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A Study of the Use of Jatropha Oil Blends In Boilers

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Sustainable Energy Technologies Department/Energy Conversion Group

Brookhaven National Laboratory

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A STUDY OF THE USE OF JATROPHA OIL BLENDS IN BOILERS

Final Report

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**THE NEW YORK STATE
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Executive Summary

This project investigated the combustion performance of blends of unrefined Jatropha oil and its blends in laboratory boilers. Although a very limited amount of testing blends in distillate oil, ASTM # 2 oil or heating oil was conducted, the primary interest was in testing the performance of blends with residual ASTM # 6 oil. The basic idea is to provide a renewable fuel option to residual oil used in space heating and in industrial applications. The intent also was to explore the use of non-edible plant oil and one that might be potentially cheaper than biodiesel. The characteristics of # 6 oil, such as high viscosity at ambient temperature, which requires it to be kept heated, make the blending with such oils feasible. Jatropha oil is one such oil and there is currently considerable interest building up in its use as a source for making biodiesel and jet fuel.

A 10% blend of Jatropha oil with heating oil was burned using a standard burner in a residential boiler. Combustion performance was shown to be comparable with that of burning heating oil by itself with some noticeable differences. Typical heating oil has about 2000 ppm of sulfur, while the Jatropha oil has about 50 ppm leading to lower levels of sulphur dioxide emissions. Stack measurements also showed that the NO_x emission was lower with the blend. We have previously reported similar reductions in NO_x with blends of biodiesel in heating oil as well as slight reductions in PM_{2.5}, particulates below 2.5 microns in size. Long term tests were not part of this project and hence deleterious effects on pumps, seals etc., if any, were not measured.

The majority of the work involved testing blends of Jatropha oil with residual oil in a 1.5 million Btu/hr boiler with a burner modified to burn residual oil. Blends of 20 and 60% Jatropha oil and 100% Jatropha oil were burned in the combustion performance tests. The residual oil used had a sulfur content of over 2000 ppm and hence dramatic reductions in sulfur dioxide emissions are measured with the blends. Again, consistent with our past experience with biodiesel blends, significant reductions in nitrogen oxide emissions nearing 50% with 100% Jatropha oil, were also measured. This is in contrast with the use of biodiesel in diesel engines, where the NO_x has a tendency to increase. In addition to the gaseous emission measurements, particulate emissions were measured using an EPA CTM-39 system to obtain both particulates, of sizes below 2.5 microns, so-called PM_{2.5}, and of sizes larger than 2.5 microns. The results show that the particulate emissions are lower with the blending of Jatropha oil. Overall, one can conclude that the blending of Jatropha oil with residual oil is a feasible approach to using non-edible plant oil to provide a renewable content to residual oil, with significant benefits in the reduction of pollutant emissions such as sulfur dioxide, nitrogen oxides and particulates.

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1. Introduction

Jatropha oil is receiving increasing attention as a non-food source for biodiesel production [1] and for renewable diesel/jet fuel production [2]. Blends of Jatropha oil and petroleum diesel have been tested in single cylinder diesel engines [3, 4]. Biodiesel to U.S. and European standard specifications has been produced from Jatropha oil [5]. However, there has been no research on the use of Jatropha oil blends with heating oil or residual oil in boilers. In an earlier phase of this NYSERDA project, blends of, commercially available ASTM D6751 biodiesel, in residual oil were tested in both the laboratory [6] and in the field [7]. In the phase of the project presented in this report, unrefined Jatropha oil was blended with heating oil and with residual oil for tests in the laboratory in appropriate test boilers. Jatropha oil is not currently produced in the United States. A fairly long search identified several companies that offered to deliver test quantities from countries in Asia and Africa. A U.S. Company, SG Biofuels was chosen to procure the test sample, which would be extracted from the seeds of plants grown in Central America. They sent us a small sample for preliminary tests and drum quantity sample was purchased for the residual oil blend tests in the large boiler.

The Jatropha plant, *Jatropha curcas* L. (JCL) is a small tree or a large shrub [8] and is primarily subtropical. It can grow without irrigation as a wild plant in a broad range of rainfall regimes from 25 cm to 300 cm per annum. Normally JCL flowers once a year during the rainy season, although in humid regions or under irrigation it may flower almost throughout the year. Oil content of a Jatropha seed ranges between 30 and 40 percent. The current yield is up to 300 gallons per acre, or 750 gallons per hectare, which is five times the yield of soy and twice that of rapeseed (canola) [9]. The oil is extracted from the seeds (three per fruit) which contain about 30-40% of oil. Standard processes, mechanical or solvent extraction can be used to extract the oil. The oil is said to contain more than 75% of unsaturated fatty acid consisting of oleic and linoleic acids. It is considered as a good oil source for biodiesel production in terms of its properties [1]. The high unsaturated fatty acid content will give reasonably good cold flow properties for the biodiesel made from it [10]. This is more important if the Jatropha oil is to be, blended with or substituted for, distillate fuels such as heating oil or petroleum diesel. The seed cake after the extraction of the oil is considered to be a good fertilizer and has also been tested in biogas production through anaerobic digestion.

2. Jatropha Oil Properties and Comparison with Heating Oils

A sample of the Jatropha oil and of the residual oil used in the tests was sent out to a test laboratory for measurement of fuel properties. The results are presented in Table 1 below along with previous measurements, for some of the properties, of samples of ultra low sulfur diesel (ULSD) and home heating oil (ASTM # 2 oil).

Table 1. Fuel Properties

Parameter	ULSD	Heating oil	Residual oil	Jatropha oil
Gross heat of combustion, Btu/lb	19,338	19,220	18,523	16,597
Nitrogen, %	<0.03	<0.03	<0.5%	<0.5%
Carbon, %	85.86	85.02	87.02%	75.52%
Hydrogen, %	13.07	12.70	11.3%	11.74%
Sulfur, ppm (%)	36.8 (.004)	2,385 (0.238)	2,260 (0.23)	53.5 (0.005)
Ash, %	NM	NM	0.11%	0.03%
Moisture, %	NM	NM	0.21%	0.11%
Oxygen, %	NM	NM	1.13%	12.60%
Acid Number, mgKOH/gm	NM	NM	32.25	35.06

Note: NM—Not Measured

In Table 1, the property values for ULSD and Heating oil are from measurements made in other projects. Not all the properties had been measured. The respective ASTM standards (D 975 and D 396) specify values for some of these properties like ash and moisture. Typically, distillate petroleum fuels have no oxygenated compounds. Copper strip corrosion numbers are specified typically as 3 maximum for distillate fuels and acid numbers are not a part of the specification for petroleum fuels.

The table shows some differences that are worth noting. Clearly, the heating value of Jatropha oil per unit mass is about 10% lower than that of the residual fuel and about 13% less than that of heating oil. This is mostly due to the oxygen in the fuel displacing the carbon. The ash and moisture contents of this sample of Jatropha oil are lower than those for this sample of residual oil. The sulfur content is significantly lower and almost similar to the sample of ULSD listed here. The acid numbers as measured by this test laboratory are comparable for the residual fuel and the Jatropha oil samples. However, we had made preliminary measurements (reported earlier) for the Jatropha oil at BNL and had recorded a number of around 12. One published paper [11] has numbers of 17.32 and 8.45 for two genus of Jatropha. In any case, it would seem that Jatropha oil's acid number is similar to or less than that of residual oil and hence might encourage the idea that the blends might not be any more and may even be less 'corrosive' than straight residual oil. Of course, this has to be demonstrated with specific tests. Reference 11 does quote copper strip corrosion values of 1a, compared with 3 specified for distillate fuels. These numbers give a qualitative indication of potential for corrosion in petroleum fuels and it is not obvious that they can be used to compare with biofuels. The acid number measures (as the name implies) the 'acidity' in the fuel and is specified in the ASTM biodiesel standard (D 6751). It is not clear as to how the numbers are related to corrosion, although it would seem that larger numbers indicate higher potential for corrosion.

Other properties obtained from previous measurements and from reference 8 are shown in Table 2 below. The density and the viscosity of Jatropha oil are between those of heating oil and residual oil. The much lower viscosity of the Jatropha oil is a significant advantage when blended with residual oil as it will make atomization easier and the fuel will not have to be heated to as high a temperature. However, home heating oil is not heated usually (although nozzle preheaters are used more commonly in Europe even for conventional heating oil) so that only small amounts of Jatropha oil can be blended before viscosity becomes an issue.

Table 2. Additional Fuel Properties

Property	Heating Oil	Residual oil	Jatropha [8]
<i>Density, g/cm³</i>	0.81-0.89	0.95-0.99	0.92
<i>Kinematic Viscosity, cSt</i>	4-8	300-400	24-30

3. Compatibility of Blends

The use of biofuels in existing equipment designed for operation on petroleum fuels will have to start with blends. Suitability, availability, economics etc. will determine, what at best, could be a gradual transition to 100% biofuels use in such equipment. If this is successful, replacement equipment might be designed to work with biofuels. Hence, for the interim use, it is important to know whether blends of the Jatropha oil with the heating oils are compatible and stable. A compatibility tester was used to measure compatibility and a sample was stored heated in an oven for an extended time to observe any separation of the mixed fuels.

The compatibility tests were carried out using the compatibility tester shown in figure 1 to ASTM D 4740. The test consists essentially of heating the blended sample, releasing one drop on to a blotter paper and observing the uniformity of the circular spread. Three sample 50% blends were made by mixing the Jatropha oil with two samples of # 6 oil and one sample of ultra low sulfur diesel in equal volumes. Figure 2 below shows a photograph of the three blotter papers containing the diffused pattern formed from the three drop samples. The ULSD blend pattern is hardly visible as this test is primarily for residual oils. There does not seem to be any apparent separation on close examination of the original. The residual oil blend patterns are also substantially uniform with no apparent incompatibility as per the chart shown in figure 3 below.



Figure 1. Compatibility Tester

Another test, somewhat ad-hoc in nature, was also carried out as follows. A 50% blend of Jatropha oil in residual oil was made. It was kept heated in an oven at 150⁰ F and examined to see whether any separation had occurred. Figure 4 below compares the photograph of the fresh sample and the same sample after nearly five months in the oven and does not reveal any visible separation of the two fuels.

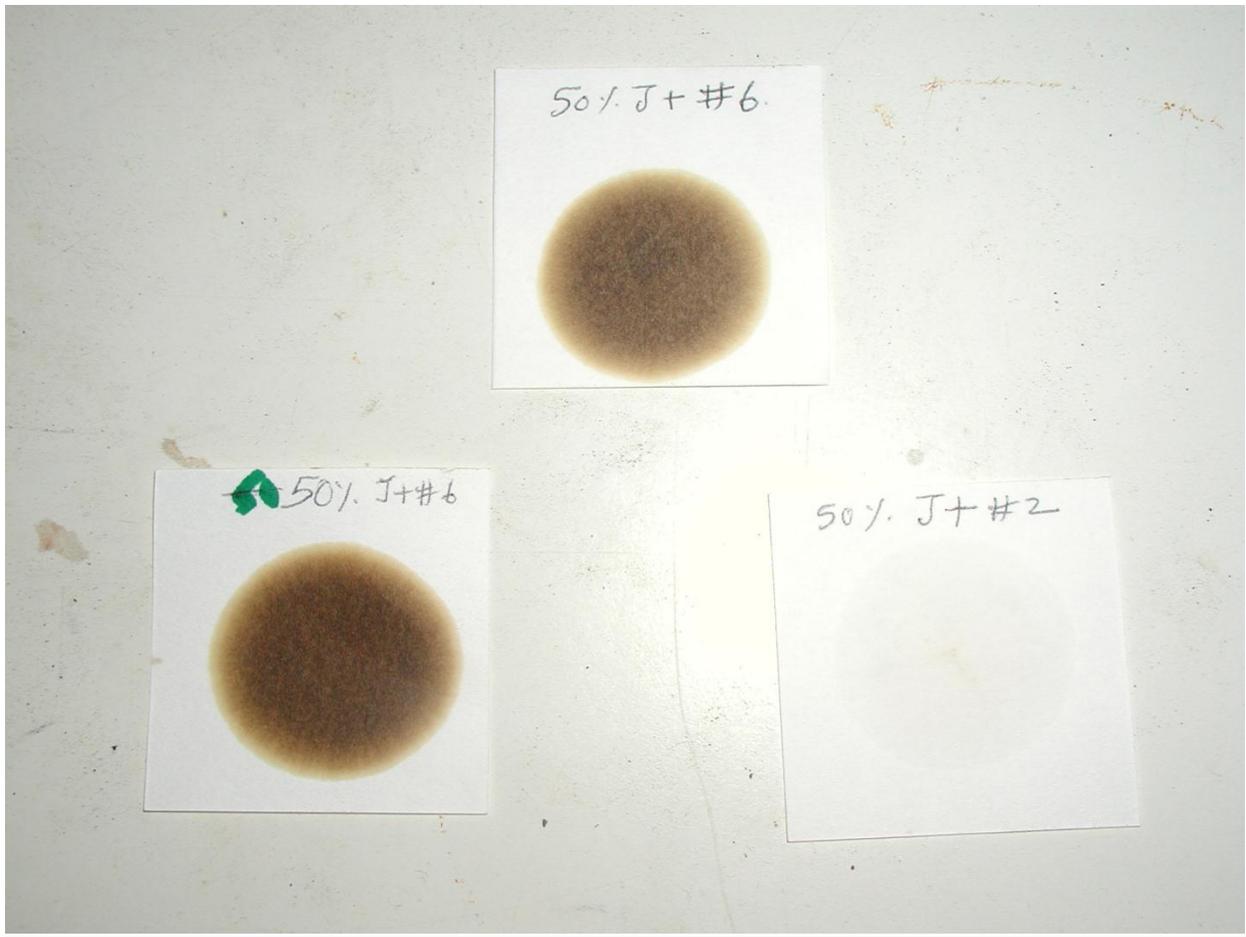


Figure 2. Compatibility Test Results

Spot Reference Chart

When the dried sample is removed from the oven, it can be compared against the spot reference chart. Differences in colour, overall darkness, spot size and appearance of outer edges should be ignored. Only the characteristics of the centre ring should be examined when determining compatibility rating.

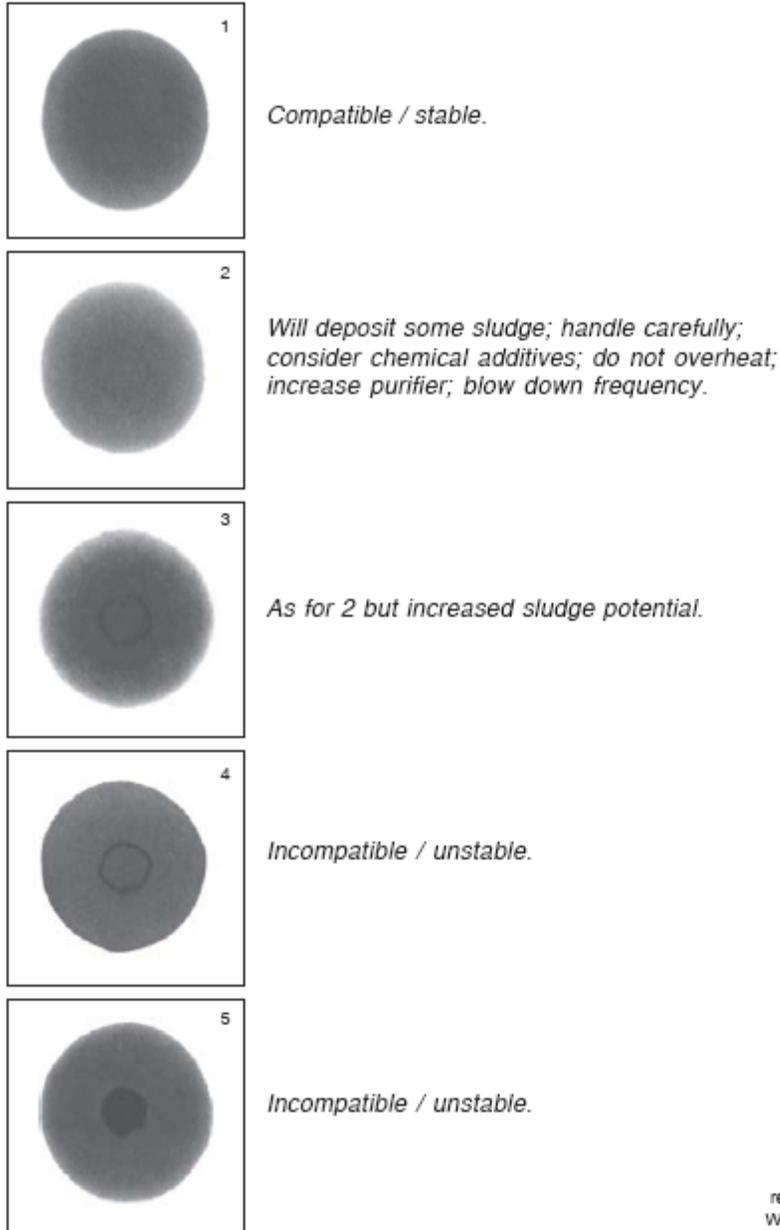


Figure 3. Compatibility Assessment Chart

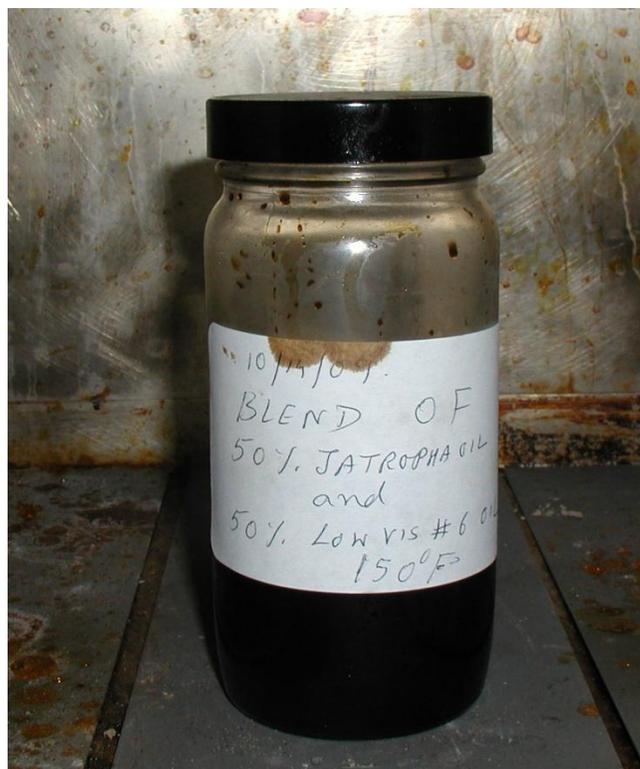
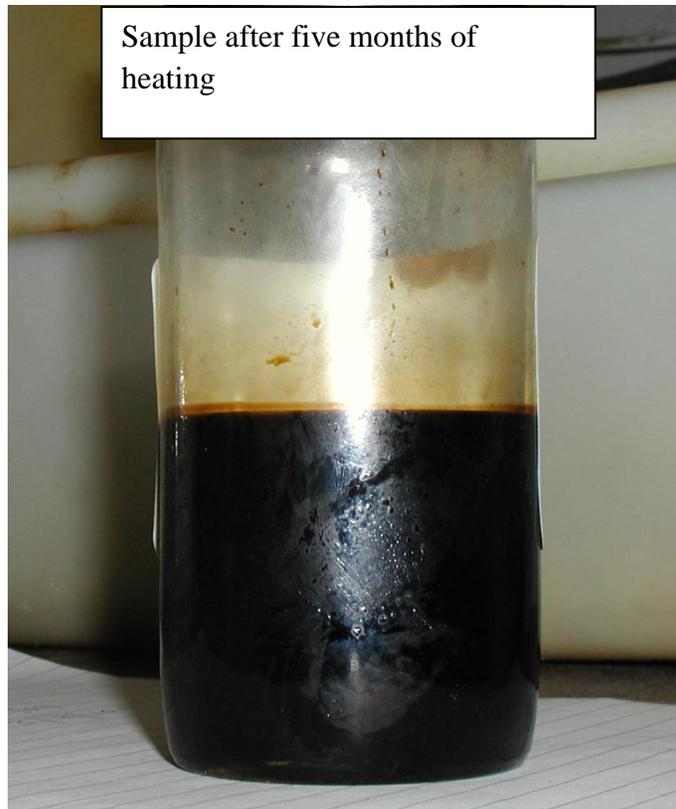


Figure 4. Heated samples of 50% Blend

4. Combustion Tests with a Home Heating Oil Blend

For reasons mentioned above, only a low blend level could be tested in residential boiler applications. For the tests reported here, a blend of 10% Jatropha oil in ASTM # 2 heating oil was used. A Thermo-Dynamics LM 75 boiler with a Beckett AFII 150 burner was used in the tests. The burner had a 0.6 gph, 70⁰ B nozzle and the pump pressure was set at 140 psi. The equipment listed was chosen because of ready availability and other similar equipment would be as suitable. Baseline tests were run with conventional heating oil and the 10% blend, designated here as J 10. This blend was made by mixing the Jatropha oil from the small sample that had been sent by SG Biofuels with the same heating oil. The homogeneity of the small liter size blend sample was ensured by mechanical mixing.

Figure 5 below shows the measured carbon monoxide levels in the stack as a function of excess air (as denoted by the oxygen concentration in the stack) for both the base oil and the blend. There is not much difference between the two fuels in this case. Figure 6 shows a similar plot, in this case, of the NO_x emission levels in the stack. The measured NO_x levels have been converted to a nominal oxygen level of 3% (to eliminate ‘dilution’ effect on their values). It is seen that the NO_x emission from the blend is lower than from the heating oil at corresponding stack oxygen levels, or excess air levels. This is consistent with our previous observations with biodiesel blends in heating oil as seen in figure 7 below [12].

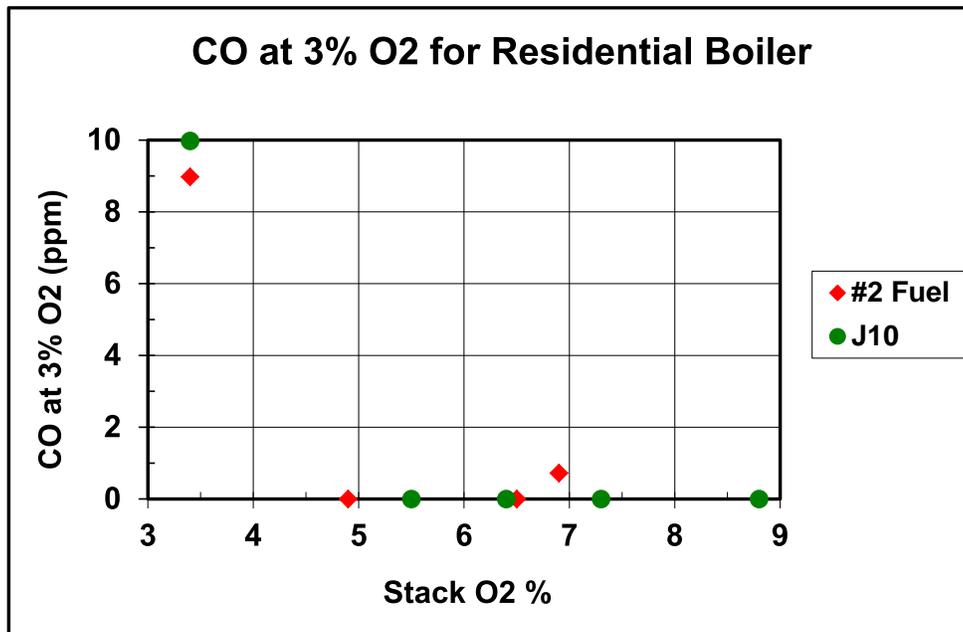


Figure 5. CO Emissions

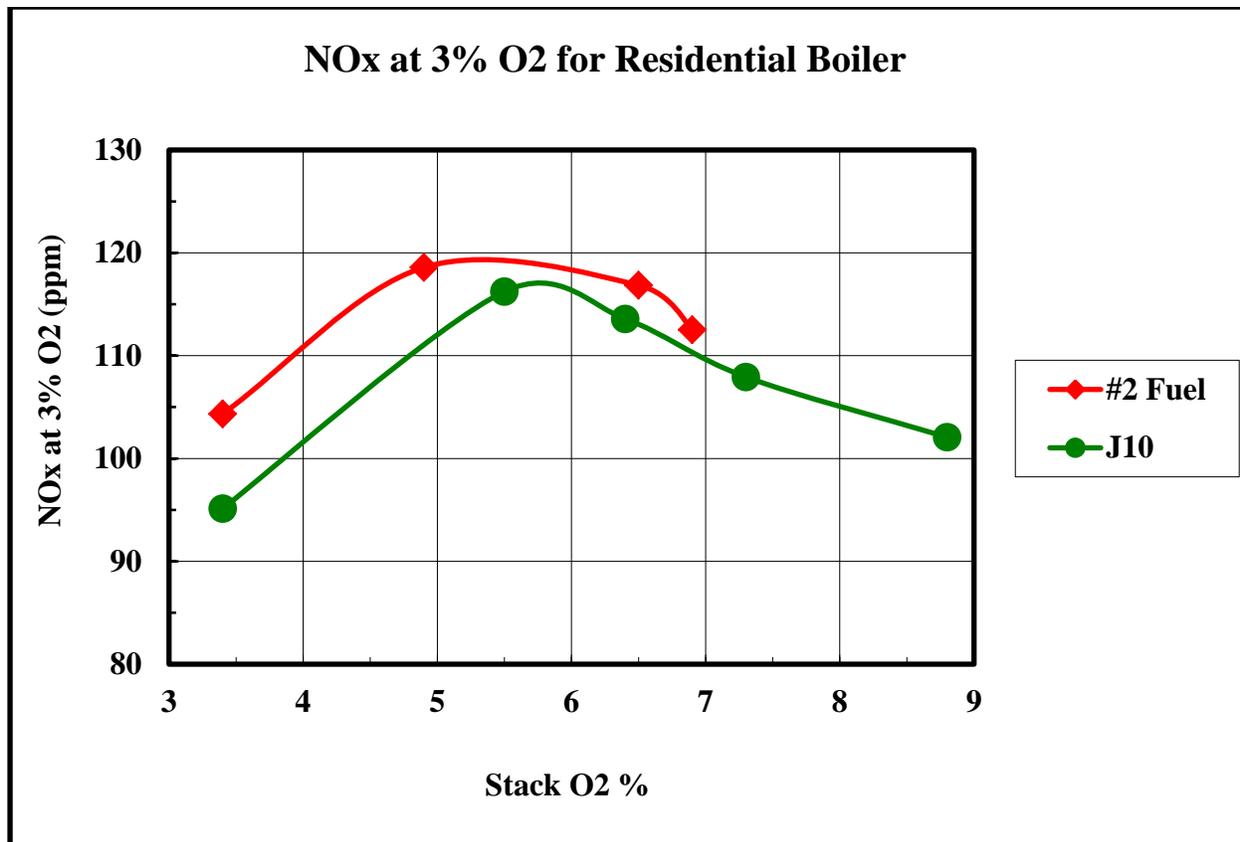


Figure 6. NOx Emissions

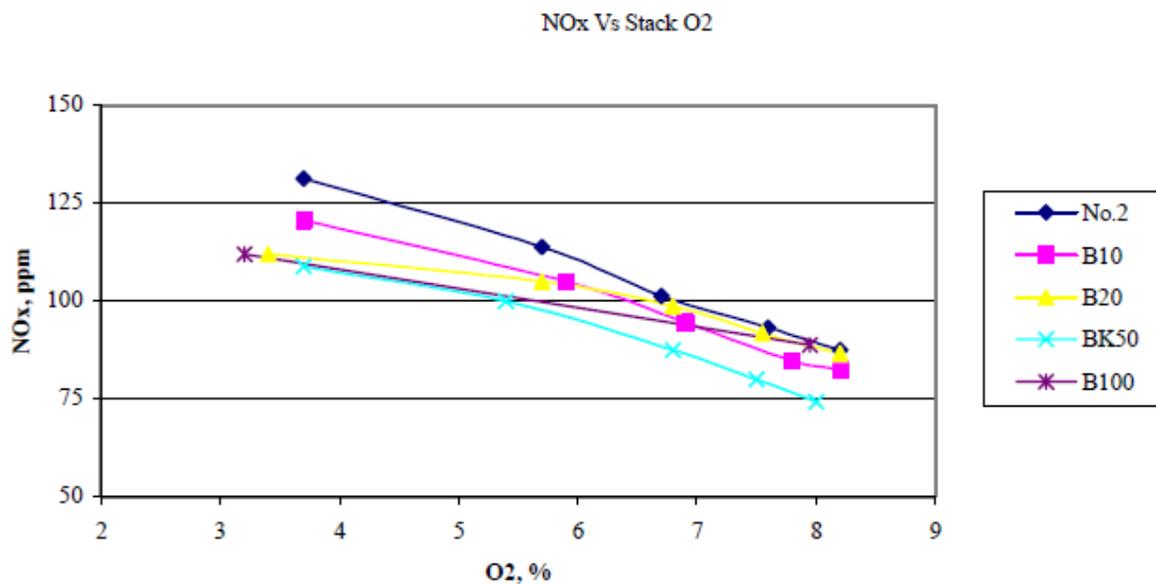


Figure 7. NOx Emissions with biodiesel Blends

5. Combustion tests of Residual Oil Blends

5.1 Test Equipment and Procedure

The primary goal of this project was to examine the performance of blends of Jatropha oil in residual oil. For these tests, a drum quantity of Jatropha oil was purchased from SG Biofuels. The blends for the combustion tests were made in the blending system shown in figure 8. It consists of 55 gallon drums to hold the base residual fuel and a drum to hold the blend and two pumps to pump the different fuels. The required connections were made with copper tubing and included valves, pressure gauges and pressure relief valves to provide control and safety. The high viscosities of the fuels at normal temperatures require the heating of all the drums by drum band heaters to make them pumpable. The mixing drum is set on a scale and the blends are made by weight of the blending fuels. Hence, because of the slight differences in densities, the volumetric blend ratios will differ slightly (for example, a 60% blend by weight would approximate to a 60.4% by volume) from the weight based values quoted here. Homogeneity of the blend is ensured by using a mixer and also by recirculating over an extended period. The fuel to the burner is supplied from this mixing drum and the flow rate can be calculated by timing the change in weight on the scale.

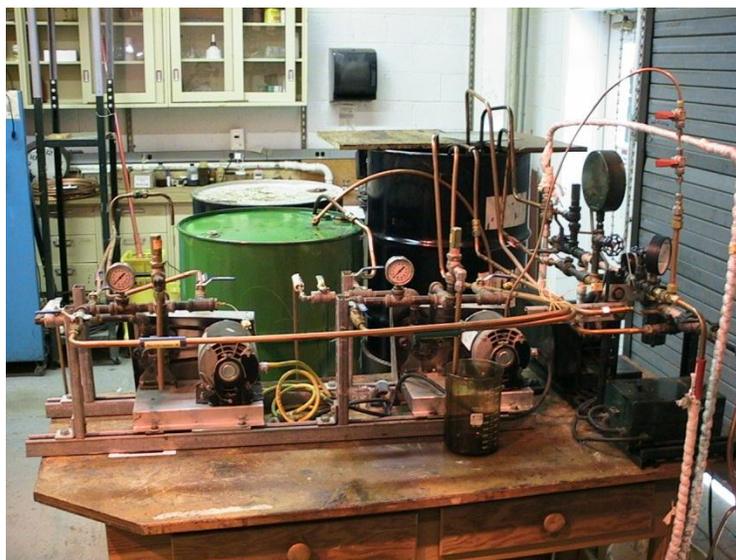


Figure 8. Blending System

The combustion of the blends is carried out in the boiler shown in figure 9. This is a Peerless 0-715-FDA-W boiler of about 1.5 million Btu/hr steam capacity. The burner is a standard distillate oil burner, common in such boiler installations. For these experiments, the pressure atomizer in the burner was replaced by a Delavan 30615-10 Airo air atomizing nozzle, which is an internal mixing type. A cutaway picture of this atomizer is shown in figure 10. Unlike pressure atomizers, the fuel flow rate is not fixed by the nozzle at a given fuel pressure

and hence a metering orifice is used in the fuel system to regulate the fuel flow rate. For the present tests, the atomizing medium was compressed air, which was generated by an air compressor. The fuel is transported to the burner by a separate pump from the blend drum. The fuel piping is also electrically heated to a location as close to the burner as possible. The distillate burner's pump is connected to the atomizer as well and supplies distillate fuel from an outside tank for starting. The burner blower is used to supply air for starting on (No. 2) distillate fuel and for firing the blends.



Figure 9. Test Boiler

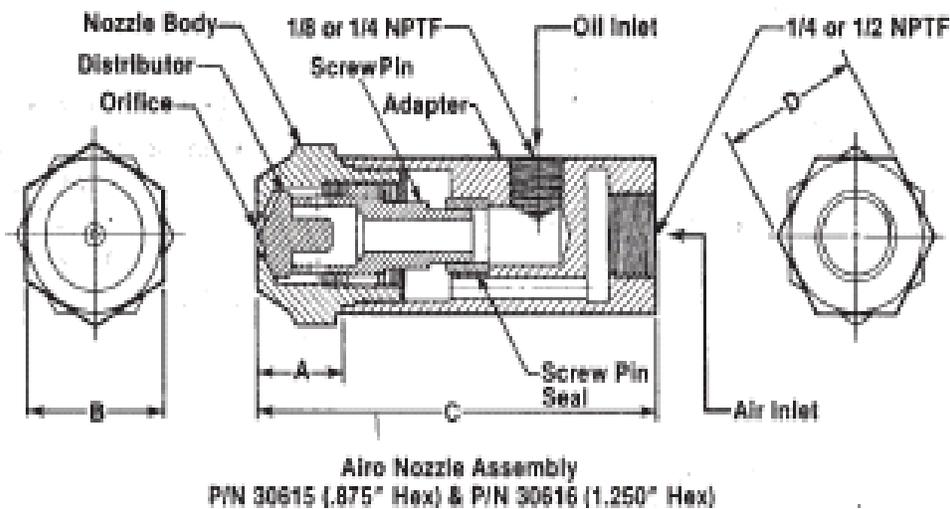


Figure 10. Delavan Airo Nozzle

The tests were performed at steaming conditions when the boiler is producing saturated steam, which is vented to the outside. The fuel flow rates are maintained constant and measured as mentioned above. The performance measures are essentially steady state measurements in the stack. The boiler as shown in figure 9 has two exhaust stacks for conveying the combusted gases outside the building. The larger one, termed the main stack, is used normally. This connects to the chimney outside the laboratory room and operates by natural convection. The conventional gaseous emission measurements were made while exhausting through the larger stack as it is easier to manipulate the excess air levels over a range. The other key measurement was that of the particulate emissions from the combustion of the fuels. However, the proximity of the right angle bend in the larger or main stack makes it unsatisfactory for particulate measurements. Hence, the smaller stack is used for making the particulate emission measurements. This stack has an extended length that brings it to a mezzanine in the lab and is connected to an induced draft fan for venting to the outside. This part of the stack with the fan is shown in figure 11 below.

The particulate dilution sampling and PM 2.5 measurement system to CTM-39 is shown with the sampling probe set up on the mezzanine level in figure 12 below. The gaseous emissions are measured with the Testo Model 350 test instrument. The fuel temperatures are measured with thermocouples, and the fuel flow rate is measured by timing with a stopwatch a known change in the drum weight.

The steady state combustion performance tests with gaseous emission measurements were performed first for all the blends. This test for each blend is followed by a steady state test at one condition for the particulate measurements using the small stack as explained above. The results of these two set of tests are given below separately.

The basic performance tests were conducted on the base # 6 residual oils, 20% and a 60% blends of Jatropha oil in this residual oil denoted as RJB 20 and RJB 60 respectively, and on 100% Jatropha oil. The particulate emission test (at one steady state condition each) was carried out with the base # 6 residual oil, and the two blends, RJB 20 and RJB 60.



Figure 11. Sampling Stack with Induced Draft Fan



Figure 12. Particulate Sampling and measurement System

5.2 Brief Discussion of Results from Tests with Biodiesel Blends

In the first phase of the project, both laboratory and field tests were conducted using blends of ASTM quality biodiesel with residual oil. For the laboratory tests, the same equipment and procedures as above were used. The field testing was carried out at a larger boiler in a New York City corporation facility. The detailed results are presented in references 6 and 7 respectively. The main results are presented below.

5.2.1 Laboratory Test Results with Biodiesel Blends

Two residual oils supplied by the collaborator and designated as LV (low viscosity) and HV (high viscosity) were used in these tests. Blends of the oils containing 30% biodiesel were also tested. The figure 13 [6] below shows the measured emission of NO_x with the baseline residual fuels and the blends. It can be seen that blending with biodiesel reduces the NO_x produced in this test boiler. Table 3 below shows the particulate emission data from tests in the same boiler. Again, in a sense as expected, the PM emissions also go down with addition of biodiesel.

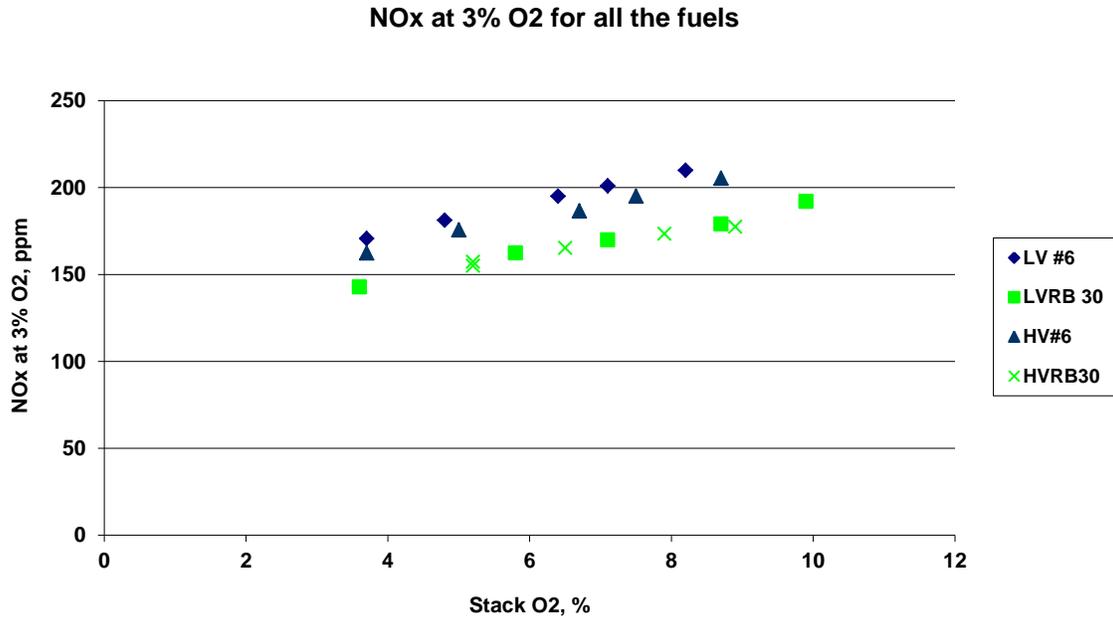


Figure 13. NOx emission from biodiesel blends with residual oil.

Table 3. PM Emissions for the biodiesel blends

	LV#6	LVRB30	HV#6	HVRB30
PM 2.5	2.7 lb/1000 gals 332 mg/kg fuel	2.1 lb/1000 gals 272 mg/kg fuel	2.9 lb/1000 gals 359 mg/kg fuel	2.5 lb/1000 gals 304 mg/kg fuel
PM>2.5	1.7 lb/1000 gals 207 mg/kg fuel	0.9 lb/1000 gals 112 mg/kg fuel	1.5 lb/1000 gals 191 mg/kg fuel	1.2 lb/1000 gals 150 mg/kg fuel
Total PM	4.4 lb/1000 gals	3.0 lb/1000 gals	4.4 lb/1000 gals	3.7 lb/1000 gals
PM 2.5 Reduction		22%		14%
PM >2.5 Reduction		47%		20%
Total PM Reduction		32%		16%

The field study was conducted with the cooperation of the New York City Authorities using a 2100 HP heating boiler [7]. The maximum boiler flow rate that could be reached was about 7 gallons per minute (420 gallons per hour) compared with a maximum of about 10 gallons per hour in the laboratory boiler. One cannot regulate the excess air independently as in the laboratory boiler. Consequently, the measurements were made at three flow rates and stack measurements made at each flow rate. Figure 14 below shows the NOx data plotted as before and it is seen again that the blend has a lower NOx emission than with the baseline # 6 oil. Thus

the laboratory measurements are validated in the field. The constraints due to the bulk of the PM measurement equipment and that due to the location of the field boiler precluded PM measurements in the field and so no PM data could be obtained. However, it is expected that reductions in the PM similar to those seen in the laboratory would be realized, at least in the PM 2.5 which as is considered to be mostly due to the sulfur content of the fuel. The brief report on the field tests is included as Appendix A.

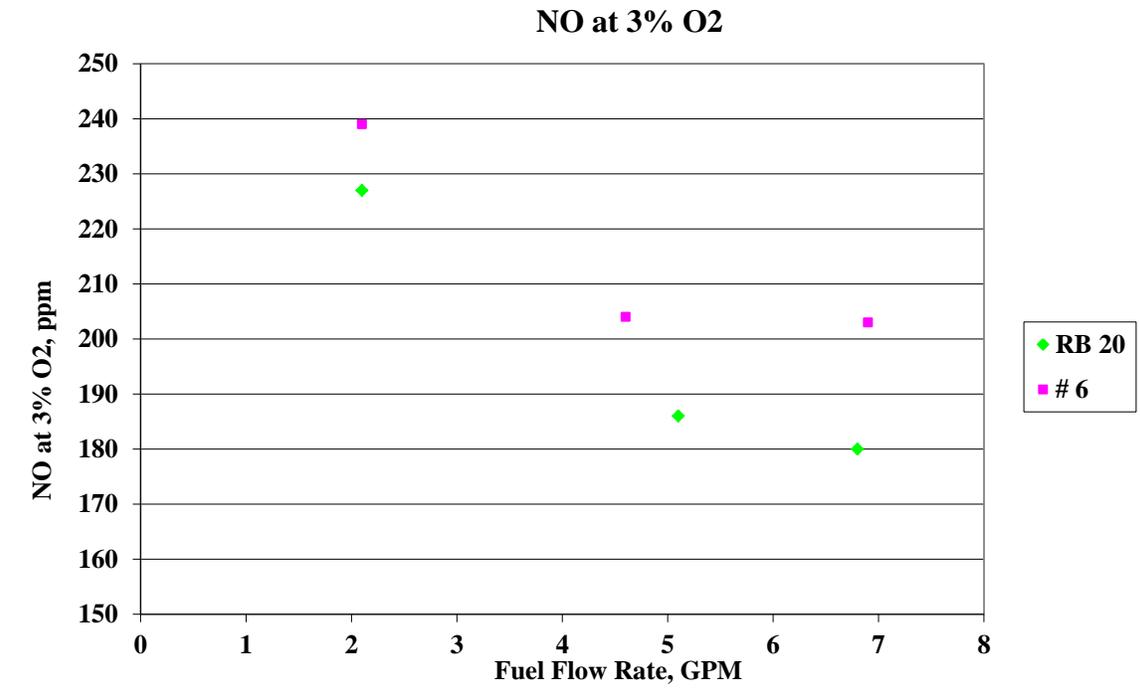


Figure 14. NOx emission from the Field Boiler

5.3 Gaseous Emission Results

Figures 15 through 18 below summarize the results of the performance tests. The gaseous emissions are always calculated for a nominal 3% oxygen in the stack and are measured for a range of excess air levels represented by the oxygen in the stack. From figure 15, it would seem that the blends and the ‘neat’ Jatropha oil burn as well as the residual oil under similar conditions as evidenced by similar levels of carbon monoxide emissions, which signify incomplete combustion. As a matter of fact, the Jatropha oil has a much lower viscosity than the residual oil (see table 2 above) and so the blends do not need to be heated to as high a temperature for good atomization. For example, during the Jatropha oil tests, the fuel temperature was about 35-40 degrees Fahrenheit lower than for the # 6 oil tests. In practice, this will translate to less consumption of auxiliary energy in operation.

Figure 16 shows the sulfur dioxide levels. Obviously, this arises from the oxidation of the sulfur in the fuel and should be constant at all levels of excess air. This is seen to be true with the

blend data, but the # 6 oil data is erratic especially at the low excess air levels. If we drop the outliers, the obvious conclusion is that the blending of Jatropha oil lowers the SO₂ emission because of the much lower sulfur in the Jatropha oil compared to the # 6 oil (See Table 1 above). Parenthetically, it should be remarked that the # 6 oil used here has to meet New York City requirements which limits it to less than 0.3% sulfur and typical residual oils can have much higher sulfur contents than this.

Figure 17 summarizes the NO_x emission data. It is very clear that the NO_x emission produced by the burning of the blends is lower than that from the # 6 oil. The reduction increases with the increase in the amount of Jatropha oil in the blend and hence the NO_x emission is lowest with 100% Jatropha oil burning. Figure 18 shows this reduction in a more direct fashion by plotting the decrease in NO_x at the maximum excess air level run (more or less the same oxygen levels in the stack) as a function of the amount of Jatropha oil in the blend. The decrease is almost 50% if we substitute Jatropha oil for # 6 oil. It should be noted here that similar reductions in NO_x emission have been seen at BNL with the blending of biodiesel in residual oil [6, 13, 14].

5.4 Particulate Emission Results

The results of the particulate emission measurements are give in tables 4 through 6 below for the base # 6 oil and the RJB 20 and RJB 60 blends. The quantity of the Jatropha oil available was not sufficient for particulate measurements (which have to be run in triplicate at least) for 100% Jatropha oil combustion. Clearly, by all the measures in the tables (see the values in **bold** in the tables), the PM 2.5, which represents the particulate matter smaller than 2.5 microns, is reduced by addition of the Jatropha oil to the blend. This is consistent with the generally accepted observation that PM 2.5 is primarily due to the sulfur in the fuel. This is overwhelmingly so with distillate fuels and predominantly true with residual fuels. The latter have higher ash content (~.05%) and some of that is trapped in the PM 2.5. Limited published data seems to indicate that over 60% of the PM_{2.5} consists of sulfates, with some organic and elemental carbon and possibly some inorganics. In the measurements carried out here, no speciation was done. The low sulfur of the Jatropha oil (Table 1 above) contributes to the lower PM_{2.5} and lower SO₂ emission (Figure 16 below). It is somewhat puzzling that the value for RJB 60 was not lower than for RJB 20 and this anomaly might be a result of some complication/error in measurement. The particulate emissions of size larger than 2.5 microns (see the values in ***bold italics*** in the tables) do decrease consistently with the addition of the Jatropha oil to the residual oil.

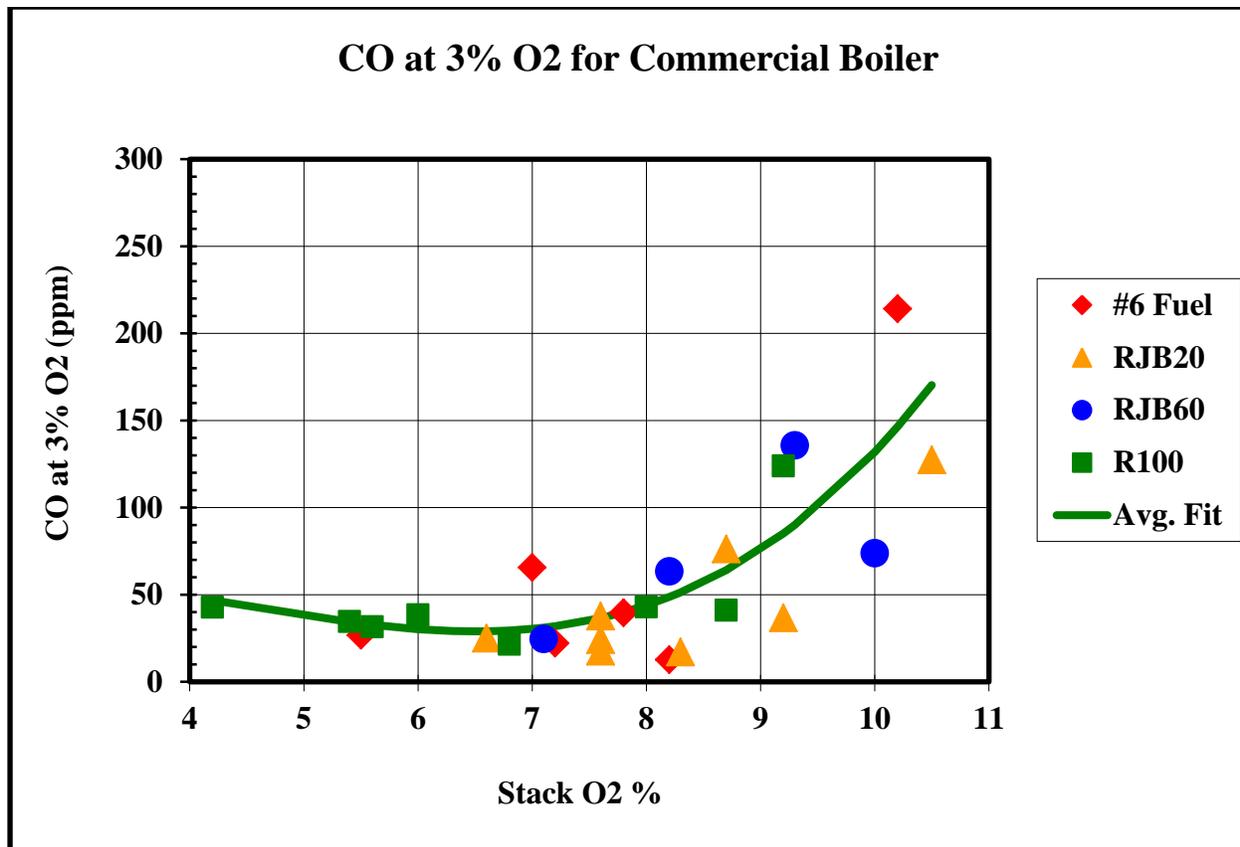


Figure 15. Carbon monoxide emissions

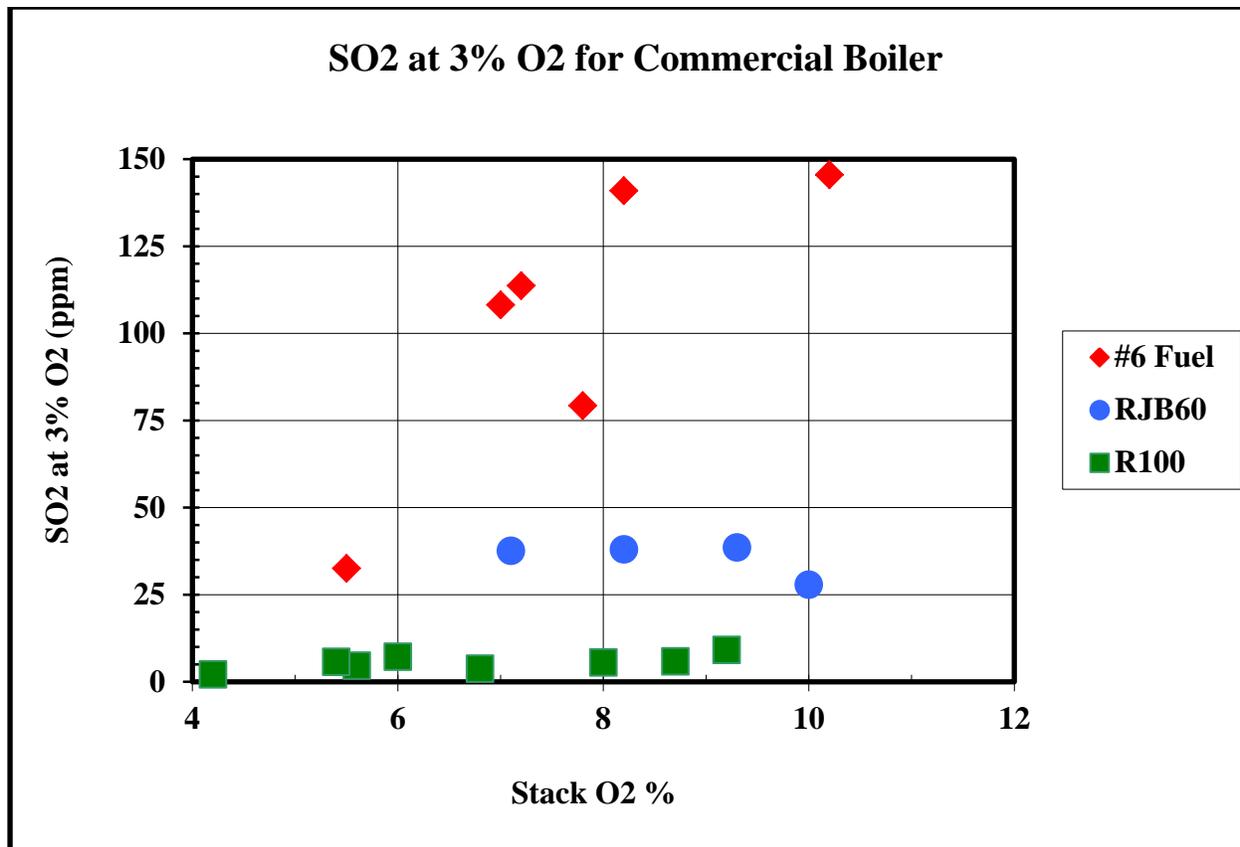


Figure 16. Sulfur Dioxide emissions

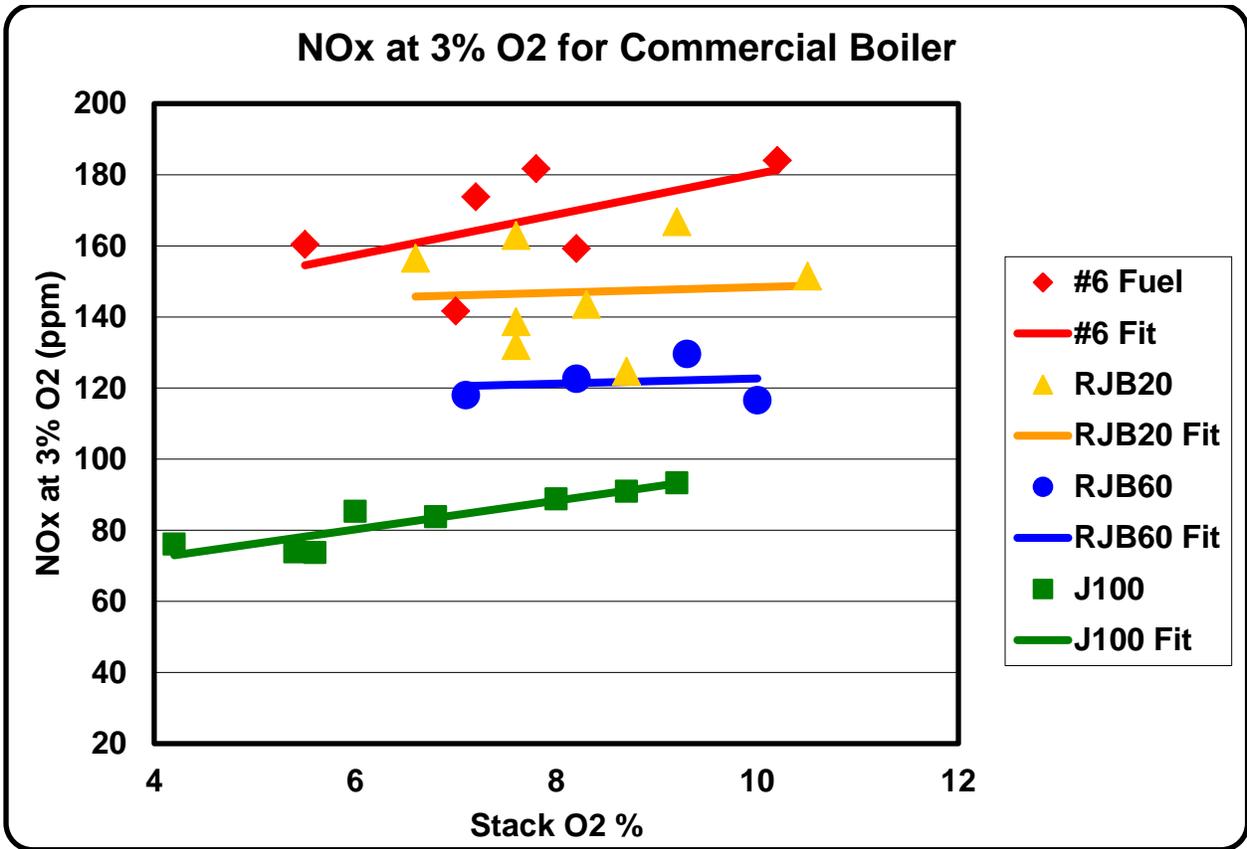


Figure 17. NOx emission data

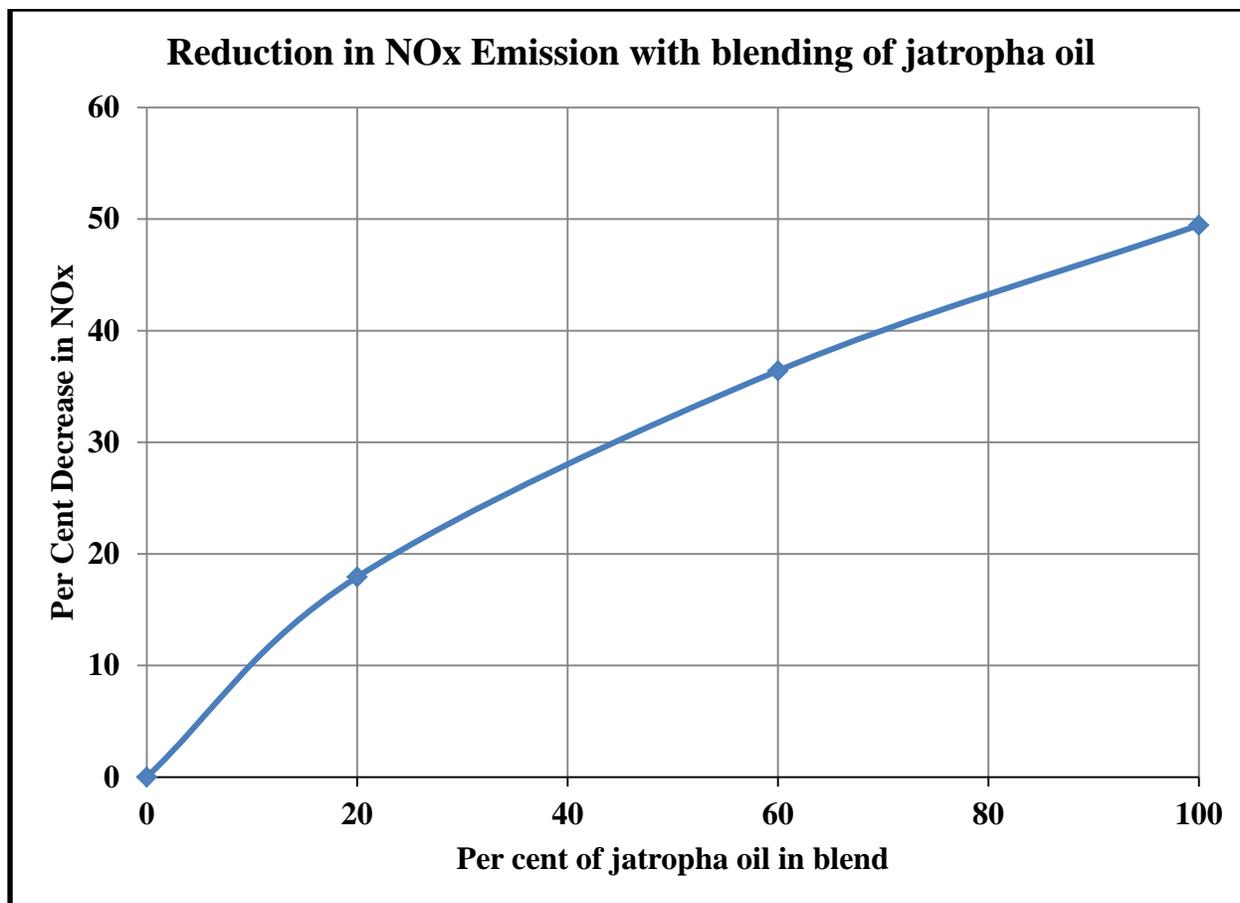


Figure 18. Per cent decrease in NOx with Jatropha addition to residual oil

Table 4. Particulate Emission data for # 6 Residual Oil

Baseline Fuel No. 6								
Run	PM 2.5				Larger than PM 2.5			
	K-2	K-3	K-4	Avg.	K-2	K-3	K-4	Avg.
Part. Concentration (dry) mg/m3	59.4	63.3	60.9	61.2	29.3	29.5	29.2	29.3
PM Conc. @ 3%Oxygen mg/m3	75.9	81.5	78.9	78.8	37.4	38.0	38.0	37.8
mg/MJ	22.0	23.6	22.8	22.8	10.8	11.0	11.0	10.9
mg/kg	928.	997.	965.	963.	458.	465.	464.	462.
lbs/MMBtu				0.05				0.02
lbs/1000 gallons				3				5
				7.4				3.6
All particulate lbs/1000 gallons								11.0

Table 5. Particulate Emission data for RJB 20 blend

RJB20 Blend								
Run	PM 2.5				Larger than PM 2.5			
	K-6	K-7	K-8	Avg.	K-6	K-7	K-8	Avg.
Part. Concentration (dry) mg/m3	22.4 2	23.7 6	20.2 7	22.1 5	22.3 4	22.4 4	22.2 3	22.3 4
PM Conc. @ 3%Oxygen mg/m3	28.0 7	27.9 8	25.7 4	27.2 6	27.9 6	26.4 3	28.2 2	27.5 4
mg/MJ	7.93	7.91	7.27	7.70	7.90	7.47	7.97	7.78
mg/kg	334. 9	333. 8	307. 1	325. 2	333. 6	315. 3	336. 6	328. 5
lbs/MMBtu				0.01 8				0.01 8
lbs/1000 gallons				2.5				2.5
All particulate lbs/1000 gallons								5.0

Table 6. Particulate Emission data for RJB 60 blend

RJB60 Blend								
Run	PM 2.5				Larger than PM 2.5			
	K-10	K-11	K-12	Avg.	K-10	K-11	K-12	Avg.
Part. Concentration (dry) mg/m3	20.4 4	20.2 9	20.7 0	20.4 8	11.3 6	11.2 2	11.2 1	11.2 6
PM Conc. @ 3%Oxygen mg/m3	29.9 9	28.8 2	29.8 8	29.5 7	16.6 6	15.9 4	16.1 9	16.2 6
mg/MJ	8.48	8.14	8.45	8.36	4.71	4.51	4.58	4.60
mg/kg	357. 8	343. 8	356. 6	352. 7	198. 8	190. 2	193. 1	194. 0
lbs/MMBtu				0.01 9				0.01 1
lbs/1000 gallons				2.7				1.5
All particulate lbs/1000 gallons								4.2

6. Conclusions and Recommendations

In an earlier phase of this project, blends of biodiesel (made from soy oil to ASTM D 6751 standard) with residual oil (ASTM # 6) were tested in the laboratory. The emission measurements showed that, as expected, there were reductions in SO₂. There were also reductions in the emission of NO_x with the addition of biodiesel and in the emission of particulates, PM 2.5 particularly. Clearly, these are beneficial effects. In addition, as one would expect, the viscosity of the blend is lower than that of the baseline residual oil and hence the fuel need only be heated to a lower temperature with obvious benefits. However, increasingly there are objections to the manufacture of biofuels including biodiesel from food sources. This has generated interest in non-edible vegetable oils including Jatropha oil for producing biodiesel. Because of the properties of residual oil, it seemed that one could use the neat Jatropha oil, without conversion to biodiesel, to blend with it. This phase of the project studied the properties of such blends. Compatibility and storage stability tests were conducted. The blends were also burned in the test boiler to examine the effects on emissions.

The compatibility and storage tests conducted on small samples show that the Jatropha oil can be mixed and stored with the residual oil. The blends and neat Jatropha oil could be burned as well as with the same burner equipment. As the blend (and the neat Jatropha oil) viscosities are lower, the fuel entering the atomizer does not need to be heated to as high a temperature. The emissions of Sulfur Dioxide and the Nitrogen Oxides are significantly lower with the addition of Jatropha oil to the residual oil. The particulate emissions are also reduced with the blending of Jatropha oil.

It is felt that successful testing in the field as done with biodiesel blends [7] would generate confidence among suppliers and users. At present, the availability of Jatropha oil seems to be limited and the cost is relatively high. This could change with time, especially if successful demonstrations of its use occur. As the Jatropha oil, at least some varieties of it, can be potentially mildly toxic, safe practices of handling and use should be established.

7. Acknowledgements

The project had the unstinting support of George Wei and Yusuf Celebi in carrying out the tests. Roger McDonald was instrumental in making the particulate measurements. Dr. Narinder Tutu (guest Scientist) gave tremendous help (with no compensation except thanks!) in processing and presenting the data and in reviewing the report. Tom Butcher's support is acknowledged. Thanks are due to Nathan Russell for considerate management of the project and facilitating the Jatropha oil work. SG Biofuels provided the initial sample of Jatropha oil. Dr. Robert Schmidt, Chief Scientific Officer of SG Biofuels, was helpful in providing information on different aspects of Jatropha oil production.

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Appendix A

Performance of biodiesel-residual oil blend in a New York City Heating Boiler

C.R. Krishna and Yusuf Celebi

4/22/2009

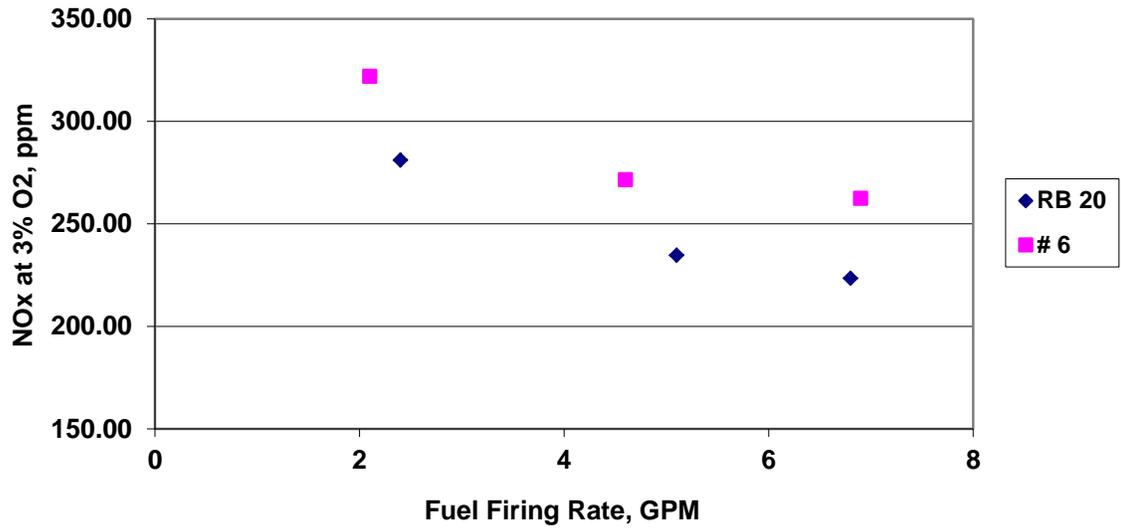
The boiler in which the blend of 20% biodiesel in residual oil was tested is a 2100 HP Tampella Power water tube boiler. A total of over 19,000 gallons of the blend was burned with no apparent problems. The observation reported was that the blend left the burner cleaner than is usual with #6 oil, hence not needing as frequent cleaning. The blend was stored in an outside underground tank for over 4 months before use. The blend was heated and kept circulating during this relatively long storage period. The boiler has a multi-fuel burner for firing natural gas or residual oil. The residual oil can be atomized with steam or compressed air. The current practice is to use natural gas as fuel most of the time and hence one of the concerns in using a bio-blend is that it can remain stored in the tank for long periods between uses.

The tests were conducted using the baseline residual fuel and the biodiesel blend, designated here RB20. Measurements of the fuel flow and of the properties of the stack gases were made at different loads on the boiler. Stack measurements included the gas temperature, and the concentrations of oxygen, Carbon monoxide, and nitrogen oxides. Unfortunately, the boiler could not be loaded to its full capacity because of lack of demand and a maximum loading of 50% was attained. Measurements were made by Brookhaven National Laboratory (BNL) personnel and the engineer from Energy Control LLC. The results will be presented in the form of charts below.

The most interesting results were those for the emission of nitrogen oxides. The carbon monoxide in the stack was a few parts per million or zero in the tested load range. The nitrogen oxide values were slightly different from the two sets of measurements, but in both cases the same trends are shown. As the charts below show, the emission of nitrogen oxides (presented as corrected to 3% oxygen in the stack) decreased with increasing firing rate in the range tested here for both fuels. Also, the values for the RB20 blend were lower than that for the residual fuel at similar firing rates. So, clearly this is a benefit to blending biodiesel. Whether this trend of reduction in nitrogen oxide emission will extend to full load can only be established by measurements.

The constraints posed by the size of the PM2.5 measurement equipment and by the boiler stack accessibility precluded direct measurement of the PM2.5 from the two fuels. However, prior work at BNL and at CANMET has demonstrated that the emission of these fine particulates correlates more or less directly with the sulfur content of the fuel. BNL has made measurements of the PM2.5 in a laboratory boiler of a much smaller capacity converted to fire residual oil with compressed air/steam atomization, and firing at about a million btu/hr (~30 hp). This demonstrates the PM2.5 reduction anticipated with the blending of biodiesel as shown in the table below. Two residual fuels supplied by a New York City supplier were used in the tests and they were blended with 30% biodiesel. The reduction in PM2.5 with the addition of biodiesel is apparent and it is anticipated that a 20% blend would lead to slightly lower reduction in fine particulate emissions.

NOx at 3 % O2, Energy Control Data



NO at 3% O2, BNL Data

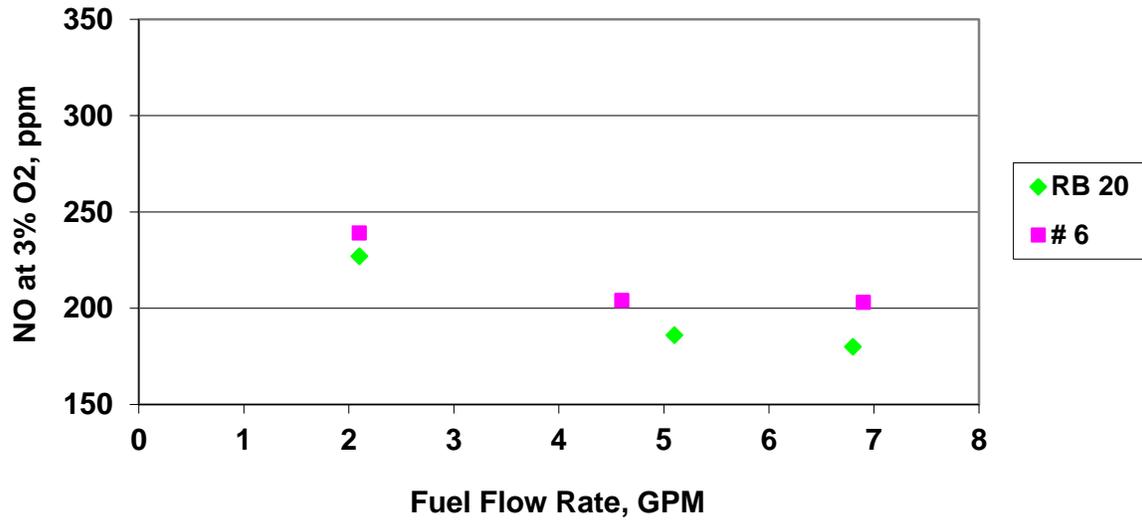


Table 1. PM Emissions for the Fuels and Blends.

	LV#6 *	LVRB30	HV#6 ^	HVRB30
PM 2.5	2.7 lb/1000 gals 332 mg/kg fuel	2.1 lb/1000 gals 272 mg/kg fuel	2.9 lb/1000 gals 359 mg/kg fuel	2.5 lb/1000 gals 304 mg/kg fuel
PM>2.5	1.7 lb/1000 gals 207 mg/kg fuel	0.9 lb/1000 gals 112 mg/kg fuel	1.5 lb/1000 gals 191 mg/kg fuel	1.2 lb/1000 gals 150 mg/kg fuel
Total PM	4.4 lb/1000 gals	3.0 lb/1000 gals	4.4 lb/1000 gals	3.7 lb/1000 gals
PM 2.5 Reduction		22%		14%
PM >2.5 Reduction		47%		20%
Total PM Reduction		32%		16%

Notes: * indicates a ‘low viscosity’ residual fuel

^ indicates a ‘high viscosity’ residual fuel

RB 30 indicates a 30% biodiesel blend with the two residual fuels.

Both residual fuels were for use in New York City.