Twelve years of using 50% RME fuel mixture in heavy trucks and light vehicles

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Abstract: The use of a 50% RME fuel mixture was tested over the 1993 – 2005 period. The experimental fleet included twenty heavy trucks from EURO 0 to EURO 3 standards, ten light vehicles with indirect injection engines and four light vehicles with common rail engines and DPF. Half of the fleet used RME50 and was compared to reference vehicles running on commercial diesel fuel. Heavy trucks ran a mileage on RME between 230,000 and 530,000 km. '406' sedan mileage exceeded 230,000 km and 'C5' 190,000 km. Behaviour, consumption and lubricant analyses were recorded over the twelve-year period. Ten trucks engines were disassembled for wear and deposits inspection. The engines showed no sign of deposits in rings and crankcases. The use of RME had no effect on injection. Effect on consumption was explained by LHV variation. Lubricant dilution observed on most vehicles was reinforced by the use of RME but did not cause any increase in wear. A reduction of wear found on some trucks was explained by lower soot contents in the lubricant.

Keywords: RME, Rapeseed Oil Methyl Esters, Biodiesel, fleet tests

1. Introduction

Fuel mixtures with high RME contents have been experimented in France for long time [1]. The cooperative Champagne Céréales and IFP tested the use of RME20 between 1988 and 1990 [2]. The cooperative manages four hundred vehicles and owns an engine repair shop. It offered a good opportunity to start comparative tests over a long mileage.

An experimental program was initiated in 1993 with trucks meeting the EURO 0 and EURO 1 standards, and with light vehicles equipped with indirect injection engines. Later, the program was continued with EURO 2 and EURO 3 trucks, then recent cars equipped with common rail injection systems and DPF. The whole program lasted until 2005.

2. Experimental conditions

The experimental fuel used was a mixture of diesel fuel and undistilled RME [3] meeting Standard EN 14214 [4] requirements, and supplied over the 12-year period by the Robbe Company. The ratio of 50% (RME50) selected in 1993 was maintained over the whole period: its volumetric LHV is about 4% lower than that of commercial diesel fuel.

The fuels were mixed and stored in a 110 m^3 tank cleaned in 1993 and 1999. First, the tank received a known volume of pure RME and was filled up with the same amount of a commercial diesel fuel. No extra additive was introduced in RME50.

Each vehicle running on RME50 fuel was associated with an identical reference vehicle carrying out a similar service and running on commercial diesel fuel.

Vehicles were inspected regularly over the twelve-year period. Carried tons, mileage and consumption were recorded, and the lubricant was analysed at defined intervals. Some trucks engines were dismantled for a survey. The injection systems were checked on Bosch-approved equipment.

3. Trucks behaviour

3.1 Overview

Vehicles	Models	Standards
1, T1, 2 & T2	Scania 113	EURO 0-1
3 & T3	VOLVO F10	EURO 0
4 & T4	VOLVO F12	EURO 1
5 & T5	RVI R330	EURO 0
6 & T6	VOLVO FH 12	EURO 2
7 & T7	RVI P260D	EURO 2
8, T8, 9 & T9	RVI P385R	EURO 2
10 & T10	Scania 114	EURO 3

Table 1: Experimental trucks fleets

The whole experimental trucks fleet (Table 1) includes 18 trailer-trucks with a permissible total laden weight (GVWR) of 40 metric tons and powers ranging from 243 to 283 kW and two vehicles of 192 kW with a 19-ton GVWR (7 and T7). Vehicles running on RME50 are marked with number 1 to 10 and reference vehicles T1 to T10. Vehicles 6, T6, 10 and T10 were equipped with pump injectors.

Lubricants were analyzed at oil changes and during intervals between changes for some vehicles. The engines of vehicle pairs 2, 3, 4, 5 and 9 were disassembled and inspected according to CEC M-02-A-78 rating method for wear and deposits.

Dates and engine mileages are reported on table 2. Six vehicles experimented RME50 for more than 440,000 km.

	Start of experimentation		End of experimentation		experimental mileage (km)
	Date	km	Date	km	
1	1993	5,170	1998	320,467	315,297
T1	*1993*	*13,520*	*1998*	*299,777*	*286,257*
2	1993	66,115	1999	508,016	441,901
T2	*1993*	*67,501*	*2000*	*521,114*	*453,613*
3	1993	169,023	2000	664,160	495,137
T3	*1993*	*173,908*	*2000*	*658,692*	*484,784*
4	1993	7,525	1998	304,277	296,752
T4	*1993*	*18,300*	*1996*	*236,600*	*218,300*
5	1993	196,995	1997	510,743	313,748
T5	*1993*	*186,740*	*1996*	*433,233*	*246,493*
6	1998	87,150	2005	577,045	489,895
T6	*1998*	*90,176*	*2005*	*568,492*	*478,316*
7	1998	103,702	2004	559,293	455,591
T7	*1998*	*92,408*	*2004*	*534,762*	*442,354*
8	1998	17,347	2005	547,911	530,564
T8	*1998*	*23,630*	*2005*	*541,509*	*517,879*
9	1998	18,953	2005	538,484	519,531
T9	*1998*	*21,221*	*2005*	*530,126*	*508,905*
10	2002	0	2005	230,664	230,664
T10	*2002*	*0*	*2005*	*275,025*	*275,025*

Table 2: Trucks mileages

The trucks service includes road transport but the engines also drive ancillary equipment (tailgate, etc.) while the vehicle is stationary. So the journey speed (journey distance divided by journey time) is about 30 km/h.

Mileages, consumptions (badge used to fill the tank), drivers' working hours and tons carried were recorded and services provided by the vehicles could be compared on vehicle load (ratio of mileage run and tons carried) and journey speed.

Consumption variations for each vehicle over the years and differences between the RME50 vehicle and its diesel fuel reference were mainly due to differences in drivers' habits and services. Table 3 shows average annual values (n values) available and their standard deviations (n-1).

The average consumption of all diesel fuel vehicles is lower by 3.3% than that of all RME50 vehicles in accordance with the LHV differences of the fuels.

	consumption (l/100 km)		load (km/t)		journey speed (km/h)		
Vehicle	*mean*	*standard deviation*	*mean*	*standard deviation*	*mean*	*standard deviation*	*years*
2	43.6		2.7		29.6		98-99
T2	40.7		2.1		27.9		98-99
3	40.5		2.7		28.7		98-99
T3	40.3		2.6		29.3		98-99
6	43.0	2.2	3.3	1.8	29.4	0.7	98-04
T6	43.0	1.5	2.6	0.3	29.4	1.2	98-04
7	24.4	0.7	43.7	3.9	34.2	1.4	98-03
T7	24.5	0.6	43.5	5.1	33.7	1.1	98-03
8	46.3	2.0	2.8	0.1	31.4	1.2	98-04
T8	44.5	1.5	2.7	0.2	31.3	1.4	98-04
9	43.8	1.4	2.7	0.4	30.8	2.9	98-04
T9	41.8	1.4	2.7	0.3	32.3	0.8	98-04
10	42.9	0.7	2.4	0.1	25.8	1.6	02-04
T10	40.3	1.4	3.5	0.2	31.2	1.5	02-04

Table 3: Average annual values for fuel consumptions and loads

None of the 10 vehicles running on RME50 was involved in an incident. The reference vehicles experienced more problems, although these were not related to the type of fuel used. No tank (bare aluminium or steel) was subject to corrosion.

The trucks were parked in unsheltered locations, with no protection from the wind. No problem for starting engines in the winter was reported despite low temperatures (below -12°C) recorded during several winters.

3.2 Trucks lubricants analysis

Lubricants were selected to be representative of the lubricants' market. Lubricant grade was 15W-40. Oil change interval was always kept to 30,000 km.

From 1993 to 1998, lubricant Elf XT 2580 which is a D5 CCMC quality grade was used on trucks. It has a kinematic viscosity of 105 cSt at 40°C, 15 cSt at 100°C and a basic number (BN) of 13.4 mg KOH/g.

This lubricant was then replaced by Elf Trophy R oil, and, in 2002, by Total Rubia TIR Max oil.

The analysis provided the contents of iron, lead, copper, tin, chromium, aluminium, nickel, silicon, water and soot. The presence of antifreeze is indicated. Dilution ratio is determined by a method based on the flash point determination. The analytical bulletin also shows viscosity, basic number (BN) and acid value (AN).

	nb of oil changes	Fe ppm	st. deviat. Fe	Pb ppm	Cu ppm	Carb. mat. %	Visc. 100 °C cSt	Visc. 40 °C cSt	B.N. mg KOH
1	11	26	7	9	7	0.39	12.2	82.3	12.2
T1	*10*	*42*	*6*	*10*	*6*	*1.13*	*13.4*	*94.7*	*11.9*
2	15	26	6	10	3	0.40	12.5	86.2	12.8
T2	*16*	*35*	*12*	*10*	*6*	*0.53*	*13.4*	*96.2*	*13.0*
3	17	53	9	5	4	1.67	13.4	95.4	11.6
T3	*17*	*53*	*13*	*14*	*7*	*1.85*	*13.7*	*98.7*	*10.6*
4	10	35	8	9	6	0.49	13.7	95.6	12.7
T4	*6*	*35*	*7*	*5*	*5*	*0.47*	*13.0*	*95.4*	*12.3*
5	10	65	12	20	10	0.91	11.5	73.1	10.0
T5	*8*	*78*	*28*	*18*	*6*	*1.33*	*14.7*	*109.6*	*11.3*
6	16	32	6	17	3	0.97	12.0	82.3	11.0
T6	*16*	*40*	*12*	*6*	*3*	*1.34*	*13.5*	*98.0*	*11.8*
7	15	10	3	4	7	0.27	11.3	75.2	12.9
T7	*12*	*14*	*8*	*3*	*6*	*0.31*	*12.3*	*86.6*	*12.9*
8	18	25	12	7	21	0.83	12.3	85.0	12.2
T8	*18*	*20*	*6*	*8*	*36*	*0.66*	*12.9*	*91.9*	*13.1*
9	17	16	4	5	15	0.39	12.1	83.4	11.9
T9	*19*	*16*	*4*	*7*	*84*	*0.60*	*12.6*	*89.4*	*12.1*
10	6	18	6	8	39	0.35	10.8	66.0	10.3
T10	*7*	*17*	*7*	*5*	*64*	*0.47*	*10.5*	*66.8*	*8.5*

Table 4 : Trucks lubricants analysis

Silicon comes from lubricant additives (15 ppm in oil Elf XT 2580) and from airborne dusts sucked in by the engine. Values always remained low for all the vehicles, demonstrating air filters' adequate maintenance and quality.

The flash point is not well correlated to RME content so dilution values are imprecise. On analysis bulletins, dilution is only significant when viscosity falls below 80 cSt. In theory, the viscosity of a mixture could be estimated according to a logarithmic law [5]. For example, a 3% adjunction of pure RME decreases the 40°C viscosity of a new lubricant from 100 cSt to 90 cSt. The calculation is inapplicable to a used lubricant, as the degradation of the product should also be taken into account. Infrared spectroscopy confirmed the presence of the C=O bond belonging to the ester function in the lubricant, but a precise analysis of numerous samples proved to be difficult. So only viscosities are reported.

Table 4 displays the results of the study. The values are averages of all the analysis at oil changes.

On each vehicle, the variations of iron contents at the successive oil changes follow minor evolutions. The average value is a significant variable that enables to compare wear among vehicles of the same type. For lead and copper, several average values are due to temporary high contents explained by the running in period and/or bearings problems connected with leaks of coolant into the lubricant. The average values of these two elements are reported but shall then not be considered. Tin, chromium, aluminium, and nickel contents are identical for RME50 and reference vehicles, so they are not reported.

When RME50 fuel is used, a fall of lubricant viscosity always occurs, except on vehicles 3 and 4. In all pairs of vehicles, the iron content is always lower or equal for RME50 vehicles. The only exception comes from vehicles 8 and T8. The fall of viscosity never caused an increase in wear metals. The lower level of iron contents is correlated with a lower level of the soot content, and RME has a well known effect of reducing smoke emissions [1, 4]. For pair 8, soot content is slightly greater in the lubricant of the RME50 vehicle and the average iron content is also slightly greater.

Once, for vehicles 8,T8 and T9, a high percentage of copper and lead was observed with antifreeze in the lubricant. This was due to defective water pump operation. Copper and lead contents returned to normal values later for vehicles 8 and T8. The expert confirmed bearings' wear of T9.

For pair 10, a significant fall of viscosity on both vehicles is due to normal microleaks of the pump on each injector. High copper percentages can be attributed to a heat exchanger.

3.3 Effect of lengthening the oil change interval

Dilution observed on vehicle 5 was significant, hence it was decided to analyse the lubricant every 5,000 km over two oil change intervals between 253,000 and 350,000 km. For comparison purposes, vehicle T5 was analysed between 293,000 and 330,000 km but only on one oil change interval.

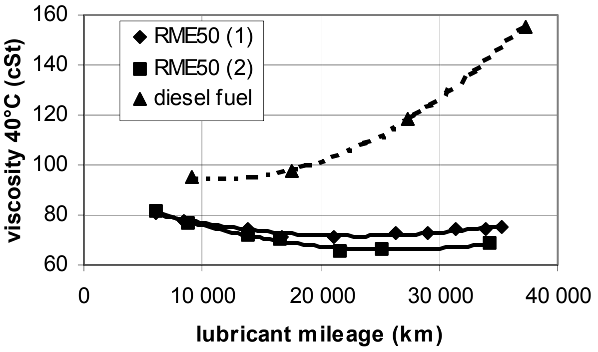

Figure 1: lubricant viscosity evolution

The basic number follows the same curves not presented here. The viscosity trend is very different for these two vehicles (Figure 1). The iron content (Figure 2) increases more for T5: the higher wear will be confirmed later with the finding of a strong degree of bore polishing at 433,000 km mileage.

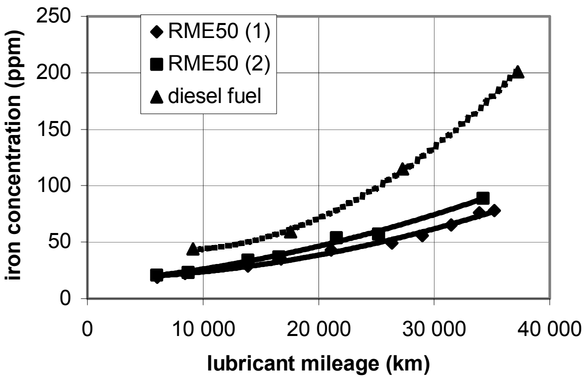

Figure 2: Iron evolution

The lead and copper curves (Figure 3) are similar in both vehicles although viscosities of the lubricants are different. The presence of RME in the lubricant then does not result in bearing corrosion.

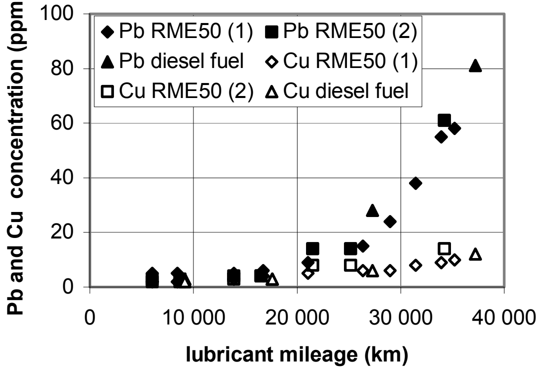

Figure 3: Lead and copper evolution

3.4 Engines surveys

Vehicles 2 and T2 were disassembled at a mileage of 200,000 km in 1995 [6]. No difference was found between the two engines, and the vehicles were included back into the experiment after reassembly.

In 1997 [7], three experts carried out an assessment on the engines of the following vehicles:

- 4: assessment at 252,774 km.
- T4: assessment at 238,884 km.
- 5: assessment at 461,613 km.
- T5: the engine had been reconditioned at 433,233 km following excessive lubricant consumption. Pistons, sleeves, and rings had been stocked so the rating method was only applied to bore polishing and piston rings wear.

Little difference was observed between vehicle 4 and T4. The rings of the reference vehicle running on diesel fuel showed more significant wear, but no significant variation in metals contents was observed in lubricant analysis.

The engines of vehicles 5 and T5 had been disassembled prior to the experiment. A marked wear of piston rings, cams and tappets of inlet valves had been found. Such wear was accentuated. Vehicle 5 engine liners showed a notable polishing effect, but T5 engine showed an excessive and abnormal polishing condition. On the other hand, analyses showed that the lubricant viscosity was particularly high and iron contents are higher than those of vehicle 5. The source of those problems could not be determined but is not related to the fuel.

Injection pumps showed no defect in both engines. The deposits inside injector nozzles, and the changes of needle lifts were considered as normal.

Vehicle 3 had run on RME50 over 495,000 km mileage. The bearings of the reference vehicle T3 had been replaced at about 500,000 km due to wear. So, in year 2000, vehicles 3 and T3 were disassembled. The mileages were respectively 664,160 km and 658,692 km [8].

Piston No. 5 of vehicle 3 showed scuffing marks on the piston skirt and the second ring land. The lubricant analysis did not indicate the time when this event occurred. This vehicle did not show any abnormal consumption (Table 3), the viscosity of the lubricant (Table 4) was normal. The fuel is not involved.

The injection pumps showed normal wear. The difference in the average flow rates of both pumps was below 1%, thus totally insignificant. The discrepancy among the 6 cylinders of each pump was insignificant in both engines.

Vehicles 9 and T9 were disassembled in 2005 [9] respectively at 538,868 and 530,792 km.

Globally, the difference between the two vehicles is small. The pink wear marks found on the reference vehicle's bearings were greater than those found on the vehicle running on RME50. They are explained by a leak of coolant into the lubricant confirmed by lubricant analysis at 351,000 km. The deposits in piston grooves were more significant in the vehicle running on diesel fuel.

To summarise, contrary to the expectation that RME fuel would have produced deposits, interiors of all engines were found to be clean, with clean crankcases and clean piston grooves. This was the case even in engines where the lubricant showed a marked viscosity fall. A slight fatty deposit with no adverse effect was only observed on inlet pipes of vehicle 4. Pistons and cylinder heads of RME50 vehicles have slight white deposits but without any effect on combustion and wear.

4. Light vehicles behaviour

4.1 Vehicles with indirect injection engines

A first two-year experimental phase started in 1993 involved three pairs of cars, Renault R21D, Renault R19D, Renault Safrane 2.l TUD, and two pairs of delivery vans Citroen C25D. All vehicles were equipped with indirect injection engines. The maximum mileage of two of these vehicles using RME50 fuel was 80,000 km. No problem resulted from the fuel.

Oil change intervals, of 10,000 km for delivery vans and 7,500 km for cars, were too small for dilution to occur, especially in the case of prechamber engines.

4.2 Vehicles with common rail and DPF

Vehicle	Model	Fuel
VL1	Peugeot 406	RME50
VLT1	*Peugeot 406*	*diesel fuel*
VL2	Citroën C5	RME50
VLT2	*Citroën C5*	*diesel fuel*

Table 5: Experimental light vehicles

A new experiment was launched in 2001 for a three-year period, with four vehicles equipped with both common rail injection systems and DPF (table 5).

The exhaust system of these four vehicles included an oxidation catalyst and a silicon carbide DPF. The soot oxidation catalyst is a fuel born catalyst automatically poured into the fuel tank at each fill-up by means of a system delivering a calculated amount of cerium additive from an auxiliary tank which is itself filled every 80,000 km.

4.3 Behaviour of vehicles with common rail

VL1 run over 231,000 km on RME50 with no incident.

For VL2, at 45,774 km, a defective tightening of an injector was reported by the Electro-Diesel Company, representative of Bosch. The injector was changed. Fuel filter clogging caused by a fatty deposit of low thickness occurred at 54,000 km. ITERG reported 20% contents of ashes in the deposit, but no polymers originating from RME or of glycerol. No other incident has been reported with this vehicle. Its mileage exceeded 191,000 km at the end of the experiment.

The turbocharger of VLT2 using diesel fuel was replaced following a breakdown in 2004.

Injections were checked at the beginning and at 80,000 km mileage, using Bosch KTS 550 equipment connected to the vehicle computer. Checks involved pressure and injection flow rate measurements on idle and 3000 rpm. No defect was observed on all four vehicles. The injection system of VL1 and VL2 was completely removed and replaced, respectively at 167,801 km and 149,518 km, and all the injection systems subject to inspection. No defect was reported.

		Mean consumption (l/100km)		
	Final mileage (2005)	2002	2003	2004
VL1	231,000	7.18	7.04	6.75
VLT1	*109,000*	*7.58*	*6.85*	*6.63*
VL2	191,000	7.49	7.26	7.37
VLT2	*135,000*	*7.76*	*7.07*	*6.90*

Table 6: Mileage and consumption of light vehicles

Table 6 displays mileage and consumption data for the four vehicles. Variations observed in consumption are due to driving habits of drivers.

4.4 Lubricant analysis

The vehicles used 5W30 lubricants supplied by the Total Company: ACEA 2002 for 406 cars and ACEA 98 for C5 vehicles.

The first oil changes was set at about 6,000 km after run-in and all the other oil change intervals were set to 20,000 km.

	Fe	Pb	Cu	Sn	Cr	Al	Ni	Si
VL1	122	18	8	0.4	5	10	1.6	11
VLT1	91	10	6	0.6	5	11	0.8	20
VL2	90	41	11	0.2	3	10	2.8	12
VLT2	121	12	9	1.0	6	15	2.0	18

Table 7: Mean values of metal contents (ppm)

Tables 7 and 8 show mean values of the lubricant analysis calculated on the first five oil changes after run-in.

The iron content is not related to the fuel nor silicon content: it is smaller for the 406 reference vehicle but smaller for the C5 running on RME50. On table 8, it seems correlated to soot contents, but in fact this is not the case when examining all the individual data.

	Soot	Vis(40°C)	BN	AN
	%	cSt	mg KOH/g	mg KOH/g
VL1	0.32	43.8	7.9	4.8
VLT1	0.26	47.4	7.1	5.2
VL2	0.24	46.2	8.0	4.8
VLT2	0.34	58.5	9.1	4.9

Table 8: Mean values of lubricant analysis

Basicity and acidity numbers are similar for all four vehicles.

Lubricant viscosity is higher for VLT2: dilution is mentioned on the analysis bulletins for VL1, VLT1 and VL2 but not for VLT2.

4.5 Pollutants emissions

Measurements of exhaust pollutants have been performed by IFP [10] on the four vehicles at 20,000 and at 80,000 km mileage. Pollutants were also measured for VL1 at 158,819 km. Results of tests based on New European Driving Cycle (NEDC) are reported in table 9.

Fuel consumptions were calculated from CO_2, CO and HC measurements with the following assumptions:

- Diesel fuel: density 0.830 87,0% carbon
- RME50: density 0.855 82,2% carbon

	vehicle mileage	CO	HC	NOx	HC+ NOx	Part.	Cons.
	km	g/km	g/km	g/km	g/km	g/km	l/100 km
VL1	18,082	0.19	0.028	0.44	0.47	0.002	6.96
VL1	75,590	0.38	0.039	0.48	0.48	0.001	7.06
VL1	158,819	0.41	0.052	0.52	0.58	0.001	7.08
VLT1	*17,329*	*0.20*	*0.031*	*0.43*	*0.46*	*0.002*	*6.60*
VLT1	*74,450*	*0.41*	*0.044*	*0.49*	*0.54*	*0.003*	*6.50*
VL2	14,919	0.21	0.040	0.53	0.58	0.003	6.88
VL2	80,494	0.73	0.111	0.57	0.68	0.002	7.30
VLT2	*19,122*	*0.21*	*0.031*	*0.46*	*0.49*	*0.002*	*6.70*
VLT2	*79,997*	*0.38*	*0.045*	*0.55*	*0.60*	*0.001*	*6.85*
	EURO 3	0.64		0.50	0.56	0.050	

Table 9: NEDC pollutants emissions

Emissions remained under or near EURO 3 limits for all the vehicles. Exception comes from VL2 at 80,494 km which is also subject to an abnormal rise in consumption for this experimental point. The phenomenon is not explained. No abnormal behaviour and consumption is reported on road before and after the test. Lubricant analysis give the same level of results for the oil changes around the test.

Particulates emissions are very low due to DPF and should not be compared. Particulates size were also measured on steady-state tests [10] at 20,000 and at 80,000 km mileage. Vehicle ageing and fuels have no effects according to IFP.

5. Conclusion

The use of RME50 was experimented over the 1993 – 2005 period. The rate of 50% mixture selected in 1993 was maintained although it is common practice to use RME30 in France.

Five trucks engines were disassembled and no negative effect of the use of RME50 was reported in the expert surveys. When incidents were reported, they were not related to the kind of fuel. Moreover, the reference vehicles were affected more frequently.

RME50 increased the dilution of the lubricant, but no wear increase and no deposits in the piston rings or the crankcases were observed.

The reduction in wear found with the use of RME50 on some trucks could be explained by the reduction in the soot contents in the lubricant. It is due to the fact that RME reduces smoke emissions.

The most recent cars ran over a significant mileage using RME50 with no injection problem reported.

This twelve-year experiment has shown that the use of a 50% RME fuel mixture did not result in incidents for heavy trucks or cars equipped with a common rail injection system and particulate filters, and the effect of RME on consumption varied, on the whole, according to the LHV variation.

Since 2005, all the vehicles of Champagne Céréales has been running on RME30.

6. Acknowledgement

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8. Glossary

RME	Rapeseed Oil Methyl Ester
DPF	Diesel Particulate Filter
LHV	Lower Heating Value
ITERG	Institut des Corps Gras
IFP	Institut Français du Pétrole