Extending Diesel Engine Life and Fuel Economy with Canola Based Fuel Additives

By Professor P. B. Hertz, Mechanical Engineering Dept., University of Saskatchewan, Saskatoon SK Canada

Hydrotreated Low Sulfur Diesel Fuels

In the environmental interests of air quality, 1990's legislation was passed requiring the sulfur and aromatic content of diesel fuels to be reduced. Previous typical sulfur values of 0.5% S were cut 90% by refinery hydrotreating. Diesel fuels now must have sulfur levels below 0.05% or 500 ppm. This was effective in decreasing diesel exhaust particulate emissions. Exhaust catalyst performance was thereby improved, while the lower sulfuric acid byproducts of combustion helped decrease acid rain. Proposed 2006 Canada and US mid-distillate diesel fuel standards will require still further sulfur level reductions, to below 15 ppm or to only 0.03% of pre-1990 levels.

Diesel Fuel Lubricity Problems

Shortly after the introduction of these low sulfur fuels, it was realized that the hydrotreatment also removed beneficial oxygen and nitrogen compounds, which are associated with diesel fuel lubricity. Due to the lost wear protection, diesel injection pump failures were reported. Volkswagen EADA documented numerous lubricity-related failures in their Bosch series VE diesel injection pumps with Canadian, low sulfur, winter diesel fuels. Excessive cam and roller wear failures were reported by VW in new pumps, which occurred between 3,000 km and 50,000 km of operation. Steps to restore fuel lubricity with additives applied at the refinery and/or in the field became necessary.

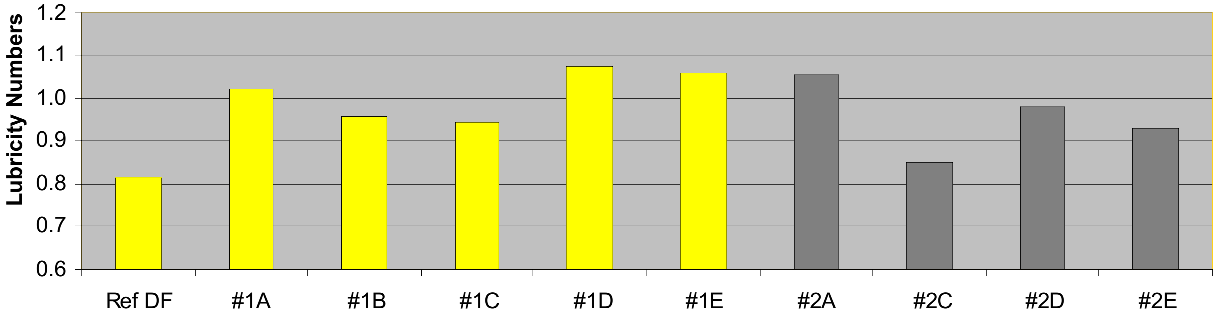
Laboratory Tests for Fuel Lubricity

Several laboratory bench tests were developed to quantify lubricity based on wear areas and friction coefficients. These included the high frequency reciprocating rig (HFRR), the scuffing load ball on cylinder lubricity evaluator (SLBOCLE) and the Munson Roller on Cylinder Lubricity Evaluator (M-ROCLE). In the HFRR test the wear scar size developed on a steel ball vibrating on a flat plate, lubricated with the test fuel, must not exceed 460 μm in diameter. Word-wide fuel lubricity surveys by Paramins in the U.K. indicated that Canadian diesel fuels were among the most deficient in the HFRR test. For years 1996, 1997, and 1998 Canadian low sulfur winter fuels produced considerably larger wear scars, averaging 590 μm in size.

The SLBOCLE test measures the maximum load a ball on rotating cylinder can sustain without experiencing scuffing wear. If the fuel supports 3100 grams without scuffing it is said to have passed the SLBOCLE lubricity test.

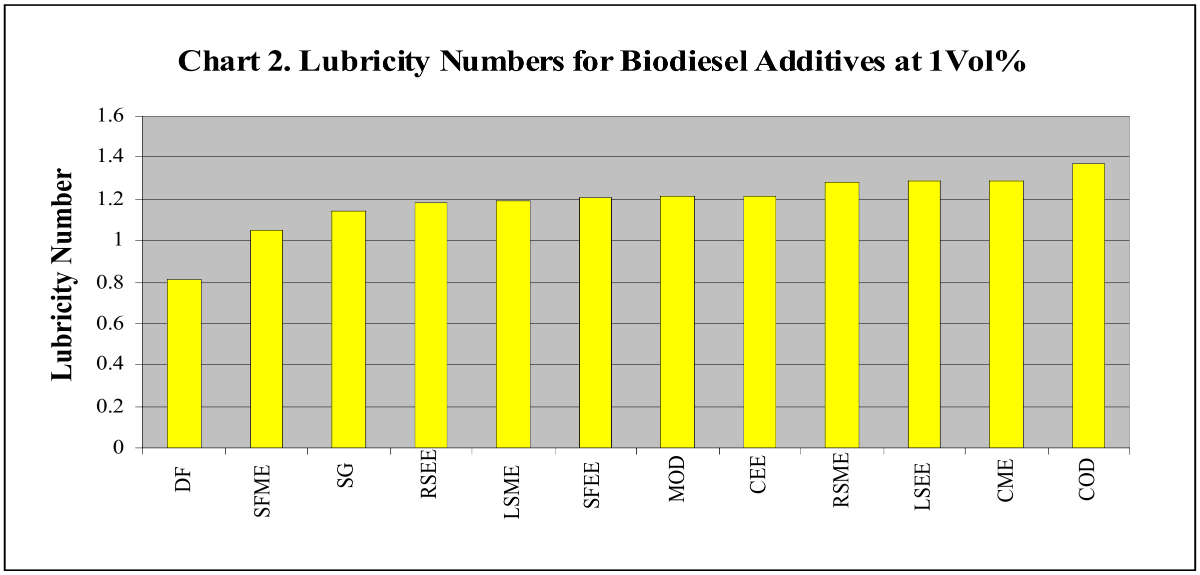
The University of Saskatchewan M-ROCLE test yields a dimensionless fuel lubricity number (LN). It is based on the roller wear area stress divided by the elastic contact stress and by the coefficient of friction. The former high sulfur (0.5%) diesel fuel obtained a LN slightly above 1.0 on the M-ROCLE machine. A 1998 survey of local commercial diesel fuels confirmed that the majority of both summer (No.2D) and winter (No.1D) fuels failed to reach the required M-ROCLE lubricity number of 1.0. (See Chart 1)

Chart 1. M-ROCLE Lubricity of Commercial Winter Fuels (1A-E) & Summer Diesel Fuels (2A-E) Purchased in Saskatoon



M-ROCLE Lubricity of Commercial and Biological Fuel Additives

With support from the Saskatchewan Agriculture Development Fund, a number of commercial and vegetable-based lubricity additives were evaluated on the M-ROCLE machine. (See Chart 2)



DF – Unadditized Diesel fuel
SFME – Sunflower methyl ester
SG – Soy Gold (soy methyl ester)
RSEE – Rapeseed ethyl ester
LSME – Linseed methyl ester
SFEE – Sunflower ethyl ester
MOD – Mustard oil derivative
CEE – Canola ethyl ester
RSME – Rapeseed methyl ester
LSEE – Linseed ethyl ester
CME – Canola methyl ester
COD – Canola oil derivative

Low sulfur reference diesel fuel was used with no additives and had a lubricity number of 0.813 using the M-ROCLE test. Alcohol esters and derivatives of different vegetable oils were added to the reference fuel at 1% by volume. The lubricity numbers are outlined on above graph. All additives exceeded the minimum required lubricity of 1.0 with the canola oil derivative performing the best.

Vegetable sources examined were Soy, Flax, Sunflower, Mustard, Rapeseed and Canola. Transesterification of these biological oils (triglycerides) with four different alcohols was accomplished by the U of Sask., Department of Chemical Engineering. Various catalysts effectively produced the biodiesel esters. Small amounts (<1.0%) of all vegetable esters were found capable of restoring the reference hydrotreated diesel fuel lubricity to acceptable M-ROCLE levels. It was discovered that the Canola based additives, Canola Methyl Ester (CME) and a Canola Oil Derivative (COD), performed among the best in these lubricity tests. The Canola based esters were still effective at treatment rates down to the 0.1% (1000 ppm) range. Wear scar areas and friction coefficients were both lower with the Canola esters present. Lubricity numbers were shown to be a semi-log function of the treatment rates. Compared to commercial additives, the Canola bio-additives proved very cost effective at the 1000-ppm application levels.

Influence of Fuel Lubricity on Engine Wear and Efficiency

As well as create havoc with fuel lubricated distributor-type injection pumps, the low lubricity fuels were logically suspected of increasing diesel engine wear and decreasing fuel economy. A lengthy series of field studies was initiated by the author in 1994 to compare engine wear rates and fuel economy using various hydrotreated low sulfur diesel fuels “without” and “with” the Canola additives applied. Field test daily logs included ambient temperatures, numbers of cold and hot engine starts, plus city and highway km driven. Road-load speeds and tire pressures were carefully monitored.

These first studies employed 1.8L Isuzu indirect-injected diesel powered Chevette test cars. As the tests proceeded, wear metal particles in the engine oil were frequently measured. Inductively coupled plasma (ICP) spectrometry, microscopic ferrography, and magnetic particle counts were employed to infer engine wear rates. The oil filter debris and engine oil physical characteristics were also analyzed at an independent laboratory. An encouraging 1995 result involved the treatment of unadditized, low sulfur winter diesel with 10% Canola methyl ester. The test data revealed a 30% decrease in iron wear rate and a small ~1% increase in fuel economy from the 10% CME biodiesel treatment. This was followed by summer tests using 10% and 5% CME in No.2 commercial diesel fuel. An 18% wear reduction in iron was measured at the 10% CME treatment, while the 5% CME produced a 30% wear reduction and 4.5% gain in fuel economy with the commercial summer fuel. Finally unadditized winter No.1 diesel fuel was compared in 1996 to the same fuel with 5% additions of CME in the ’82 and ’85 Chevettes. The presence of the Canola ester decreased wear iron by 42% and 20%, respectively, in these vehicles. Winter fuel economy increased by 27% and 21%, respectively, for both units. This unusually large increase in fuel economy was attributed to both somewhat warmer weather and the 5% CME fuel additive. These engines performed well with the biodiesel additives present, even at –35°C.

Engine Performance with Canola Additives made from Heated Seed

During 1997 a winter field study, commissioned by Agriculture and Agri-Food Canada, was expanded to include Canola esters made from sub-standard, heated, Canola seed. A Dodge/Cummins 5.9L truck, a Ford/Mazda 2.0L car, and a Volvo/Volkswagen 2.4L car were the winter test vehicles used. (See Chart 3)

When 2% CME was placed in unadditized winter diesel in the direct-injected Cummins, ICP engine wear iron was decreased by 8%, while magnetic wear iron decreased by 23%. Ferrographic wear particles were some 30% lower and oil filter debris was reduced by 21% in the Cummins diesel, while fuel economy improved by 6% for the Canola Methyl Ester additive. Using 1% CME, the Volvo indicated a 24% decrease in ICP wear iron while fuel economy improved by some 7%. When a Canola Oil Derivative (COD), also obtained from heated seed, was tried at 1% in the Mazda diesel, it responded with a 39% decrease in spectrometric wear iron and indicated a 10% increase in fuel economy under arctic-like ambient conditions.

Chart 3. Summary of Wear & Mileage Effects of Canola Additives on Cummins, Volvo & Mazda Engines

Vehicle/ Engine, L	Season	Driving	Diesel Fuel "Brand”	Wear Iron	MPG
IDI- indirect inj.	Year	Cycle	1D - Winter; 2D - Summer	ICP	Change
DI - direct injected			and % Vol. Bio-additive	- is better	+ is better
Ram/Cummins 5.9 DI	Winter '97	Highway	"A" UA 1D + 2% CME	- 8.8%	6.7%
Volvo/ VW 2.4 IDI	Winter '97	City UA	"A" 1D + 1% Canola ME	-24.2%	7.5%
Ford/ Mazda 2.0 IDI	Winter '97	City UA	"A" 1D + 1% Canola OD	-39.5%	10.0%
Ford/ Mazda 2.0 IDI	Summer '97	Highway	"A" 2D vs. UA 1D + 1% COD	-17.2%	-9.6%
Ford/ Mazda 2.0 IDI	Winter '98	Combined	"A" 1D + 0.5% COD	-0.3%	4.2%

Canola Oil Derivative Additized Fuels Compared to Commercial Diesel

Sponsored by the Saskatchewan Canola Development Commission, the efficacy of COD was further challenged during the summer of 1997 in two 10,000-km tests with the Ford/Mazda diesel. Here the low lubricity unadditized winter No.1D reference fuel was supplemented with just 1% COD and compared to the recommended commercial summer No.2D. The 1% COD treatment again managed to decrease ICP engine wear iron by 17% and oil filter debris by 50%. However the lower energy content of the lighter winter diesel resulted in a 9% drop in fuel economy compared to the more dense No.2 fuel under hot summer conditions.

Winter of 1998 checked the performance of 0.5% COD in commercial winter diesel fuel. This time the usual spectrometry wear iron was not significantly changed although magnetic iron dropped 53%, ferrography was some 15% lower, and filter wear debris was 25% less with the Canola Oil Derivative present. Fuel economy was improved by 4% in this Ford/Mazda 1998 test.

Minimal Canola Treatment Responses in a VW TDI

The most recent research vehicle was a 1998 Volkswagen NewBeetle 1.9L TDI. After break-in, an alternative brand of low lubricity commercial winter diesel fuel was substituted and found to increase established engine wear rates by ten-fold! The TDI normal ICP wear rose from 2 ppm Fe/1000km to over 20 ppm Fe/1000km with this fuel! The addition of 0.5% CME, when applied in this commercial winter diesel fuel, was found able to reduce engine wear by 45% and increase fuel economy by 2% (See Chart 4). Other commercial winter fuels indicated similar percentage wear reductions of 57%, 52%, and 50% while corresponding fuel economy numbers rose by 3%, 13%, and 6% for these same winter tests.

Summer 1999 data comparing No.2D commercial diesel to the same fuel containing 0.2% COD revealed a decrease in TDI wear iron of 36% while fuel economy rose by some 11%. The influence of only 0.1% COD in seasonal No.1-2D fuels provided a wear reduction of up to 27% with little change in fuel economy. When, in 2000, another brand of winter diesel fuel was supplemented with 0.1% of the Canola Oil Derivative, a wear reduction of 9% was measured while fuel economy rose by some 3%. The vehicle operated without difficulties with the Canola additives present.

Chart 4. Engine Wear & Fuel Mileage Benefits on VW TDI Diesel Engine

Season	Driving Cycle	Engine Oil	Diesel Fuel "Brand" % Vol. Bio-additive	Wear Iron - is better	MPG + is better
Fall '98	Combined	0W-30	"B" 1D + 0.5% CME	-45.4%	1.9%
Fall '98	Combined	0W-30	"A" 1D + 0.5% CME	-57.0%	2.6%
Winter '99	Combined	0W-30	"A" 1D + 0.5% CME	-52.6%	13.0%
Spring '99	Combined	0W-40	"A" 1D + 0.5% CME	-50.5%	5.8%
Summer'99	Highway	0W-40	"A" 2D + 0.2% COD	-36.7%	11.3%
F.'99/Sp'00	Combined	0W-40	"A" 1-2D + 0.1% COD	-27.5%	-0.4%

Conclusions

The application of Canola based lubricity additives in both unadditized and commercial low sulfur diesel fuels has been shown effective in reducing engine wear by as much as one-half, thereby potentially doubling diesel engine life. Fuel economy gains of up to 13% have also been recorded. These engine field tests corroborate the smaller wear areas and lower friction coefficients measured in M-ROCLE lubricity bench tests for the Canola supplemented diesel fuels. The engine wear reductions and fuel economy improvements appear to be directly related to diesel fuel lubricity.

Based on these encouraging research results, it is concluded that the Canola lubricity additives could extend diesel engine life and fuel economy when applied in hydrotreated, low sulfur, diesel fuels. It would seem prudent for refiners to more thoroughly investigate, and seriously consider the production and introduction of these effective Canola-based lubricity additives to their future mid-distillate fuels.

References

Contact S.C.D.C. at 306-975-0262 or scdc@scdc.sk.ca for further information.