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INVESTIGATIONS OF COLLATERAL EFFECTS OF FUEL ADDITIVES ON DIESEL ENGINE SMOKE EMISSIONS

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Abstract: *Five multifunctional fuel additives were tested in a truck diesel engine in order to evaluate their smoke reduction effect. The research multifunctional additive packages A1-A5 were based on functions of dispersant-detergent, antiknock, friction modifier, thermal stabilizer and corrosion inhibitor, being mixed in the recommended concentration of the supplier. The engine was operated under test cycles ECE R 24 and ECE R 49. Results indicated that three out of five additives proved to contribute to the lowering of the smoke emissions.*

Key words: *heavy duty diesel engine, fuel additives, smoke abatement.*

1. Introduction

Besides the gaseous exhaust emissions specific to diesel engines (carbon monoxide CO, nitrogen oxides NO_x and unburned hydrocarbons HC) there is a controversial pollutant - particulate matter, (PM), which is defined as all solid and liquid (condensate) matter presented in diluted and cooled diesel exhaust gas.

An optical approach of the PM used the term "visible pollutants" which is known also as smoke.

There is a fair correlation between the mass of soot, the major contributor of PM and opacity of diesel smoke measured by light absorbtion of a column of exhaust gas, both of them indicating the presence of the same complex pollutant whose composition is mainly made of carbon, hydrocarbons from fuel or lubrication oil, sulfates and water.

As recent studies of the International Agency for Research on Cancer reveal [8], diesel exhaust gas was classified as carcinogenic to humans, having sufficient evidence that exposure increases the risk for lung cancer, a significant contribution being attributed to smoke constituents.

Many smoke abatement technologies were already efficiently applied, but the legislative limitations imposed by European regulations known as Euro levels become more stringent, so the potential of fuel addition is still far to be completed.

Especially for older type engines fitted on truck and buses, meeting the emission requirements of Euro 3 or Euro 4, as many of those currently in operations in Romania, a solution for the certification of some emission could be the use of after-market additives. The literature indicates several research works to improve diesel combustion by means of adding oxygenated compounds (di-methoxy-methane and di-methoxy-propane)

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[6] and dimetyl-carbonate [7] metallic based components [2], [3], [5] which contributed to the reduction of smoke emissions.

This paper intends to study the effect of lowering smoke emission by means of fuel addition with multifunctional organic additives already developed as fuel additives with other functions. So the additive packages having more than one characteristic may demonstrate "collateral effects", which may be evaluated through smoke measurement.

2. Description of the Diesel Engine

A 392-L4 DT, turbocharged, water-cooled, four stroke diesel engine manufactured at Roman Truck company was used in additives evaluation, the main technical characteristics being given in Table 1, with power, torque and fuel consumption corrected according to requirements of the engine performance standard ISO 1585.

Engine parameters Table 1

Bore x Stroke	102 x 120 [mm]
Compression ratio	17.5 : 1
Rated power	77 [kW]
Rated speed	2800 [revs/min]
Maximum torque	34 [daNm]
Maximum torque speed	1800 [revs/min]
Minimum specific fuel consumption	227 [g/kWh]

The tests were performed at the Road Vehicle Institute in Braşov (INAR) on a continuous current dynamometric test bench MEZ-VSETIN of 300 kW power, instrumented for measuring fuel consumption, engine speed, torque, air flow rate and pressure, air, water and exhaust gas temperatures. The smoke opacity was measured on the Hartridge scale of opacity, in HSU (Hartridge Smoke Units).

3. Fuel Additives

Fuel additives may solve several problems associated with diesel engine operation in terms of power, fuel economy, emissions and durability. The most demanding requirements are the following: improving the combustion process, limiting the smoke emissions, increasing cetane number, cleaning the injection nozzles, inhibit the oxidation and foam formation, improving the fuel flow. Multifunctional additives are designed to solve these requirements simultaneously being added in concentration ranging from 500 to 3300 ppm [1].

Five additives synthesized at Petroleum Research Institute - ICERP Ploiesti, some of them under the trade name ADIROL, are listed in Table 2.

Additive characteristics Table 2

Additive/Type	**Concentration [% vol.]**
A1. Nitrogen compound in solvent/Detergent	0.25
A2. Nitrogen compound in solvent/Thermal stabilizer	0.05
A3 Alkane amide/Corrosion inhibitor	0.05
A4. Cyclic amines/ Antiknock	0.05
A5. Polyisobutene succinimide/Detergent	0.05

Due to nondisclosure agreements with additive manufacturing company, the chemical composition of the additives cannot be disclosed, being precised only the type of the chemical family and the concentration recommended.

The tests were performed using diesel fuel in two distinct situations - without and with additives. The diesel fuel commercially available was Euro Diesel, having the standard parameters according to EN 590:2004 [11].

The test was initially undergone with pure, no-additive diesel fuel, being considered as the reference test, then with diesel fuel with each of A1-A5 additives in the prescribed concentrations.

4. Test Cycles

In order to verify the smoke abatement, there were chosen two emission test standards, ECE R 24 [9] at steady speeds and ECE R 49 [10].

The measurements were performed with the opacimeter AVL 465 which determines the opacity of diesel exhaust emissions; the apparatus is a continuous dynamic partial-flow instrument, based on the Beer-Lambert law, a 430 mm length chamber is filled with exhaust gas and due to black soot particles the light intensity between a light source and a receiver is reduced. The measurement value output is opacity (HSU) [%] or the absorption coefficient k m^{-1}, with the measure range of 0 to 100% for HSU and 0 to 10 m^{-1} for k. The resolution of displayed measurement was 0.01% opacity or 0.0025 m^{-1}.

All measurements were done three times, in the same conditions of testing, being used in calculation of the average values.

4.1. Full-load, steady speed, free acceleration test

The test was carried out on the engine, being measured the opacity of the exhaust gases running under full-load and at steady speeds defined according to [9], between minimum and maximum rated speed, in this case 1400-2700 rpm.

For each of the engine speeds at which the absorption coefficient is measured, the nominal gas flow was calculated as a product between the cylinder capacity of the engine and its speed, in revolutions per minute (rpm). The results of the smoke measurements are presented in Figure 1 [12]. There were also measurements of smoke emission in free acceleration which characterizes gross polluters, the tests being relevant, rapid and economic - the values are presented in Table 3.

Free acceleration smoke Table 3

Test type	Smoke number [HSU]
Reference fuel	62
Additive 1	55
Additive 2	54
Additive 3	62
Additive 4	56
Additive 5	59

4.2. Steady speed, variable load test

The emission tests were undergone according to the regulation [10] having 13 stages of steady state operation mode which are defined as engine speeds expressed in rotation per minute, loads, expressed in percentage of nominal load and weights expressed as percentage of each step in the total test cycle.

The smoke was measured for two relevant engine speeds (2700 rpm and 1800 rpm) and presented in Figures 2 and 3, respectively, in function of the increasing load (10%, 25%, 50%, 75% and 100% of rated power).

The profile from Figure 1 shows that smoke emissions depend on engine speeds, being the highest at the maximum torque; similarly, the profiles from Figures 2 and 3 indicate an increase of smoke emission with engine load. A general evaluation of smoke emission is performed in the points indicated in Figures 2 (five points) and 3 (five points), the three points up to 13 being measured in the idle mode. The weight coefficients of each point vary from 0.02 to 0.25, with the maximum value being attributed to the idle mode.

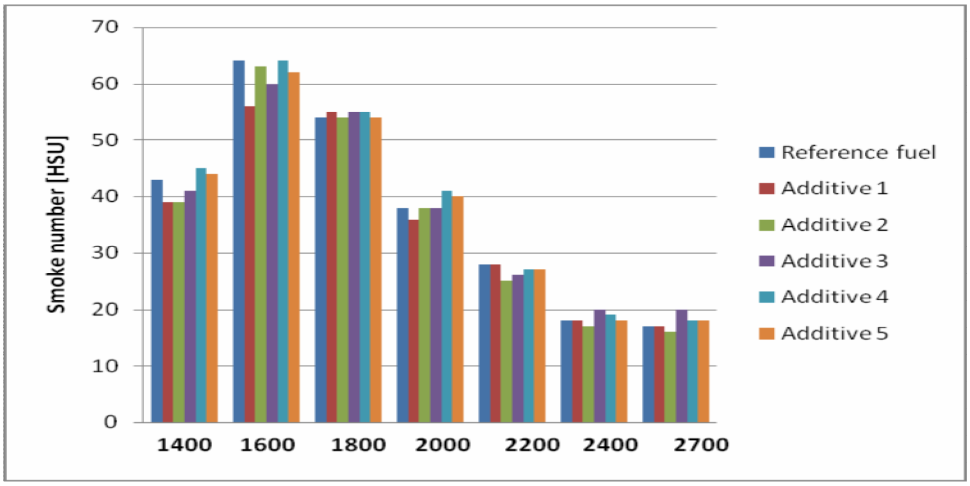

Fig. 1. *Smoke number versus engine speed at full load in different additions of the fuel*

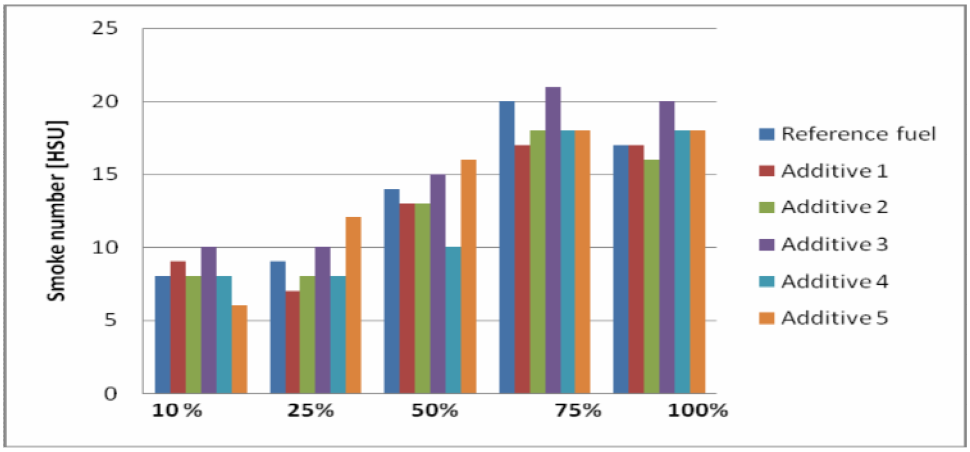

Fig. 2. *Smoke emissions at 2700 rpm and different percentage loads*

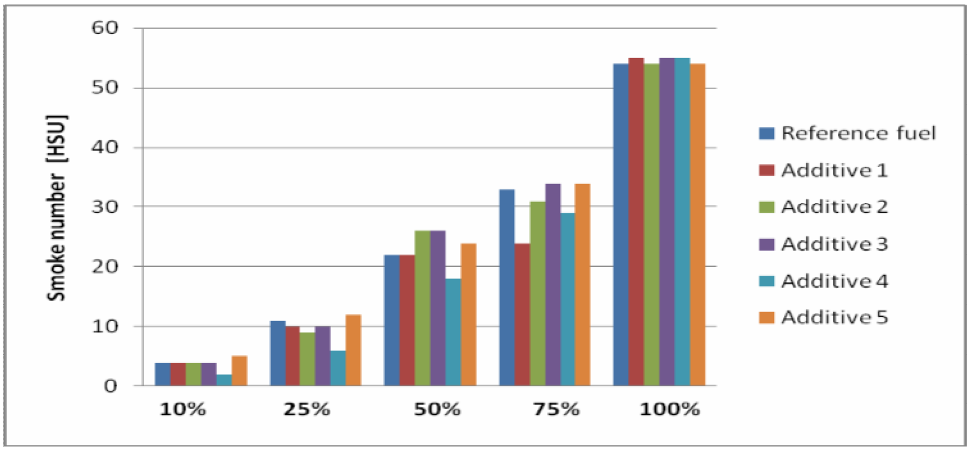

Fig. 3. *Smoke emissions at 1800 rpm and different loads*

The particulate matter (*PM*), expressed in g/m^3, was calculated indirectly using equivalence with the measured smoke emissions in Hartridge units (*H*), indicated in [4] with the averaged formula:

$$PM = 0.349^{+0.183}_{-0.089} \cdot \ln\left(1 - \frac{H}{100}\right)^{-1}. \qquad (1)$$

5. Test Results and Data Interpretations

A synthesis of the results is presented in Table 4:

- In the free acceleration test, which evaluates the combustion process during engine transient operation modes, the additives A2, A1 and A4 have significant particulate reductions;
- In the full load-steady speeds test, which evaluates the engine operation under heavy duty operation, the A1 and A2 have fair particulate reductions;
- In variable loads, steady speeds test, which features the operation in partial loads, the most frequent ones especially in urban traffic, the additives A4 and A1 proved to lower the particulate emission.

Out of five additives three were selected and it must be asserted a certain preference on them, based on the relevance of emission tests over the life span of the engine and type of application. It may be considered that free acceleration test features the engine operation modes which represent less than 5% of the life span; similarly the engine operation at full load is less than 15%, so the main weight lies on the operation at steady speeds and variable loads, mostly medium loads. By applying these considerations the order of preference for the additives promotion is A4, A1 and A2, being however influenced by the nature of the application.

6. Conclusions

The tested additives demonstrated that even if their function is not of smoke depressant, they do not increase the smoke numbers, three of them having a slight effect of lowering smoke number (8-10%) and particulate emission.

Out of the five additives, the selection for studies nominates A4, A1 and A2 to be included in multifunctional packages, with recommendation for performing further tests to assess the effect of increasing concentration in the fuel, simultaneously with the study of deposit formation in the engine.

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Additive effects in three tests Table 4

Fuel	Free acceleration test		Full load-steady speeds		Steady speeds variable loads	
	Equivalent particulate matter [g/m^3]	**Reduction from ref. fuel [%]**	**Equivalent particulate matter [g/m^3]**	**Reduction from ref. fuel [%]**	**Equivalent particulate matter [g/m^3]**	**Reduction from ref. fuel [%]**
Ref.	0.337	-	0.1839	-	0.1090	-
A1	0.279	17	0.1630	11	0.0986	9
A2	0.271	19	0.1688	8	0.1004	8
A3	0.337	0	0.1718	6	0.1093	-0.1
A4	0.286	15	0.1817	1	0.0977	10
A5	0.311	7	0.1778	3	0.1034	5

and from ICERP Ploiești who manufactured the research additives: Aurica Dumitru, Teodor Decean and Victor Boiangiu.

References

1. Andrews, G.E., Charalambous, L.A.: *An Organic Diesel Fuel Additive for the Reduction of Particulate Emissions*. SAE Paper 912334, 1991.
2. Chlopek, Z., Darkovwski, A., et al: *The Influence of Metallo-Organic Fuel Additives on CI Engine Emissions.* In: Polish Journal of Environmental Studies **14** (2005) No. 5, p. 559-567.
3. Corporan, E., DeWitt, M., et al: *Evaluation of Soot Particulate Mitigation Additives in a T63 Engine*. In: Fuel Processing Technology **85** (2004), p. 727-742.
4. Dodd, A., Holubecki, Z.: *The Measurement of Diesel Exhaust Smoke*. MIRA Report Number 1965/ 10, 1965.
5. Keskin, A., Guru, M., et al: *Influence of Metallic Based Fuel Additives on Performance and Exhaust Emissions of Diesel Engines.* In: Energy Conversion and Management **52** (2011), p. 60-65.
6. Sathiyagnanam, A.P., Saravanan, C.G.: *Effects of Diesel Particulate Trap and Addition of Di-Methoxy-Methane and Di-Methoxy-Propane to Diesel on Emission Characteristics of a Diesel Engine.* In: Fuel **87** (2008), p. 2281-2285.
7. Zhang, G.D., Liu, H., et al: *Effects of Dymethyl Carbonate Fuel Additive on Diesel Engine Performances.* In Proc. IMechE **219** (2005), p. 897-903.
8. http://www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf. Accessed: 29-01-2013.
9. *** ECE-R 24.03: *Uniform Provisions Concerning the Approval of the Compression Ignition Engines with Regard to the Visible Pollutant Emissions of the Engine*.
10. *** ECE-R 49.02: *Uniform Provisions Concerning the Measures to be Taken Against the Emission of Gaseous and Particulate Pollutants from Compression-Ignition Engines for Use in Vehicles.*
11. *** EN 590:2004: *Automotive Fuels - Diesel - Requirements and Test Methods.*
12. *** *Study on the Reduction of Pollutant Emissions by Fuel Additives*. No. 34646, INAR Braşov.