The Identification of PM Parameters in Compression Ignition Engines

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ABSTRACT

The paper discusses the possibility of a synthetic approach to the parameters of PM generated by Diesel engines. The author felt compelled to realize the task following the obtainment of positive results of the PM parameters research under different operating conditions of combustion engines.

The proposed mathematical models, including the experiment planning, that served to identify the PM in terms of their mass, number and diameter, have been developed based on the results of the emission measurement and engine parameters under stationary and dynamic conditions.

Keywords: particle mass, particle number, Diesel engines

1 INTRODUCTION

In contemporary empirical research of combustion engines (due to their wide range of application), related to the determination of the relations between the quantities characterizing the research object the theory of experiment planning is more and more widely applied. Based on these data the construction of the mathematical model was realized following the adoption of its structure as a result of the identification of the model parameters. The research on the model led to formulating of conclusions on a higher level of generality than it was in the case of only interpreting of the measurement results. Particularly, the authors succeeded not only in the analysis of the model but also the analysis of its sensitivity. The models of particulate matter were identified through determination of their characteristics based on the input and output quantities.

2 METHODOLOGY

The realization of the task required research that comprised the measurements of the engine operating parameters (torque, engine speed), exhaust gas composition (concentrations of the gaseous components and the parameters of the PM – mass, number and diameter distribution) and the additional parameters (fuel consumption, exhaust gas recirculation rate, exhaust gas temperature, main injection and the duration of the main injection). As a result in the experiment the author have distinguished the vector of the input quantities X influencing the output vector Y (the parameters of PM in the exhaust gas). The potential impact of the vector of constant quantities C, whose values remain unchanged throughout the experiment (type of lubricant) and the vector of the distorting quantities Z, whose quantities may change (temperature, pressure, relative ambient humidity as well as other quantities not conspicuously included in the model) have also been taken into account.

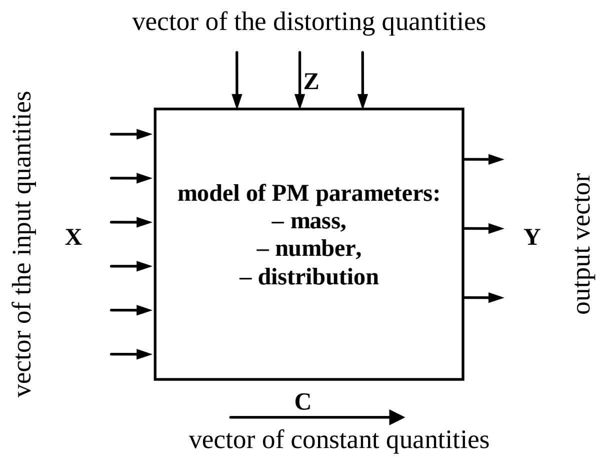


Figure 1: Characteristic included in the experiment.

The recording of the input parameters for the created models were done during three cruises of approximately 5 hours in duration under different traffic conditions (time share: 25% – urban driving, 50% – extra urban driving, 25% – expressway driving). The recorded data were averaged in individual speed and acceleration range (in line with the procedure of formulating the time density characteristics). The research object subjected to the measurements was a passenger vehicle (diesel engine) fitted with measuring equipment for the analysis of the PM parameters and a data acquisition system from the vehicle OBD.

Parameter	Value
Engine	R4, 16 V
Volume	1248 cm^3
Power	51 kW @ 4000 rpm
Load	180 N·m @ 1750 rpm
Mileage	25,000 km
Diagnostic protocol	ISO 14230
Exhaust limit	Euro 4
Three Way Catalyst	yes

Table 1: Parameters of motor vehicle (research facility).

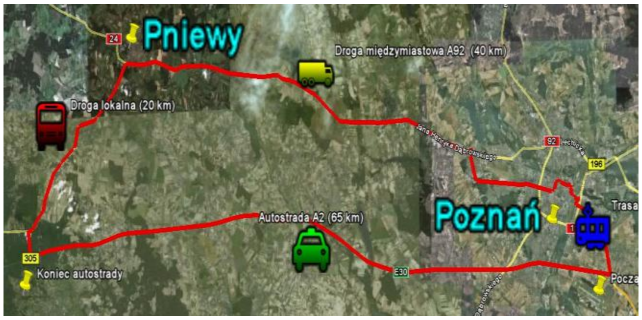


Figure 2: The most important points of the route.

Figure 3: Vehicle with a mounted apparatus for measuring particle parameters.

3 RESEARCH

For the creation of the model of PM the following input data were used (characteristic) dependent on the vehicle speed and acceleration: engine speed, engine load, carbon dioxide concentration, carbon monoxide concentration, hydrocarbon concentration and NO_x concentration.

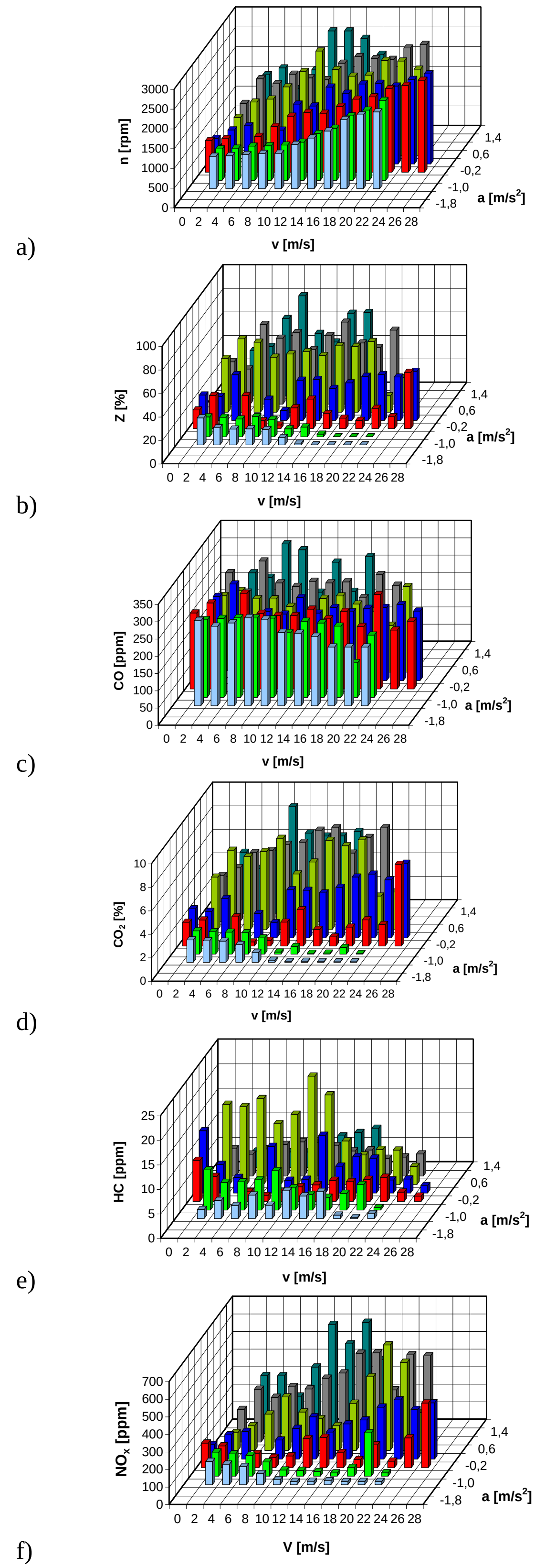
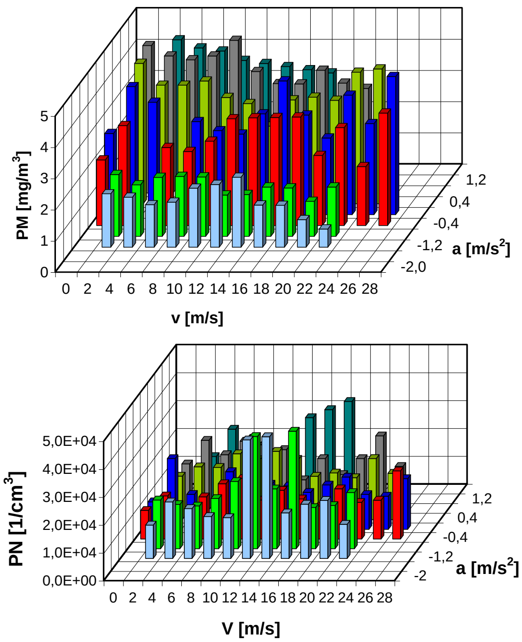


Figure 4: Sets of input data for models of PM parameters: a) engine speed, b) load, c) CO, d) CO_2, e) HC, f) NO_x.

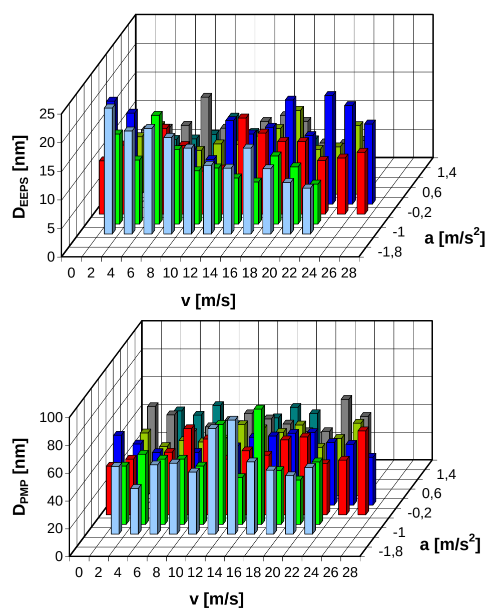
The output quantities were the parameters of PM: mass, number and diameter. The first two characteristics were presented in Fig. 5 and the last parameter is presented for two variants: as a parameter of the whole range of diameters and the measurement compliant with the PMP protocol (only for the diameter range greater than 23 nm) – Fig. 6.



a)

b)

Figure 5: Particle mass (a) and particle number (b) during real road test.



a)

b)

Figure 6: Particle diameter – whole range of diameters (a) and only for the diameter range greater than 23 nm (b).

For the prepared input data approximating functions were determined (models) of the PM parameters under real traffic conditions:

– particle mass PM [mg/m^3]:

$$\mathrm{PM} = \frac{(a+2)^{0,672} \cdot n^{0,052} \cdot Z^{0,082} \cdot \mathrm{CO}^{0,092}}{v^{0,014} \cdot \mathrm{CO_2}^{0,016} \cdot \mathrm{HC}^{0,035} \cdot \mathrm{NO_x}^{0,037}} \quad (1)$$

– particle number PN [1/cm^3] (D > 5,6 nm):

$$\mathrm{PN} = \frac{v^{0,022} \cdot n^{0,45} \cdot Z^{0,42} \cdot \mathrm{CO}^{0,56} \cdot \mathrm{HC}^{0,18} \cdot \mathrm{NO_x}^{0,44}}{(a+2)^{0,093} \cdot \mathrm{CO_2}^{0,84}} \quad (2)$$

– particle number PN [1/cm^3] (D > 23 nm):

$$\mathrm{PN} = \frac{(a+2)^{0,17} \cdot n^{0,61} \cdot Z^{0,15} \cdot \mathrm{CO}^{0,22}}{v^{0,006} \cdot \mathrm{CO_2}^{0,41} \cdot \mathrm{HC}^{0,053} \cdot \mathrm{NO_x}^{0,42}} \quad (3)$$

– particle diameter D (D > 5,6 nm) [nm]:

$$\mathrm{D} = \frac{n^{0,051} \cdot Z^{0,081} \cdot \mathrm{CO}^{0,36} \cdot \mathrm{NO_x}^{0,28}}{v^{0,065} \cdot (a+2)^{0,70} \cdot \mathrm{CO_2}^{0,16} \cdot \mathrm{HC}^{0,032}} \quad (4)$$

– particle diameter D (D > 23 nm) [nm]:

$$\mathrm{D} = \frac{n^{0,15} \cdot Z^{0,17} \cdot \mathrm{CO}^{0,32} \cdot \mathrm{HC}^{0,067} \cdot \mathrm{NO_x}^{0,164}}{(a+2)^{0,056} \cdot \mathrm{CO_2}^{0,37}} \quad (5)$$

Upon obtaining of the function relations they were subjected to evaluation of the adequacy done based on the value of the coefficient of correlation between the actual results and those calculated from the models (Fig. 6a). The obtained coefficient of correlation ($R = 0.82$ for the model of concentration of PM utilizing all the input parameters) is greater than the assumed value of 0.5, hence w can accept the adequacy of the determined model describing the concentration of PM.

Similar comparisons were done for the particle number and diameter. The research possibilities have also been taken into account using the whole range of diameters of PM (Fig. 6b) and the measurement of PM according to PMP (the range of PM diameters above 23 nm – Fig. 6c). The comparison of the values of the PN done with two measurement methods and calculated from the formulas confirms similar coefficients of correlation, yet the values of concentration are much varied. In the measurements of the PN (diameters above 23 nm) we obtain lower values of this parameter, which is a result of not only the measurement of PN of greater diameter but also the use of the system (according to PMP requirements) of evaporation of light hydrocarbon fractions fixed on the PM.

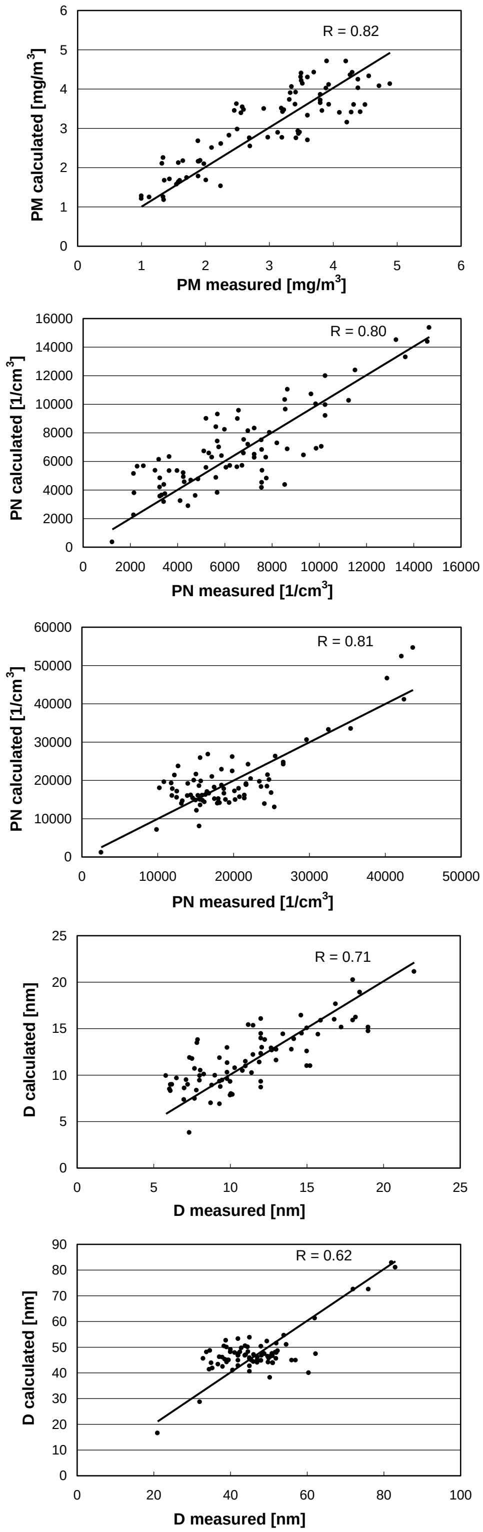


Figure 6: The relationship between measured and calculated parameters of particle: a) mass, b) number for D > 5,6 nm, c) number for D > 23 nm, d) diameter (D > 5,6 nm), e) diameter (D > 23 nm).

For the same reasons the results of the measurements of the characteristic particle diameter have been presented for two mentioned cases. Conspicuous is the range of the characteristic diameter that amounts to approximately 5÷20 nm (for the measurements of al PM – Fig. 6d) and the range of 40÷60 nm for the measurements according to PMP (Fig. 6e). From the comparison it results that in the exhaust gases the PM of the lowest diameter are the highest in number, but these can also be different compounds (liquid hydrocarbons).

4 CONCLUSIONS

The continuation of the topic is a new approach towards the use of the values characterizing engine operation and vehicle driving conditions for the identification of the PM parameters in compression ignition engines. For the description of the engine and vehicle operating conditions time density characteristics have been used that combined the engine speed and engine load (or the vehicle speed and acceleration) with its operating time under such conditions. The result of the actions is a proposal of a mathematical model that describes the basic properties of the PM (their mass, number and diameter) under real road conditions.

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