Comparison of exhaust emissions of diesel fuels derived from oil sands and conventional crude

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COMPARISON OF EXHAUST EMISSIONS OF DIESEL FUELS DERIVED FROM OIL SANDS AND CONVENTIONAL CRUDE

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INTRODUCTION

In Canada, 21% of petroleum crude is produced from oil sands. This figure will increase as the conventional crude oil resources are depleted. In the diesel boiling range, the oil-sands-derived crude oil is low in sulphur but higher in aromatics (although low in multi-ring aromatics) compared to conventional crude oil. The oil-sands-derived crude also contains more cycloparaffins. Diesel fuels produced from oil-sands-derived crude tend to have relatively poor cetane quality but good low temperature properties. The specific emission behaviour of oil-sands-derived diesel fuel is not well documented.

The focus of this study was to investigate the emission behaviour of oil-sands-derived diesel fuels and compare it with diesel fuels derived from conventional crude oil. The main objective was to answer the question whether oil-sands-derived diesel fuel is different from conventional-crude-derived diesel fuel (with the same total aromatic content) as far as the exhaust emissions are concerned.

EXPERIMENTAL APPARATUS AND TEST FUELS

The engine used in this program is a single-cylinder research version (Ricardo Proteus) of a Volvo TD123 heavy-duty truck engine. The engine is a direct-injection type and had a displacement volume of 2 litres. The research engine incorporates many features of contemporary medium- to heavy-duty diesel engines. It is tuned to meet the U.S. EPA 1994 emission standards. Detailed information on the engine and the emission measurement system can be found in [1]-[3].

To establish a link of the results from this program to those obtained with the EPA transient test procedure, the AVL 8-mode steady-state simulation test procedure was adopted [4]. In the steady state simulation, the engine emissions were measured at eight different mode/speed combinations. The engine speed settings were varied from low idle speed (600 rpm) to rated speed (1900 rpm). The load settings were varied from 0% to 95%. Different weighting factors were used at different modes, with the low idle condition weighted heavily.

For all test fuels, the speed and the load at each mode were kept the same. Therefore, discrepancies in the amount of fuel per cycle supplied to the engine should be eliminated for fuels having different densities. Nevertheless, fuels having different densities still had slightly different injection timing and duration.

To determine the repeatability of the emission measurements, a reference fuel (Ref2 see [2] for its properties) was run in the engine periodically. The results of repeatability tests indicate that if single tests were run on two fuels, the smallest differences the system can detect between the emissions from the two fuels are: for PM, around 13%; for NOx, around 3%; for CO, around 7.5%; and for HC, around 22%. However, the ability to detect emission changes caused by a certain fuel property can be increased by measures such as running repeated test on the fuels and properly designing the fuel matrix so that some of the random test errors can be reduced.

The 12 fuels used in this program were blended by Shell Canada using refinery streams produced in

Canada (the properties of these fuels can be found in [2]). Two groups of fuels were blended, one group from refinery components derived from conventional crude oil, the other from refinery components derived from oil sands crude. The intention was to blend fuels from the two sources that had matching properties, and their properties were within the range of typical commercial diesel fuels in Canada. The following are the parameters controlled in the fuel blending:

- Have total aromatics in three levels, 10, 20 and 30%
- Keep sulphur less than 500 ppm by weight
- Target cetane number in low forties, and allow the use of 2-ethyl hexyl nitrate to adjust cetane number to within the range of 42 to 46
- Have low and high mid-boiling point for each pair of fuels at the same aromatic level from the same source
- Keep other fuel properties (such as viscosity, cloud point and distillation) within the typical range of current commercial diesel fuel in Canada.

RESULTS AND DISCUSSIONS

Three repeated runs at each mode were conducted, yielding 3 composite gaseous emission values. Two filter measurements were performed for PM emissions. The averaged emission results were used in the analyses. To guard against unknown systematic errors, fuels were run in random order. The pair of fuels having the same total aromatic content but derived from different sources (oil sands or conventional crude oil) was run back to back.

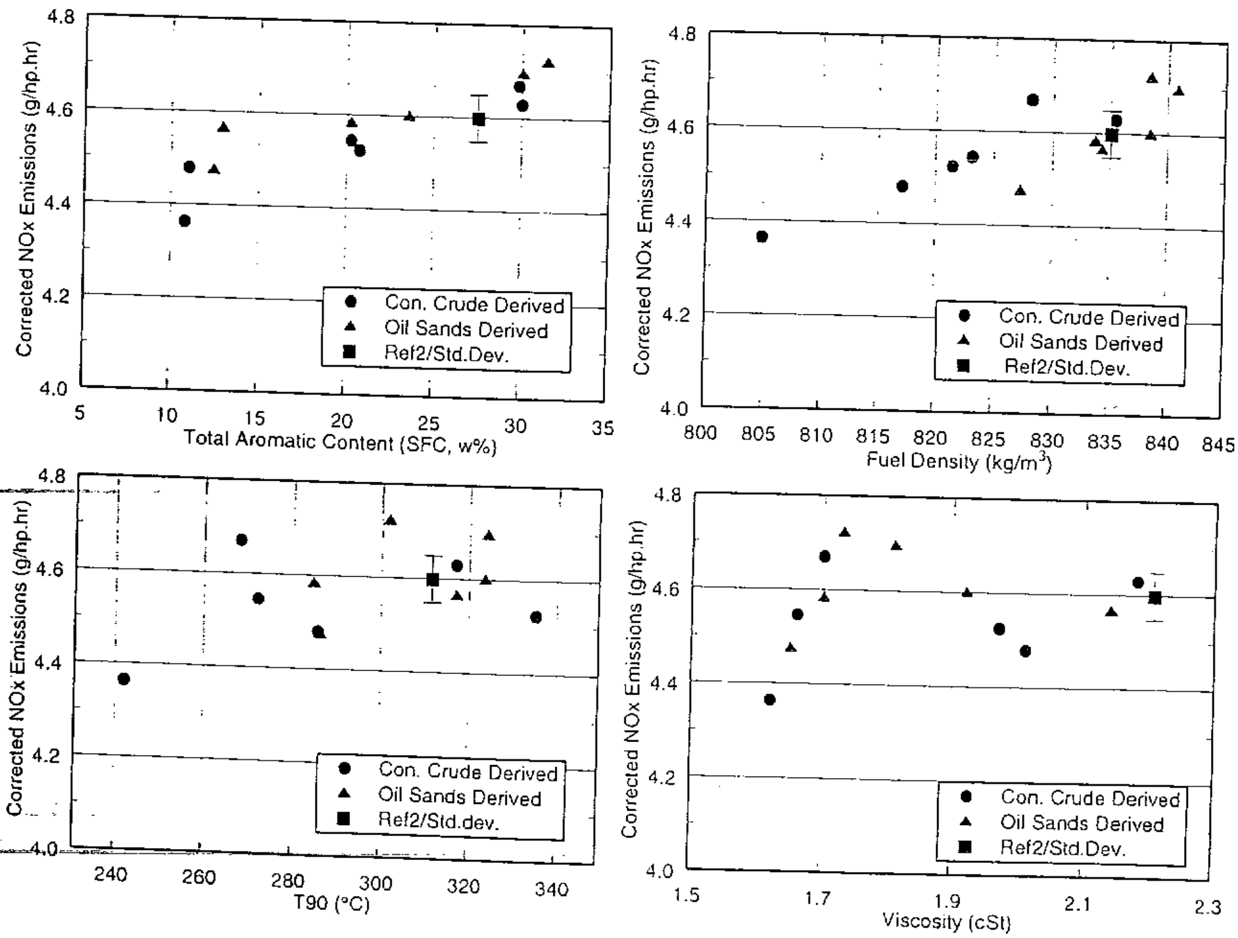

Figure 1 Corrected NOx Emissions versus Different Fuel Properties

Using correction factors generated in the program, the NOx and PM emission results were corrected to 150 ppm sulphur content and 44 cetane number. The effect of slight difference in injection timing caused by the difference in fuel properties was also corrected. The corrected NOx and PM emission data are shown in Figure 1 and Figure 2.

A correlation between NOx emissions and both total aromatic content and density was observed. The higher the total aromatic content and the density, the higher the NOx emissions. NOx emissions did not correlate with T90 or viscosity. At the same aromatic content, the oil-sands-derived fuels had NOx emissions similar to the conventional-crude-oil-derived fuel blends. At equal densities, oil sands derived fuels had lower NOx emissions.

A correlation between PM emissions and fuel density was observed. A higher density led to higher PM emissions. A slight increasing trend was also observed in PM emissions when total aromatic content was increased. There was no correlation between PM emissions and T90 or viscosity.

Comparing the two fuel groups, oil-sands-derived fuels generated higher PM emissions at the same aromatic level. This difference can be attributed mostly to the density difference between the two fuel groups in the test fuel matrix – the oil-sands-derived fuels having higher densities than the conventional-crude-oil-derived fuels at the same aromatic level. This suggests that fuel components other than total aromatics could play a role in particulate formation.

Since density has been shown to correlate with both NOx and PM emissions, it is necessary to

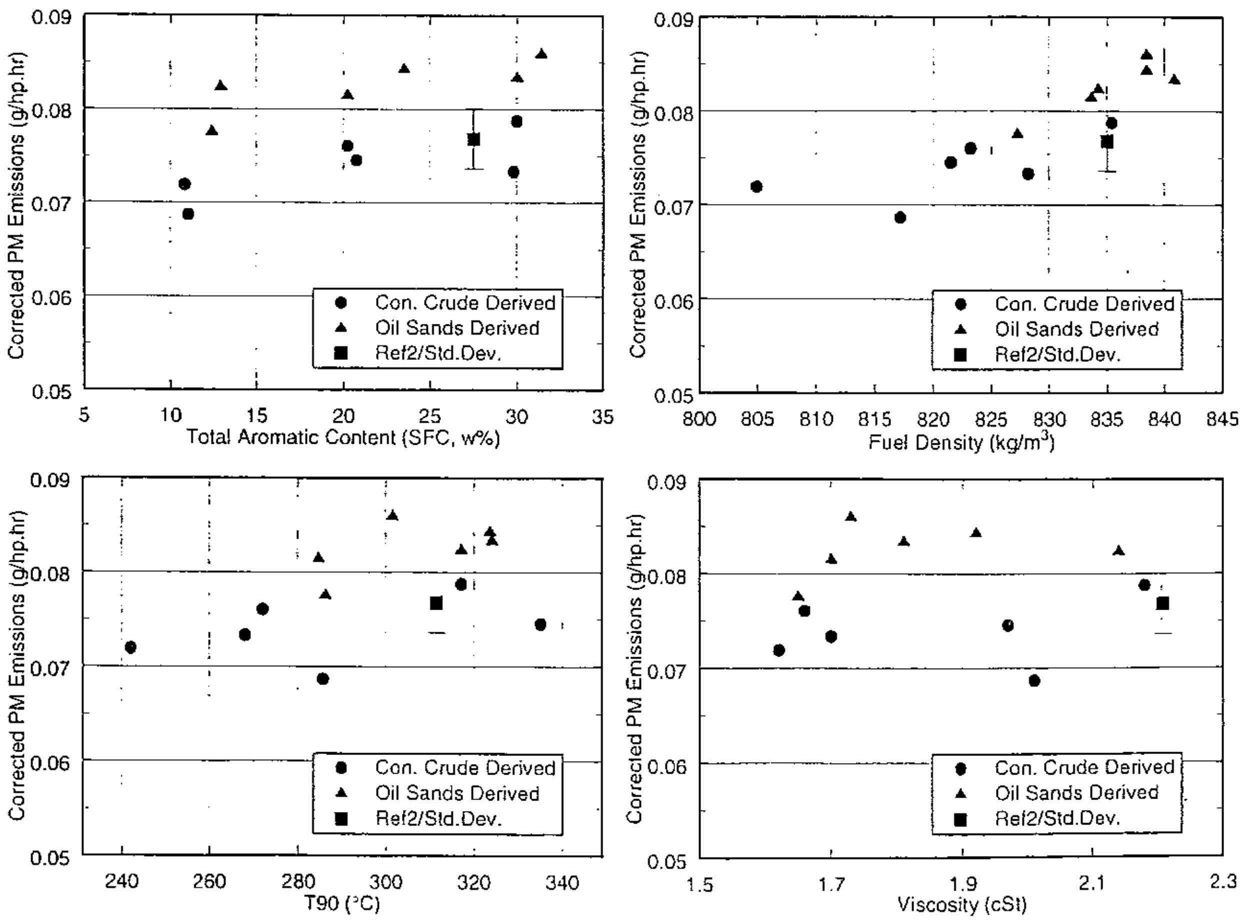

Figure 2 Corrected PM Emissions versus Different Fuel Properties

Table 1 Regression Analysis of Corrected Composite Emissions

Emission	Variables	Standard Error	Standard Coefficient	F-Value	Probability	R^2
NOx	Density	0.0012	0.4559	14.3053	0.0043	0.928
	Total Aromatics	0.0016	0.5964	24.4841	0.0008	
PM	Density	0.0004	0.7293	11.3602	0.0071	0.532

examine the fuelling rates. The brake-specific-fuel-consumption data showed only small changes, less than ±1% deviation from the mean. The fuel consumption rate did not correlate with density. It is evident that fuelling rate was not a major factor causing the emission differences among the test fuels.

As shown previously, the emission data indicated that NOx and PM emissions were related to density and total aromatic content. There was also evidence suggesting that other fuel properties might be linked to PM emissions. Regression analyses were performed to examine the correlation between the engine exhaust emissions and various fuel properties. The fuel properties considered in the regression analyses were: density, viscosity, T90, T50, T10, total aromatic content, and poly-aromatic content (di+-aromatics).

The regression analysis results are shown in Table 1. Fuel density and total aromatic content were found to be the significant variables for NOx emissions. These two properties account for 92.8% of the total changes in NOx emissions (R^2 = 0.928). Both factors are highly significant, although total aromatic content is more so.

Density is the sole significant variable for PM emissions, accounting for 53.2% of the changes. The total aromatic content was not significant. Considering the low R^2 value, there should be factors other than density, which affected PM emissions. Because the fuel matrix was not designed to reveal the role of different types of aromatics and some other fuel properties, and also considering the measurement error associated with PM emission measurements, the model can not be viewed as conclusive.

The proposed models were used to predict the NOx and PM emissions of the 7 test fuels that had not been included in generating the correlations. The results are shown in Figure 3. The model was able to predict the NOx emission results of the six fuels. The prediction of fuel Ref3 was 3.8% higher than the measured NOx value. Since fuel Ref3 had properties far away from those represented by the 12 test fuels, it was not surprising that the model was not able to predict its emissions. The fact that the regression model was able to predict the NOx emissions for other fuels indicates that total aromatic content and density are likely to be two important factors affecting NOx emissions.

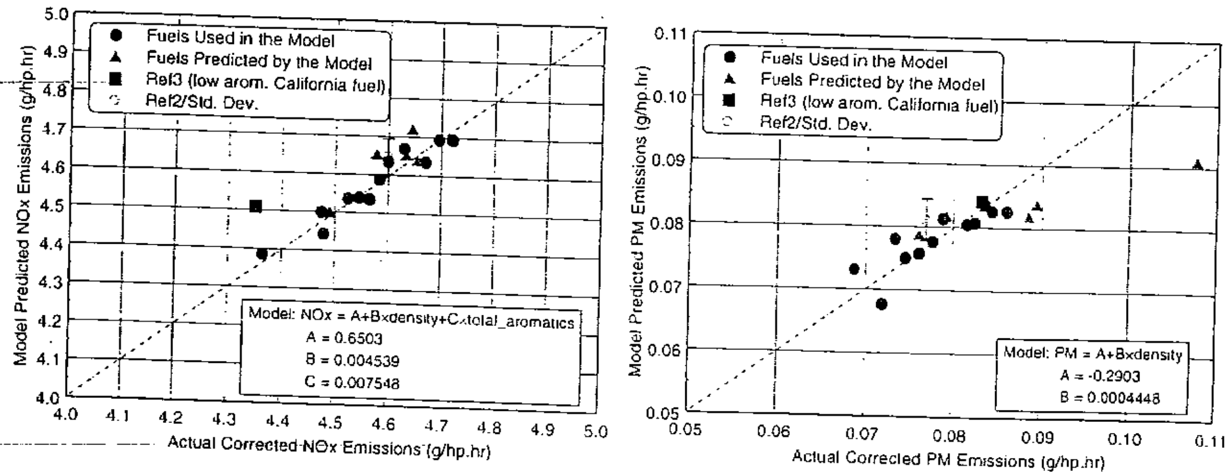

Figure 3 Regression Models for NOx and PM Emissions

The PM model predictions for 6 of the 7 fuels were reasonable. The exception was fuel F. The model prediction was substantially lower than the actual measured PM emission result. Since fuel F had a substantially higher tri+-aromatic content, the result seems to suggest that multi-ring aromatics might be a factor for PM emissions. It is hoped that the role of multi-ring aromatics will become clear after the second stage of this program.

The density of the fuel has been shown by the regression analyses to correlate with both NOx and PM emissions. In conducting the engine experiments, engine power was kept constant at each mode for all fuels. Fuel consumption rates changed little among the test fuels. The effect of injection timing change due to density was also eliminated in the corrected emissions results. One possible reason is that fuel density is a "surrogate" variable that represents the effect of a number of other variables, since density and chemical composition are intrinsically related in commercial diesel fuels.

CONCLUDING REMARKS

1. The analysis of the emission results with 12 fuels showed that at a constant cetane number (44) and sulphur content (150 ppm), oil-sands-derived fuels produced similar NOx emissions as their conventional-crude-oil-derived counterparts. At the same total aromatic content, the-oil- sands-derived fuel blends produced 5-10% higher PM emissions in the test engine. This could be attributed to higher densities of the oil-sands-derived test fuels.

2. Although the test procedure ensures that the fuelling rate did not change with fuel density, NOx emissions and PM emissions were both found to correlate with fuel density. At the same cetane number and sulphur content, total aromatic content and fuel density could be used in a regression model to predict NOx emissions. Fuel density was also a better defining parameter than total aromatic content for PM emissions when the cetane number and sulphur content were kept constant.

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