OIL BURNER EMISSIONS: COTTONSEED OIL VERSUS DIESEL

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Abstract

Cottonseed oil has been used as a fuel source either as a blend with diesel in varying proportions or undiluted (100%) in numerous studies evaluating its potential use in internal combustion engines. However, limited research is available on the use of cottonseed oil as a fuel source in a multi-fueled burner similar to those used by cottonseed oil mills and cotton gins in their drying operations. The purpose of this study was to evaluate emissions from five fuel oil treatments while firing a multi-fueled burner in a setup similar to those used for drying operations of both cottonseed oil mills and cotton gins. Four of the treatments were cottonseed oils. The five fuel oil treatments evaluated were: 1) No. 2 Diesel at 83 °F, 2) Prime Bleachable Summer Yellow (PBSY) cottonseed oil at 83°F (PBSY-83), 3) Crude cottonseed oil at 83°F (Crude-83), 4) PBSY at 140°F (PBSY-140), and 5) Crude at 140°F (Crude-140). For each treatment, gaseous emissions of oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxide (NO), and nitrogen dioxide (NO_2) were measured while firing the burner with 2, 14, and 23 gallons/hour of fuel oil. Results indicate that PBSY treatments had the lowest overall emissions of all treatments. The other treatments varied in emission rates based on treatment and fuel flow rate. Preheating the oil to temperatures higher than 83°F resulted in higher nitrogen oxide emissions but displayed varying results in regards to CO. The CO emissions for the crude treatments were relatively unaffected by the preheat temperature whereas the PBSY treatments demonstrated lower CO emissions when the fuel was heated to 140°F. Overall, both cottonseed oils performed well in the multi-fueled burner and displayed a promising potential as an alternative fuel source for cottonseed oil mills and cotton gins in their drying operations.

Introduction

Due to rising fuel costs, industries across the country are looking for alternatives to current fuel sources. The cottonseed oil mill and ginning industries are no exception. One alternative is to use a renewable energy source such as vegetable oil. The idea of using vegetable oils as a fuel source is not new. Extensive research has been performed on using both diesel/vegetable oil blends as well as raw vegetable oils as a fuel source in diesel engines (Hawkins and Fuls, 1982; Ventura, et al. 1982; Koβmehl and Heinrich, 1998; Altin, et al. 2001; Monyem, et al. 2001). Previous studies have covered a wide spectrum of topics ranging from; 1) economics of production and use (McIntosh, et al., 1982; Broder, et al. 1982); 2) engine performance such as fuel consumption and power output (Mazed et al., 1985); 3) wear and coking of engine components (Walter, et al. 1982; McDonnell, et al. 2000); 4) fuel quality measurement and standards (Pryde, 1982; Syassen, 1998; Knothe, 2001); 5) atomization characteristics (Allen and Watts, 2000); and 6) pollutant emissions (Sams, 1998; Peterson, et al. 2000), to name a few. Even though the vegetable oils evaluated are numerous, the one of primary interest to the cotton industry is cottonseed oil. Although the use of cottonseed oil as a biodiesel or blend with diesel fuels has been evaluated extensively, research on its potential use as a fuel in drying seed cotton, in a cotton gin, is limited.

Cottonseed oil has various levels of refining and production that result in the oil being separated into varying classifications. Classifications range from crude cottonseed oil to salad oil. With each level of processing and refining, the value of the oil increases. Crude oil is the basic level and results from the initial extraction or crushing process. The initial processing is accomplished by either mechanical or solvent extraction of the oil. Depending on the process used, the basic level produces either crude or Prime Bleachable Summer Yellow (PBSY) oil. PBSY is a semi-refined oil. For the purposes of this paper, the term "crude" will refer to oil that has been mechanically extracted. Due to the recent price fluctuations of natural gas, crude cottonseed oil, and PBSY, burning cottonseed oil as a fuel source for the drying operations in gins and oil mills may be an economically viable alternative for these industries.

The purpose of this study was to take an initial evaluation of using crude and/or PBSY cottonseed oil as a fuel source for burners used in the drying operations of cotton gins and cottonseed oil mills.

Objective

The objectives of this study were two-fold. First, to evaluate crude and PBSY cottonseed oils versus diesel as a fuel source in a conventional dual fuel burner. Evaluation focused on measuring stack gas emissions of oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxide (NO) , and nitrogen dioxide (NO_2), while firing a dual fuel oil burner at optimum operational settings of No. 2 diesel. Secondly, determine what affect, if any, preheating the cottonseed oil would have on emissions. The two temperatures the cottonseed oils were preheated to prior to firing the burner were approximately, 83°F and 140°F.

Equipment, Materials, and Procedures

Equipment and Materials
The type of burner used was a 4-MMBTU Maxon model 500-SP Ovenpak gas/oil nozzle mixing burner. The burner was installed in an automated combustion chamber manufactured by CIMCO Incorporated of Lubbock, Texas. For this study, three fuel sources were evaluated: 1) No. 2 diesel fuel; 2) PBSY cottonseed oil; and 3) Crude cottonseed oil. To determine the gaseous emissions of oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxide (NO) , and nitrogen dioxide (NO_2), an ECOM A-Plus gas analyzer was used. The calibration gases used for the analyzer were certified gases that were within ± 2 percent of the manufacturers tag value.

Setup and Procedure
Figure 1 shows a schematic of the test setup used for this study. For all runs, the air flow through the pull fan was maintained at a constant 10,000 cfm. Before each run, a given fuel type was selected and preheated to the desired temperature. A warm-up period of approximately 10 minutes was used to verify the combustion chamber had reached the desired operating temperature and that a "steady state" had been reached. Measurements were recorded after the desired temperature was obtained. The fuel flow rates were performed in a random order for each fuel type. The three fuel flow rates evaluated for this study were 2, 14, and 23 gallons per hour. The volume of combustion air used for each fuel flow rate was 41, 320, and 610 acfm, respectively. After each run, the fuel flow to the burner was adjusted for the next run and allowed time to stabilize before commencing the run. Upon completing observations for a given fuel type, the next fuel type was selected and the procedure repeated.

Prior to taking emission measurements, the gas analyzer was checked for proper zero, calibration error, sampling system bias, and zero/span drift using certified calibration gases that covered the range of emissions measured. The testing was conducted using chapter seven of the Test Q/A Plan for Verification of Portable NO/NO2 Emission Analyzers document (Environmental Technology Verification Program, 1998) and the EPA Reference Method 6C (U.S. EPA, 1997) as guidance documents.

Experimental Design and Analysis
This experiment was analyzed as a split plot design with treatment and replications as main effects and fuel flow rate as the subplot. The five treatments were: 1) Diesel at 83 °F, 2) PBSY at 83°F (PBSY-83), 3) Crude at 83°F (Crude-83), 4) PBSY at 140°F (PBSY-140), and 5) Crude at 140°F (Crude-140). Each treatment/fuel flow combination was replicated three times for a total of 45 runs. Standard analysis of variance techniques were used to analyze the data to determine statistically significant differences among the three treatments by the Ryan-Einot-Gaberiel-Welsch Multiple Range Test at the 95% confidence interval.

Results

The results are shown in tables 1 - 4 and in figures 2 and 3. Table 1 shows various properties of the fuels used in the study along with the analytical methodology used to obtain those values. The table 1 values for diesel were obtained from literature (Mazed et al., 1985; Sams, 1998; McDonald and Spears, 1998) whereas the values for cottonseed oil were obtained from lab analyses on the two oils used. Table 2 and 3 show exhaust stack oxygen (O_2) and carbon dioxide (CO_2) values based on treatment and fuel flow, respectively. The higher in-stack O_2 levels were observed with diesel and PBSY-83 while the lowest O_2 levels were observed with the other cottonseed oil treatments. As expected, table 3 shows the lower firing rates having higher in-stack O_2 levels, and consequently lower CO_2 levels, than the higher firing rates. There was no significant interaction between treatment and fuel flow for the O_2 and CO_2 analysis.

Table 4 shows the exhaust gas mass emission rates of CO, NO, and NO_2 for the various treatments and fuel flows evaluated. The values in table 4 are based on actual velocity and have not been corrected to standard temperature and pressure. Due to the fuel flow rate/ treatment interaction the results in the table compare each treatment within a given fuel flow rate. For example, at the higher fuel flow rate of 23 gallons/hour the diesel and crude-83 exhibited the highest CO values while both

PBSY treatments displayed the lowest. However, for total NOx (NO plus NO2) the crude cottonseed oils had the highest emissions ranging from 0.215 to 0.225 lbs/hr followed by diesel and PBSY-140 with 0.160 and 0.149 lbs/hr, respectively. The lowest NOx emissions were from PBSY-83 at 0.084 lbs/hr. Overall, the crude-140 had the highest emissions of both CO and NOx across all fuel flow rates with the other fuels varying depending on the fuel flow rate. Diesel had the lowest CO and NOx values at 2 gph while the PBSY treatments had the lowest emissions at the 23 gph flow rates. The emissions measured at the mid-range flow rates varied from treatment to treatment according to the pollutant measured. During this study, the analyzer was calibrated and set up to measure sulfur dioxide (SO2) emissions. However, the values measured throughout the various runs were negligible. For most runs, a value of zero SO2 was recorded with an occasional maximum value of 0.2 ppm which occurred while testing the diesel fuel. For the cottonseed oils, sulfur emissions were zero.

Figures 2 and 3 show the concentrations of CO and NOx for the three fuel flow rates evaluated. The concentration values shown have been corrected to 3% oxygen using the following equation:

$$CO (@ 3\% O2) = COm * (21 - 3) / (21 - O2m)$$

where: COm = measured concentration (ppm) in the stack
$O2m$ = measured oxygen (%) in the stack.

The graphs shown in figures 2 and 3 display an increase NOx emissions as the fuel flow rate increased. However, the highest CO emissions occurred at the 14 gph flow rate except for crude-83 which had the lowest emissions of CO for this flow rate. Figure 2 graphically illustrates an improvement in efficiency, of the burner, at the higher flow rate. Based on the graphs, the PBSY treatments had the overall lowest CO and NOx emission concentrations with the crude and diesel treatments displaying the highest concentrations for the high fuel flow rate of 23 gph.

Heating the cottonseed oils, over the range evaluated in this study, had some effect on the emissions. Figure 3 shows that preheating the oil to 140°F had an adverse effect on NOx emissions since the treatments heated to 140°F had higher emissions than those only heated to 83°F. However, figure 2 shows that both crude oil treatments had roughly the same CO concentrations regardless of level of heating. On the other hand, PBSY-140 had slightly lower CO emissions than PBSY-83. From this study, it would appear that, for crude cottonseed oil, the lower level of preheat would yield lower overall emissions than heating the oil. In the case of PBSY, it is difficult to say that one preheat level was better than another due to the emissions trade-off between the two fuels. If these same cottonseed oil treatments were evaluated for different air-to-fuel ratios and atomization pressures a more "clear cut winner" may result.

Overall, cottonseed oil performed well in the burner system. It should be understood that these tests are a preliminary look at using cottonseed oil in this type of application and do not imply that cottonseed oil would perform better than diesel in all such applications. Likewise, the optimum burner settings for cottonseed oil would need to be adjusted, from those used in this study, to optimize the combustion process. This study was performed while operating the burner at the optimum settings for diesel fuel. Preliminary evaluations using other fuel atomization pressures, than the one used in this study, indicated lower CO and NOx emissions than those presented in this paper. It is recommended that a range of atomization pressures and air-to-fuel ratios be evaluated to determine the ideal settings for cottonseed oil. Likewise, in addition to determining optimal burner settings, particulate emissions need to be measured which were not performed in this study. One advantage of cottonseed oil over diesel is its naturally low Sulfur content. The use of this type of fuel in drying operations in the cottonseed milling and cotton ginning industries needs further evaluation to determine its economic viability as well as its effect, if any, on fiber quality. Evaluating the effect on fiber quality would be more relevant to the ginning industry since the seed cotton is conveyed using the burner exhaust stream during drying operations.

<u>**Summary**</u>

Using cottonseed oil as a fuel source has been researched extensively in regards to applications such as internal combustion engines. Likewise, blending cottonseed oil with diesel in various proportions in similar combustion devices has been thoroughly studied. However, research in the use of cottonseed oil as a fuel source in multi-fueled burners for drying applications in cottonseed oil mills or cotton gins is limited. The purpose of this study was to evaluate emissions from five fuel oil treatments while firing a multi-fueled burner in a setup similar to those used for drying operations of both cottonseed oil mills and cotton gins. The five fuel oil treatments evaluated were: 1) Diesel at 83 °F, 2) PBSY at 83°F (PBSY-83), 3) Crude at 83°F (Crude-83), 4) PBSY at 140°F (PBSY-140), and 5) Crude at 140°F (Crude-140). For each treatment, gaseous emissions of oxygen (O2), carbon dioxide (CO2), carbon monoxide (CO), sulfur dioxide (SO2), nitrogen oxide (NO) , and nitrogen dioxide (NO2) were measured while firing the burner at 2, 14, and 23 gallons/hour of fuel oil.

The PBSY treatments exhibited the lowest overall emissions of CO and NOx. For diesel and the crude oil treatments, the CO and NOx emissions varied according to the pollutant and the fuel flow rate. In some instances diesel was better than the crude treatments and worse in others. The effect of using higher oil temperatures had some minor effect on emissions. Overall, the cottonseed oils preheated to 140°F had higher NOx emissions than those preheated to 83°F. However, both crude oil treatments had roughly the same CO concentrations over the fuel flows evaluated whereas the PBSY-140 had higher NOx concentrations than PBSY-83 but lower CO concentrations. Even though the fuel atomization pressure was at the burner manufacturer's optimal setting for firing diesel, the cottonseed oil performed well. From other preliminary evaluations performed during testing, it is believed the emission numbers reported in this paper for cottonseed oil can be reduced even further by lowering the atomizing pressure from that used in this study.

The use of cottonseed oil as fuel for multi-fueled burners used in drying applications has potential but further research is needed to optimize the combustion process and further reduce the emissions. Ultimately, its use will depend upon economics, availability, and the environmental permitting requirements.

Acknowledgment

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Table 1. Properties of treatment fuels.

Properties	Test Methods for Diesel/Oils‡ (ASTM No.)	Fuel Oils		
		Diesel§	Crude (Cottonseed)	PBSY (Cottonseed)
Specific Gravity (60° F/60 °F)	----/D1298	0.851	0.928	0.921
Viscosity @ 68°F (cSt)*	D445/D445	2.37	38.19	34.22
Viscosity @ 212°F (cSt)	D445/D445	5.73	5.91	5.69
Gross Heat Content (BTU/lb)	D240/D240	19400	16987	17015
Cloud Point (°F)	D2500/D2500	-2	38	32
Pour Point (°F)	D97/D97	-5	20	10
Carbon Residue (%)	D524/D4530	0.08	1.60	0.30
Ash (%)	----/D482	0.02	0.21	0.02
Flash Point (°F)	D93/D93	165	535	560
Sulfur (%)	----/D2622	0.20	0.002	0.004

‡ Analytical methods used to determine fuel properties. Methods are listed by the analytical procedures used to get the diesel first followed by the procedures used to obtain the cottonseed data second. All methods are ASTM methods unless otherwise specified. If analytical methods are unknown, "-----" is listed.

§ Fuel values for diesel were obtained from various literature sources and are not specifically for the No. 2 low sulfur diesel used in this study.

* cSt = centistokes

Table 2. Exhaust stack oxygen and carbon dioxide values (%) for the five fuel oil treatments evaluated in this study.

Gas Measured (%)§	Treatments‡				
	Diesel	PBSY-83*	Crude-83	PBSY-140	Crude-140
O_2	19.48a	19.18ab	18.72b	18.88b	18.93b
CO_2	1.12b	1.41ab	1.74a	1.63a	1.60a

‡ Means within the same row followed by different letters are different at the 95% confidence limit.
* PBSY-83 and Crude-83 are fuel oils preheated to 83 deg. F prior to firing. PBSY-140 and Crude-140 were preheated to 140 deg. F.
§ O_2 = oxygen and CO_2 = carbon dioxide.

Table 3. Exhaust stack oxygen and carbon dioxide values for the three fuel flow rates evaluated in this study.

Gas Measured (%)§	Fuel Flow Rates (gpm)‡		
	2	14	23
O_2	19.57a	19.03b	18.51c
CO_2	1.09c	1.49b	1.91a

‡ Means within the same row followed by different letters are different at the 95% confidence limit.
§ O_2 = oxygen and CO_2 = carbon dioxide.

Table 4. Average gaseous mass emission rates for fuel type and fuel flow for the fuel oils evaluated in this study.

Fuel†	Fuel Flow (gal/hour)	Average Mass Emission Rates*			
		CO (lbs/hr)§	NO (lbs/hr)	NO2 (lbs/hr)	NOx (lbs/hr)
Crude-140	2	0.125abc	0.044a	0.023a	0.067a
Crude-83	2	0.164a	0.019c	0.023a	0.042b
Diesel	2	0.097c	0.029abc	0.00b	0.029bc
PBSY-140	2	0.108bc	0.039ab	0.023a	0.062a
PBSY-83	2	0.149ab	0.022bc	0.000b	0.022c
Crude-140	14	0.270a	0.089a	0.068a	0.157a
Crude-83	14	0.199a	0.079a	0.055ab	0.134ab
Diesel	14	0.363a	0.039b	0.031c	0.071c
PBSY-140	14	0.222a	0.074a	0.046bc	0.120b
PBSY-83	14	0.339a	0.053b	0.00d	0.053c
Crude-140	23	0.301ab	0.154a	0.071b	0.225a
Crude-83	23	0.324a	0.094c	0.121a	0.215a
Diesel	23	0.352a	0.109b	0.039c	0.149b
PBSY-140	23	0.155c	0.114b	0.046c	0.159b
PBSY-83	23	0.233b	0.084c	0.00d	0.084c

* Column means for a given fuel flow followed by the same letter are not statistically different at the 0.05 level of significance
† PBSY-83 and Crude-83 are fuel oils preheated to 83 deg. F prior to firing. PBSY-140 and Crude-140 were preheated to 140 deg. F.
§ CO = Carbon Monoxide, NO = Nitrogen Oxide, NO2 = Nitrogen Dioxide, NOx = Total Nitrogen Oxides (NO + NO2).
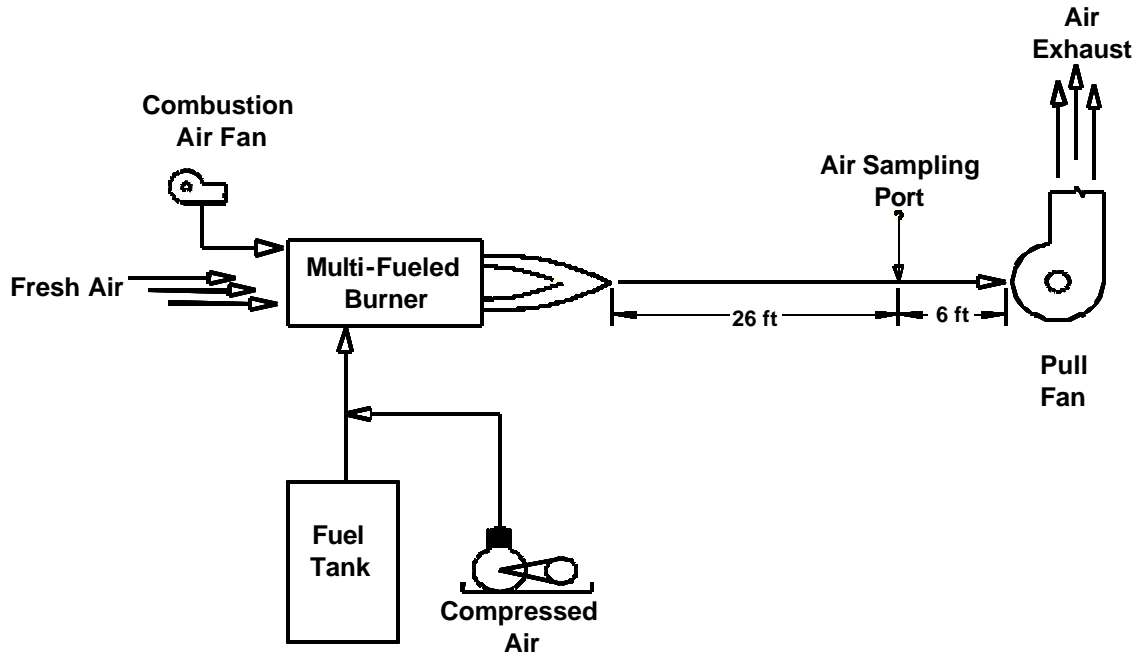
Figure 1. Schematic of test setup for the five fuel treatments evaluated in this study.
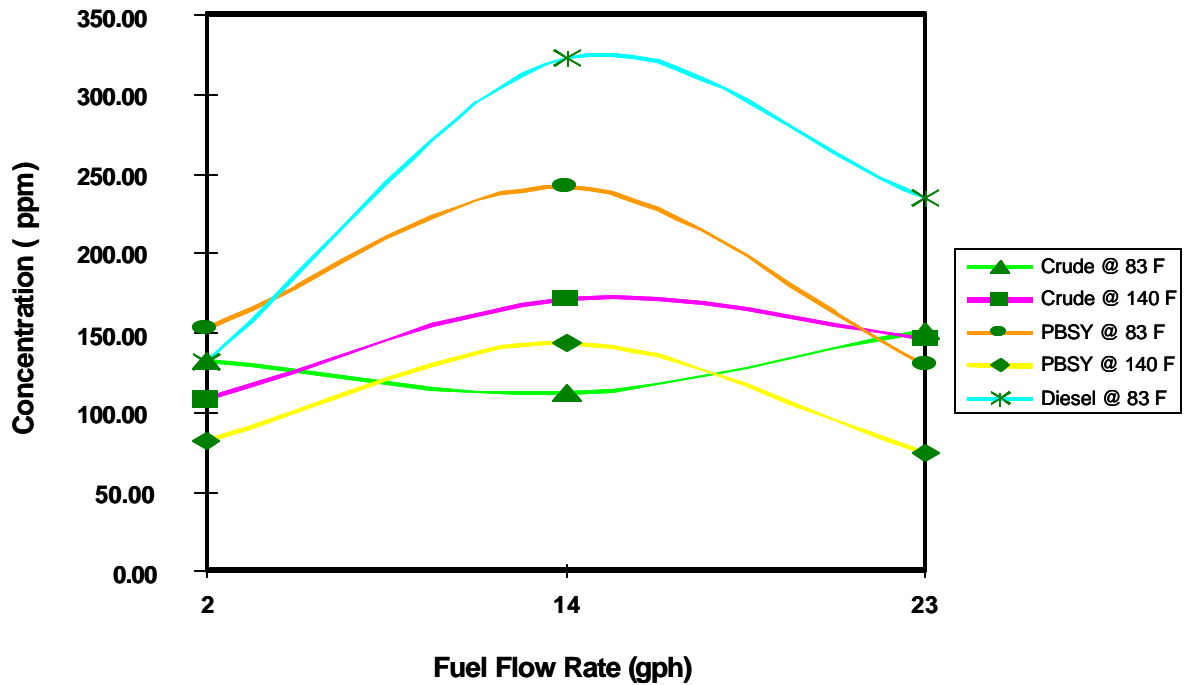

Figure 2. Graph of carbon monoxide (CO) emissions, corrected to 3% oxygen, for the five treatments and three fuel flow rates evaluated in this study.
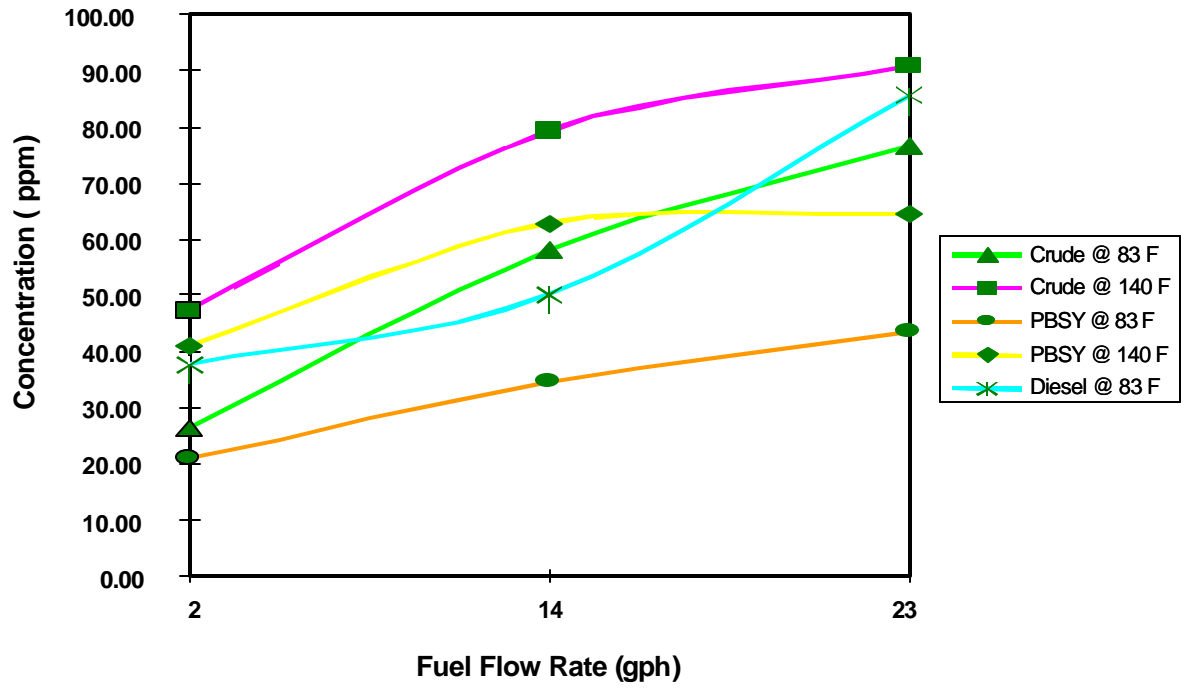
Figure 3. Graph of nitrogen oxide (Nox) emissions, corrected to 3% oxygen, for the five treatments and three fuel flow rates evaluated in this study.