Mieczysław Sikora¹, Mateusz Bednarski², Piotr Orliński³

SIMULATION STUDIES AND EMPIRICAL RESEARCH OF PARTICULATE MATTER’S EMISSION IN DIESEL ENGINE POWERED BY LIQUID ALTERNATIVE FUELS

1. Introduction

Diesel engines are used in different groups and types of vehicles. The diesel engines’ s advantage is their high ability and lower fuel consumption. However it is important to remember that in diesel engines are created more PM – Particulate Matter. Emission of PM is unwanted, adverse air pollution. PM owe their damaging nature to littleness, complicated structures and complex chemical composition with large content of harmful substances. The PM’ s essential ingredient are products of incomplete fuel and oil consumption which contain the main particles of soot. Cause of creation incomplete fuel products, being precursor of PM, is local lack of air in combustion chamber [1, 3, 13, 14]. The automotive industry is forced to intense research in this area by parameter connected with PM. One of the technical solution is using alternative fuels which have a task to provide the lowest environmental effect by vehicles [2, 4, 16]. This article presents the analysis of simulation and empirical research of PM’ s emission in diesel engine powered by liquid alternative fuels.

2. Extend of realised works

The aim of this article is to compare the results of simulation and empirical studies of PM concentration and PM’ s emission in diesel engine powered by liquid alternative fuels for three angles of the fuel injection. Simulation studies and empirical research have been determined for five fuels: ON, L10, L20, L30, L100 and for three angles of the fuel injection A, B, C. The empirical research have been achieved on the test stands according to ISO 8178. Five fuels: diesel fuel (ON), methyl esters derived from camelina oil (L100) and their mixtures: L10 (90% of diesel fuel and 10% ester of camelina oil), L20 (80% diesel oil and 20% ester of camelina oil), L30 (70% diesel oil and 30% ester of camelina oil) have been used for simulation studies and empirical research. Physicochemical properties of five fuels are presented in Table 1.

Table 1. Physicochemical properties of five fuels ON, L10, L20, L30, L100 [9, 15, 18, 19, 20]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ON</th>
<th>L10</th>
<th>L20</th>
<th>L30</th>
<th>L100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cetane number</td>
<td>52.4</td>
<td>51.6</td>
<td>51.2</td>
<td>51.1</td>
<td>51.0</td>
</tr>
<tr>
<td>Fuel value [MJ/kg]</td>
<td>43.2</td>
<td>42.5</td>
<td>42</td>
<td>41.5</td>
<td>37.7</td>
</tr>
<tr>
<td>Density at temperature 15°C [g/cm³]</td>
<td>0.835</td>
<td>0.846</td>
<td>0.849</td>
<td>0.854</td>
<td>0.892</td>
</tr>
<tr>
<td>Kinematic viscosity [mm²/s] (~40°C)</td>
<td>2.64</td>
<td>3.26</td>
<td>3.55</td>
<td>3.67</td>
<td>4.26</td>
</tr>
</tbody>
</table>

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The empirical research have been realized by the supercharged diesel engine Perkins type 1104C-E44TA (Fig. 1). This is the most optimal engine to research because it satisfy actually norms of toxic exhaust emissions and it is used in tractors, power-generating. Engine Perkins parameters are presented in the Table 2. The study has been carried out at three angles of the fuel injection, indicated at work - A, B, C. Setting A is the factory setting of this parameter. Setting B will generate a delay fuel injection (approximately 5°TDP), and the setting C will generate acceleration fuel injection (approximately 5°TDP).

Table 2. Engine Perkins parameter 1104C-E44T [7]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cylinders/cylinder arrangement</td>
<td>4/straight</td>
</tr>
<tr>
<td>Cylinder bore</td>
<td>Ø105 mm</td>
</tr>
<tr>
<td>Piston stroke</td>
<td>127 mm</td>
</tr>
<tr>
<td>Engine cubic capacity</td>
<td>4,4 dm³</td>
</tr>
<tr>
<td>Injection type</td>
<td>direct</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>18,23:1</td>
</tr>
<tr>
<td>Cylinder operation order</td>
<td>1-3-4-2</td>
</tr>
<tr>
<td>Maximum engine power</td>
<td>85 kW for 2000rpm</td>
</tr>
<tr>
<td>Maximum engine torque</td>
<td>390 Nm for 1400rpm</td>
</tr>
</tbody>
</table>

Fig. 1. Engine Perkins 1104C-E44T [7]

The maximum engine power is 85 kW, therefore the engine qualified to the category ISO 8178 C1 and empirical research have been executed according to 8-stage test. Figure 2 shows percentage input particular stage. During the test, the engine works according to full-load characteristic for constant rotational speed:
• 1400 rpm - maximum torque rotational speed
• 2000 rpm - maximum engine power speed
Based on test results and calculations has been assessed PM’s emission.
3. Simulation studies

The PM’s model creation has been used for simulation studies. It was created by prof. N.F. Razleitsev [6]. This is the PM’s model creation which provides for spray and combustion parameters [6].

During PM’s creating, PM are burning and their density is going down. There are finally formulas of the PM’s model creation in diesel engine down below. This is formula which provides for the rate of PM’s creation and PM’s burning [5, 8, 11]:

\[
\frac{d[C]}{d\tau} = B \left( \frac{d[C]}{d\tau} \right)_k + B \left( \frac{d[C]}{d\tau} \right)_n - \frac{1}{B} \left( \frac{d[C]}{d\tau} \right)_B - \left( \frac{d[C]}{d\tau} \right)_V
\]

Where:

\begin{align*}
B &= A \left( \frac{n_{nom}}{n} \right)^m \quad \text{– empirical coefficient} \\
B &= \text{– rotational speed} \\
n_{nom} &= \text{– maximum torque rotational speed} \\
A, m &= \text{– coefficients selected during model calibration}
\end{align*}

Concentration of PM in exhaust gas [5, 8, 11]:

\[
[C]_H = \int_{\phi_B}^{480} \frac{d[C]}{d\tau} d\phi \left( \frac{0.1}{p_{480}} \right)^\frac{1}{k}
\]

Where:

\begin{align*}
p_{480} &= \text{pressure at the angle of rotation of the crankshaft 60 ° before the bottom dead centre} \\
k &= \text{heat capacity ratio} \\
\phi_B &= \text{crank angle, when is the beginning of the combustion process}
\end{align*}

4. Test results

Some simulation studies and empirical research results have been presented down below on external speed characteristic. They present concentration of PM which depend on engine speed. In the next stage has been presented test results of PM’s emissions. Test results are connected with five fuels (ON, L10, L20, L30, L100) and three angles of the fuel injection (A, B, C).
Fig. 3. Concentration of PM attained in simulation studies and empirical research for C angle of the fuel injection and ON fuel

Fig. 4. Concentration of PM attained in simulation studies and empirical research for A angle of the fuel injection and L20 fuel

Fig. 5. Concentration of PM attained in simulation studies and empirical research for B angle of the fuel injection and L100 fuel

Fig. 6. Concentration of PM attained in simulation studies and empirical research for A angle of the fuel injection and n=1400rpm

Fig. 7. Concentration of PM attained in simulation studies and empirical research for B angle of the fuel injection and n=1400rpm
5. Conclusions

External speed characteristic which connected with concentration of PM for simulation studies and empirical research show minor differences. Comparing concentration of PM we can observe that both figures are decreasing function (by the increase of engine speed). Concentration of PM for simulation studies was about 30% lower than for empirical research. The most similar concentration of PM were for 1400-2000 rpm (Fig. 3-5).

Simulation studies and empirical research PM’s emission for five fuels and for three angles of the fuel injection let say that large oxygen content in ester of camelina oil (even 10%) was advantage because this oxygen is more active than oxygen in the atmospheric air. It let us cut concentration of PM in exhaust gas. Therefore concentration of PM for all angles of the fuel injection was crowning for ON and was going down with bringing amount of camelina oil up in fuel. The concentration of PM for L100 is about 10% lower than ON (Fig. 6-8). When ester of camelina oil is used in diesel engine the concentration of PM is lower and PM’s emission is lower too (Fig. 9-12).

This results show that when ester of camelina oil has been used in diesel engine it is advantage. We can cut concentration of PM. The angles of the fuel injection had influence on test results. Setting B generate a delay fuel injection what has influence on decrease of pressure in engine. Setting C generate acceleration fuel injection which has
influence on increase of pressure and temperature in engine. It impacts on decrease of concentration of PM.

To sum up, theoretical model which was presented in this article is correct in case of powering diesel engines by ester of camelina oil and mixtures of diesel fuel and ester of camelina oil. External speed characteristic which connected with concentration of PM which are results of simulation studies and empirical research are similar. In case of PM’s emissions the results are analogous.

References:
[3] Orliński P.: Wybrane zagadnienia procesu spalania paliw pochodzenia roślinnego w silniku o zapłonie samoczynnym, Instytut Naukowo-Wydawniczy SPATIUM, Radom 2013,
Abstract

The paper shows selected results of simulation studies and empirical studies of determining emissions of PM in diesel engine powered by liquid alternative fuels. In the first stage of the thesis a facility and the test plan has been proposed, and then the effect of injection for emissions of PM has been examined. The test stand was the supercharged diesel engine Perkins type 1104C-E44TA. The study has been carried out at three angles of the fuel injection, indicated at work - A, B, C. Setting A is the factory setting of this parameter. Setting B will generate a delay fuel injection (approximately 5°TDP), and the setting C will generate acceleration fuel injection (approximately 5°TDP). The results of simulation studies and empirical studies are presented in the diagrams.

Keywords: compression ignition engine, alternative fuels, toxic substances

BADANIA SYMULACYJNE I EMPIRYCZNE EMISJI CZĄSTEK STAŁYCH W SILNIKU O ZAPŁONIE SAMOCZYNNYM ZASILANYM CIEKŁYM PALIWAMI ALTERNATYWNYMI

Streszczenie

W artykule przedstawiono wybrane wyniki badań symulacyjnych oraz badań empirycznych dotyczących wyznaczania emisji PM w silniku o zapłonie samoczynnym zasilanym ciekłymi paliwami alternatywnymi. W pierwszym etapie artykułu...
zaproponowano obiekt i plan badań, a następnie zbadano wpływ zmiany kąta wyprzedzenia wtrysku badanego paliwa na stężenie PM w spalinach. Stanowisko do badań bazowało na doładowanym silniku o zapłonie samoczynnym marki Perkins typu 1104C-E44T. Badanie te realizowano przy trzech kątach wyprzedzenia wtrysku paliwa oznaczonych w pracy - A, B, C. Ustawienie A kąta wyprzedzenia wtrysku to ustawienie fabryczne tego parametru. Ustawienie B będzie powodowało późniejszy wtrysk paliwa (o ok. 5°OWK), a ustawienie C wtrysk wcześniejszy o ten sam kąt. Wyniki badań symulacyjnych i empirycznych zestawiono na wykresach.

Słowa kluczowe: silnik o zapłonie samoczynnym, paliwa alternatywne, składniki toksyczne spalin