TEKA Kom. Mot. Energ. Roln., 2005, 5, 87-95

SOME OUTPUT PARAMETERS OF INDIRECT INJECTION DIESELS RUNNING ON RAPE BIOFUEL UNDER TRANSIENT CONDITIONS

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Summary. The results of transient tests of Diesel engines with precombustion chamber and swirl chamber have been presented in the paper. Dynamic characteristics of the tested engines fuelled with rape biofuels have been obtained. The test fuels were standard diesel oil, rape oil – diesel oil mixture and rape oil methyl ester. The dynamic output parameters of the two typical IDI engines have been shown.

Key words: renewable fuels, transient conditions, dynamic characteristics, Diesel engine, indirect injection

INTRODUCTION

Alternative fuels for Diesel engines have recently appeared on the fuel market [Pągowski 1997, Podniało 2002]. In conformity with actual law the plant derived components are added to pure diesel fuel. However, the appearance of this information in the public media has made many drivers anxious. Many owners of cars equipped with diesel engines ask about the effects of the plant derived fuel use. These fears are caused by owner preoccupancy of engine durability, especially injection system durability. Car owners fear also about engine parameter worsening and fuel consumption increasing. In these circumstances, the long-term advantages of renewable fuel use, such as reduction of environmental pollution, could be moved to secondary position. In fact the possibility of decreasing the greenhouse effect and reduction of sulphur emission is most important.

Vegetable fuels, so-called biofuels, may be produced in our climactic conditions only from rape oil. Deep investigations on the use of rape biofuel have been carried out lately but it concerned mostly engine tests in steady state conditions (also diesel 4C90 [Lotko 1995]). In this paper the researches concerning indirect injection diesel tests in transient conditions have been presented. It is known that this engine type is very popular and its number grows on the market for the reasons of used car import. The exact knowledge about vegetable fuel combustion process, also in transient conditions, could result in a wider use of renewable fuels [Pągowski 1997, Podniało 2002].

EXPERIMENTAL TECHNIQUE

Dynamic speed characteristics of the engine are obtained by the inertial method [Kiernicki 1993]. This method is based on the measurements of engine crankshaft speed and crankshaft angular acceleration calculation. When mass moment of engine inertia and crankshaft angular acceleration is known it is possible to calculate the engine torque T_e but angular acceleration is also serviceable for the purpose of comparison researches.

Functional dependencies among engine parameters in transient conditions [Bernhardt *et al.* 1988] are shown in the formula:

$$T_e = f(\omega, p_e, \alpha, ..., t) \tag{1}$$

where:

T_e, p_e – torque and mean effective pressure of the engine,
α – injection pump control element position,
ω – crankshaft angular velocity,
t – time.

The components of the formula have instantaneous running values dependent on time t. Torque balance under transient conditions can be noted as:

$$J_z \cdot \frac{d\omega}{dt} = T_e - T_{op}, \qquad \frac{d\omega}{dt} \neq 0 \tag{2}$$

where:

T_e – running output torque,
T_{op} – running torque of receiver, including resistance connected to receiver inertia,
J_z – equivalent mass inertial torque of mobile engine elements in relation to crankshaft axis.

If the energy receiver is detached ($T_{op}=0$), the equation (2) will present the engine torque change caused for example by the quick increase of the fuel dose supplying the cylinders:

$$T_e = J_z \cdot \frac{d\omega}{dt} = J_z \cdot \varepsilon \tag{3}$$

But in case of engine supply switched off ($T_e = 0$), the equation (2) will present the internal resistance change during engine retardation started at high initial rotational speed:

$$T_{op} = -J_z \cdot \frac{d\omega}{dt} = J_z \cdot (-\varepsilon) \tag{4}$$

The research process was the following: for every tested fuel and engine the measurement cycle was executed. Measurement cycle included the following steps:

– engine operation at idling,
– quick increasing of engine speed (acceleration),
– engine operation at maximum speed,
– return to idling (retardation after the dosing is switched out).

Sample courses of engine free acceleration and retardation are presented in Figure 1. Rotational speed changes $n = f(t)$ during measurement cycle is presented in Figure 1a, and crankshaft angular acceleration changes $\varepsilon = f(n)$ during measurement cycle is presented in Figure 1b. The recorded process was about 10 seconds long.

The testing of fuel properties comprised 20 measurement cycles when the engine operated without any external load. Representative values have been assessed for the goal of fuel influence comparison. First the utmost courses were rejected and next mean value and intervals were worked out from the remaining 10 (or 5) courses. Parameter mean value has been calculated as

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \tag{4}$$

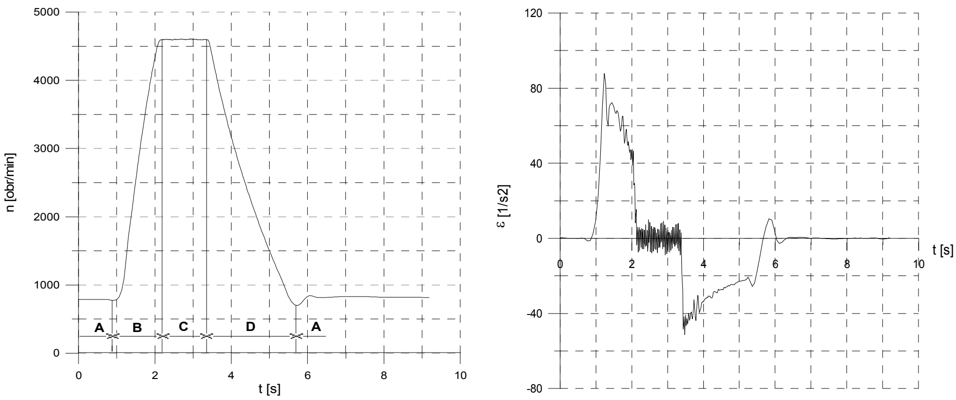
Mean standard deviation was obtained as

$$\sigma = \frac{1}{n-1}\sqrt{\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2} \tag{5}$$

where:

n – number of analysed measurement cycles,
i – cycle number.

Mean standard deviation has been taken as repeatability factor because it simply influences the confidence interval width of the parameter in the case of small samples.



a) b)

Fig. 1. Acceleration-retardation measurement cycle:

a) engine speed change $n = f(t)$. There are four phases: A – operation at low engine speed, close to idling speed, B – speeding up after step change pump lever to maximum position (in time < 0.1 s), C – operation at maximum engine speed, D – retardation after quick dose switching-off, b) crankshaft angular acceleration change $\varepsilon = f(n)$

The tests have been executed with the same thermal conditions (temperature of motor oil and liquid coolant). Fuel filter was changed and fuel supply system was flushed during the exchange of tested fuel. Atmospheric conditions have been covered by results reduction to normal conditions.

TEST SET-UP AND TEST OBJECT

Measurements were done at brakeless test set-up [Kiernicki 1993, Hołowiński 2004,] whose block diagram is presented in Fig. 2. The actual angular acceleration was measured and recorded by the measurement system that was controlled by the computer PC 486/33MHz. Photoelectric sensor reacting on light beam bounced from the marker glued to flywheel (sheave) generated impulses that were rateable to engine crankshaft speed. Computer with the software making it possible to assess the needed values recorded the results and controlled measurement maintenance. Acceleration-retardation measurement cycle has been recorded in simple file and in adequate memory catalogue. It simplified the statistical workout and next data handling of the measurement results.

The objects of the tests were two indirect injection (IDI) diesels:
– diesel 4C90 with swirl chamber, line injection pump PM, engine displacement – 2400 cm^3, cylinder number – 4, used in the commercial car Lublin,
– diesel OM617.912 with precombustion chamber, line injection pump Bosch, engine displacement – 2996 cm^3, cylinder number – 5, used in the car Mercedes Benz.

The tested engines were in good technical condition [Hołowiński 2004]. The cylinder pressure conformed to the values given by the manufacturer. The fuel system's technical condition (injection pump and initiative heating-up system) was faultless. The engines were equipped with standard accessories and have been set according to the manufacturer's specifications.

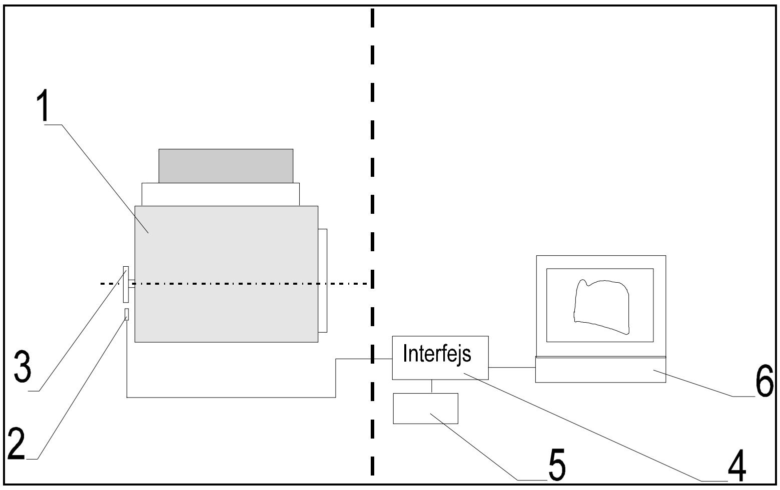


Fig. 2. Block diagram of the test set-up: 1 – tested engine, 2 – engine speed photoelectric sensor, 3 – contrast marker on flywheel (sheave), 4 – measurement interface, 5 – supplier, 6 – notebook 486/33MHz

Refined rape oil – standard diesel fuel (DF) mixtures containing 20%, 40%, 50%, 60%, 80% and 100% of rape oil (RO) and methyl ester of RO were used as test biofuel.

RESULTS

Physical properties of the tested mixtures ingredients are presented in Table 1. It may be assumed that mixture properties will change proportionally to ingredient composition.

Table 1. Physical properties of the tested fuel mixtures ingredients [Hołowiński 2004, Kiernicki 2004]

The tested parameter	ON	50%OR-50%ON	Rape fuel	Methyl ester OR
Density at 20ºC [g/cm^3]	0.81÷0.84	0.835	0.92	0.88
Kinematic viscosity [mm^2/s]	2.64/40ºC	5.46/20ºC	76/20ºC	6.9÷8.2/20ºC
Ignition temperature [ºC]	59	81	285	168
The cold filter blocking temperature [ºC]	-30	-	-20	-7
Cetane number	54	-	34	56
Burning value [MJ/kg]	43.0	42.93	37.4	37.0-39.0

Dynamic characteristics $\varepsilon = f(n)$ of the tested diesel OM617.912 obtained with injection pump maximum dosing have been presented in Fig. 3. These courses are the mean courses of ten measurement cycles. The course part over the speed axle *n* shows the acceleration process and the part under the speed axle show the retardation process.

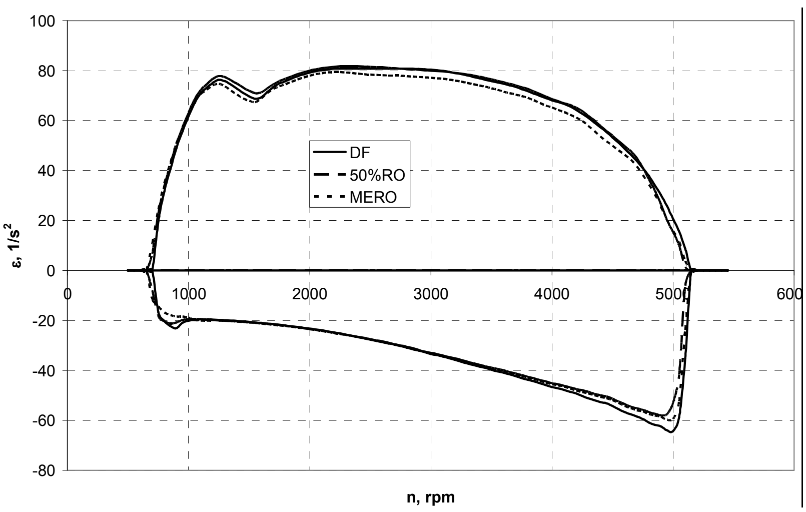
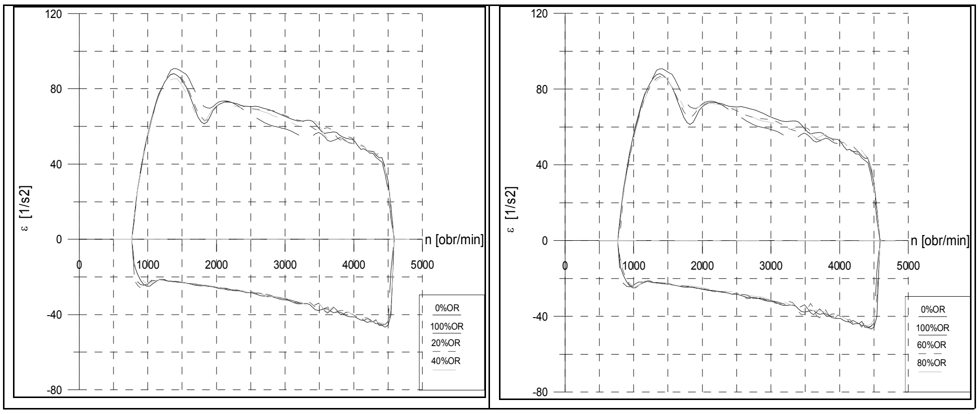


Fig 3. Dynamic characteristics $\varepsilon = f(n)$ of diesel OM617.912 obtained with injection pump maximum dosing and three different fuels

Dynamic characteristics $\varepsilon = f(n)$ of the tested diesel 4C90 have been presented in Fig. 3. These characteristics have been obtained with injection pump maximum dosing and fuelling with pure DF and mixtures containing 20%, 40%, 60%, 80%, 100% RO. These courses are the mean courses of five measurement cycles.



a) b)

Fig. 4. Dynamic characteristics $\varepsilon = f(n)$ of the tested diesel 4C90 obtained with injection pump maximum dosing and fuelling with pure DF and mixtures containing: a) 20%, 40%, 100% RO , b) 60% OR, 80% OR i 100% RO

The courses of angular acceleration of engine crankshaft during the retardation period are practically the same. It proves that measurement conditions were stable, especially engine thermal conditions. It means that test results are useful for fuel effect on engine outputs comparison.

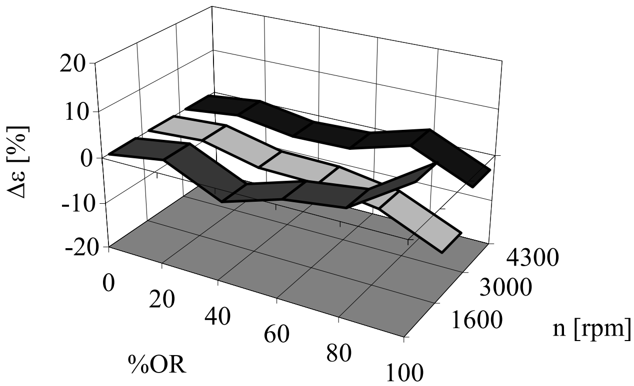


Fig. 5. Percentage changes of crankshaft angular acceleration of 4C90 diesel during free acceleration, at engine speed values adequate to: 1600, 3000 and 4300 rpm

It should be emphasized that dynamic characteristics $\varepsilon = f(n)$ of diesel OM617.912 with precombustion chamber and diesel 4C90 with swirl chamber are essentially similar to adequate characteristics of diesels with direct injection, for example S-359 [Podniało 2002] or S-4002 [Kiernicki 1993]. Rape oil addition in fuel does not change the shape of the tested engines dynamic characteristics. The special shape of the course, initial increase and following decrease of acceleration value in the first period of speeding up, exist for all the tested fuel types.

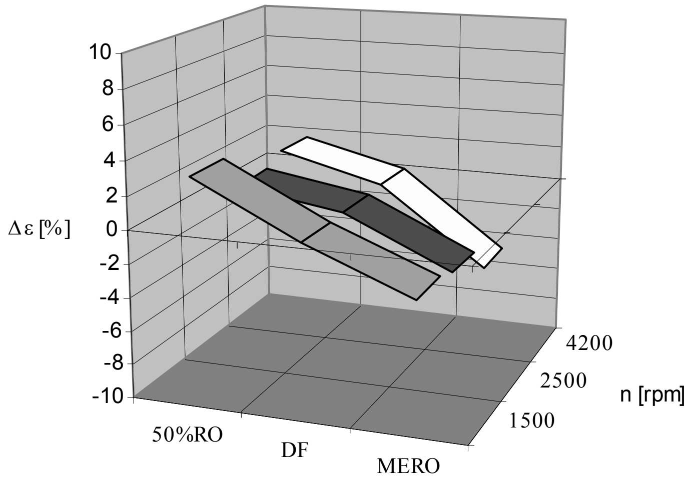


Fig. 6. Percentage changes of crankshaft angular acceleration of OM617.912 diesel during free acceleration, at engine speed values adequate to: 1500, 2500 and 4200 rpm

The course of engine acceleration shows that rape oil content change influences IDI diesel parameters values slightly. The stated differences of crankshaft angular acceleration values are not higher than +8% and -10% for 4C90 diesel and up to +3,5% (mixture 50% RO) i -6% (ROME) for OM617.912 diesel. These differences are small unlike the ones for DI diesels (i.e. S-4002) where RO content influence is significant [Kiernicki 1993].

Higher acceleration values for biofuels appear in the initial period of 4C90 engine speeding up, within the range of 1000-1800 rpm. But RO addition causes a decrease in acceleration values in the further part of process. The diesel with precombustion chamber, unlike the one with swirl chamber, uses biofuel more effectively because an increase in acceleration value (about 3%) has been stated for 50% RO mixture [Hołowiński 2004]. It seems that the unfavourable effect of the lower heating value of the smaller biofuel dose is recompensed by quite good burning of the bigger fuel dose which appears as the result of better injection pump assembly sealing

The decrease of acceleration value of 2-6% has been stated in the whole speed range when rape oil methyl ester is used.

The percentage changes of crankshaft angular acceleration versus fuel type and engine speed for 1500–1600, 2500–3000 and 4200–4300 rpm ranges are shown in Fig. 5 and 6.

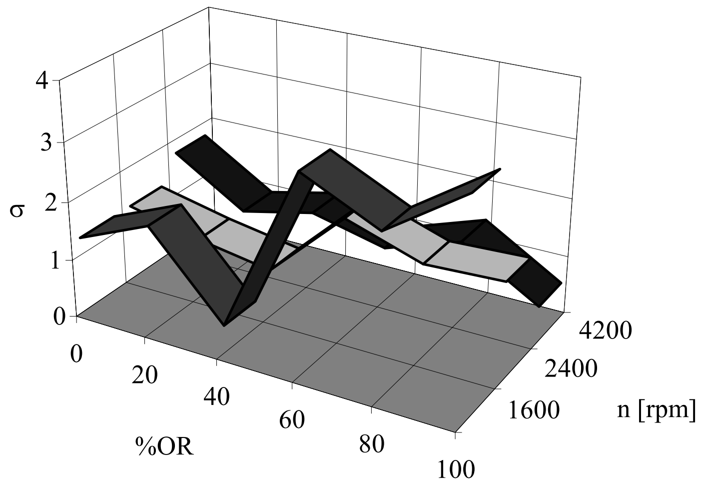


Fig. 7. Standard deviation σ values of angular acceleration of 4C90 diesel fuelled with rape oil diesel fuel mixtures

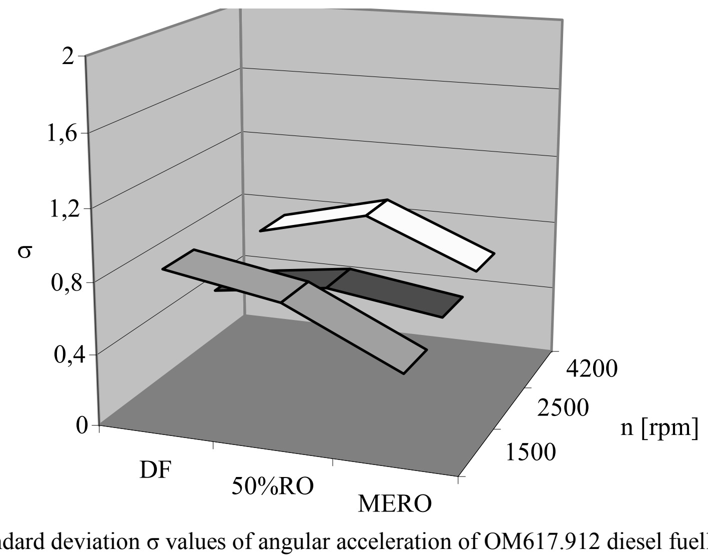


Fig. 8. Standard deviation σ values of angular acceleration of OM617.912 diesel fuelled with diesel fuel, 50% RO mixture and ROME

Free running acceleration of the engine is usually the stochastic process. The effect of biofuel composition on measurement results repeatability is presented in Fig. 7 and 8. The standard deviation of acceleration for different biofuels at chosen speed values does not exceed 1 (OM617 engine) and 3.5 (4C90 engine). Speed values respond to special points of engine characteristics obtained in steady state conditions – maximum torque speed n_M and rated speed n_N. It is stated that in the initial period of acceleration the scatter of results increases with the increase of RO quantity in the fuel, but this tendency wanes in the further part of process. During the tests engines operated without any abnormalities apart from fuel composition and combustion chamber type. It corresponds with the results presented in papers [Kiernicki 1993, 2004].

CONCLUSION

On the grounds of the obtained results it may be stated that:

1. Dynamic characteristic courses $\varepsilon=f(n)$ obtained for the tested diesels with precombustion chamber and swirl chamber are analogous to adequate dynamic characteristic courses for DI diesels, presented in [Kiernicki 1994, 2004].
2. The effect of rape oil content in the fuel on tested IDI engines parameters under transient conditions is little with regard to quantity. The stated differences of crankshaft angular acceleration do not exceed 14%.
3. The influence of rape oil addition on IDI engine parameters is reverse than on DI engines. Rape oil quantity increase in the fuel causes the decrease of crankshaft angular acceleration values. An effect of biofuel combustion in diesel with precombustion chamber is better and more stable than in diesel with swirl chamber.
4. Fuelling IDI diesel with rape oil methyl ester causes 5% decrease of parameter values obtained by the inertial method.
5. Rape oil addition in the fuel did not cause significant increase of acceleration measurement results repeatability at middle and higher speed ranges.
6. All the tested fuels allowed for normal operation of the engine both with swirl and precombustion chamber.

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