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Noise emission of diesel engine powered by blends of diesel oil and ethyl tert-butyl ether

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The article presents results of research on noise emission from AD3.152 diesel engine powered by blends of diesel fuel (DF) and ethyl tert-butyl ether (ETBE). Measurements were executed in steady-state conditions for different engine partial loads, crankshaft rotational speeds and angles of fuel injection start. The research shows that engine noise emission increases for all tested ETBE/diesel blends in comparison to pure diesel fuel. The highest values of noise emission were recorded for ETBE40. Preliminary analysis of the combustion process suggests that noise emissions increase in line with the value of in-cylinder pressure.

1. Introduction

Excessive noise is considered a form of environment pollution. In case of diesel engines the most important sources of noise are: exhaust, turbocharger, fuel injection system, drive chain and combustion process due to in-cylinder pressure variations. Gas dynamic engine noise depends on the value of maximum pressure rise and diesel knock intensity. Both of them are closely connected with fuel properties such as cetane number, viscosity, density and surface tension etc.

For many years, an increasing trend towards using blends of diesel oil with different oxygenated additives such FAME (fatty acid methyl ester) has been observable. However, there are some problems associated with the use of plant fuels. These include an increase in nitrogen oxide (NO_x) exhaust emissions and relatively poor low temperature flow properties compared to diesel [1]. Another problem is the oxidation stability of biodiesel. DuPoint brochures suggest that the old FAME (6-8 weeks after production) cannot be used for engine fuelling due to excessive risk of seals swell.

FAME are not the only oxygenated fuel for diesel engines. Additional examples of other fuels are presented in references [2 - 5].

Potential semi-renewable alternative fuels for diesel engines are blends of ETBE with diesel oil. It should be noted that ETBE’s cetane number is very low. For this reason, ETBE cannot be used alone in standard diesel engines, but can be blended with petroleum based oil.

Ethers are not so polar as ethanol and for this reason may be blended with petroleum oil at any concentration. Research confirms the effect of significant reduction in PM emission when an engine runs on ETBE/diesel oil blends [6]. Research into engine noise emission is an important part of environment protection too. For this reason, in this paper we would like to present influence of ETBE addition in diesel oil on engine noise emission.

2. Methods and materials

Research was carried out in an engine laboratory of Technical University of Radom. The laboratory is equipped with AD3.152 diesel engine and a measurement system of high-speed parameters such as: in-cylinder pressure, needle lift and pressure in delivery pipe. Technical specification of the measurement system of high speed parameters for IC engines is described in reference [7].

2.1. Test stand

A view of the tested engine connected to a water type brake (2) is presented in figure 1. Measurements of the engine noise were carried out by means of advanced Brüel & Kjaer 2595 model sound level meter (3) connected to a B&K model 2595 microphone (4). In-cylinder pressure variations were recorded with the use of Keithely KPCI3110 data acquisition board inserted in a PC work station (5). The engine load, coolant temperature and crankshaft rotational speed were controlled monitored with a dynamometer system (11).

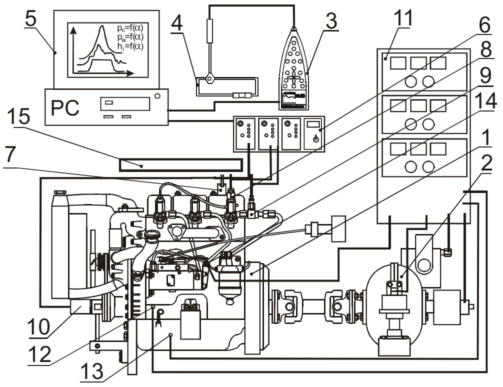

Fig. 1. View of the test stand: 1 – AD3.152 engine, 2 – engine brake, 3 – sound analyser, 4 – B&K model 2595 microphone, 5 – PC with a measurement card, 6 – signals amplifier, 7 – in-cylinder pressure transducer (AVL QC34D), 8 – needle lift sensor, 9 – fuel pressure sensor (AVL QL61D), 10 – engine crankshaft encoder, 11 – dynamometer control system, 12 – engine temperature sensor, 13 –oil temperature sensor, 14 – fuel temperature sensor, 15 – measurement surface.

Rys. 1. Widok stanowiska pomiarowego: 1 – silnik AD3.152, 2 – hamulec silnikowy, 3 – analizator dźwięku, 4 – mikrofon pomiarowy (B&K, typ 3595), 5 – komputer z kartą pomiarową, 6 – wzmacniacz sygnału, 7 – czujnik ciśnienia w komorze spalania (AVL QC34D), 8 – czujnik wzniosu iglicy, 9 – czujnik ciśnienia paliwa w przewodzie wtryskowym (AVL QL61D), 10 – nadajnik kąta obrotu wału korbowego, 11 – system kontroli hamulca, 12 – czujnik temperatury czynnika chłodzącego silnik, 13 – czujnik temperatury oleju, 14 – czujnik temperatury paliwa, 15 – powierzchnia pomiarowa.

The engine testing was performed on an in-line 3-cylinder 2.5-litre diesel engine (AD3.152) with a peak torque of 165 Nm at about 1200 rpm and a peak power of 34.6 kW. Selected technical specifications of the tested engine are presented in Table 1.

Table. 1. Technical specification of AD3.152 diesel engine.
Tabela. 1. Specyfikacja techniczna silnika AD3.152.

No.	Parameter	Value
1.	Cylinder number and arrangement	3, in line
2.	Cylinder diameter	91.44 mm
3.	Piston stroke	127 mm
4.	Engine capacity	2502 cm^3
5.	Compression value	16.5
6.	Maximum power	34.6 kW
7.	Maximum torque	165.4 Nm
8.	Crankshaft speed at idle run	750 rpm
9.	Fuel injection system	Lucas - CAV type DPA

2.2. Measurements of engine noise emission

Acoustic measurements were carried out with Brüel & Kjaer 2260 sound analyzer connected to 3595 microphone (Fig. 2). It is a two-microphone probe for measuring sound intensity. Application of a two-microphone technique allows to obtain information on both the instantaneous pressure and pressure gradient in the sound field. The microphones are separated by a fixed distance in the sound field, and the microphone signals are fed to a sound intensity processor which calculates the sound intensity. The sound intensity is calculated as the average time of the sound pressure multiplied by the particle velocity (calculated from the measured pressure gradient). Such a system measures the component of the sound intensity along the probe axis and also indicates the direction of energy flow [8, 9].

Fig. 2. View of Brüel & Kjaer 2260 sound analyser with measurement microphones and calibrator.
Rys. 2. Widok analizatora 2260 firmy Brüel & Kjaer z mikrofonami pomiarowymi i kalibratorem.

The analyzer is equipped with BZ7205 software designed to measure sound intensity and calculate sound power. The sound level meter allows real-time 1/1- and 1/3-octave frequency analysis and broadband statistical distributions.

Area of the measurement surface equals 0.48 m^2 and is located directly above the tested engine's head. Sound power measurements were carried out according to ISO 9614-2:1996 standard "*Acoustics. Determination of sound power levels of noise sources using sound intensity. Measurement by scanning*". The measurement period equals about 10 seconds. The tested surface was scanned twice over such a short time.

2.3. Properties of the tested fuels

ETBE (etyl tert-butyl ether) is considered a semi-renewable compound produced from ethanol and isobutene. In Poland, ETBE is currently used as an oxygenated compound in the formulation of gasolines. One of the most important properties of ETBE is its high octane number (approximately 119). For this reason, such an ether can be used as an excellent gasoline's antiknock additive. In the case of diesel engines, cetane number is a more important fuel property. As can be seen in Table 2, the progressive addition of ETBE to diesel oil causes a significant decrease of the cetane number. It affects the first phase of the fuel combustion process (longer ignition delay). The ignition delay in diesel engines has an important, indirect effect on higher engine noise. If the ignition delay is too long, the rate of fuel burning can be too rapid, resulting in engine knock that decreases efficiency while increasing engine noise and wear.

Table 2. Selected physico-chemical properties of tested fuel blends.
Tabela 2. Wybrane właściwości fizykochemiczne badanych mieszanin paliwowych.

Parameters	Values				
	DF	ETBE10	ETBE 20	ETBE 30	ETBE 40
ETBE content in diesel oil, [%, by vol.]	0	10	20	30	40
Density at 15 °C, [kg/m^3]	839	831	821	814	804
Kinematic viscosity at 40 °C, [mm/s^2]	2,79	2,24	1,79	1,47	1,21
Lubricity at 25°C , [μm]	222,1	254	244,5	267,1	256,1
Surface tension, [mN/m]	25,9	24,6	23,3	22,1	21,2
Lower heating value, [MJ/kg]	42,8	42,1	41,1	40,8	40,0
Cetane number, [-]	51,2	46	42,7	38,4	31,4

*diesel oil lubricity measured at 25 ºC cannot be higher than 380 μm [10].

The addition of ETBE to diesel fuel affects other physicochemical properties of the tested blends as well. The increasing addition of ETBE in diesel oil leads to a proportional decrease of: density, viscosity, surface tension, and heating value. For this reason, injection and combustion processes of such fuel blends are different than for neat diesel oil. Results of these investigations will be presented in further publications.

2.4. Testing conditions

All testing was performed at steady-state conditions for engine partial loads and selected crankshaft rotational speeds and nominal angle of beginning of fuel injection. Detailed conditions of the engine testing are presented in Table 3.

Table. 3. Test conditions of AD3.152 diesel engine fuelled with blends of ETBE and diesel oil.
Tabela. 3. Warunki badań silnika AD3.152 zasilanego mieszaninami EETB z olejem napędowym.

Parameters	Values		
Crankshaft rotational speed, n [rpm]	1200	1600	2000
Angle of beginning of fuel injection, α_{dpt} [ºCA]	17 deg. before TDC		
Engine torque, M_o [Nm]	40; 60; 80; 100 and 120		

Graphical interpretation of angle of beginning of fuel injection α_{dpt} is presented in Figure 3.

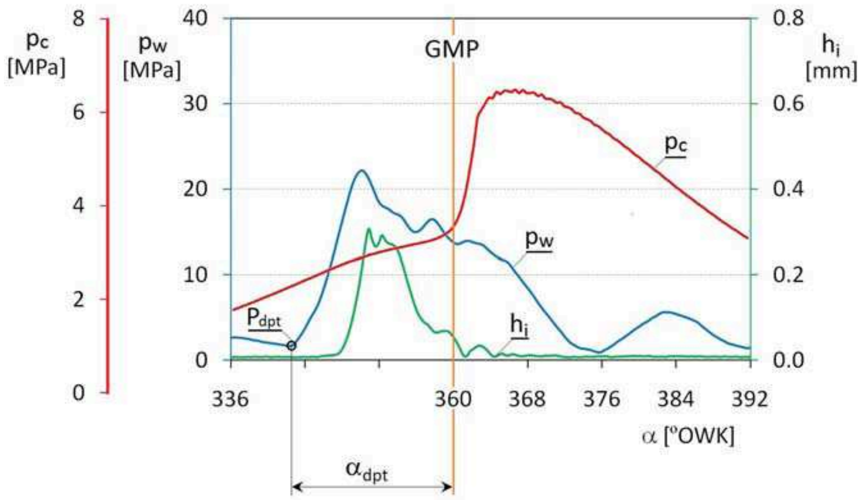

Fig. 3. Graphical interpretation of angle : GMP – top dead center (TDC), α [ºOWK] - angle position of engine crankshaft (ºCA), p_w – pressure variations in delivery pipe, p_c – pressure variations in combustion chamber, h_i – fuel injector needle lift.
Rys. 3. Interpretacja graficzna kąta dynamicznego początku tłoczenia paliwa α_{dpt}: GMP – górne martwe położenie tłoka, α [ºOWK] – położenie kątowe wału korbowego, p_w – przebieg ciśnienia w przewodzie wtryskowym paliwa, p_c – przebiegi ciśnienia w komorze spalania, h_i – wznios iglicy rozpylacza.

The loading of the engine was controlled by an water brake coupled to the crankshaft.

3. Results

Figure 4 shows the effect of ETBE content in diesel fuel on variations of engine noise. Research shows that at all tested speeds the value of engine noise increases as ETBE content in diesel oil climbs. This is seen for all values of the engine load.

a) b) c)

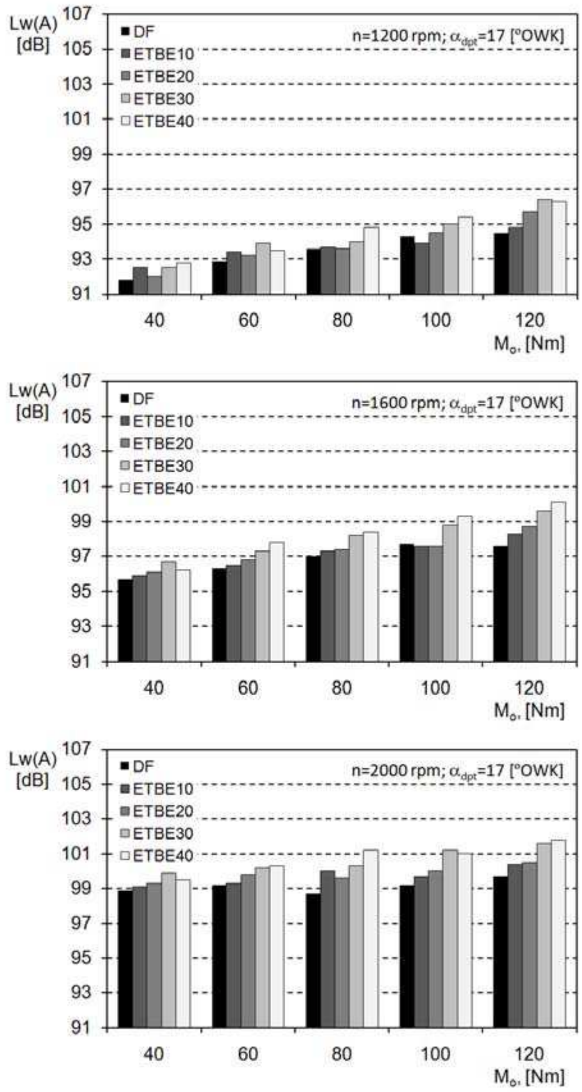

Fig. 4. Noise emission of AD3.152 engine in comparison to its load and kind of tested fuel obtained at nominal angle of beginning of fuel injection α_{dpt} and crankshaft speed: a) 1200, b) 1600, c) 2000 rpm.
Rys. 4. Wartości hałasu silnika AD3.152 w zależności od jego obciążenia i rodzaju badanego paliwa uzyskane przy nominalnym kącie początku tłoczenia paliwa α_{dpt} i prędkości wału korbowego: a) 1200, b) 1600, c) 2000 obr/min.

4. Conclusions

Engine noise is mainly dependent on crankshaft rotational speed. Sound energy of AD3.152 engine measured at 2000 rpm was about 6 dB higher than at 1200 rpm. It was observed for all tested fuels. Noise emission also depends on engine load.

The highest values of noise emission were recorded for engine torque 120 Nm, and the lowest for 40 Nm. A maximum difference in sound emission recorded in these conditions equals approximately 4 dB.

The combustion process, dependent on physico-chemical properties of fuel, is an important source of engine noise. Cetane number is the crucial characteristic. Fuel blends with the highest ETBE content in diesel oil have the lowest cetane number. For this reason, ignition delay of ETBE40 is longer in comparison to neat diesel oil. A longer period of ignition delay causes greater rises of in-cylinder pressure. It generates high - frequency vibrations of the combustion chamber and resonances of other engine structures.

Test results show that noise emission of AD3.152 engine fuelled with ETBE10 or ETBE20 was comparable with that of neat diesel fuel. Maximum differences between the two were below 1.5 dB.

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Hałas silnika wysokoprężnego zasilanego mieszaninami eteru etylo-tert-butylowego z olejem napędowym

Streszczenie

W artykule przedstawiono wyniki badań emisji hałasu silnika AD 3.152 zasilanego mieszaninami standardowego oleju napędowego i eteru etylo-tert-butylowego. Pomiary wykonano w warunkach ustalonych dla różnych obciążeń częściowych, prędkości obrotowej wału korbowego i kątów początku wtrysku paliwa. Badania pokazują, że emisja hałasu silnika wzrastała dla wszystkich badanych mieszanin paliwowych w stosunku do oleju napędowego. Największe wartości emisji hałasu zarejestrowano dla ETBE40. Wstępna analiza procesu spalania wskazuje, że emisja hałasu wzrasta wraz z prędkością narastania ciśnienia w komorze spalania.