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Interactions between Modern Engine Oils and Reformulated Fuels

J. Hancsók*, J. Auer**, J. Baladincz**, Z. Kocsis**, L. Bartha*, M. Bubálik*, I. Molnár***

*University of Veszprém, H-8201, Veszprém, P.O. Box 158, Hungary
**MOL-LUB Lld., H-2922, Komárom P.O. Box 3, Hungary
***MOL Plc., DS TPD, H-244,3 Százhalombatta, P.O. Box 1, Hungary

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Abstract

The paper presents the reasons and tendencies of the changes of the quality requirements of engine oils and fuels having significant influence also on the interactions between the two types of products (operating materials). The possibilities of grouping the relationships between engine oils and engine fuels are summarized. Interactions between engine oils and engine fuels are presented with the use of some actual examples. The paper presents some results of the authors' experiments about the possibilities for improving the interactions between engine oil and fuels (e. g.: to prevent increase of viscosity of lubricating oils by cold and black sludge formation in gasoline engines applying new types of detergent-dispersant additives; in direct injection diesel engines by application of appropriately chosen DD-additive package, in order to prevent increase of viscosity of engine oils and therefore higher fuel consumption because of higher soot loading caused by EGR, longer drain interval, etc.; both engine oils contain reduced sulphate ash, chlorine, phosphorus and sulphur). The final conclusion is that solution of the numerous problems originating in the multi-faceted interactions will only be possible by optimizing the methods defined on the basis of technical, environmental and economic considerations of lubricating oils, fuels and engines themselves.

Key words: *reformulated fuels, low SAPS engine oils, fuel economy, low emission*

1. DRIVING FORCES FOR INVESTIGATION OF THE INTERACTIONS BETWEEN MODERN ENGINE OILS AND REFORMULATED FUELS

Governing factors of the developments of vehicles are the protection of environment and human health, saving of resources, developments of engines and satisfaction of customers (Figure 1). In this system the determining factors are the interactions between the engine and the operating materials (fuels, lubricants), developments and in the latter case interactions between the fuels and lubricants. These interactions influence the combustion process, power, deposits, friction, wear, driveability, fuel consumption, compatibility of materials, oil drain interval, composition of exhaust gases, activity of catalysts in the exhaust system, maintenance etc.

The areas of engine oils and fuels comprise very complicated, complex and multi-variable systems by themselves. In the last few years development and application of improved engine design, enhanced quality of lubricating oil and reformulated fuels brought changes also in the locations of occurrence and mode, nature and quality of interactions.

Some partial areas of the interactions between fuels and engine oils, such as dilution of engine oil, reductions in the basic reserves of engine oils by the combustion products of halogenated hydrocarbons (dichloroethane, dibromoethane) contained in leaded gasolines and by the sulphur compounds of combustion products of gasolines and diesel fuels containing sulphur, fuel-economic engine oils, etc. have been discussed earlier in several publications[1-14].

Accordingly, it is useful and important to establish a modern classifying system for the interactions possible between engine oils and fuels and to present and evaluate the new interactions between reformulated fuels and modern lubricants.

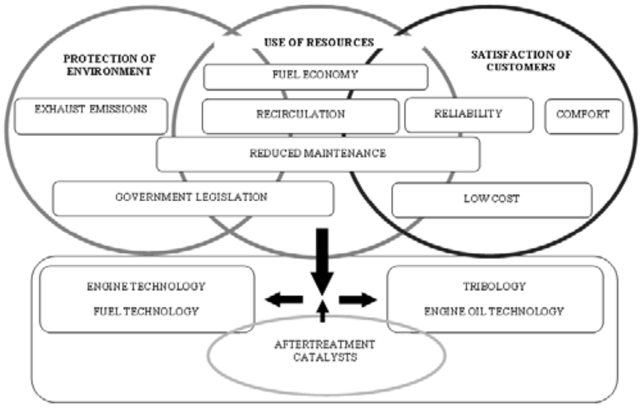

Figure 1. Future technology – Governing factors

2. CLASSIFICATION OF INTERACTIONS BETWEEN MODERN LUBRICANTS AND REFORMULATED FUELS

Principles of classification were published recently in the literature, as far as we know, in relation to engine oils/fuel. Possibilities of the considerations of classification chosen arbitrarily, without any claim for completeness, are as follows:

By mode of action
- direct (reduction of viscosity and basic number of engine oil, etc.)
- indirect (fuel economy, deposits in the combustion chamber, etc.).

By nature of action
- physical (dilution, formation of sludge, etc.)
- chemical (neutralization, formation of sludge and gelation, etc.).

By quickness of action
- slow (wear: more than 10 000 km)
- quick (inlet valve deposits: more than 1000 km).

By engine type
- Otto engines
  - o gasolines ↔ engine oils
- Diesel engines
  - o diesel fuels ↔ engine oils
- gas engines
  - gases ↔ engine oils

By origin of fuels
- conventional fuels ↔ engine oils
- alternative fuels ↔ engine oils.

By basestocks used for engine oils
- petroleum-based basestocks ↔ fuels
- synthetic basestocks ↔ fuels
- semi-synthetic basestocks ↔ fuels
- plant oils ↔ fuels.

By results of interactions (advantages, disadvantages).

There are no sharp borders among the individual groups listed above and even overlaps may exist sometimes.

3. EXAMPLES OF INTERACTIONS BETWEEN MODERN ENGINE OILS AND REFORMULATED FUELS

In Figures 2 and 3 we demonstrate examples of typical causes and effects in the development of gasolines and diesel fuels, while reasons and tendencies of the development of engine oils are in Table 1 and Figure 4. These and the improved engine designs brought the mentioned changes in the interactions.

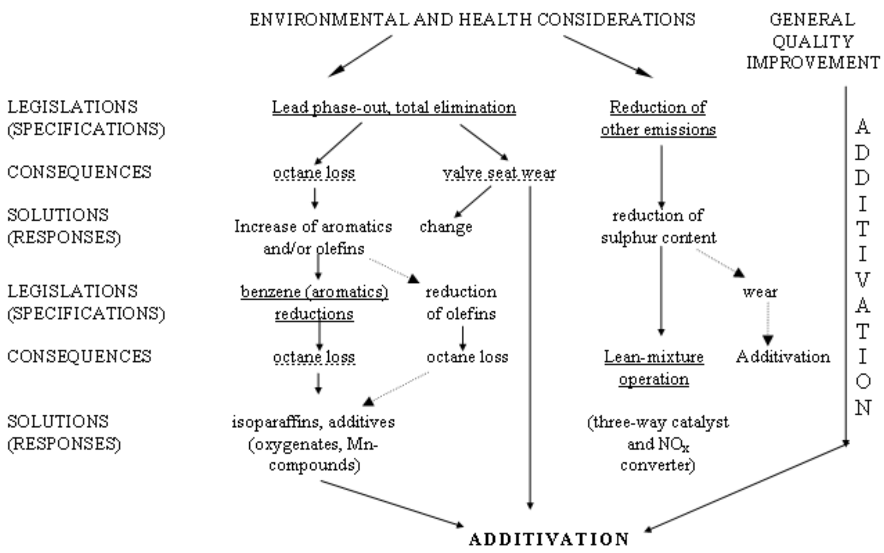

Figure 2. An example of causes and trends of quality changes in engine gasolines

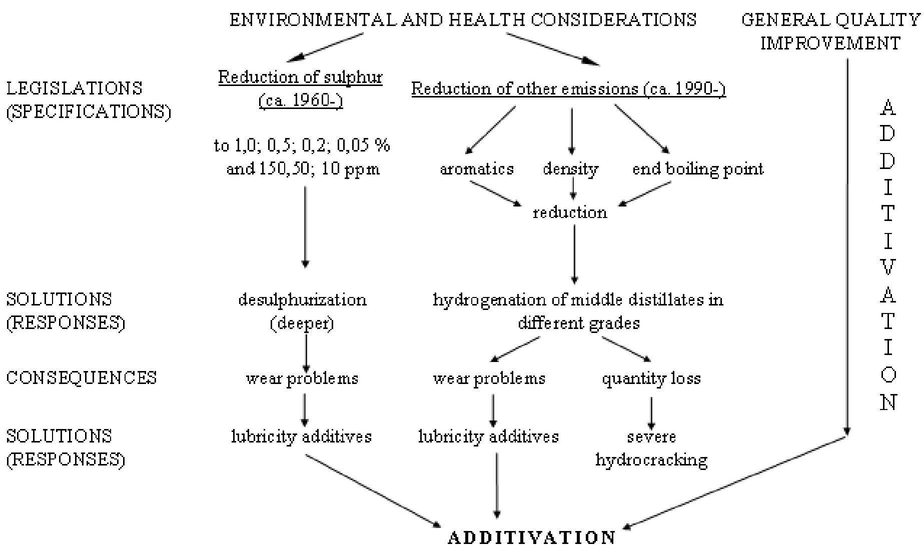

Figure 3. An example of causes and trends of quality changes in diesel fuels

Table 1.
Novel requirements of various engine oils

Classification of car engine oil based on SAPS*	Sulphate ash content, %	Phosphorus content, %	Sulphur content, %
Low SAPS	0.5	0.05	0.2
Medium SAPS	0.8	0.08	0.2
Universal SAPS	~1.2	~0.1	~0.5

**SAPS – sulphated ash, phosphorus and sulphur content*

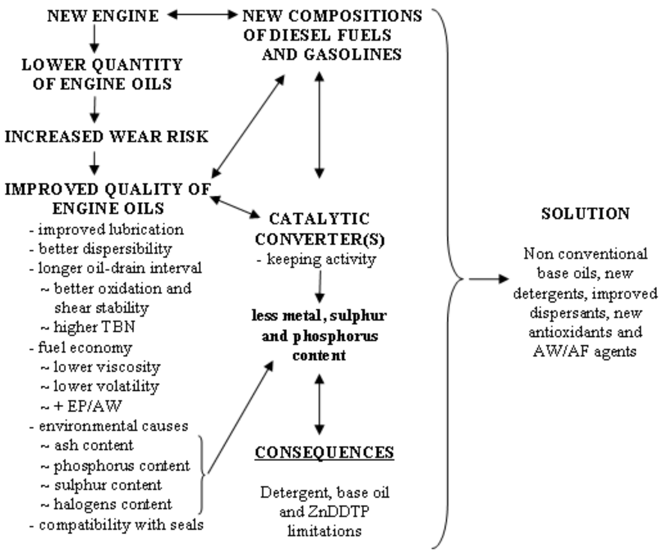

Figure 4 The arguments and tendencies of changes of the quality of engine oils

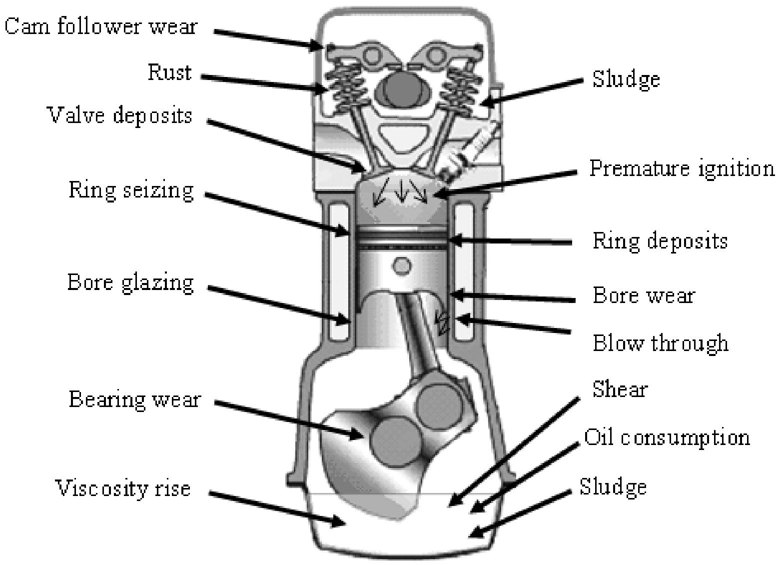

Figure 5. Consequences of harmful effects of fuel & engine oil

In general the mentioned interactions can occur at the locations shown in Figure 5 both for gasoline and diesel vehicles. In the latter case, however, compatibility problems arise in fuel injection pumps which are lubricated by engine oil.

3.1. INTERACTIONS BETWEEN THE ENGINE OILS AND FUELS IN GASOLINE ENGINES

In general, the direct interactions may occur at the following locations: valve lifting, piston and bearing areas.
Some examples (in direct interaction):

- dilution of oil with high end-boiling point gasolines (decrease of viscosity → poor lubricity → wear), resulting in insufficient lubrication that leads to wear
  - reformulated gasolines of low $T_{70°C}$ (20-55 V/V%) and $T_{100°C}$ (46-71 V/V%) (better driveability) → lower amount of heavier hydrocarbons → lower danger of dilution of the oil
- increase of viscosity of the oil:
  - by formation of cold sludge (by fuel – e.g. oxygenates and olefins – combustion → plugging)

- by formation of black sludge (by recirculation of exhaust gas → soot loading → poor pumpability, difficult starting, filter plugging → poor oil supply → wear;
- unleaded gasolines of high olefin and oxygenate are related to black sludge in engine oils (Figure 6 and 7; one solution is given in Table 2)[15]
- by inlet valve deposits (influencing factors: quality of gasoline and engine oil, engine design, driving conditions) → in cylinder → exhaust valve (particle emission) and engine oil
- Solution: application of new type detergent-dispersant additives (Figure 8, Table 2)[15, 16].

➢ shorter oil drain interval:

- by sulphur and nitrogen content of the fuel → acidic combustion products reducing the basic reserves of engine oils
- by antagonistic effect between fuel and oil additives → sludge forming.

Areas of indirect interactions in engines between gasolines and engine oils.

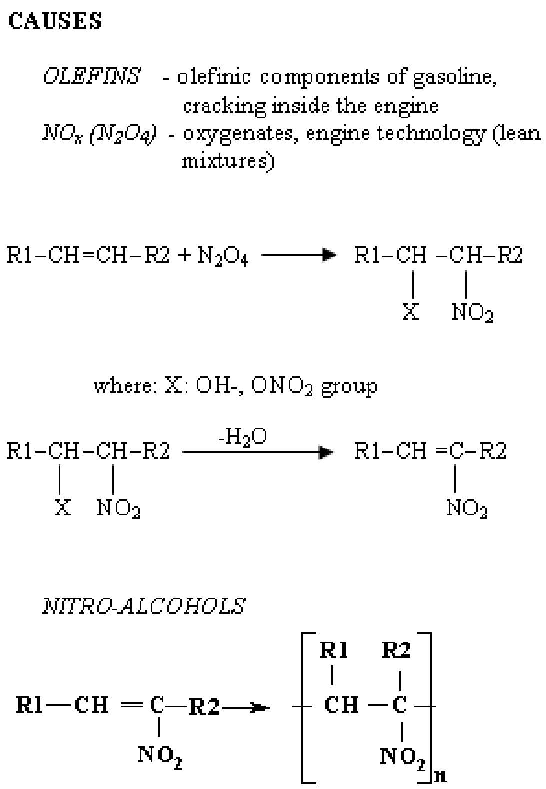

Figure 6 Mechanism of formation of the black sludge

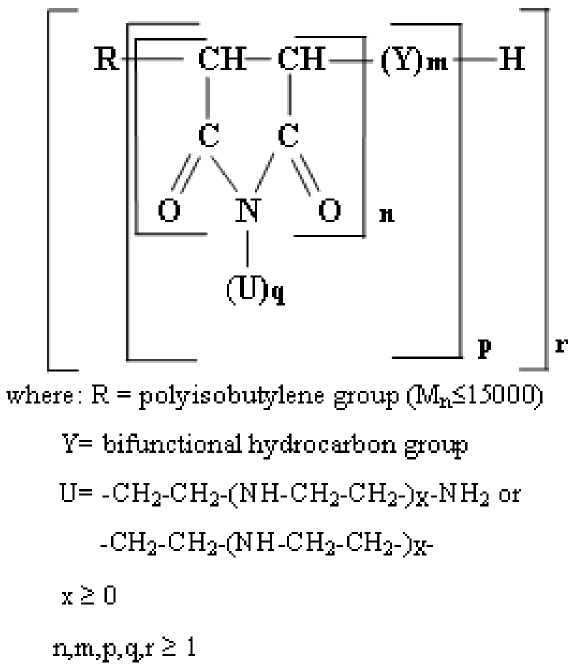

Figure 7 The black sludge affects the formulation of engine oils

Figure 8 Polysuccinimides

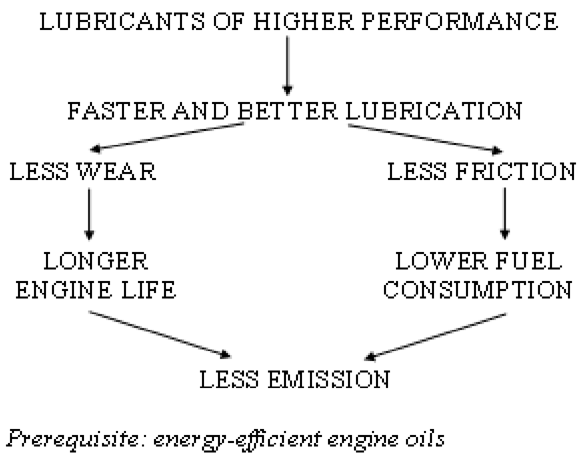

Figure 9. Effects of lubricants on fuel consumption and environment, heavy diesel vehicles (summary of a case study)

Table 2. Analytical properties of a typical polysuccinimide and results of sequence VE performance test of an API SH level engine oil formulated with it

Properties	**Conventional-**	**Poly-**
	succinimide	
$\overline{M}_{nPIB}$	980	2500
End product $\overline{M}_n$	2450	4500; 31000*
Additive content in SN-150 base oil	3.0	3.0
Viscosity improving efficiency, %	11.5	27
Viscosity index, VI_E	107	123
Detergent-dispersant efficiency, %, (max. 100)	63	90
Deposit on panel, mg	10	4.6
Engine oil		
10W-40 (concentration of additive)	(7.2)	(7.2)
Seal compatibility (VW-3344)	fail	pass
Engine test results, Sequence VE	Results	Pass limits
Average engine sludge	9.39	9.0 min.
Rocker arm cover sludge	9.14	7.0 min.
Average engine varnish	6.01	5.0 min.
Piston skirt varnish	6.94	6.5 min.
Average cam wear, mils	1.32	5 max.
Maximum cam wear, mils	2.8	15 max.
Oil ring filling, %	1.0	15 max.
Oil screen clogging, %	2.0	20 max.

*Data of GPC spectrum of bimodal molecular mass distribution of the additive

Effect of engine oils on the quality of gasolines:

- increase of the requirement of octane number
  - by combustion chamber deposits (produced partly by combustion of engine oils and partly by recirculation of exhaust gas containing burned and unburned oil components)
- inlet valve deposits → no uniform fuel supply → no uniform engine function → worse driveability → higher fuel consumption.

Effects of lubricants on fuel consumption and environment

Lubricants of higher performance → faster and better lubrication → lower wear (longer engine life) and less friction →

lower fuel consumption → less emission. Prerequisite: energy-efficient lubricants. Consequences: saving of energy resource (reduced fuel consumption), protection of environment (less carbon dioxide and other emissions) and satisfaction of customers (lower operating costs) [8,9]. According to the newest results of our work the polyisobutylene-polysuccinimides molybdenum containing (MoPIBPSI) type additives have excellent anti-friction and anti-wear (AF/AW) properties beside their good oxidation, thermal and shear stability in engine oil of API SJ performance level and SAE 0W-30 viscosity grade. Without ZnDDTP the AF/AW efficiency better than that of the reference oil having same performance level and viscosity grade and containing Mo-DDTC. From the point of view of the AF/AW properties the mentioned MoPIBPSI additives are very efficient in diesel engine oils without using ZnDDTP [17,18].

3.2. INTERACTIONS BETWEEN THE ENGINE OILS AND FUELS IN DIESEL ENGINES

Some examples of interactions between diesel fuels and engine oils:

- Disadvantageous interactions:
  - During not regular injection of diesel fuels of higher viscosity the fuel can get into the engine oil between the piston and the cylinder-wall decreasing the viscosity of the oil and resulting in less efficient lubricity and in wear.
  - In case of diesel fuels of lower cetane number the concentration of particulate matters is higher in the exhaust gases; so more particulates can get into the engine oil during the recycling of exhaust gas, and the soot emission will be higher; this effect can be compensated by using more efficient and/or higher amount of dispersant additive in the engine oil.
  - Diesel fuels always contain some sulphur compounds: the acidic compounds formed at the ignition of these – only a small percentage but continuously – get into the engine oil between the piston and the cylinder-wall decreasing the base number and consequently the neutralizing action of it.
  - Lubrication of some charging pumps is accomplished by the diesel fuels. Because of the significant decrease of sulphur content together with that of neutral components providing lubricating functions, the fuels cannot ensure appropriate lubrication. In order to eliminate this, so-called lubricity improving additives are added to the diesel fuels. In the other large group of the charging pumps lubricated by the engine oil, these additives may directly interact with the engine oil, and then the fuel may be gelled according to the experiences, that may cause filter and wear problem in the supplying and charging pumps, and these may lead to irregular distribution of the fuel and so worse driveability or even increase of the controlled emissions happen. It is important to apply optimalized additivation of the diesel fuel and engine oil, respectively [6].
- Advantageous interactions:
  - Reformulated diesel fuels of low $T_{95\%}$ and end boiling point contain lower amount of heavier hydrocarbons that leads to lower danger of oil dilution (and of wear).
  - Concentration of acidic components (SO_2, SO_3, H_2SO_4) is less in the exhaust gases during the combustion of low sulphur diesel fuels and these cannot considerably reduce the basic character of the oil at the blow through between the piston and the cylinder-wall, therefore the amount of additives ensuring this character can be reduced. These additives are mainly metal-containing ones, so the metal content of the engine oils can be reduced (this is an environmental advantage, too). The metal compounds getting into the exhaust gases from the engine oil decrease less the efficiency of the particulate filters, thus this can ensure small emission of particulates for a long time.
  - At the application of the so-called energy- saving engine oils, gear oils and shaft oils of low viscosity and acceptable lubricity, the frictional drag will be less and this results in lower fuel consumption and overall emission, resource saving, customer interest, too. This is an important capability of decreasing the carbon-dioxide emission (Figure 9)[1-14]; and ensuring longer oil drain intervals.
  - The products of combustion of diesel fuels which contain additives and

have low sulphur content – interact with the engine oil as mentioned – damage the quality of the oil less and so contribute to longer change-period, that results not only in lower operational costs, but can decrease the environmental detriment of the crush and recycle of used engine oils.

- Our research and development work lasting since several decades, produced important results in the field of developing and commercial scale production of ashless additives of different structure, having detergent-dispersant effect. These – together with other additives – are suitable to formulate engine oils for modern and energy-effective (fuel-saving) diesel engines. The results of soot dispersing engine tests (MACK T8) and the composition of engine oils (ACEA E_2, ACEA E_3) produced by using these polyisobutenyl-succinic-anhydride derivatives (KOMAD-X_1, -X_2, -X_3), having low and high molecular mass and adequate molecular structure, are summarized in Table 3. Based on these results it is stated that increment of the kinematic viscosity (at 100°C) using perhaps the most severe engine test in case of engine oils – having 3.8% soot content − approached the maximum limit of 11.5% in case of sample "B" while in case of sample "C" it was significantly lower than the former one. By the application of the latter diesel engine oil, the significant increase of viscosity, due to the previously discussed increased soot loading, and thus the fuel consumption can be highly reduced by applying mixture of appropriately selected dispersants.
- Lubricity additive in diesel fuels may reduce wear rating of the combustion chamber, and results in lower oil consumption.
- In the recent heavy duty vehicles turbo-charging and cooling of the charging-air is required to comply the emission limit of EURO II. In consequence of these solutions and of recirculation of blow-by gases from the crank-case, deposits may be formed in the intake-system and on the lamellas of the cooler of charge-air. These deposits worsen the heat transfer and change the ratio of the air and fuel, causing increase of fuel consumption and of emission.

- Other Interactions.

In the last five years sulphur content of the diesel fuels – as it was pointed out – was decreased in more steps in the European Union and in several other countries to maximum 50 and 10 ppm. As a result, the amount of sulphur containing acidic compounds was measurably decreased. (Naturally, in the most cases deep desulphurization means also deep denitrogenation, so the amount of acidic compounds containing nitrogen decreased, too.) So the main goal became the neutralization of organic acids formed during the oxidation of engine oil. Accordingly, the base number of high performance engine oils can be decreased step by step to 8 mg KOH/g and in longer term till 6 mg KOH/g, that needs application of additives of new composition. This was the result partially of the mentioned reasons but also of recycling of one part of the exhaust gases as well as of the formation of resinous compounds during the oxidation. The previous causes mainly increase of the soot loading of the engine oils. In consequence of the latter, application of ashless antioxidant additives of good efficiency is needed at the formulation of engine oils to prevent their oxidation.

Table 3. Composition of engine oils and results of soot dispersing engine-tests

Component	**Composition of engine oils**		
	"A"	"B"	"C"
Base oil -mineral	68.93	68.48	57.18
-synthetic	-	-	10,0
Viscosity modifier	21	15.7	15.5
Flow improver	0.5	0.3	0.3
Detergent + other additive	5.55	5.5	5.5

Dispersant KOMAD-X_1	3.0	-	-
KOMAD-X_2	1.0	7.0	8.0
KOMAD-X_3	-	3.0	3.5
Antifoam additive	0.02	0.02	0.2
Results of engine test			
Mack T8* Increment of kinematic viscosity (at 100°C) having 3.8% soot content, %	68.8	13.4	5.0
Mack T8E Relative viscosity ($KV_{100°C}$) having 4.8% soot content, informative value	-	2.7	1.4

**The limit value for increment of kinematic viscosity is maximum 11.5% in case of 3.8% soot content, the limit value by repeated tests after averaging 12.5 and 13%, respectively*

4. SUMMARY

A great number of direct and indirect interactions may develop between the fuels and lubricants of gasoline and diesel engines, inside the engines and in the fuel supply systems. These may have both advantageous and disadvantageous effects in respect of motor vehicle operations and environmental impacts. The solution of the numerous problems originating in the multi-faceted interactions will only be possible by optimizing methods developed on the basis of technical, environmental and economic considerations.

References

[1] Renner, G., Joeris, P., Neudörfl, P., 'Bestimmung der Kraftstoffeinsparung durch polymerhaltige Mehrbereichsöle in verschiedenen Prüfverfahren', *Mineralöltechnik*, 3 (1996) 1-22.

[2] Bartz, W.J., 'Fuel Economy Improvement by Engine and Gear Oils', *In: Proceedings of 5th CEC International Symposium on the Performance Evaluation of Automotive Fuels and Lubricants*, May 13-15, (1997) 31. Göteborg

[3] Korcek, S., Johnson, M.D., Jensen, R.K., McCollum, C., 'Retention of Fuel Efficiency of Engine Oils', *Technische Akademie Esslingen,* January (1998) 1281-1287.

[4] Bergstra, R.J., Baillargeon, D.J., Deckman D.E., Goes, J.A., 'Advanced Low Viscosity Synthetic Passenger Vehicle Engine Oils', *J. Synthetic Lubrication*, 16, 1 (1999) 51-72.

[5] Macduff, M., Wall, S.W., Arters, D.C., Bardasz, E.A., Righi, D., Schieferl, E.A., 'A Comparison of Fuel System Deposits and Lubricant Performance in Gasoline Direct Injection and Port Fuel Injection Vehicles', *In: Proceedings of 2nd Int. Coll. on Fuels, Editor: Bartz, W.J., Technische Akademie Esslingen,* January 20-21, (1999) 639-649. Ostfildern

[6] Davenport, J.N., Caprotti, R., Cochrane, H.D., 'Background, Development and Validation of a Bench Test for Compatibility between Diesel Fuel and Lubricating Oil', *In: Proceedings of 2nd Int. Coll. on Fuels, Editor: Bartz, W.J., Technische Akademie Esslingen,* January 20-21, (1999) 169-175. Ostfildern

[7] Brown A. J., Robson R., 'Challenges for Future Passenger Car Gasoline and Diesel Engine Lubricant Development', *Technische Arbeitstagung*, March 20, (2003) Hohenheim

[8] Castle, R.C., Arrowsmith, S., Locke, C.J., Bovington, C.H., 'The Role of Lubricant Additives in Improving Fuel Economy for Heavy Duty Diesel Applications', *Mineralöltechnik*, 2 (2003) 1-16.

[9] Bleimschein, G., Fotheringham, J., Plomer, A, Reboul, P., 'Lubricant Base Oil Effects on Regulated EURO II Heavy-Duty Diesel Engine Emissions and Fuel Economy', *Mineralöltechnik*, 5 (2003) 1-20.

[10] Castle, R.C., Bovington, C.H., 'The Behaviour of Friction Modifiers under Boundary and Mixed EHD Conditions', *Lubrication Science,* 15, 3 (2003) 253-263.

[11] Hedrich, K., Renner, G., Dardin, A., 'Beiträge von VI-Verbesserern zur Kraftstoffeinsparung und Pumpfähigkeit von Motorenölen', *Mineralöltechnik,* 11 (2000) 13-24.

[12] Brown, A.J., Bell, A.W., McConnachie, J.M., Stiefel, E.I., 'Molybdenum Dithiocarbamates for Enhanced Friction Control and Fuel Economy', *Symposium on Recent Advances in the Chemistry of Lubricant Additives, Presented before the Division of Petroleum Chemistry, Inc.,218th National Meeting, American Chemical Society New Orleans,* August 22-26., 44, 3 (1999) 326-331.

[13] Bovington, C., Spikes, H., 'Prediction of Influence of Lubricant Formulations on Fuel Economy, from Laboratory Bench Tests', *Proceedings of the International Tribology Conference,* October 29-November 2, (1995) 817-822.

14. Korcek, S., 'Engine Oil Fuel Efficiency-Practical Issues', *Tribology for Energy Conservation, Elsevier Science B.V.,* (1998) 25-33.

15. Hancsók, J., Bartha, L., Baladincz, J., Kocsis, Z., 'Relationship between the Properties of Polyisobutenyl Succinic Anhydrides and their Additive Derivatives', *Lubrication Science*, 11, 3 (1999) 297-310.

16. Hancsók, J., Bartha, L., Auer, J., Baladincz, J., 'Development of Modern Engine Oils by the Application of Succinimide Type Additives', *Hungarian Journal of Industrial Chemistry*, 25, 1 (1997) 47-52.

17. Kis, G., Bartha, L., Baladincz, J., 'PIB-Polysuccinimide Type Additives with Complementary AF and AW Effect', *In: Proceedings of 13rd Int. Coll. Tribology, Editor: Bartz, W.J., Technische Akademie Esslingen,* January 15-17, (2002) 525-531.

18. Kocsis, Z., Baladincz, J., Bartha, L., Hancsók, J., Sági, R., 'Mo-Containing Dispersant Additives for the Formulation of Low SAPS Engine Oils', *In: Proceedings of* 14th *Int. Coll. Tribology, Editor: Bartz, W.J., Technische Akademie Esslingen,* January 13-15, (2004) 1555-1559.