B20 to B100 Blends as Heating Fuels

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Combustion Performance and Flame Sensor Response

Successful use of a fuel in home heating applications requires demonstration of acceptable combustion performance and satisfactory operation of the other combustion related components contained in a home heating oil system, particularly the flame sensor. Combustion of No. 2 heating oil in a home heating oil system is very different than combustion of No. 2 diesel fuel in a high-pressure compression ignition diesel engine, although heating oil and diesel fuel have very similar properties and are in many cases interchangeable.

In today's diesel engines, the fuel typically passes through an on-board fuel filter with nominal pore size between 2 and 30 microns into a high-pressure common rail pump and is atomized through a multi-hole injector into a closed cylinder. The tolerances of the high-pressure fuel pump and injectors are very tight, as fuel injection pressures commonly exceed 20,000 psi.

In a home heating oil system, fuel passes through a strainer and gear pump into a retention head style burner with a swirl pressure nozzle. The fuel filter, upstream of the pump and strainer is commonly rated for 10 microns. The burner atomizes fuel at 100-150 psi into an open chamber fire box. Fuel is lit by an igniter located close to the burner nozzle which provides a spark similar to that of a spark plug in an engine, which initiates open flame combustion of the fuel oil. The hot gases then flow through the convective section of the boiler or furnace, transferring heat to the boiler water or air, and then exit through the flue. Home heating oil systems are much less complicated and operate at higher tolerances and much lower pressures than today's high-performance diesel engines.

In comparison to the closed cylinder system in a diesel engine, heating oil systems are open flame systems and excess air (or excess flue gas oxygen, O_2) is always used to ensure essentially complete combustion. The amount of excess flue gas oxygen to insure good combustion, generally between 3% and 6% excess O_2 or 15% and 40% excess air to minimize smoke and ensure very low levels of carbon monoxide, is generally set by the installation technician when the burner is installed versus being controlled by an electronic control module found on diesel engines. The combustion performance and excess O_2 level is normally re-checked on services calls or when the nozzles are replaced, typically once every one or two years.

In a home heating oil system, the key aspects of acceptable combustion include providing reliable ignition under field conditions, a flame which is stable and does not pulse substantially, low potential for formation of carbon deposits on burner head and nozzle tip, and low levels of exhaust smoke and CO. Since properly operating home heating oil systems burn the fuel completely in excess air and emissions are low, emissions are not regulated like those of gasoline or diesel engines although sulfur dioxide emission are indirectly regulated through the fuel sulfur level. Due to this clean combustion, heating oil emission are typically not measured or monitored, with the exception of smoke and CO which are used in the field to ensure the heating oil system is properly tuned to avoid the practical issues of particulate buildup on boiler tubes and any appreciable amount of carbon monoxide in the home.

Each home heating system is also equipped with a sensor that detects if a viable flame has been established and is being maintained as fuel is being sprayed into the fire box. Most flame sensors in home heating systems are relatively low-cost cadmium sulfide photoconductors (commonly called a 'cad cell') which respond largely to visible light from incandescence in the combustion flame zone. This visible light is translated by the cad cell into a resistance value that can be used to stop the fuel flow in the event a flame is not established during ignition or is suddenly extinguished during normal operation.

Another option for flame sensing is photodiode-based systems. These have faster time response and can be used with a matched circuit to respond to the alternating part of the flame brightness signal. This provides better discrimination between the flickering light of a flame and the steady light from combustion chamber refractory. These sensors are commonly used in residential oil burners in Europe with highly recirculating burners which have less visible light. These sensors are also used in larger (commercial) boilers.

The goal of the work done in this area was to evaluate the proper atomization and combustion performance of biodiesel blends in conventional home heating oil burner systems and to determine any impacts of the presence of biodiesel on flame sensor operation and effectiveness. Prior studies have shown that biodiesel flames emit less light overall than petroleum-based flames and this is largely a function of particulate concentration in the flame zone. This impact was also studied during this project.

Experimental

As discussed in the introduction section, a general review of the combustion performance is included in Appendix I. Generally, biodiesel blends have combustion performance similar or better than that of petroleum-based No. 2 oil. Biodiesel has sulfur levels typically under 10 ppm and so sulfur dioxide emissions are reduced compared to home heating oils with higher sulfur values. Although NOx emissions are not regulated and are not normally monitored or measured for home heating oil applications, in many tests in boilers and furnaces flue gas NOx levels were found to be reduced with biodiesel but some results were reported to be similar to those with No.2 fuel oil. Smoke and CO emissions are typically as low or lower than with petroleum No. 2 heating oil.

During this project, additional experimental data was obtained specifically on the impact on combustion, excess air values, and flame sensor sensitivity to changing biodiesel content in delivered fuels. As an oxygenated and ultra-low sulfur fuel, biodiesel typically requires less combustion air and burns with less particulates than conventional No. 2 fuel oil. A conventional cast iron home heating boiler and a common retention head oil burner and cadmium sulfide flame sensor were used in these tests. While there are some small technical differences from manufacturer to manufacturer, this system is a good example of the vast majority of systems in the home heating oil market in the US. A fresh sample of B100 meeting ASTM D6751 was provided by a major biodiesel producer for these tests.

The fuel system was arranged with split suction so that the test fuel could be changed without shutting down the burner. Test fuels were located on lab balance for direct measurement of the mass flow rate. During these tests, the burners safety control was bypassed to enable direct measurement of the cadmium sulfide photoconductor resistance. With the common burner control used in these tests, a resistance level under 1600 ohms in steady state is associated with proper performance.

The testing was done in two phases. In the first, the burner excess air value was tuned as is normally done for a home heating oil system (i.e. low CO and smoke number) and set at approximately 4.75% excess oxygen (27% excess air) based on operating in steady state with B0. After this, the biodiesel blend level was changed and combustion performance measurements were made keeping the air flow control damper position fixed. This would simulate a home set up and running on conventional No. 2 oil switching to the higher blends without making any adjustment in the flame sensor operation or excess air setting.

In the second phase, the burner operated on just B100. The burner’s air shutter setting was then changed to evaluate the impact on the flame sensor resistance as a function of flue gas O_2 measured in the exhaust.

<u>Results</u>

Figure 5-1 shows the impact of biodiesel blend level of fuel mass flow and shows an increase with increasing biodiesel content. It is well known that these nozzles have higher mass flow with higher fuel viscosity and this is likely the cause of this small increase.

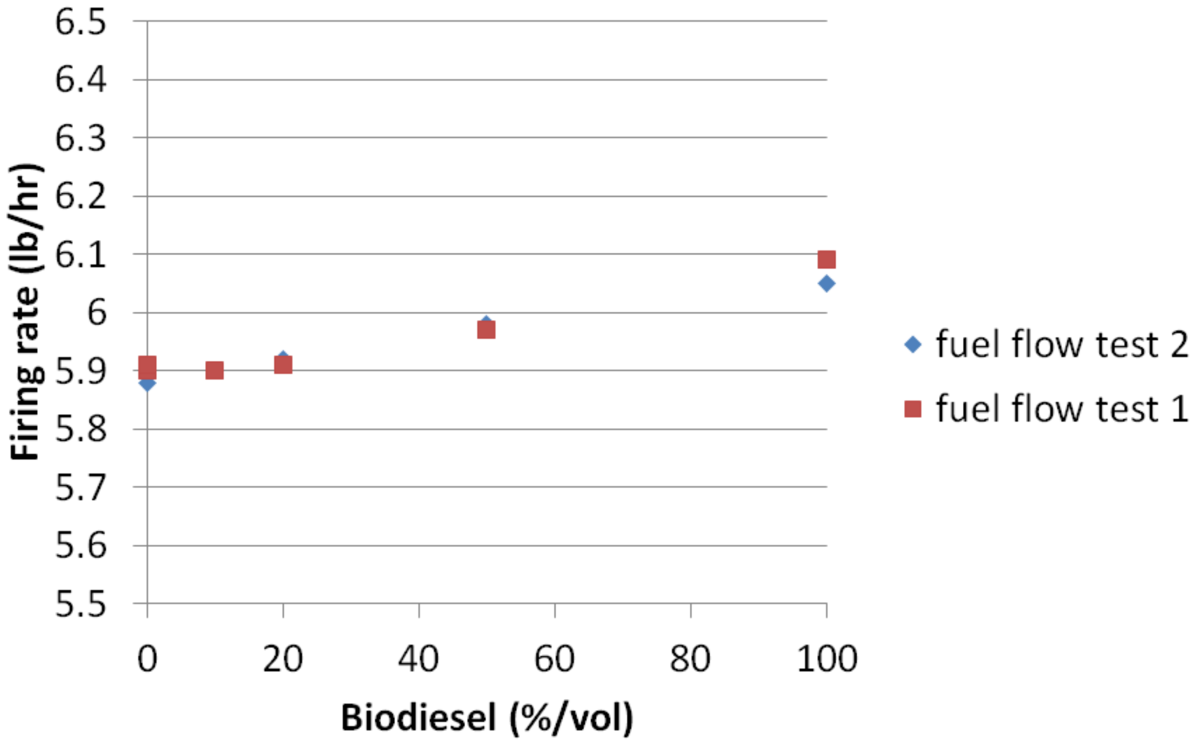

Figure 5-1 Fuel mass flow vs. biodiesel content.

In Figure 5-2 this fuel mass flow has been converted to a volume flow, based on density. In Figure 5-3 this is further converted to input rate (Btu/hr.) based on typical heating value of No. 2 petroleum heating oil and the heating oil reported by the fuel supplier for the test fuel. Figure 5-4 shows the measured flue gas oxygen content. In Figure 5-5 this flue gas oxygen content has been converted to excess air based on typical ultimate analyses for petroleum No. 2 oil and biodiesel. This is then calculated from the measured flue gas oxygen. It should be noted that in all these tests the flue gas CO and smoke number were negligible and so these would not affect the excess air calculation.

Figure 5-6 shows the resistance of the cadmium sulfide photoconductor flame sensor as a function of biodiesel content. At biodiesel levels above ~ 50% without changing the air setting this burner would have a cad cell resistance too high for reliable operation with the specific burner primary control evaluated.

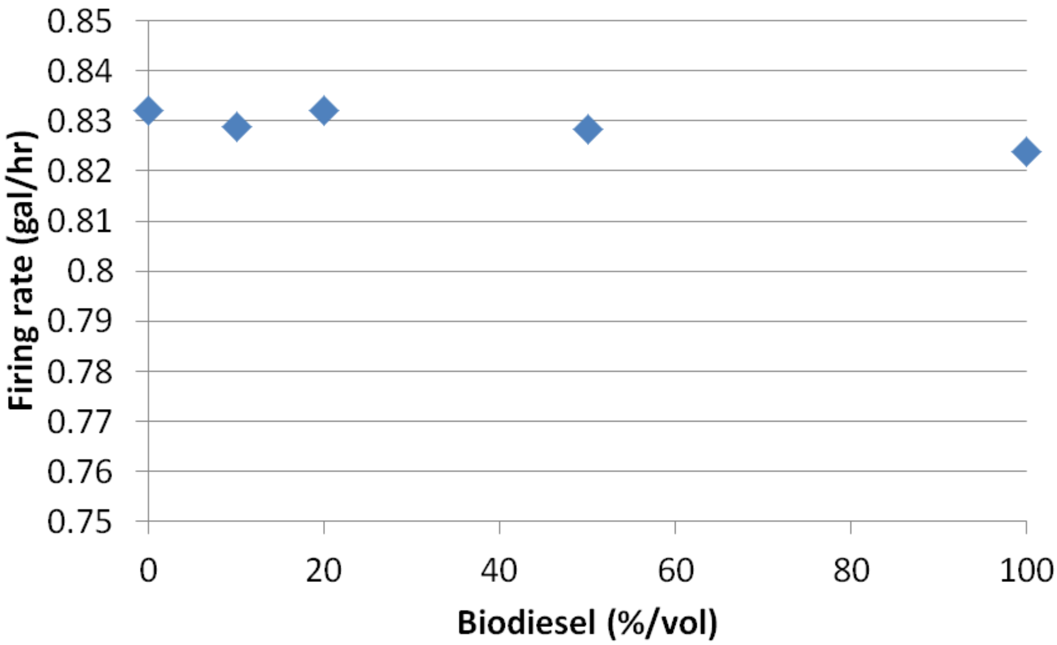

Figure 5-2 Fuel volume flow vs biodiesel content

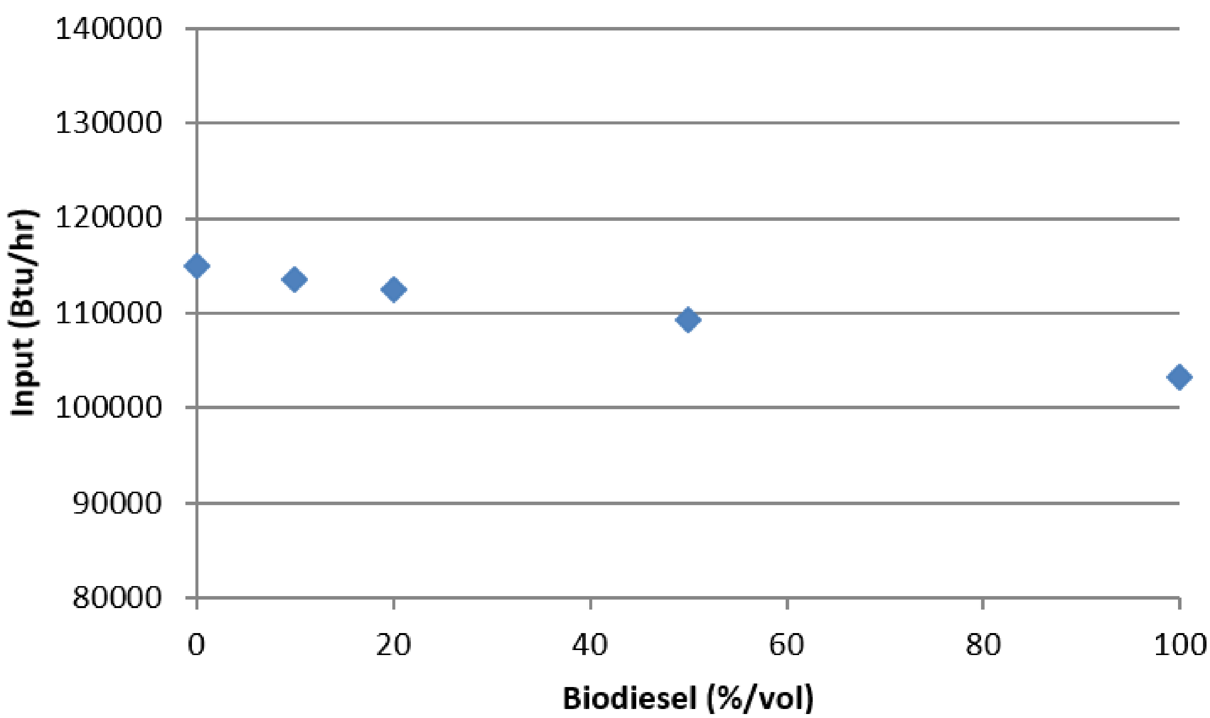

Figure 5-3 Fuel energy input rate vs biodiesel content.

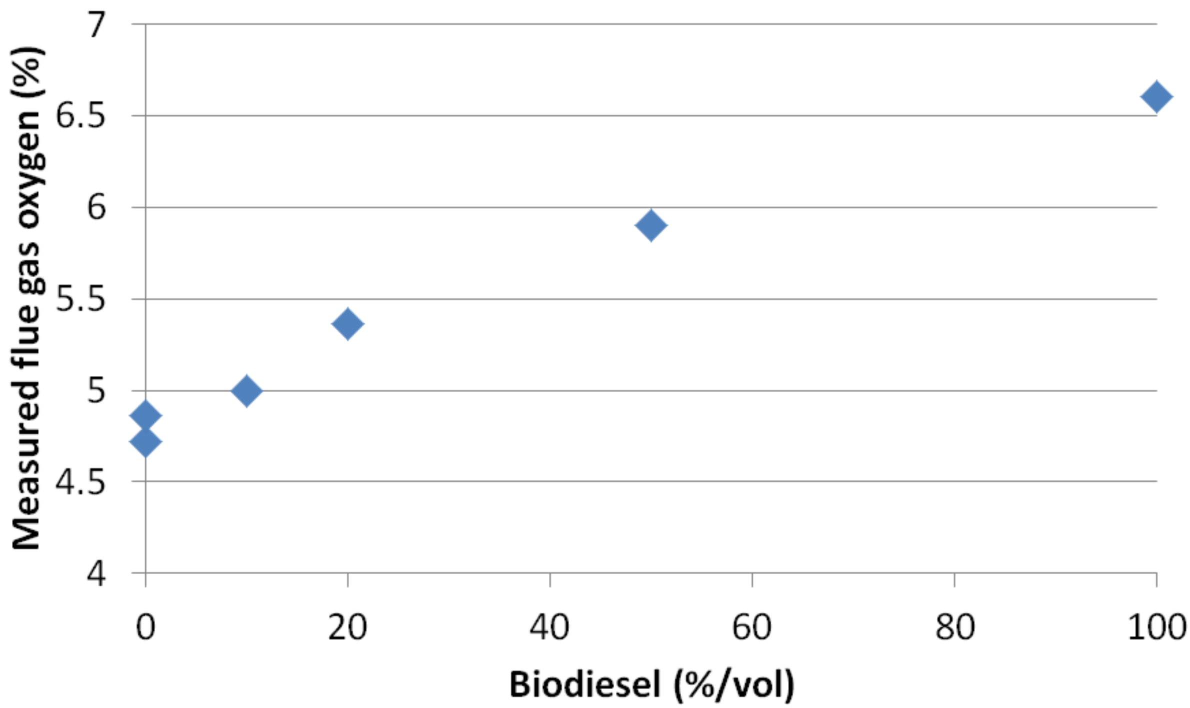

Figure 5-4 Flue gas oxygen vs biodiesel content

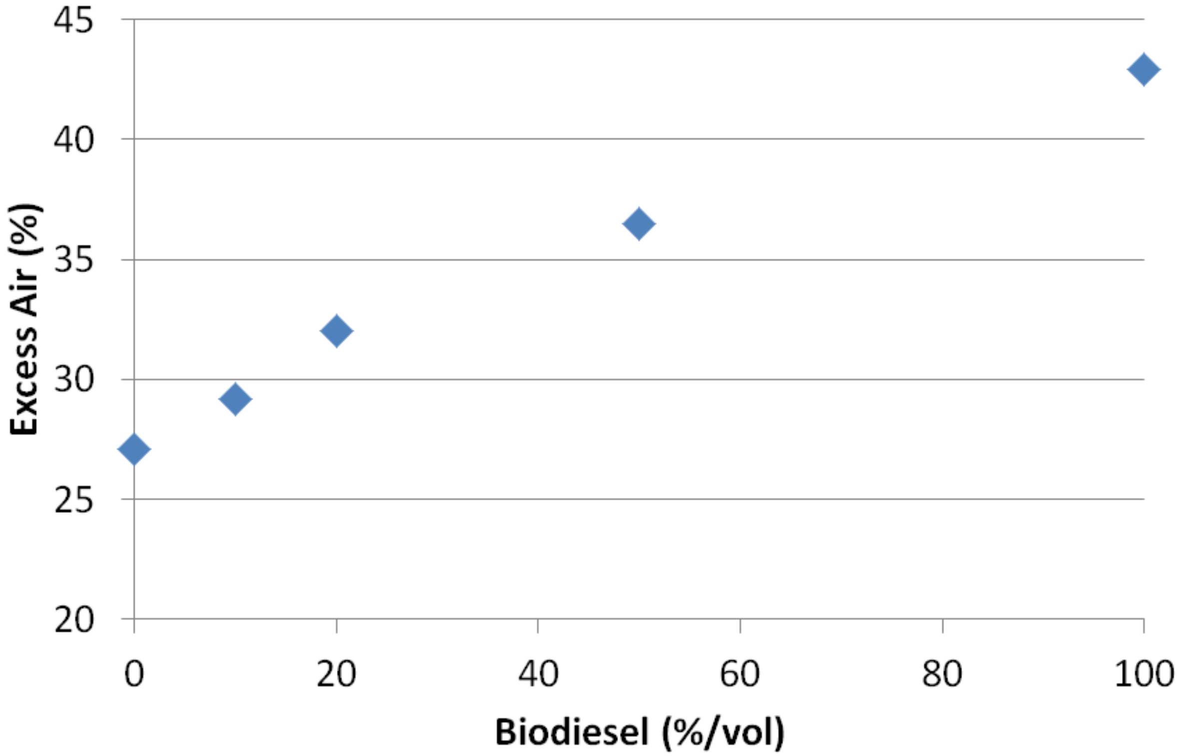

Figure 5-5 calculated excess air vs. biodiesel content

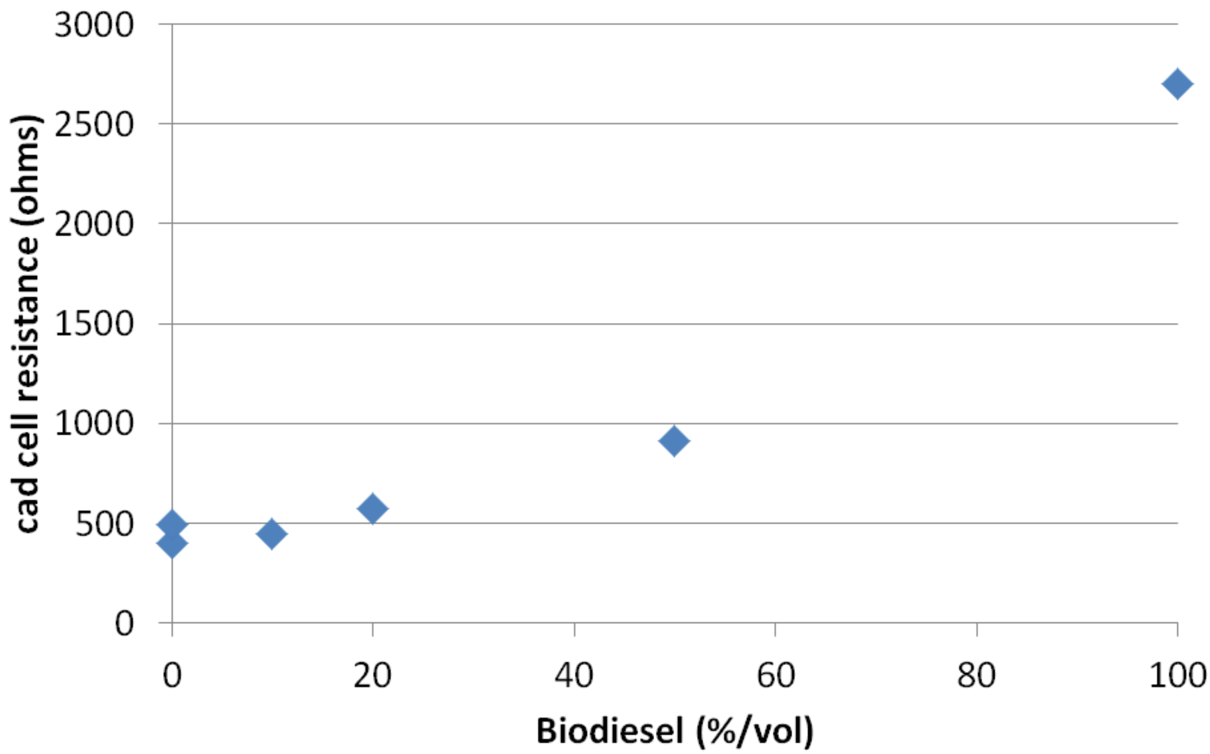

Figure 5-6 Cad cell flame sensor resistance vs biodiesel content

In the next phase of testing, at the B100 level the air shutter setting was adjusted. Results of this are shown in Figure 5-7 as a composite set of charts. This figure shows that the burner can be readjusted to a lower excess air point and this will bring the cad cell resistance down to a level acceptable for common operating controls without leading to an elevated level of CO or smoke.

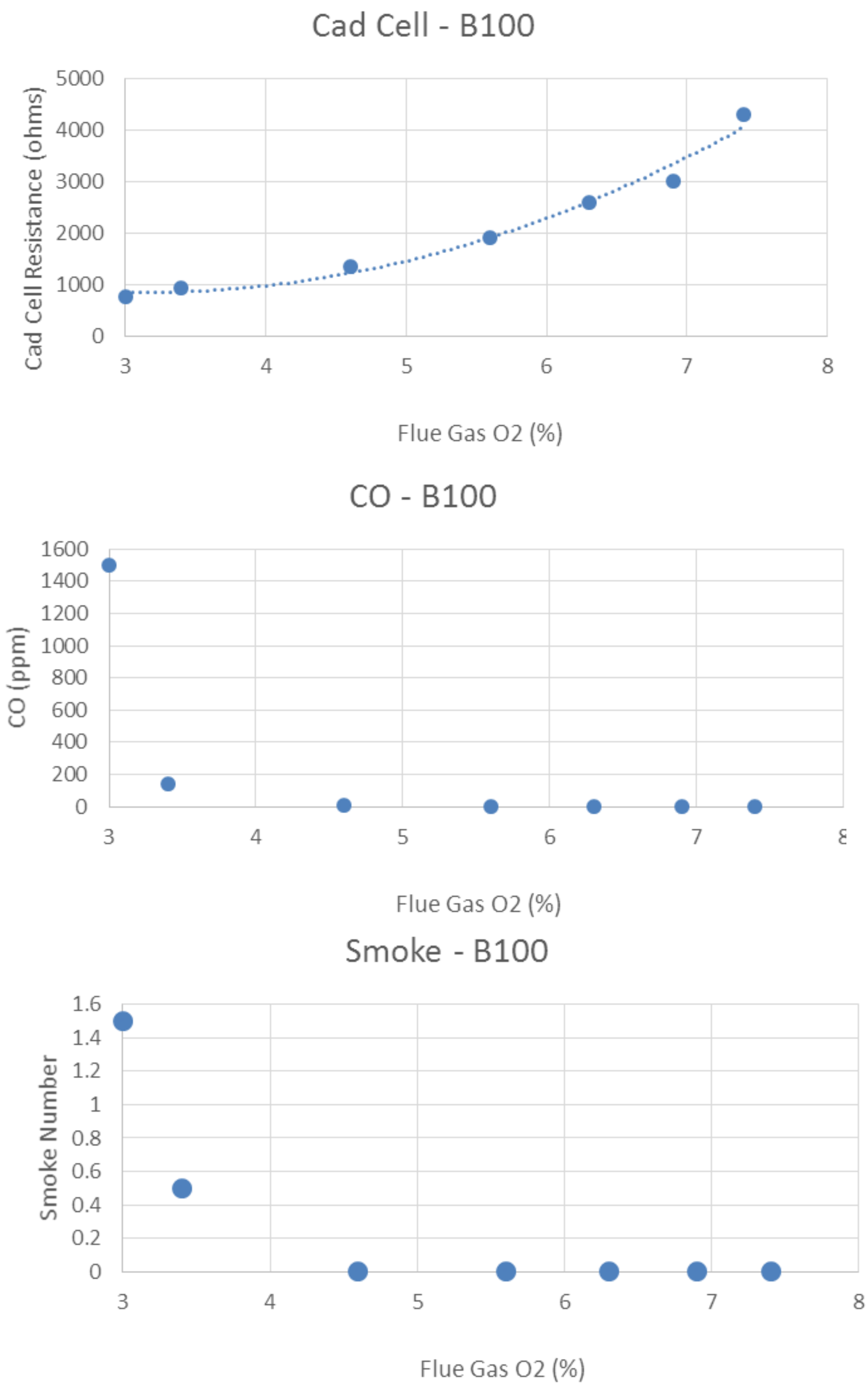

Figure 5-7 Testing at the B100 level. Cad cell resistance, flue gas CO, and smoke number vs flue gas O_2

<u>Conclusion</u>

The results in this section show that typical burners set up on No. 2 petroleum fuel oil can operate acceptably over the entire range of biodiesel blend levels without making changes in air/fuel ratio. However, as the blend level is increased, the operating excess air level will increase since biodiesel already contains some oxygen. The relatively small changes in B20 did not affect flame sensor performance. As the blend level is increased above 50%, however, the increased excess air may affect the ability of some flame sensors to detect the presence of a flame, which could result in the premature shut down of a properly operating burner. Adjusting the air/fuel ratio to reduce the excess air with high biodiesel blends can bring the cad cell resistance down to a level acceptable for common flame sensors without leading to an elevated level of CO or smoke. If a unit has been adjusted to lower the air/fuel ration for high biodiesel blends, it will likely need to be readjusted if switching back to No. 2 oil to maintain adequate CO and smoke levels.