Combustion Tests of Ethyl Levulinate Biofuel in a Commercial Boiler

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Introduction

Ethyl Levulinate (EL) is an advanced cellulosic biofuel derived from wood waste. In the process this waste is converted into a liquid fuel which can be considered for use in stationary boilers, furnaces and engines [1-4]. Biofine Development Northeast, Inc. (BDNE) is currently working toward the commercialization of this fuel for this market in the Northeast. A basic comparison of the properties of EL and petroleum-based No. 2 heating fuel is provided in Table 1, below. As can be noted, EL is an oxygenated fuel with a higher density than petroleum No. 2 and a much lower volumetric heating value.

Table 1 Comparison of the Basic Properties of Petroleum No. 2 Heating Fuel and Ethyl Levulinate (EL)

	Petroleum No. 2 Heating Fuel	Ethyl Levulinate (EL)
Higher Heating Value (Btu/gal)	139,000	95,500
Density (lb/gal)	7.1	8.5
C (wt %)	86.8	58.3
H (wt %)	13.2	8.3
O (wt%)	0	33.3

In collaboration with BDNE and the Dead River Company of Portland Maine, the National Oilheat Research Alliance (NORA) has been exploring the technical aspects of the potential use of EL as a heating fuel. This work has included lab combustion tests and field trials of 10% blends of EL in petroleum No. 2 heating fuel and limited field tests of the combustion of 100 % EL in a residential and a commercial burner. NORA has also done considerable in-lab testing of 100% EL in residential burners and studies of material compatibility and EL.

The goal of this test was to obtain a set of data that provides a direct comparison of the combustion performance of EL and petroleum No. 2 in a commercial boiler under carefully controlled, steady state conditions. These tests were done in the development lab of Carlin Combustion Technologies, a major burner manufacturer in North Haven, Connecticut on November 24, 2020. Tests were done at a nominal input rate of 1.4 million Btu/hr. NORA does not have in-lab capability to test at this high rate. For comparison, a typical residential boiler has an input rate of 0.14 million Btu/hr. Further, testing in the field, in an operating commercial building, does not provide the ability to run under steady state conditions continuously.

Experimental

Tests were conducted in a Weil-McLain 688 Cast Iron Section boiler configured with direct cold water at the boiler inlet. In the field, boilers of this type operate with much higher temperatures at the boiler inlet but with large boilers of this type it is common practice to test with cold water in, simply to reduce the water flow rate required to enable the burner to run continuously without cycling. The burner installed in the boiler for this test was a Carlin 601 CRD.

With EL as a fuel, conventional pump seal materials such as nitrile cannot be used. For this test NORA configured a pump with EL compatible seals. This included silicon-based seals and a pump shaft lip seal made of a Teflon-graphite composite material. For testing on petroleum No. 2 oil, a conventional, unmodified pump was used. In both cases the burner was configured for a single firing rate. The tests were conducted with a nominal heat input rate with both fuels of 1.4 million Btu/hr. Because the heating value of the two test fuels is different, a different size nozzle and pump pressure was used for the two cases. For the EL test nominal 9.5 gph nozzle with an operating pressure of 250 psi was used. For petroleum No. 2 oil an 8.0 gph nominal rate nozzle with an operating pressure of 150 psi was used. Both nozzles are manufactured by Hago and have a 60-degree nominal fuel spray angle.

The EL fuel was provided from 55-gallon shipping drums for this test. The petroleum No. 2 fuel was provided from the normal lab fuel supply tank. Flue gas analysis was done using an Ecom instrument with wet electrochemical cell sensors. Figure 1 provides a photo of test lab as arranged for this test.

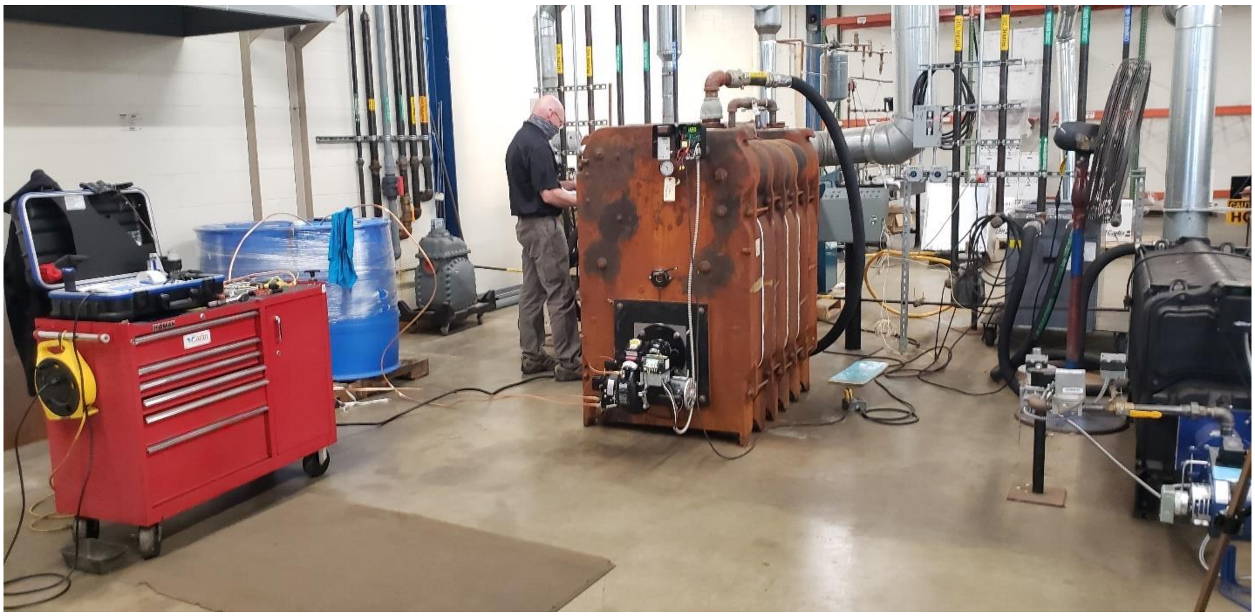

Figure 1 Test arrangement

Testing was started with EL. Once steady boiler temperature was reached the burner air flow was adjusted to obtain operating data over a range of excess air levels. Following this the burner was converted to operation with petroleum No. 2 heating fuel and the procedure repeated.

Results

With both fuels, the burner ran with a stable flame over a wide excess air range. Result parameters here are presented as a function of excess air. This was calculated based on measured flue gas oxygen and using the ultimate analysis (C,H,O) for each of the fuels.

Figure 2 shows as-measured flue gas CO as a function of excess air for both fuels.

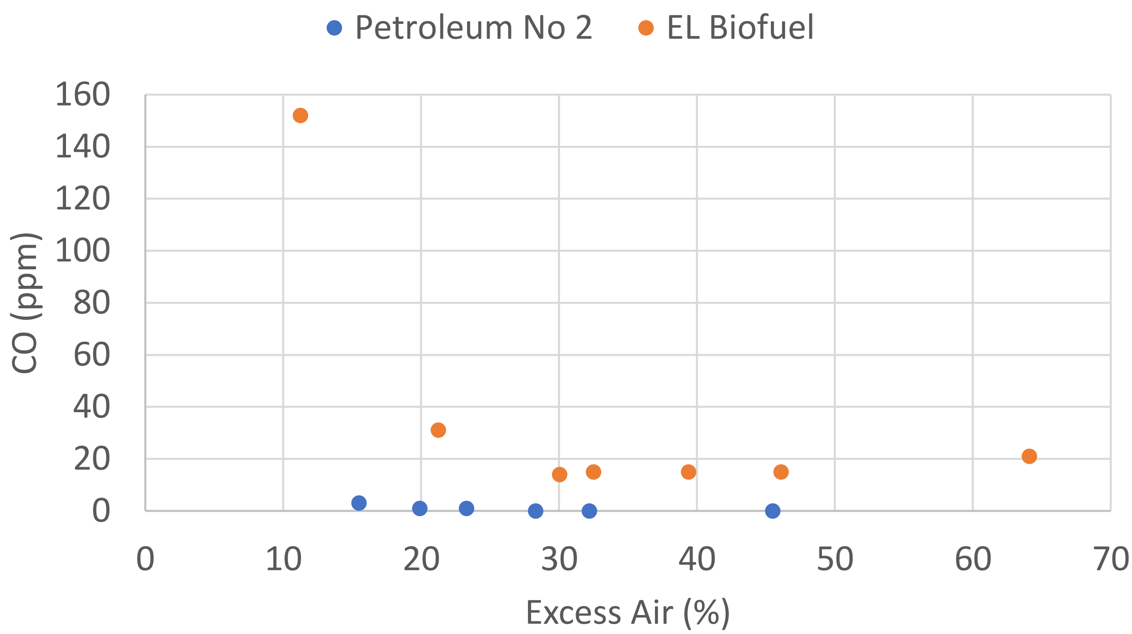

Figure 2 Measured flue gas CO vs. excess air.

The flue gas CO was higher with EL although the levels with both fuels are very low and certainly considered to be acceptable. An exception is the test with EL at the very lowest excess air where the CO rose to 150 ppm. With burners of this type it is typical that CO increases as the low excess air limit is reached. Smoke number was measured for all test conditions but was found to be zero or, at most, #1 and certainly acceptable.

Figure 3 provides a comparison of measured flue gas NOx with both fuels and this shows significantly lower values with the EL fuel. In Figure 4 the measured NOx has been converted to units of pounds per million Btu of heat input which provides a better way to compare these two fuels. This conversion was based on the nominal ultimate analysis and heating value of these two fuels. At a mid-range excess air level of 32%, the NOx with EL is 28% lower than with petroleum No. 2 fuel.

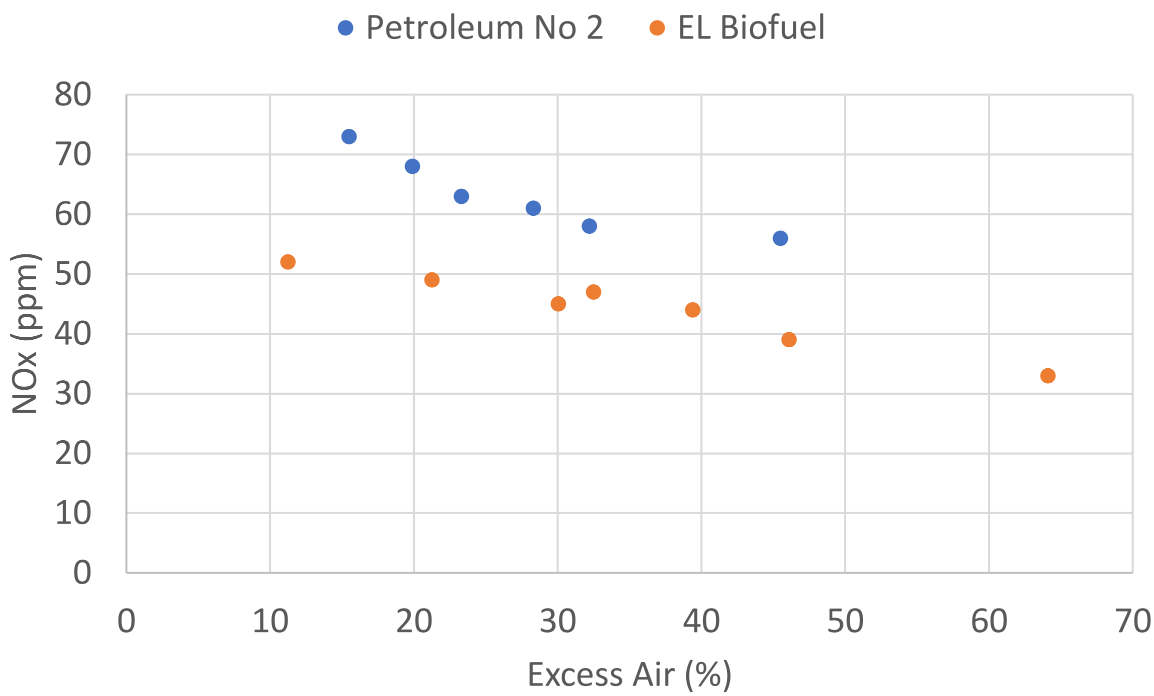

Figure 3 Measured flue gas NOx

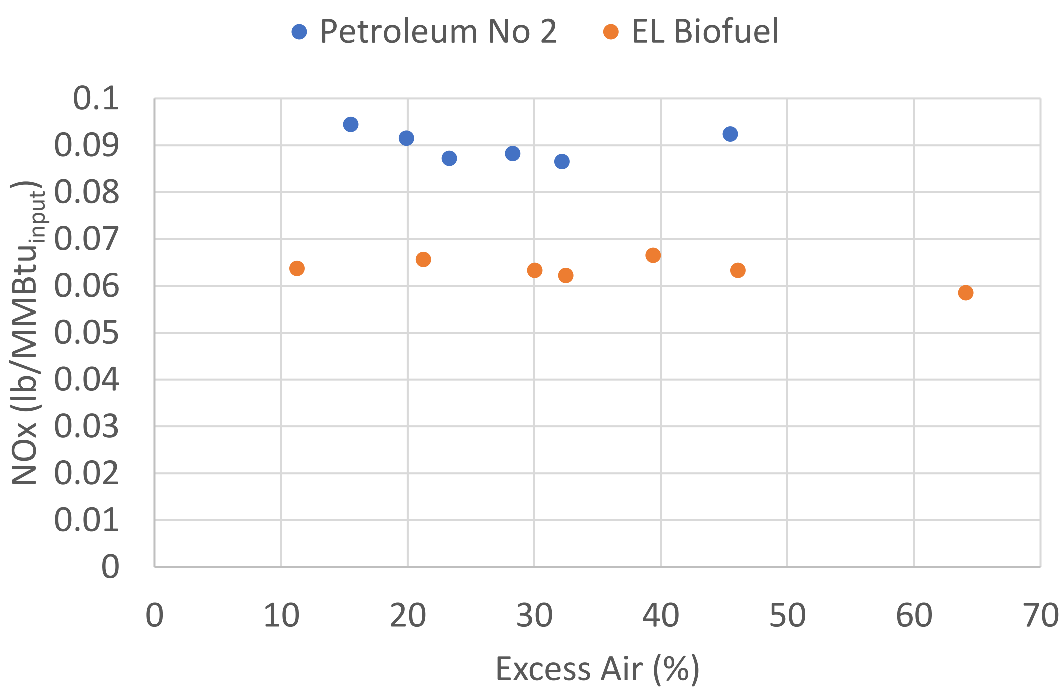

Figure 4 Comparison of fuel NOx emissions on a heat input basis

Figure 5 shows the calculated boiler efficiency for both fuels. Again, this was based on the nominal ultimate analysis and heating value for the two fuels. This is a “combustion” or “stack loss” efficiency based on excess air and flue gas temperature and so does not include jacket losses. Efficiency with both fuels are similar with EL having slightly higher values over the excess air range.

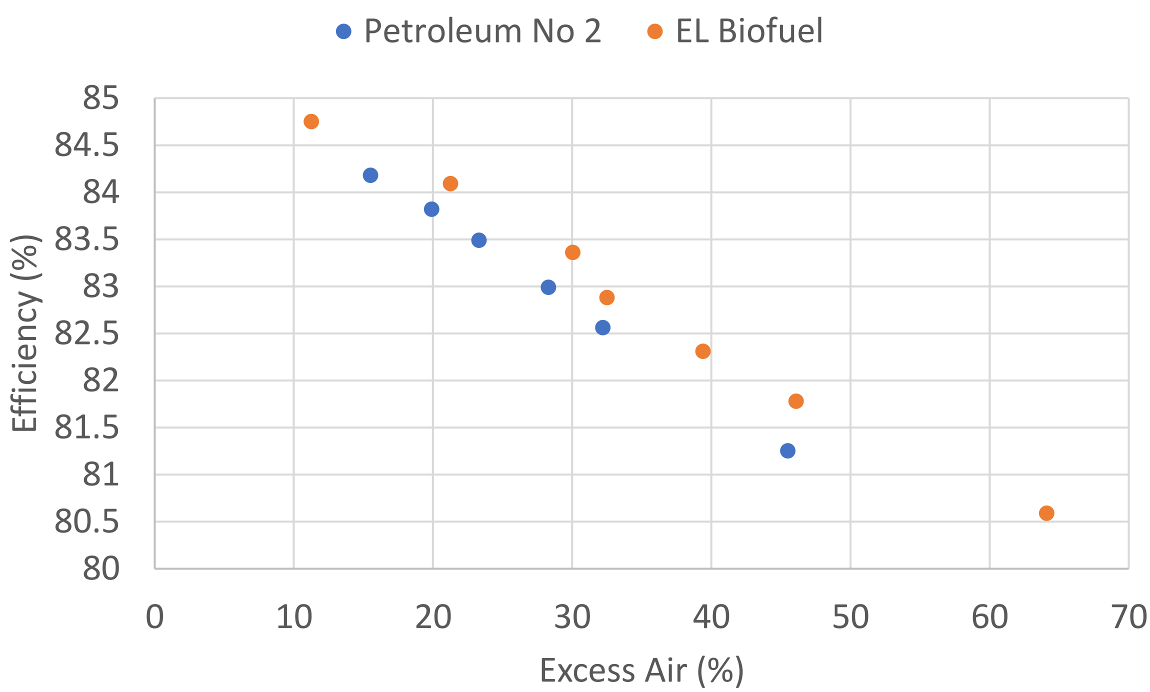

Figure 5 Boiler efficiency comparison

In Figure 6 a comparison is made of the measured flame sensor signal. This burner uses a cadmium sulfide (“cad cell”) flame sensor and the measured parameter is sensor resistance in ohms. This is very commonly used for burners in this size class. A brighter flame produces less cad cell resistance. The burner control used requires a cad cell resistance less than 5500 ohms to prove the presence of the flame and to allow continued operation of the burner fuel injection system. As shown in this figure the measured cad cell resistance with EL is much higher than with petroleum No. 2 fuel. This indicates that EL is a much less emissive flame and this is consistent with prior tests done by NORA with this fuel. In all cases the cad cell resistance with this burner was lower than the level required by the control and the burner operated without interruption.

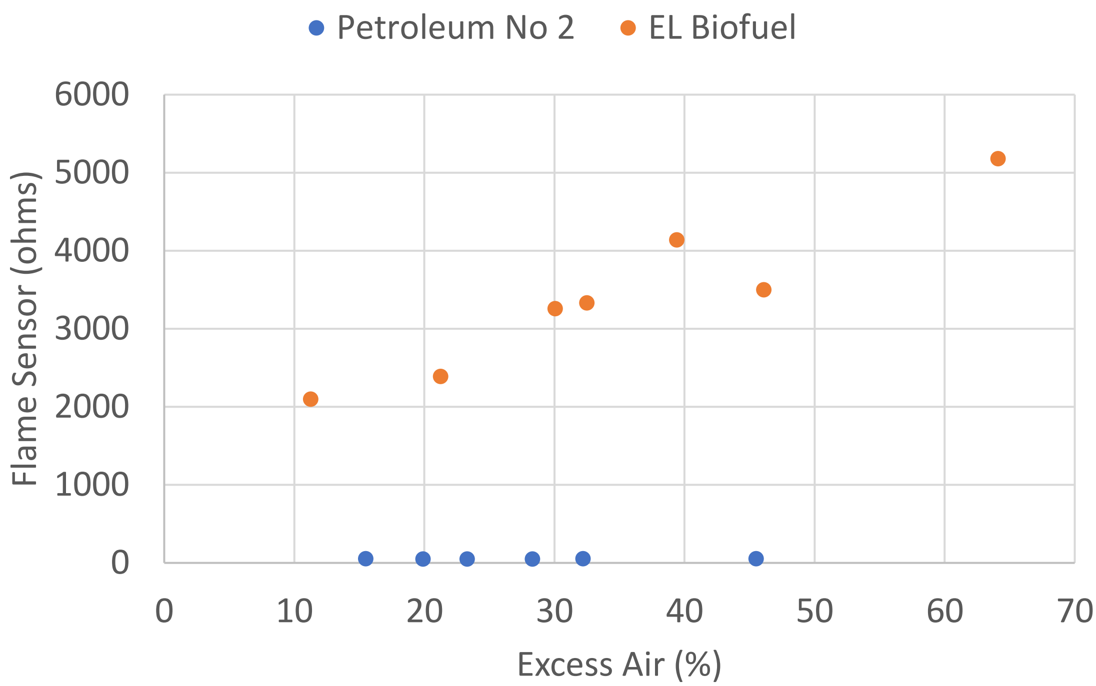

Figure 6 Flame sensor signal (cad cell ohms)

The less emissive flame with EL is likely due to the fuel oxygen which produces a "cleaner" flame. This boiler has a viewport window on the far end and the flames were inspected throughout the test with video and photos taken. Figure 7 provides a comparison of the appearance of the two flames at a similar excess air level. This shows that the EL flames are lighter and possibly more diffuse, which contributes also to the lower measured NOx. While these flame photos provide some insight, the recorded videos provide a clearer representation of the flame behavior and support the conclusion that the EL flames are much less bright.

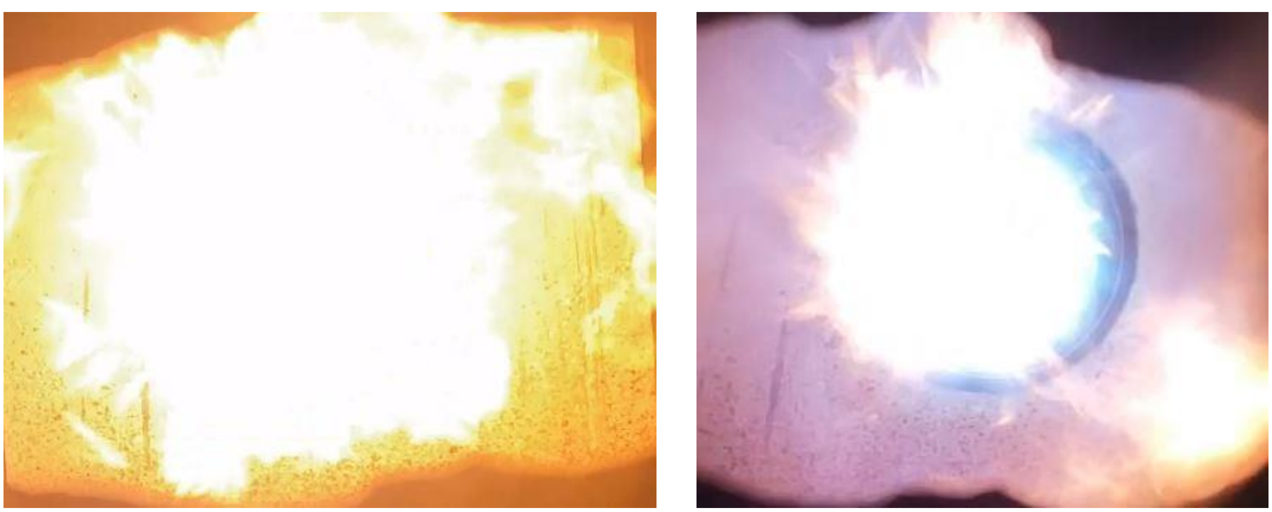

Figure 7 Comparison of the appearance of the petroleum No. 2 fuel flame (left) and the EL flame (right). Both at ~ 6.5% flue gas oxygen and a nominal input rate of 1.4 million Btu/hr.

Conclusions

Overall, these test results indicate that EL can be used as a boiler fuel. The burner was found to operate with a stable and reliable flame. NOx emissions are significantly lower with EL fuel. The flame is much less emissive than with Petroleum No. 2 fuel. While this did not cause any concerns in this test it might require changes to the flame sensing and control arrangement in some applications.

References

1. Christensen, E., Williams, A., Paul, S., Burton, S., McCormick, R.L., *Properties and performance of levulinate esters as diesel blend components.* Energy and Fuels, 2011. **25**: p. 5422-5428.
2. Joshi, H., Moser, B.R., Toler, J., Smith, W.F., Walker, T., *Ethyl Levulinate: a potential bio-based diluent for biodiesel which improves cold flow properties.* Biomass and bioenergy, 2011. **35**: p. 3262-3266.
3. Windom, B.C., Lovestead, T.M., Mascal, M. Nikitin, E.B., Bruno, T., *Advanced distillation curve analysis on ethyl levulnate as a diesel fuel oxygenate and a hybrid biodiesel fuel.* Energy and Fuels, 2011. **25**(4): p. 1878-1890.
4. Lei, e.a., *Ethyl levulinate in diesel fuel.* BioResources, 2013. **8**(2): p. 2696-2707.

Attachment I – Test Data Sheets

Carlin Combustion Technology, Inc.

#2 Fuel

Commercial Test Sheet

		Test Series No.:	112420	**Tested By:**	**MS**
Burner Model:	601CRD	**Insertion Depth:**	4	**Page:**	1
Appliance Model:	Weil-McLain 688	**Input:**	GPH	**Date:**	24-Nov-20
Appliance Type:	Cast Iron - Wet Base			**Vent Type:**	Rear - 10"

Smoke 0.5 = Trace	Test 11	Test 12	Test 13	Test 14	Test 15	Test 16	Test	Test	Test	Test	Test	Test	Test	Test
Nozzle	8.00													
Angle/ Pattern	60H													
Nozzle Mfr.	Hago													
Pump Pressure														
Input, GPH	9.93													
Air Setting	15/16	15/16	15/16	15/16	15/16	1 1/8								
Head Setting	7/8	5/8	1	1 1/8	1 1/4	1 1 /4								
O.F. Draft	0.35	0.31	0.45	0.50	0.50	0.65								
Breech draft	0.01	0.005	0.015	0.02	0.02	0.035								
Smoke	Tr	1	Tr	LTr	0+	0								
O2, %	3.7	3.0	4.2	4.9	5.4	6.9								
CO2, %	12.9	13.4	12.5	12.0	11.6	10.5								
CO, ppm	1	3	1	0	0	0								
NOx, ppm	68	73	63	61	58	56								
Excess Air, %	21	71	25	30	35	50								
Stack Temp, °F	413	411	416	421	426	436								
Room Temp, °F	64	64	65	65	65	65								
Efficiency, %	86.1	86.5	85.9	85.5	85.1	83.9								
Water: Out °F	163	166	169	171	172	172								
Water: In°F	75	75	75	78	78	78								
Ohms, Ω	53	50	50	50	53	56								
Starts/ Stops														

Comments

Analyzer:

Carlin® Combustion Technology, Inc.

EL Fuel

Commercial Test Sheet

		Test Series No.:	112420	**Tested By:**	**MS**
Burner Model:	601CRD	**Insertion Depth:**	4	**Page:**	1
Appliance Model:	Weil-McLain 688	**Input:**	**GPH**	**Date:**	24-Nov-20
Appliance Type:	Cast Iron - Wet Base			**Vent Type:**	Rear - 10"

Smoke 0.5 = Trace	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**	**Test 7**	**Test 8**	**Test 9**	**Test 10**	**Test**	**Test**	**Test**	**Test**
Nozzle	9.50													
Angle/ Pattern	60H													
Nozzle Mfr.	Hago													
Pump Pressure	250													
Input, GPH	15.02													
Air Setting	15/16	3/4	3/4	11/16	11/16	7/8	15/16	15/16	15/16	1 1/8				
Head Setting	7/8	7/8	3/4	13/16	15/16	1	1	1 1/8	1 1/4	1 1 /4				
O.F. Draft	0.33	0.30	0.26	0.28	0.30	0.40	0.41	0.45	0.51	0.70				
Breech draft	0.005	0.005	0	0.005	0.005	0.015	0.02	0.025	0.03	0.045				
Smoke	0	0	0	0	0	0	0	0	0	0				
O2, %	4.9	3.8	2.3	3.2	3.7	5.3	6.0	6.5	6.8	8.3				
CO2, %	12.0	12.8	13.9	13.2	12.9	11.7	11.1	10.8	10.5	9.4				
CO, ppm	16	28	194	57	34	16	16	16	15	21				
NOx, ppm	45	49	52	53	51	47	44	41	39	33				
Excess Air, %	30	22	12	18	21	35	40	45	48	65				
Stack Temp, °F	385	394	388	395	400	411	416	419	415	424				
Room Temp, °F	62	63	64	64	64	64	65	64	64	66				
Efficiency, %	86.3	86.6	87.3	86.8	86.5	85.4	85	84.7	84.6	83.3				
Water: Out °F	140	143	146	151	153	155	156	157	159	160				
Water: In°F	56	56	56	56	72	72	72	78	78	78				
Ohms, Ω	3260	2680	2100	2230	2390	3330	4140	3900	3500	5180				
Starts/ Stops														

	Comments
Analyzer:	