Measurement of Particle Matter Composition in Common Rail Diesel Engine

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Abstract

The article presents the results of PM emission tests carried out with the Horiba 1220 PM analyzer (flame-ionization) and the gravimetric method in comparison with the results of PM emission obtained with the AVL 438 Opacimeter, which provided with the smokiness value of exhaust gases. The paper also presents the mathematical correlations between PM emission, exhaust gases blackening and their coefficient of extinction. The aim of the tests is to develop a measuring methodology and to indicate measuring instruments so that the assessment of PM emission rate with the use of indirect measuring methods is possible.

The purpose of the tests was to determine the correlation between particle emission measurements with the use of various devices: Smart Sampler 472 – particle measurement by the gravimetric method (partial exhausts gases flow) and Horiba Mexa 1220 PM using the Flame Ionization Detector method. The latter method also allowed obtaining the results in real time; furthermore, the comparison of the methods with exhaust opacity was proposed and measured by the optical and filtration method. Assuming small participation of ash (engine w/o aftertreatment) and small participation of SO_4 (free sulfur fuel) in PM a hypothesis of PM division into two fractions: SOL and SOF could be accepted.

Methodology

STEADY-STATE TEST. Basic (cognitive) correlation tests for concentration of PM and substitutes of these measurements were carried out in the ESC. Since this is a stationary type of a test, dynamic properties of an engine have a small influence on the obtained relations (and disturbances that occur). Earlier tests of the authors proved that in order to obtain representative results it is necessary to consider a big number of various measuring points set for the characteristics of the engine operation. Such a method of measurement required extra measuring points to be added to the basic ESC. Additional points were set by means of a method for setting measuring points in the ESC. As compared with the ESC cycle the duration of each phase was increased (to 6 min) in order to ensure thermal stabilisation of the engine and maintain values of the evaluated parameters; PM measurement was carried out in the last minute of the phase duration. Operating points were presented in a form of tables showing percentage values of engine load for an adequate engine speed.

The assignment of additional points of engine operation meant setting new engine speed and load values. It was agreed that percentage load values would remain unchanged while new engine speed values (A1, B1, C1) were derived from the following formulas:

$$A1 = n_{low} + 0.125\ (n_{high} - n_{low}),\ B1 = n_{low} + 0.375\ (n_{high} - n_{low}),\ C1 = n_{low} + 0.625\ (n_{high} - n_{low}).$$

The method in this shape allowed for setting 12 additional measuring points. Absolute values and a distribution of measuring points in the characteristics of the engine operation is show in Fig. 1.

$$ESC(n_{A,B,C}; M_{\%}) = \begin{bmatrix} & 100 & 100 & 100 \\ & 75 & 75 & 75 \\ & 50 & 50 & 50 \\ \text{idle} & 25 & 25 & 25 \\ & A = 2425 & B = 3300 & C = 4125 \end{bmatrix}; \quad Add\ (n; M_{\%}) = \begin{bmatrix} 100 & 100 & 100 \\ 75 & 75 & 75 \\ 50 & 50 & 50 \\ 25 & 25 & 25 \\ A1 = 1850 & B1 = 2850 & C1 = 3750 \end{bmatrix}.$$

Results

Two main fractions can be distinguished in emitted particulates: SOF – Soluble Organic Fraction, i.e. the fraction of PM which is extracted by means of dichloromethane CH_2Cl_2 and SOL – Solid Fraction whose main content is solid coal which in its form is similar to graphite. The remaining components of SOL include: water-soluble sulphates, water combined with sulphates, nitrates, metals and other particles containing coal RPM (Residual Particulate Mass). It was possible to obtain information on fractional composition of a PM due to the employment of MEXA 1220 PM analyzer which measures particulates by means of fragmentation into solid fraction SOL and soluble organic fraction SOF. This enabled to define the relation SOL/SOF as a function of the main engine parameters, e.g. in relation to the engine speed and load, brake specific fuel consumption, exhaust pressure, crank angle, time and quantity of main injection, crank angle of pre injection. The article features only these descriptions of dependences of fractional composition on particular engine operating parameters for which the correlation coefficient exceeds 0.2. Most of the observed dependences show a relation between the fractional composition of PM and a tested operating parameter of an engine. Fuel injection-related parameters have the biggest influence on the fractional composition of PM. Fractional composition of PM mostly depends on engine operating parameters related to the type of the injected fuel: quantity of the main injection and a crank angle of the pre-injection.

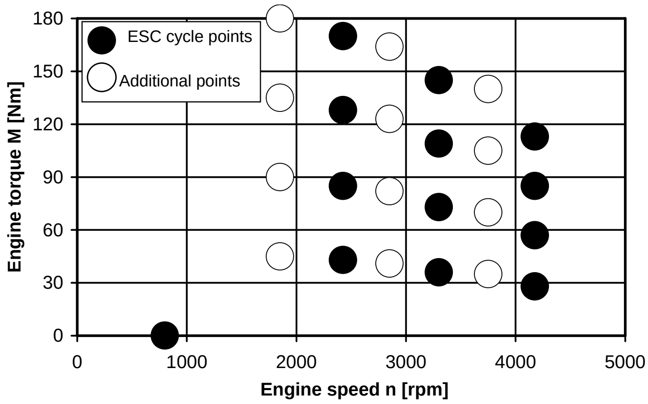

Fig. 1. The set measuring points during engine tests

On the basis of the analysis of PM fractional composition values as a function of engine operating parameters conclusions concerning its change can be drawn; it mainly depends on the fuel injection characteristics (including the size and angle of the main injection and pre-injection), engine speed and load, unitary fuel consumption value. The value of a relation SOL/SOF (coal fraction share) increases upon the growth of load, size and time of main fuel injection and fumes temperature (measured after the exhaust manifold and before the turbocharger), whereas it decreases upon the increase of engine speed, unitary fuel consumption, fumes pressure (which may be the consequence of the growth of supercharging pressure) and the angle of preliminary injection. The obtained values of correlation coefficients are tabulated below (Table 1).

Table 1. Values of correlation coefficients obtained in tests

Parameter	Equation	R^2
Engine speed – n [rpm]	$SOL/SOF = 3.0\times10^{6}\times n^{-1.82}$	0.49
Engine load – M [Nm]	$SOL/SOF = 3.9\times10^{-1}\times M^{0.28}$	0.20
Brake specific fuel consumption – BSFC [g/kWh]	$SOL/SOF = 2.8\times10^{3}\times BSFC^{-1.81}$	0.21
Exhaust pressure – p_{exh} [bar]	$SOL/SOF = 1.8\times p_{exh}^{-0.85}$	0.32
Exhaust temperature – T_{exh} [^{o}C]	$SOL/SOF = 9.0\times10^{-7}\times T_{exh}^{2.25}$	0.34
Crank angle of main injection – α_{main} [deg CA]	$SOL/SOF = 4.3\times\alpha_{main}^{-0.56}$	0.44
Time of main injection – t_{main} [deg CA]	$SOL/SOF = 9\times10^{-6}\times t_{main}^{1.82}$	0.25
Quantity of main injection – Q_{main} [mm^3]	$SOL/SOF = 4.4\times10^{-3}\times Q_{main}^{1.73}$	0.73
Crank angle of pre injection – α_{pre} [deg CA]	$SOL/SOF = 36.2\times\alpha_{pre}^{-1.16}$	0.56

Summary

The result of the analysis carried out proved a significant correlation between a unitary PM emission obtained in the gravimetric method and other values which are substitutes of such a measurement. According to the expectations the organic content of particles in modern engines accounts for less than 50% of PM mass. It points to a certain rule of the measurements made: smoking of exhaust is mainly caused by the coal fraction of particles, while hydrocarbons presence in fumes is hardly taken into account. Therefore, a greater reliability (possibility of a changeable application of smoking measurement and PM emission) can be achieved when particles emitted by engines will mainly comprise of coal, while solid organic fraction will remain limited.

Fractional composition of PM mostly depends on engine operating parameters related to the type of the injected fuel: quantity of the main injection and a crank angle of the pre-injection.

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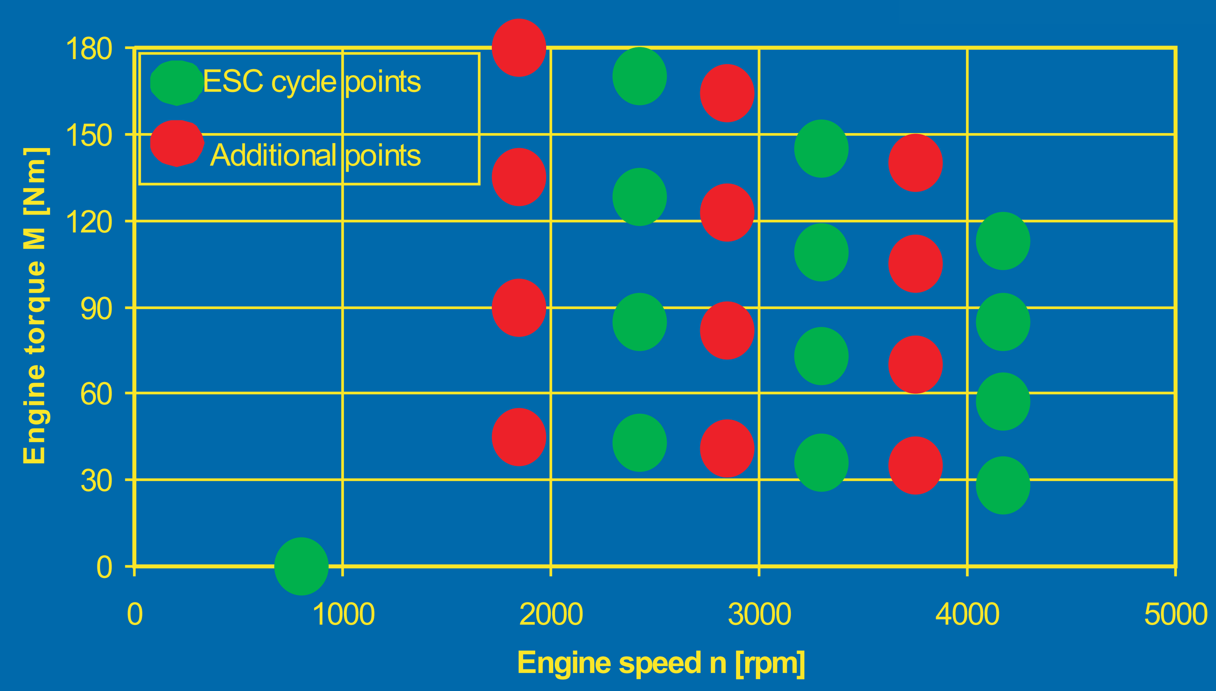
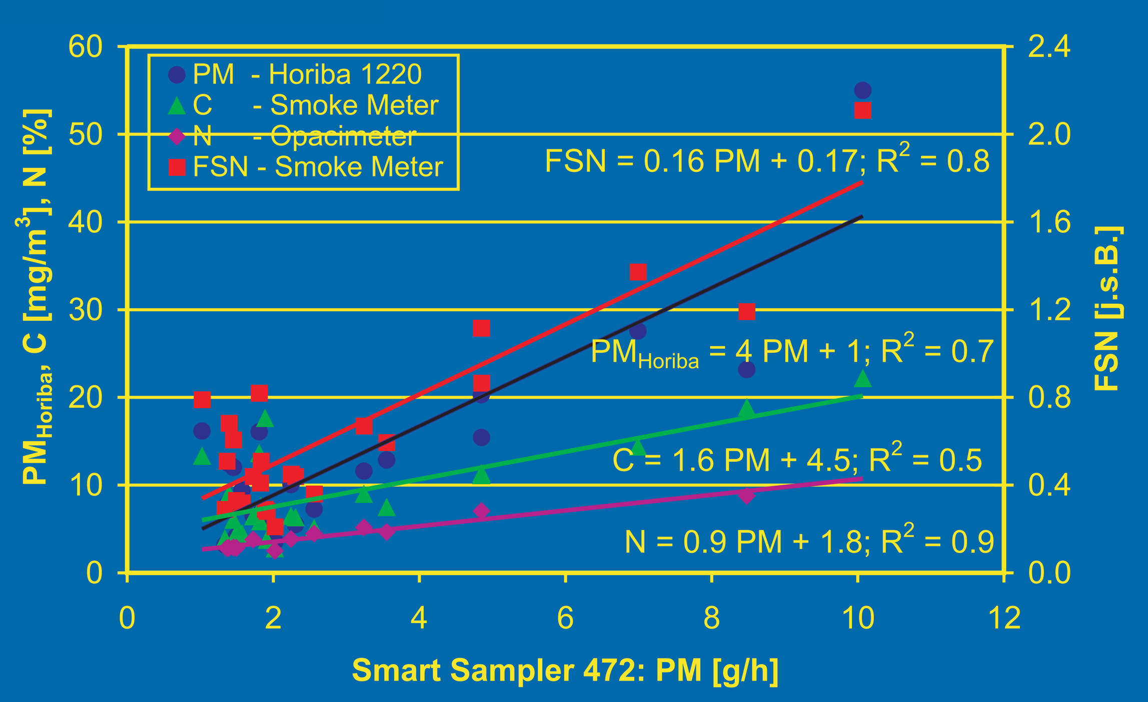
ABSTRACT

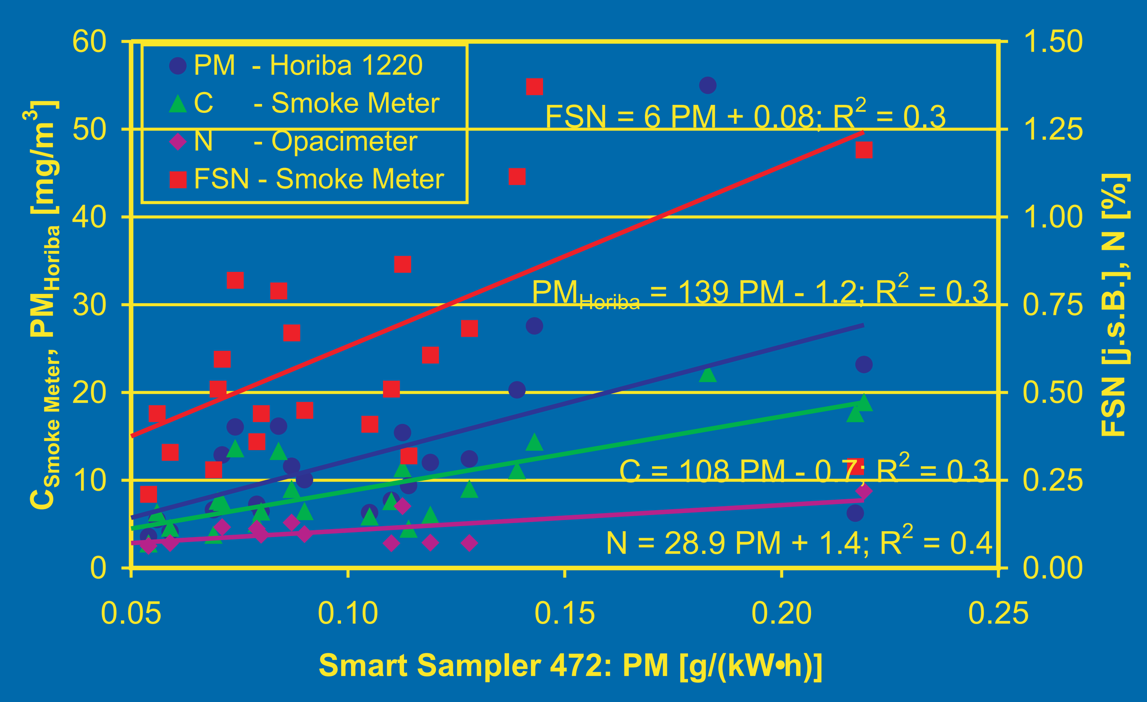
The article shows the results of particulate matter emissions obtained in the Euro-pean Stationary Cycle (ESC) which was carried out at Poznan University of Technol-ogy on an engine test bed. In order to carry out the tests different devices were ap-plied for the measurement of particular matter (AVL Smart Sampler - measurement by means of a gravimetric method of a partial exhaust smoke dilution, Horiba Mexa 1220 PM - measurement with the use of two flame ionising detectors), which were then compared to the smokiness values (AVL 415 - measurement of exhaust smoke values, Opacimetr 439 - measurement of exhaust opacity). Having compared the obtained correlation results, main relationships of fractional composition of particular matter, obtained in the tests, were defined (SOL - solid fraction (carbon), SOF - soluble organic fraction).

The purpose of the tests was to determine the correlation between particle emission measurements with the use of various devices: Smart Sampler 472 particle measurement by the gravimetric method (partial exhausts gases flow) and Horiba Mexa 1220 PM using the Flame Ionization Detector method. The latter method also allowed obtaining the results in real time; furthermore, the comparison of the methods with exhaust opacity was proposed and measured by the optical and filtration method. Assuming small participation of ash (engine w/o aftertreatment) and small participation of SO_4 (free sulfur fuel) in PM a hypothesis of PM division into two fractions: SOL and SOF could be accepted.

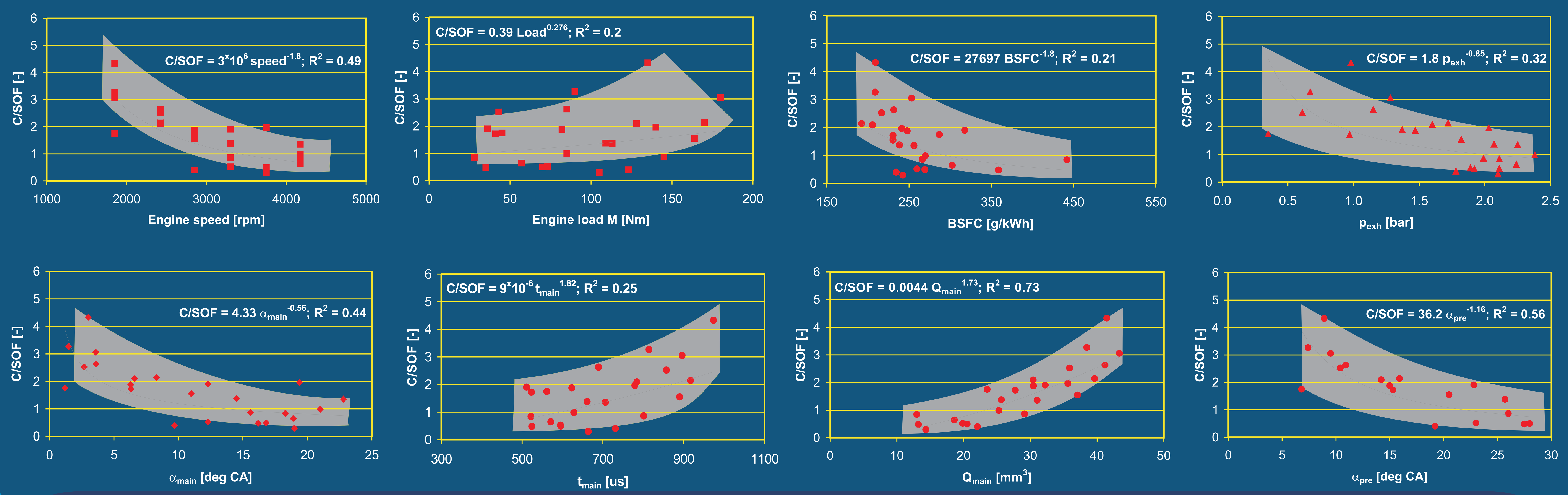
METHODOLOGY







SOL/SOF ANALYSIS



CONCLUSION

The result of the analysis carried out proved a significant correlation between a unitary PM emission obtained in the gravimetric method and other values which are substitutes of such a measurement. According to the expectations the organic content of particles in modern engines accounts for less than 50% of PM mass. It points to a certain rule of the measurements made: smoking of exhaust is mainly caused by the coal fraction of particles, while carbohydrate's presence in fumes is hardly taken into account. Therefore, a greater reliability (possibility of a changeable application of smoking measurement and PM emission) can be achieved when particles emitted by engines will mainly comprise of coal, while carbohydrate fraction (organic) will remain limited.

The analysis of changes in the fractional composition of particulates proves that the increase of PM measurement temperature does not affect the mass of the coal fraction, whereas it decreases the mass of the organic fraction SOF. The above analysis shows that the mass of the organic fraction of a particulate seated on the filter is inversely proportional to the measurement temperature (filter temperature).

The estimation of PM fractional composition on the basis of engine operating parameters will be most probable if the following order will be obeyed: quantity of main injection, crank angle of pre injection, engine speed, crank angle of main injection, exhaust pressure, time of main injection, brake specific fuel consumption, and engine load.