



Emission reduction potential from the combustion of soy methyl ester fuel blended with petroleum distillate fuel

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Received 28 August 2003; revised 23 January 2004; accepted 4 February 2004; available online 1 March 2004

Abstract

Combustion performance of a blend containing 20% soybean methyl ester in heating No. 2 fuel was examined using a residential-scale hot water boiler. The blend burned satisfactorily with no modifications to the appliance and fuel delivery system. SO₂ emissions were $19.7 \pm 2.5\%$ lower than that of No. 2 fuel while NO_x emissions were similar. Particulate emissions, as determined by a source dilution measurement system, were on average $15.7 \pm 7.5\%$ lower than that of No. 2 fuel. The particulate bound sulphates were also lower by $14.1 \pm 6.1\%$. Results indicate potential reductions of PM_{2.5}, SO₂ and greenhouse gas emissions for the petroleum distillates that can be replaced with biofuels. Reduction of sulphate in PM_{2.5}, which is associated with adverse health effects, is considered significant. Crown Copyright © 2004 Published by Elsevier Ltd. All rights reserved.

Keywords: Biodiesel; Combustion; Fine particulate

1. Introduction

The heightened awareness of harmful effects associated with ambient air pollution compels introduction of more stringent environmental regulations worldwide. Renewable fuels such as biomass-derived products receive increased attention as they would promote energy efficiency and reduce green house gases and other harmful emissions. In addition, reduced dependency on external oil imports and fluctuating energy prices can also be realized if ever-increasing global energy demands can be partially subsidized by indigenous renewable sources. Biodiesels, biofuels and bio-oils processed from biological materials such as vegetable oils, recycled cooking oils, animal fats and plant and forest waste products are such fuels that can be blended with petroleum distillates for use in transportation engines, space heating and industrial processes to help offset increasing energy demand. Biodiesel has diesel like properties, but essentially does not contain undesirable constituents such as sulphur, nitrogen and polycyclic aromatic compounds. The product, in the most original form, is derived from transesterification of pure vegetable oils such as soybean, rapeseed and cottonseed oils although

post-consumer waste vegetable oils can also be used. Biodiesel is basically made up of methyl or ethyl esters containing several alkyl groups with C15 to C17 hydrocarbon chains, collectively known as fatty acid alkyl esters. Because of these unique properties, the biodiesel use as an alternative transportation fuel has progressed more rapidly than bio-oils, which are normally derived from pyrolysis of wood and plant products. The most promising blend at present is the mixture of 20% biodiesel and 80% of petrodiesel by volume, commonly known as B-20 blend. Regardless of the source and the process involved to produce biodiesel, the neat product, or B-100, is required to meet the ASTM D 6751 specifications to ensure its acceptable performance as a blending stock as well as on engines. In Europe, fuel specifications for B-100 and the lower content mixtures of B0-B5 are being developed, designated as prEN 142 and prEN 590, respectively. The 'prEN' designation indicates that the standard is in the proposed stage. On the other hand, the oils processed from fatty acid based oil seeds or animal fat derived oils that are not restricted by biodiesel specifications are loosely termed as biofuels. They can be produced at a lower cost than biodiesel due to less stringent product quality restrictions. For example, biofuel is produced as byproducts from industrial processes using soybeans in manufacture of additives, cosmetics, pharmaceuticals and special

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chemicals. They have promising potential in heating and industrial process applications providing increased energy efficiency and resource management flexibility. Heating oils containing biofuels are generally known as fatty acid methyl esters or FAME and their specifications are being developed in Europe as prEN 14213 method. Bio-oil is another generic name given for liquids processed from biomass-based materials such as wood pyrolysis liquids. If these renewable energy products can be used much like petroleum fuels with no or little equipment modifications significant benefits can be realized in energy costs, regional agricultural economy, emission reduction and extended equipment life.

Of all these biomass-derived alternative fuels, applications of biodiesel have gained increasing recognition and support by regulators and industrial sectors in recent years, especially for equipment with compression ignition engines such as in transportation vehicles and off-road commercial and industrial equipment [1–3]. Most often biodiesels are referred to as soybean methyl esters as soybean dominates in the oil seed production in North America. Remarkable advantages of using biodiesel in heavy duty highway vehicle engines have been reported including reduced pollution emission of particulate matter (PM), unburned hydrocarbons, carbon monoxide and polycyclic aromatic hydrocarbons and decreased odor in exhaust gas. The results for nitrogen oxides (NO_x) emissions are, however, inconclusive at present. A much higher positive energy balance for biodiesel is also noted, when compared to ethanol, another alternative fuel product [4]. This is the amount of energy it takes to produce and transport the alternative fuel as end product. Realistically, there are still several issues that need to be addressed before the widespread use of biodiesel and biofuel products as environmentally advantageous alternative fuels can be realized. The most technically challenging is the low temperature performance of the fuel. Biodiesels have higher pour point temperatures than petroleum fuels that could present cold flow problems due to fuel gelling. For example, the average pour point of B-20 blended in the US is -18°C , compared to -24°C for No. 2 fuel oil. In Canada, where the fuels are processed for colder climates, the corresponding values are -24°C , compared to -38°C , respectively. For very cold climates, the biodiesel content may have to be reduced to lower than 20% in the fuel blends to avoid low temperature performance difficulties for engines and burners. Alternatively, fuel in-line heaters could be installed on the combustion equipment to assist cold start ignition. Additional research is needed to fulfill the apparent knowledge gaps in this domain. The thermal and storage stability of biodiesel is also under investigation. Incompatibility of biodiesel with some components in combustion equipment is another area of concern. For example, seals and other components made of buna-nitrile rubber tend to react with biodiesel and this is being studied by burner manufacturers. The price and availability of biodiesel will also play a major role in consumer acceptance. It is expected

that biofuel products will receive better acceptance when technical challenges identified during the early technology transfer stage are resolved.

As for other non-transportation applications, biodiesel also showed promising results when used in boilers for space and water heating [5]. The results demonstrated that B-20 blend exhibited acceptable normal combustion performance on both residential and commercial oil-fired units. No modifications to the combustion and fuel delivery systems were necessary. While combustion emissions are also similar to those of No. 2 fuel oil, noticeable reductions in stack SO₂ and NO_x emissions from B-20 were reported. However, only limited data is available at present for the potential advantages that can be provided by biodiesel and biofuel in non-transportation equipment, particularly in space and water heating and industrial processes where substantial energy and environmental benefits exist. Moreover, health benefits associated with pollution reduction features that can be gained from these fuels warrant further investigations. For the oil industry, immediate benefits could be realized by full or partial use of biofuels in meeting emission regulations. It is apparent that more research is needed in this area to provide new information in terms of combustion performance and emission benefits of biodiesels and biofuels on different equipment type.

A recent study examined the suitability of biodiesel blends as commercial fuels for residential space and water heating. Potential reductions in gaseous as well as PM emissions were determined, particularly of fine PM. Fine PM emission measurement of the new fuel blend is important in view of the new Ambient Air Quality Standards in Canada and the US that limit the ambient concentrations of fine PM, commonly known as PM_{2.5} and PM₁₀ [6,7]. These are the particles with aerodynamic diameter less than 2.5 and 10 μm , respectively. The new North American regulations are based on their reported associations with adverse health effects including lung cancer and cardiopulmonary ailment [8–11]. While energy and environmental benefits of renewable fuels are well recognized, information on their advantages relating to health impacts is relatively scarce. This paper reports initial findings from this research initiative with respect to the potential gains in energy efficiency and environmental and health impacts that could be realized from biofuel use.

2. Experimental

2.1. Experimental fuels

This initial investigation employed a commercial No. 2 type heating oil and a B-20 blend. The biofuel blend was prepared using the same No. 2 fuel by mixing with 20% by volume of soybean methyl ester. The No. 2 oil is used as the reference or control fuel for the performance evaluation of the biofuel blend. The soy ester was produced in Canada

using a proprietary process and was provided by a local fuel supplier. This blend ratio was selected based on the results from a previous research [5]. The B-20 blend was properly mixed and mechanically agitated prior to each combustion experiment to ensure fuel homogeneity. The drums containing test fuels are stored and conditioned overnight in the temperature controlled test room to achieve desired test temperatures. Table 1 gives properties of the two experimental fuels.

2.2. Fuel oil combustion test facility

The facility was part of the integrated oil combustion test rig that is constructed with a stationary combustion unit, fuel supply and delivery system, advanced continuous emission analyzers, temperature and pressure sensors and online data acquisition and data analysis systems. A cast iron, 30 kW residential hot water boiler of wet based configuration was used as combustion equipment and was equipped with a high efficiency oil burner. The test rig is located inside a constant temperature room that maintains test conditions at selected temperatures. The water circulation system and pneumatic control valves were operated using computer-controlled data acquisition software to maintain the boiler inlet and outlet water temperatures at 54 ± 2 and 83 ± 2 °C, respectively. The laboratory standard continuous emission analyzers installed on the test rig provided the gas phase emission concentrations of O₂, CO₂, CO, NO_x and SO₂ concentrations in the stack gas. The operation of the entire test facility including online emission and temperature monitoring was automatically controlled by a dedicated computer system.

PM_{2.5} emissions from the fuels were measured using a source dilution particulate sampler previously developed at the laboratory. The description and method protocol of the fine particulate measurement system were previously

reported [12–15]. The protocol involves isokinetic withdrawal of flue gas followed by 20- to 60-fold dilution with pre-cleaned air inside a Teflon[®]-coated inert dilution tunnel. Subsequent sampling of PM_{2.5}, PM₁₀ and total particulate (PM_{Total}) fractions is accomplished at specified sampling ports using appropriate inlet and filter-pack arrangements. The sample temperature and humidity inside the dilution tunnel were maintained at near-ambient conditions, preferably 20–25 °C and 40% relative humidity. Source dilution sampling attempts to promote simulation of ambient PM formed under atmospheric conditions. Analysis of PM samples was performed in an ambient-comparable manner for mass, size distribution, carbon, trace element concentrations and soluble sulphates. Briefly, particle size distribution was examined by transmission electron microscopy; trace elements were determined by energy dispersive X-ray fluorescence (XRF); organic and elemental carbon contents by thermal-optical reflectance procedure and particle bound acidic species such as sulphites, sulphates, nitrates and hydrogen ions by ion chromatography. Mass determination of all PM fractions was done by gravimetry using a microbalance placed inside a humidity-controlled chamber maintained at 21 °C and 40% relative humidity.

2.3. Experimental procedures

For this preliminary evaluation, accelerated laboratory procedures were used to obtain the most useful results possible within a relatively short timeframe. At the preparatory stage, the test boiler was optimized using a reference No. 2 heating oil to obtain maximum thermal efficiency of the unit. The selected conditions include a burner setting of trace smoke and a stack exhaust draft of 0.05 in. of water. The experimental combustion protocol was set to simulate average field performance procedures but in a much shorter operation mode. The selected combustion test procedure included two specific burner operation patterns, a short cycle emission monitoring run and one particulate emission sampling run during which the boiler is operated to be continuously running with no on/off cycles. The short cycle test starts from a cold temperature ignition for a 1-h steady state burner 'on' mode, to be followed by three 10 min 'on'/10 min 'off' cyclic operation. The test room temperature of 17–18 °C was maintained for all experiments to ensure reproducible results from replicate runs. The experimental fuels were stored inside the test room overnight. A typical combustion experiment commenced with pre-conditioning of the test room and fuel temperatures overnight, followed by calibration of emission analyzers in the morning. Examination and adjustment of boiler exhaust draft and fuel temperature were then made to attain optimum conditions. The selected burner combustion air initially optimized during combustion trials using No. 2 fuel was used without any additional adjustments for all final experiments. Multiple combustion runs were performed for

Table 1
Properties of No. 2 oil and B-20 biofuel blend

Properties	No. 2 fuel	B-20 blend
Ultimate analysis (wt%)		
Carbon	87.00	85.10
Hydrogen	13.10	12.90
Nitrogen	0.01	0.01
Sulphur	0.19	0.15
Ash	<0.001	<0.001
Water content—Karl Fisher (wt%)	<0.01	<0.01
Total acid number (mg KOH/g)	0.09	0.32
Density at 25 °C (kg/m ³)	839.9	847.9
Density at 15 °C (kg/m ³)	847.2	855.2
Specific gravity (60/60F)	0.848	0.856
Gross calorific value (cal/g)	10,831	10,527
Kinematic viscosity at 25 °C (cSt)	2.991	3.416
kinematic viscosity at 40 °C (cSt)	2.234	2.549
Cloud point (°C)	−16.4	−3.6
Pour point (°C)	−38	−24

both No. 2 fuel and B-20 blend under similar experimental conditions optimized for No. 2 fuel. It is important to note that no modifications to the burner, boiler or fuel delivery systems were made for burning B-20 blend.

Replicate sets of fine particulate emission measurement were also conducted for both fuels under similar experimental conditions using the established source dilution sampling protocol. A typical particulate sampling experiment for a residential scale oil-fired appliance requires 6–20 h of continuous operation, depending on the emission rate of the fuel. After sampling, the filter samples were immediately stored and conditioned inside the temperature and humidity-controlled chamber. Samples were later analyzed following the established procedure [14]. Typical analysis scheme for each PM fraction filter involves gravimetric determination of particle mass concentrations and quantification of three main PM constituents, namely, sulphates, carbons and trace elements. Each analysis was conducted using separate samples collected on individual filters that are of different material. For example, characterization of PM_{2.5} fraction required four samples of different filter materials collected subsequently in the filter pack attached to the size selective cyclone. A simple mass balance for each particulate fraction was later calculated using the composite mass data from the three constituents analyzed.

3. Results and discussion

3.1. Combustion appliance performance

Laboratory observations showed acceptable combustion performance of the B-20 blend on a high efficiency oil burner under normal operating conditions at temperatures of 15–18 °C. There were no apparent difficulties in cold start burner ignition at these temperatures as indicated by a similar rise in stack gas temperature usually seen under normal burner operating conditions. Transient burner on/off operations also showed normal performance characteristics and the flame sustenance was evident for up to 10 h of continuous operation. The maximum boiler 'on' time was limited to 10 h during these preliminary experiments, but no apparent operational difficulties are expected for much longer operation periods. However, lower fuel temperatures appeared to affect the cold start ignition as indicated by subsequent increase in the CO emission peak as the test room temperature was lowered from 15 to 0 °C. The cold start CO emission peak registered 100, 140, 160 and 725 ppm at the fuel temperatures of 15, 10, 5 and 0 °C, respectively. This suggested a poorer than normal ignition performance of the fuel at low fuel temperatures as indicated by the increased CO emission, which is an incomplete combustion product. Based on previous research data, high emissions of CO, hydrocarbons and smoke opacity normally indicate poor fuel atomization that is often

associated with increased soot or particulate emissions. However, once the fuel successfully ignited the burner sustained the operation with no interruption or failure for an additional 2 h, at which time the experiment was terminated. It is likely that poor atomization at lower temperatures were contributed by increased viscosity of B-20. The temperature effect on fuel viscosity appeared to be more pronounced for B-20 than No. 2 fuel as seen in Table 1. Although only limited investigations were completed during the initial work, research has recently resumed to systematically examine the cold temperature effects by incorporating additional online monitoring of smoke opacity and hydrocarbon emissions.

3.2. Emission performance

Gaseous emissions. Gas phase stack emissions from the combustion of No. 2 fuel and B-20 blend are shown in Tables 2 and 3, respectively. Results of the multiple experiments are given to demonstrate the reproducibility of the experimental results from different days. The averaged results for B-20 show a $19.7 \pm 2.5\%$ reduction of SO₂ in the stack emissions, when compared with No. 2 fuel, while other gaseous emissions are similar for both fuels. The similarity of O₂ and CO₂ concentrations indicates a good control of burner excess air conditions. Although nitrogen oxides appear to be slightly higher for the B-20 fuel, the results are not considered statistically significant. However, according to the analytical data for the fuels reported in Table 1 that show similar reductions by about 21% in both sulphur and nitrogen contents for the biofuel, one would expect a similar reduction in the two emission data. Emission results for both fuels were reviewed after normalizing them to 3% oxygen. A similar reduction in SO₂ reduction as well as the comparable NO_x concentrations was noted. The data were, however, excluded in view of the presence of additional oxygen in the stack gas that could be associated with oxygen in the original biofuel. A previous study using B-20 showed noticeable reductions in both SO₂ and NO_x [5], suggesting a disagreement between the NO_x emission data. An additional experiment was, therefore,

Table 2
Steady state gaseous emissions from No. 2 fuel

Parameter	Experiment no.				Average
	1	2	3	4	
Test room temperature (°C)	17	17	17	17	17
Stack temperature (°C)	255	253	253	253	253
<i>Stack emissions</i>					
Oxygen (%)	4.6	4.8	4.4	4.6	4.6
Carbon dioxide (%)	12.9	12.8	12.8	13.1	12.9
Carbon monoxide (ppm)	35	28	30	29	30
Sulphur dioxide (ppm)	95	95	na	98	96
Nitrogen oxides (ppm)	112	101	100	103	104

na, not available.

Table 3
Steady state gaseous emissions from B-20 biofuel blend

Parameter	Experimental no.						Average
	1	2	3	4	5	6	
Test room temperature (°C)	17	17	17	18	18	18	17
Stack temperature (°C)	259	256	256	252	253	254	255
<i>Stack emissions</i>							
Oxygen (%)	4.4	5	4.6	4.8	4.9	4.6	4.7
Carbon dioxide (%)	13.2	12.8	13	12.9	12.7	12.9	12.9
Carbon monoxide (ppm)	39	28	35	31	28	30	32
Sulphur dioxide (ppm)	79	76	78	75	78	78	77
Nitrogen oxides (ppm)	110	109	112	106	109	110	109

specifically conducted where an instant fuel switch from No. 2 oil to B-20 blend was done during an experiment without interrupting the boiler operation. No significant changes in the NO_x emissions were noted suggesting that biofuel does not have any noticeable effects on this gas, under the selected experimental conditions described above. The boiler configuration, particularly of combustion chamber design and the burner setting, may play important roles in the observed differences in NO_x values between the two studies. Research data for the transportation diesel engines reported both the reduction and increase of NO_x emissions when biodiesel blends were used [16]. The need for additional research in this area is apparent. Nitrogen oxide compounds are known precursors of particulate and ground level ozone formation and the use of biofuel blends in residential heating would be of great environmental benefit if the fuels can reduce these air emissions to the local air shed. This information may even be more valuable in view of the fact that very limited research is in progress, unlike numerous activities being taking place in transportation engine research. Similarly, there are no NO_x regulatory guidelines for small residential and commercial combustion equipment while the auto vehicle emissions are subjected to increasingly stringent NO_x emission regulations. Nonetheless, current data suggest that the observed reduction in SO₂ from biofuel blend is an attractive feature, given the known impacts of sulphur emissions on the combustion appliance integrity, the environment and human health. Moreover, significant reduction of green house gases from fossil fuels could also be achieved by utilizing biofuels as an alternative option.

Particulate emissions. Table 4 reports PM mass emission results including the fine fractions of PM_{2.5}, PM₁₀ and PM_{Total} for both fuels. Results are expressed in terms of PM mass concentrations in mg/m³ dry flue gas at standard temperature and pressure. Each sampling run collects one filter sample each for PM_{2.5} and PM₁₀ fractions and two for the PM_{Total} fraction. The total mass emission result therefore represents the average result of duplicate runs. The results for all independent runs are given along with the calculated relative standard

deviations to demonstrate the data reproducibility. However, it should be noted that each mass emission data has an average error of 0.84 mg/m³, contributed by the uncertainties associated with the determinations of mass, diluted sample flow and dilution ratio calculations that involves the CO₂ measurement in gases using a multi-channel analyzer. New information that is of significance can be noted in the experimental results. Firstly, the data show the apparent similarity of the mass concentrations for all PM fractions for both fuels. This suggests that all particulates emitted from both fuels when fired in a residential boiler fall in the PM_{2.5} fraction. Previous research at CETC on low sulphur diesel and No. 2 type distillate fuels have shown similar results, which were supported by size analysis of particles using scanning electron microscopy [15]. Similar studies done for the transportation and mining engines elsewhere also reported that diesel fuels normally generate very small particles less than 1 μm in diameter, known as ultra-fine PM. Secondly and more importantly, the results demonstrate that the total PM mass emission concentrations from B-20 biofuel are lower than those from No. 2 oil by approximately 13%. It should be noted that the results are preliminary since only a limited number of replicate runs were completed in this brief study. However, this is a significant emission benefit that can be realized from the application of biofuel blends in stationary combustion systems. As for the size properties

Table 4
Fine particulate emissions from No. 2 oil and B-20 biofuel blend

Fuel	Run	PM _{2.5} (mg/m ³)	PM ₁₀ (mg/m ³)	PM _{Total} (mg/m ³)
B-20	1	12.89	12.66	12.83
	2	14.00	11.82	14.42
	3	12.67	11.79	12.89
	AVG	13.19	12.09	13.38
	RSD (%)	5.41	4.06	6.74
No. 2	1	15.74	15.48	15.18
	2	13.95	14.00	14.65
	AVG	14.84	14.74	14.92
	RSD (%)	8.54	7.08	2.51

of biofuel-derived particulate, ongoing work will address this important topic in more details since particle size characteristics are known to influence their entry dynamics into deeper parts of the lungs.

PM chemical composition. A better understanding of the chemical constituents of ambient particles is fundamental in bridging the knowledge gap between air quality and its health effects. Ambient fine particles are generally made up of numerous species depending on the quantity and composition of emissions from contributing sources and the sampling location. These include acidic species such as sulphates and nitrates that mostly exist as ammonium salts and free acids, carbon species, water, trace elements mainly in the form of oxides, earth crustal matter and other airborne fragments of natural and anthropogenic origins. On the other hand, combustion source particulate from fossil fuel burning is mainly composed of carbon species, condensed acidic species, water and trace elements. Sulphates and nitrates in particles are formed during the secondary PM formation process when primary emissions such as SO_x and NO_x undergo a gas-to-particle transformation process. Sulphuric and hydrochloric acids also condense on particle surfaces and are usually detected as soluble sulphate and nitrate ions when the samples are dissolved in water. Two types of carbons are produced during fossil fuel combustion, organic carbons (OC) and elemental or graphitic carbons (EC), the latter being a key contributor to the atmospheric visibility degradation. OC are associated with numerous and complex organic species, some of which are known air toxic compounds. These source emissions contribute to ambient particle pollution that is implicated with significant health and environmental impacts. The acids and toxic trace elements found in ambient fine PM have been linked to a few known illnesses in humans and research animals. A comprehensive analysis protocol for quantifying these important chemical constituents of particulate emissions has been developed and this protocol was applied to examine the changes in PM characteristics of heating fuel when blended with biofuels.

Preliminary results for the B-20 blend of soybean methyl ester are reported in Table 5 along with those of No. 2 fuel oil. For each PM fraction, averaged concentrations of the key components are reported in terms of mass in mg/m^3 dry flue gas at standard temperature and pressure. It should be noted that trace element data by XRF analysis has associated instrumental uncertainties although they are not reported here. Trace element content was calculated as twice that of the total elemental mass using the assumption that metals exist mainly as divalent oxides. The OC/EC analysis technique is known to be method dependent and the results could be slightly different if the analysis was done using a different technique. However, these limitations are well recognized in air pollution research and

Table 5

Constituent concentrations of particulate matter from No. 2 oil and biodiesel blend

Fuel	Constituents	PM _{2.5} (mg/m^3)	PM ₁₀ (mg/m^3)	PM _{Total} (mg/m^3)
B-20	Metal as oxides	0.11	na	0.26
	Organic carbon	0.64	0.62	0.71
	Elemental carbon	0.04	0.05	0.05
	Sulphates	5.9	5.5	5.9
	Water associated with sulphate	6.5	6.1	6.5
	Total mass by composition analysis	13.2	12.3	12.8
	Total mass by gravimetry	13.2	12.1	13.4
No. 2	Metal as oxides	0.18	na	0.19
	Organic carbon	0.63	0.57	0.61
	Elemental carbon	0.21	0.23	0.21
	Sulphates	6.7	6.3	6.6
	Water associated with sulphate	7.4	6.9	7.3
	Total mass by composition analysis	15.1	14	14.9
	Total mass by gravimetry	14.8	14.7	14.9

Note. Constituent concentrations are average values for multiple runs. na, not available.

the current data were carefully interpreted with this knowledge. The OC concentration in PM was estimated as 1.6 times that of the measured OC. Elemental carbons require no correction in mass calculation since most of them exist as graphitic carbons. As for the sulphates, the original results from the ionic chromatography analysis and the water content associated with sulphate are included, as is normally done in diesel engine emission research. The sulphate bound water content was calculated using the procedures established by the Society of Automotive Engineers [17] and the United States Environmental Protection Agency [18]. Results indicate a relatively comparable agreement between the composite mass or speciated mass data and the actual mass data from gravimetric analysis.

The overall speciated results indicated a much higher concentration of sulphates than those of trace elements and the carbons, suggesting that particles are relatively free of carbon and ash are made up of sulphates as the dominant species. As for the ash, only minute quantities of trace elements are normally generated during combustion of distillate fuels since they contain only minute amounts of inorganic trace elements in the fuel matrix. More importantly, particle bound sulphate contents found in B-20 emissions are lower than that of No. 2 oil emissions. A reduction of $14.1 \pm 6.1\%$ in sulphate content from biofuel was noted when compared with those from No. 2 oil. These appear to be in line with the observed $19.7 \pm 2.5\%$ reduction in stack SO_2 emissions for the biofuel blend. This significant reduction in PM sulphate has positive implications regarding appliance integrity, environmental impacts and more important, health effects on local population.

4. Conclusions

This brief study covered short-term laboratory investigations of a 20% biofuel blend. The conclusions derived from this study are based on initial results and are only intended as a research update. Additional experiments are underway to verify these results and until such time, this information should only be considered preliminary. The experiments conducted in this investigation were systematically controlled to provide reproducible results. Advanced equipment and novel emission measurement protocols provided new scientific information that can be used for important health effect studies of oil combustion generated pollutants.

A soybean methyl ester blended into No. 2 fuel oil by 20% by volume showed normal combustion performance comparable to that of No. 2 fuels on a residential oil-fired boiler. No modifications to the procedure or the combustion equipment were required. However, transient CO emissions at cold start increased when the test room and fuel temperature were gradually reduced to levels lower than 15 °C. The combustion of B-20 biofuel blend exhibited similar gaseous emissions to those of No. 2 fuel oil, with the exception of SO₂, which was 19.7 ± 2.5% lower. Nitrogen oxide emissions from the biofuel and No. 2 oil are similar. PM emission concentrations from biofuel are lower than those from No. 2 oil by 13%. Significant reductions in particle bound sulphate were also noted, by 12%, when compared with those from No. 2 oil. These indicate several potential benefits of using the biofuel blend in residential space and water heating and in industrial processes.

Long-term studies need to be conducted to determine appliance performance and unit component integrity over several seasons. Research on the effects of biofuel matrix on the integrity of certain combustion equipment and the long-term chemical and thermal stability of the biofuel blends needs to be investigated as well. Future research will focus additional work on cold temperature performance of the blends and necessary modifications to allow for the safe and efficient use of these blends in cold climates. More laboratory experiments are considered necessary to confirm the preliminary data.

Acknowledgements

This work was supported by the Program on Energy Research and Development at Natural Resources Canada. Technical assistance provided by Mr. E. Kelly and the fuel supplied by UPI Inc. are greatly acknowledged.

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