CO based on deviation from design Excess Oxygen, site Furnace Temperature, and site Combustion Air Temperature. Correction for Excess Oxygen is performed using EPA methods. Correction for Furnace Temperature and Combustion Air Temperature are performed using empirical, proprietary curves and equations developed specifically for each type of Callidus burner through extensive testing. These curves are similar to those found in API 535.

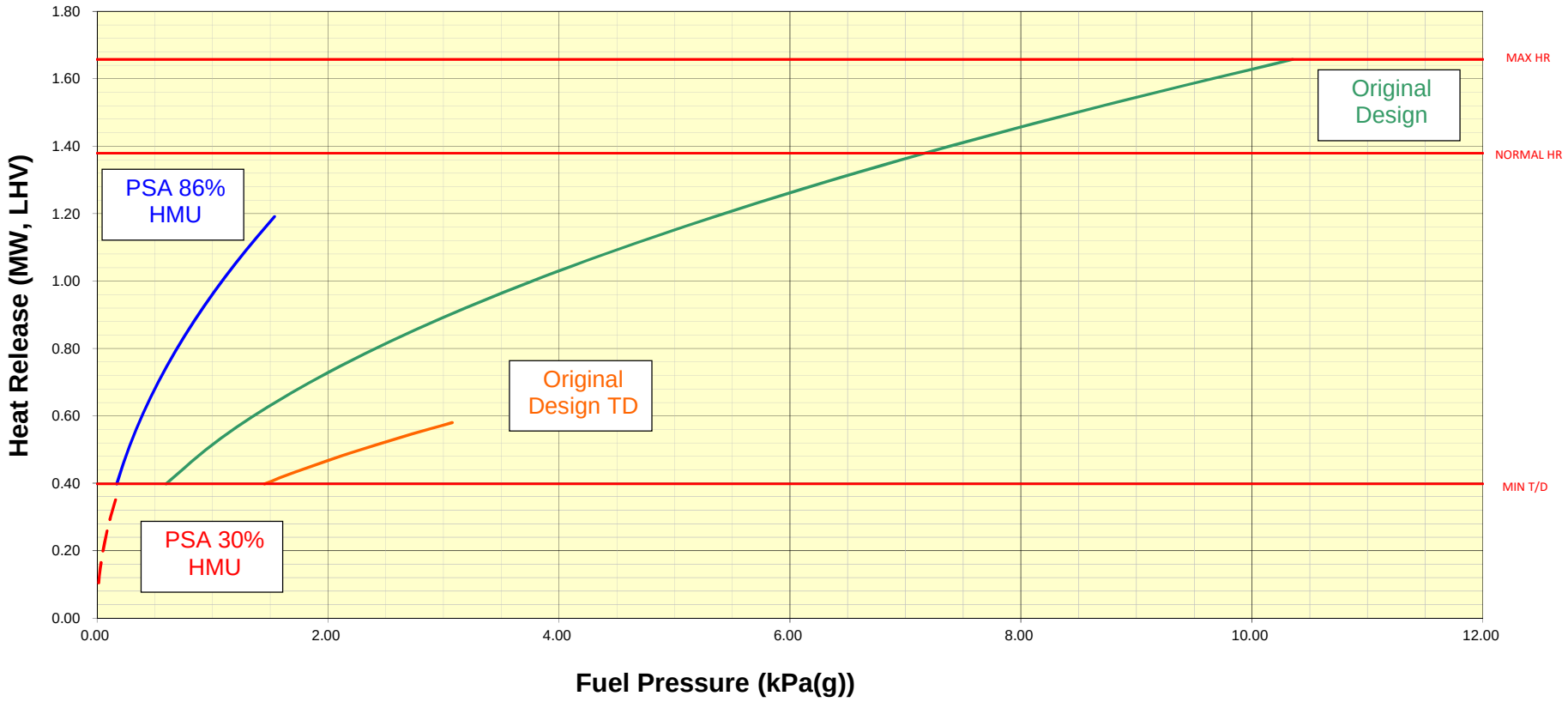
Pressure Loss (Draft) across the burner is corrected for deviation from design site elevation (atmospheric pressure), site humidity, and combustion air temperature. Fuel pressure is corrected for deviation from design fuel temperature.

Data is acquired by the system every one (1) second. The DCS provides a ten (10) second rolling average to the spreadsheet. When equilibrium is attained for a particular operating condition, the data is saved.

Customer:	Amec Foster Wheeler Energy Ltd
End User:	BOC Hydrogen Plant Teeside
Heater #	H-101
W.O. #	B-9011196
P.O. #	28612-MP-003
Burner:	CUBLF-6W-PSA
Ref. Drawing:	DB-9011196-301
Cap. Curve #:	AB-9011196-182

FUEL INFORMATION

DESIGNATION		PSA 30% HMU	PSA 86% HMU	Original Design	Original Design TD
HEATING VALUE (LHV)	MJ/kg	18.03	11.26	8.47	5.29
HEATING VALUE (HHV)	MJ/kg	20.44	12.60	9.46	6.04
SPECIFIC GRAVITY		0.544	0.779	0.883	0.933
MOLECULAR WEIGHT		15.70	22.47	25.48	26.91
FUEL TEMPERATURE @ BURNER	°C	25	25	25	25
FUEL PRESSURE @ BURNER (Available)	kPa(g)	15.0	15.0	15.0	15.0



Rev. 3		Date:		By:
Rev. 2	Added new conditions per B-9050770 Performance Testing	Date:	1-Dec-20	By: MPS
Rev. 1	PER FINAL TEST CHANGES, ADDED LINES FOR MAX, NORMAL AND MIN	Date:	12-Oct-16	By: DEW
Rev. 0	FOR APPROVAL	Date:	9-Jun-16	By: DEW