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THE USE OF JET FUEL IN A DIESEL ENGINE

REAKTYVINIŲ DEGALŲ PANAUDOJIMAS DYZELINIAME VARIKLYJE

(1)Gvidonas Labeckas, (1)Stasys Slavinskas, (2)Valentina Vilutienė

(1)Aleksandras Stulginskis University Kaunas-Academy, P.O.Box LT-533661
(2) The General Jonas Zemaitis Military Academy of Lithuania, P.O.Box LT-10322,
Vilnius, Lithuania
E-mail: gvidonas.labeckas@lzuu.lt, stasys.slavinskas@lzuult valentina.vilutiene@mil.lt

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The article presents a comparative analysis of the bench test results of a four-stroke, four-cylinder, direct-injection diesel engine operating on the normal 95vol% (class C) diesel fuel + 5vol% RME (DF), F-34 jet fuel (JF) and F-34 jet fuel treated with the cetane improver (JF+0.12vol%). The purpose of the research was to investigate the possibility to use of military jet F-34 fuel in the land-based direct injection diesel engine and examine the effect of F-34 and F-34 fuel treated with 0.12vol% 2-ethylhexyl nitrate on the autoignition delay, combustion, performance, emissions and the smoke opacity.

The maximum cylinder gas pressure produced from fuel JF and JF+0.12vol% was lower 4.3% and 2.8% at speed of 1400 rpm, and 2.5% and 5.7% at speed of 2200 rpm compared to 86.6 MPa and 82.5 MPa of the normal diesel. At rated 2200 rpm speed, the use of the jet fuel treated with the cetane improver led to smoother engine performance under all loads and the maximum cylinder pressure gradients were reduced by 9.4% as against 15.9 bar/deg of the normal diesel. The minimum brake specific fuel consumption (bsfc) for F-34 fuel and treated F-34 fuel was decreased by 4.8% and 3.5% at 1400 rpm and increased by 2.7% and 3.7% at 2200 rpm compared to 249.5 g/kWh and 251.8 g/kWh of the normal diesel.

Maximum NO emissions produced from JF fuel and JF+0.12vol% fuel were reduced by 11.5% and 7.0% at 1400 rpm, and 17.1% and 17.3% at speed of 2200 rpm compared to 1705 ppm and 1389 ppm emanating from the normal diesel. Maximum CO emissions were suppressed by 39.3% and 16.8% compared to 4988 ppm produced from the normal diesel running at 1400 rpm speed. At speed of 2200 rpm, the ecological effect of using F-34 fuel was minimal and the CO emissions sustained over the whole load range at the same level and increased by 2.5% and 3.0% with regard to the normal diesel operating under high load. The HC emission was correspondingly 78.3% and 58.8% lower for the low and high loads compared to 230 ppm and 1820 ppm of the normal diesel running at speed of 1400 min^{-1}. The smoke opacity produced from fuels JF and JF+0.12vol% sustained at lower levels over the whole load range with the maximum values being 14.6% and 8.1% lower with regard to 94.9% of the normal diesel operating at speed of 1400 rpm. The experimental test results showed that military jet F-34 fuel is a cleaner-burning replacement of the diesel fuel and suggests better fuel economy with reduced all harmful emissions, including NO, NO_2, NO_x, CO, HC and smoke opacity of the exhausts.

Diesel engine, jet fuel, autoignition delay, combustion, performance, emissions, smoke opacity

Introduction

The MC-473 Directive provides guidance to NATO and national authorities on the policies, principles, and characteristics of the NATO Petroleum Supply Chain. The aim of the original Single Fuel Concept (SFC) was conceived after the Second World War in order to simplify the logistic supply chain for petroleum products in the NATO nations and to achieve maximum equipment interoperability through the using of a single fuel, namely F-34, on the battlefield for land-based military aircrafts, vehicles, and equipment. Since its inception as a concept in 1986, the adoption of the SFC has been supported by a number of studies and trials in Member and Partner nations. At its autumn meeting in 2004, the NATO Pipeline Committee (NPC) adopted the SFP as the NATO Single Fuel Policy [1].

Prior to the decision, member nations of NATO have undertaken studies in order to identify problems that could arise in practice by the use of the kerosene based fuel in diesel engine vehicles (tanks, transporters etc.). One of the problems can be linked with the reduced lubricity of a lighter kerosene based jet fuel that may affect reliability and durability of diesel engine. The development of biomass derived substitutes for diesel fuel is a possible attractive outlet, as it could help to improve the fuel quality. The bench tests conducted with a single cylinder, stationary direct injection Petter engine, model AV1-LAB showed that the substitution of F-34, which is comparable with commercial aviation fuel JP-8, with sunflower oil and/or olive oil at proportions from 10% to 50% results in slightly increasing the volumetric fuel consumption, a strong tendency to decreasing PM emissions and both positive and negative changes of nitrogen oxide emissions depending on the percentage of biofuel added in the JP-8 and engine load [2].

An experimental study carried out in an optically-accessible single-cylinder heavy duty diesel engine equipped with a high pressure common-rail injection system showed that spray tip penetration of JP-8 was shorter than that of diesel fuel by approximately 16% when the injection pressure was 30 MPa and 10% with increased injection pressure at 140 MPa. The decreased spray tip penetration was accompanied by 15.9^o to 6.2^o wider spray angle of JP-8 under considered fuel injection pressures than that of diesel fuel [3]. This variation in the spray tip penetration and spray angle is thought to be a result of the differences in fuel properties, such as density, boiling point, and viscosity. These and other properties of fuel JP-8 contribute to higher fuel-air mixing rate and improve atomisation, resulting from shorter spray tip penetration and wider spray angle [4].

Investigating the impact of JP-8 fuel (F-34) on diesel engine performance and emission is very important for military combat vehicles, due to its great potential as alternative fuel under single fuel strategy program for military operation. Experimental studies showed that JP-8 fuels have the potential for lowering NO_x, CO, HC emissions and smoke compared to diesel fuel. The test results of a 558 kW, B-46-6, supercharged, 12-cylinders, CIDI engine with a hydraulic dynamometer indicate that torque and horsepower of diesel fuel can be matched with fuel economy penalty lower than 4.5%, by increasing the volumetric fuel quantity to compensate the lower density of JP-8 fuel. The lower cetane number of JP-8 fuel caused a slight increase in ignition delay but improved the combustion at load conditions, thus lowering the combustion noise [5].

There is a known torque and fuel economy penalty associated with the operation of a diesel engine with JP-8 fuel, due to its lower dencity and viscosity. On the other hand, a few experimental studies have suggested that kerosene-based fuels have the potential for lowering exhaust emissions compared to diesel fuel (DF-2). The test results obtained at the Detroit Diesel Corporation (DDC) with S60 engine outfitted with exhaust gas recirculation indicate that torque and fuel economy of diesel fuel can be matched, without smoke or NO_x penalty, by increasing the duration of injection to compensate for the lower fuel density. The lower cetane number of JP-8 cause an increased ignition delay and increased premixed combustion, and their cumulative effect led to relatively unchanged combustion phasing. Under almost all conditions, JP-8 led to lower NO_x and PM emissions and shifted the NO_x-PM trade-off favourably [6].

Purpose of the research

The purpose of the research was to investigate the effect of fuel F-34 and F-34 fuel treated with the cetane improver (0.12vol% of 2-ethylhexyl nitrate) on the autoignition, combustion, performance efficiency of DI diesel engine, emission characteristics and smoke opacity of the exhausts. Objectives of the study were as follows:

1. To investigate the autoignition delay, the peak cylinder gas pressure and the brake specific fuel consumption when operating alternately on the normal diesel fuel, jet F-34 fuel and F-34 fuel treated with 0.12vol% of the cetane improver over a wide range of loads and speeds.

2. To examine the emission composition changes, including nitrogen oxides NO, NO_2, NO_x, carbon monoxide CO, total unburned hydrocarbons HC and smoke opacity of the exhausts when running the engine on fuel F-34 and F-34 fuel treated with 0.12% of the cetane improver over a wide range of loads and revolutions per minute.

Objects, experimental apparatus and methodology of the research

The tests have been conducted on four-stroke, four-cylinder, direct-injection, naturally aspirated, 60 kW diesel engine D-243 with a splash volume 4.75 dm^3, cylinder bore 110 mm, piston stroke 125 mm and compression ratio 16:1. The fuel was delivered by an in line fuel injection pump thorough five holes injection nozzles into a toroidal combustion chamber in a piston head with the static fuel injection advance of 25° before top dead centre (TDC). The needle-valve lifting pressure was adjusted equal to 17.5±0.5 MPa for the all injectors.

Load characteristics of the engine were taken at speed of 1400 rpm and 2200 rpm when operating alternately on the normal 95vol% diesel fuel (class C) + 5vol% RME (DF), jet fuel F-34 (JF) and F-34 fuel treated with the additive 2-ethylhexyl nitrate (JF+0.12vol%). The additive was produced at Sigma-Aldrich Chemic Gmbh CAAS Nr. 27247-96-7 (Germany) for these experiments.

Torque of the engine was measured with 110 kW electrical AC stand dynamometer and speed was controlled by using the universal ferrite-dynamic stand tachometer TSFU-1. The fuel mass consumption was measured by weighting it on the AVL fuel balance (0-150 kg/h) with an accuracy of ±0.12% and the air mass consumption was measured with the AVL air metering equipment installed at the air tank to reduce pressure pulsations and guarantee an accuracy of ±0.25%. The coolant liquid and lubricating oil temperatures were within the range 80-85 °C.

The single and summarized over 100 engine cycles cylinder gas pressure diagrams versus the crank angle were recorded at every 0.1° crank angle degree (CAD) by using the AVL indication and data acquisition system. A piezoelectric uncooled transducer GU24D (range 0-280 bar) mounted into the first cylinder and connected to the MICROIFEM piezoelectric amplifier-signal conditioning along with the AVL crank angle encoder 365C (±0.1°) have been used to monitor gas pressure for every load-speed setting point with an accuracy of $\geq\pm0.1$ bar. The AVL IndiModul 622 was introduced as a multi-channel (8) indicating system for the acquisition and processing of fast crank-angle and time-based cylinder gas pressure signals. For the analysis of data and to calculate the heat release rate was used the averaged cylinder gas pressure of 100 engine cycles.

The static fuel delivery angle of 25° CAD before top dead centre was the same for the diesel fuel and the jet fuels tested under all loads and speeds. The fuel was delivered by an in-line fuel injection pump through five holes (diameter 0.34 mm) injection nozzles into a toroidal combustion chamber in a piston head. The fuel-line high-pressure was measured by using Kistler piezoresistive pressure sensors (type 4067) mounted on the high-pressure line at the fuel pump and at the end of a line before the injector with an accuracy of ±0.5% within the range 0-100 MPa.

The dynamic start of fuel injection and injection duration were determined by recording the nozzle-needle-valve lifting and its travel history by using the Hall effects position sensor ASMB 470004-1 produced at the Wolff Controls Corporation. The fuel line pressure and needle-valve lifting signals have been transmitted to the Kistler type 4665 and 5247 amplifier modules mounted on the signals conditioning platform Compact 2854 A. The data acquisition and processing system based on personal computer and equipped with a 12-bit A/D converter was used in these experiments.

The autoignition delay was determined as a period in degrees (φ_i) and/or units of time (τ_i) between the dynamic start of the fuel injection and the actual start of combustion. As a dynamic start of injection was taken the point at which the needle-valve lift compiles about 5% of its total 0.28 mm travel. As the start of combustion was taken the point at which the differential curve of the heat release characteristic's crosses the zero line and changes its value from minus to plus one. These critical points were determined with an accuracy $\pm 0.1^o$ of the crank angle degrees.

The amounts of nitric oxide NO (ppm), nitrogen dioxide NO_2 (ppm), carbon monoxide CO (ppm) and total unburned hydrocarbons HC (ppm) in the exhausts were measured by using the Testo 350 XL gas analyser. Total emissions of nitrogen oxides NO_x was determined as a sum of both NO and NO_2 harmful species.

The smoke density D (%) of the exhausts was measured with a Bosch RTT 100/RTT 110 opacity-meter, which readings are provided as Hartridge units with an accuracy of ±0.1% in the range 0 to 100%. The temperature of the exhausts was measured by using chromel-kopel thermocouple and indicator N20 that guaranteed an accuracy of $\pm 0.2^o$C.

The test results and analysis

The technical parameters of the normal diesel fuel, jet F-34 fuel and jet F-34 fuel treated with the cetane improver (CI) by the addition 0.12vol% of 2-ethylhexyl nitrate have been evaluated at the Internationally accredited according standard EN ISO/IEC 17025-2005 Quality research centre “ORLEN Lietuva“ Ltd., Mažeikiai, as is shown in Table 1.

On the one part, the reduced density and viscosity of jet fuel along with lower the start of distillation curve at temperature of 145.4 ^{o}C compared to diesel fuel (177.8 ^{o}C) and the vaporization end at temperature of 258.0 ^{o}C as against 345 ^{o}C of the normal diesel improved the evaporation characteristics and preparation of the combustible mixture. The enhanced atomisation of jet fuel, reduced aromatics content (19.3%) compared to diesel fuel (27.5%) and lower latent heat of vaporization (250 kJ/kg) also contributed to faster evaporation and mixing process [3]. On the other part, the lower 42.3 cetane number of fuel F-34 compared to 51.3 of the normal diesel fuel may lead to the longer autoignition delay and bigger fuel portions premixed for rapid combustion that affects the rate of heat release during the first kinetic phase, increases cylinder gas pressures and pressure gradients.

The autoignition delay depends on the atomisation of the liquid jet fuel, vaporisation of the fuel droplets and mixing of the fuel vapours with the cylinder hot air-charge as well as by the cetane number determined prehistory of combustion reactions of the fuel, cylinder compressed air-and-residual gas mixture conditions, which lead to autoignition [7]. Analysis of the needle-valve lifts and cylinder heat release characteristics showed that the replacement of the diesel fuel by commercial aviation fuel F-34 leads to the autoignition delay longer for all loads and speeds than that of the normal diesel. Such autoignition delay behaviour matches well with the experimental test results of commercial JP-8 aviation fuel, which is comparable with military F-34 fuel, on various types of DI diesel engines obtained by other researchers [3,5,6].

Table 1. Properties of diesel fuel (grade C) and jet fuel (NATO code F-34)
1 lentelė. Dyzelinių degalų (klasė C) ir reaktyvinių degalų (NATO kodas F-34) savybės

Property parameters	Test methods Diesel fuel / Aviation fuel	DF EN 590	F-34 ASTM-D 1655	F-34 + CI 0.12vol%
Chemical formula		C10 - C29	C8 - C18	C8 - C18
Density at 15 ^{o}C, kg/m^{3}	EN ISO 12185:1999/ ASTM D 4052	843.6	797.2	797.2
Kinematic viscosity at 40 ^{o}C, mm^{2}/s	EN ISO 3104 at 40^{o}C / ASTM D 445 at -20^{o}C	2.893	4.0	4.0
Lubricity, corrected wear scar diameter (wsd 1.4) at 60^{o}C, µm	EN ISO 12156-1:2007/ indeterminable	460	611 -	729 -
Flash point, Pensky-Martens closed cup, ^{o}C / Flash point by Tag closed cup tester	EN ISO 2719:2003/ ASTM D 56	59.0	40	40
Auto-ignition temperature ^{o}C		230	≈229	-
Cold filter plugging point ICFPP), ^{o}C / Freezing point, ^{o}C	EN ISO 116 / AC:2002	-7	-58.0	-58.0
Cloud point, ^{o}C	EN 23015 / indeterminable	-2	-	-
Cetane number	EN ISO 5165:1999	51.3	42.3	48.5
Sulphur, mg/kg	EN ISO 20846:2004/ ASTM D 5453-09	8.9	11	11
Acid value, mg KOH/g	indeterminable / ASTM D 3242	-	0.001	0.001
Carbon residue (in 10% distillation residue), % m/m	EN 10370 / indeterminable	0.03	-	-
Net heating value, MJ/kg	ISO 8217:2007 / ASTM D 4529-01	43.10	43.30	43.27
Ash content, mass-% / Existent gum, mg/100 ml	EN ISO 6245:2002 / IP-540	0.001	1	1
Water content, mg/kg	EN ISO 12937:2002 / -	39	-	-
Total contamination, mg/kg (ppm) / Contamination, mg/l	EN 12662:2008 / ASTM D 5452	2.0	0.2	0.2
Fraction, ^{o}C	-	180-350	140-230	140-230

The fully loaded DI diesel engine fuelled with fuel F-34 exhibited the autoignition delay longer 0.84° (10.1%) and 1.12° (11.0%) compared to that 8.34° and 10.22° measured in CAD for the normal diesel running at 1400 rpm and 2200 rpm speeds. The addition 0.12vol% of 2-ethylhexyl nitrate into fuel F-34 the cetane number improved by 14.7% (48.5). As a result, the autoignition delay decreased over a whole load range reaching the biggest improvement of 1.29° (15.5%) compared to that 8.34° of the normal diesel running under the fully opened throttle at speed of 1400 rpm. After engine speed increased to 2200 rpm, the positive effect of the cetane improver on the autoignition delay φ_i reasonably decreased due to increased by faster piston's velocirty instant cylinder gas pressure and temperature. Due to cumulative effect of all promoting factors, the autoignition delays in CAD of both the diesel fuel (10.22°) and the military jet fuel F-34 treated with 0.12vol% of the cetane improver (10.25°) coincided actually when operating under the high load at rated speed of 2200 rpm.

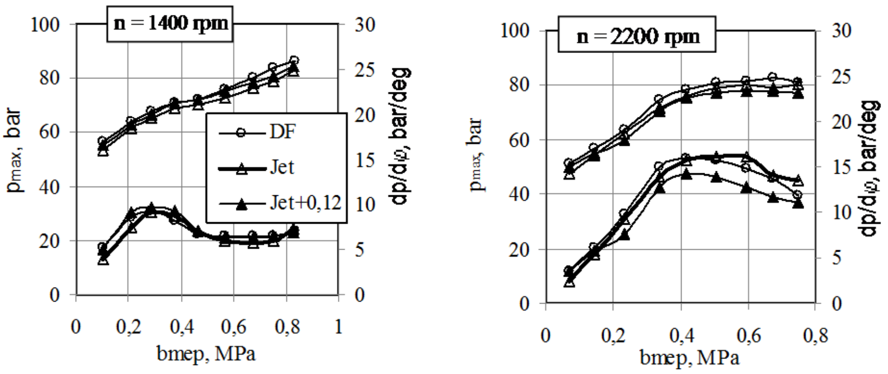

Fig. 1. The peak cylinder gas pressure (p_{max}) and pressure gradients $(dp/d\varphi)_{max}$ as a function of engine load (bmep) at 1400 rpm (a) and 2200 rpm (b) speed

1 pav. Maksimalaus dujų slėgio cilindre (p_{max}) ir slėgio gradientų $(dp/d\varphi)_{max}$ priklausomybė nuo variklio apkrovos (bmep), dirbant 1400 min^{-1} (a) and 2200 min^{-1} (b) sūkiais

When using fuel JF and JF+0.12vol% the peak cylinder gas pressure was 4.3% and 2.8% lower at speed of 1400 rpm, and 2.5% and 5.7% at rated 2200 rpm speed compared to those 86.6 MPa and 82.5 MPa of the normal diesel (Fig. 1). The influence of using the F-34 and F-34 fuel treated with the cetane improver on the cylinder pressure gradients was negligible at low 1400 rpm speed, however the treated jet fuel suggested pressure gradients lower for all loads at speed of 2200 rpm. Because of better atomisation and homogeneous distribution of treated jet fuel droplets, the maximum cylinder pressure gradients decreased by 9.4% compared to that 15.9 bar/deg of the normal diesel. Smother performance of the diesel engine on aviation fuel F-34 can be attributed to better air-fuel mixture prepared by a wider spray angle, shorter fuel tip penetration and improved atomisation [3].

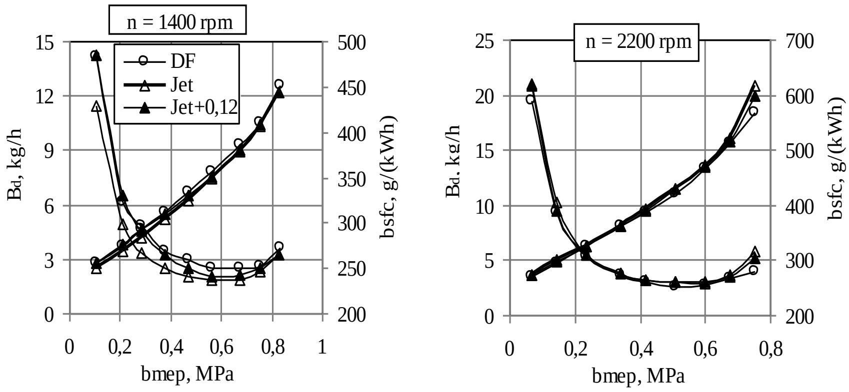

Fig. 2. The fuel consumption per hour (B_d) and brake specific fuel consumption (bsfc) for DF, JF and JF+0.12vol% as a function of engine load (bmep) at 1400 rpm (a) and 2200 rpm (b) speed

2 pav. Valandinių degalų sąnaudų (B_d) ir lyginamųjų degalų sąnaudų (bsfc), panaudojus DF, JF ir JF+0.12vol%, priklausomybė nuo variklio apkrovos (bmep), dirbant 1400 min^{-1} (a) and 2200 min^{-1} (b) sūkiais

Using for the diesel engine fuelling of aviation F-34 fuel ensured the minimum brake specific fuel consumption (bsfc) 4.8% lower for speed of 1400 rpm and 2.7% higher for rated 2200 rpm speed compared to that 249.5 g/kWh and 251.8 g/kWh of the normal diesel (Fig. 2). Similar the bsfc changing behaviour remained in value when the engine operated on jet F-34 fuel treated with the cetane improver, consequently the minimum bsfc for JF+0.12vol% relatively decreased by 3.5% and increased 3.7% at corresponding 1400 rpm and 2200 rpm speeds.

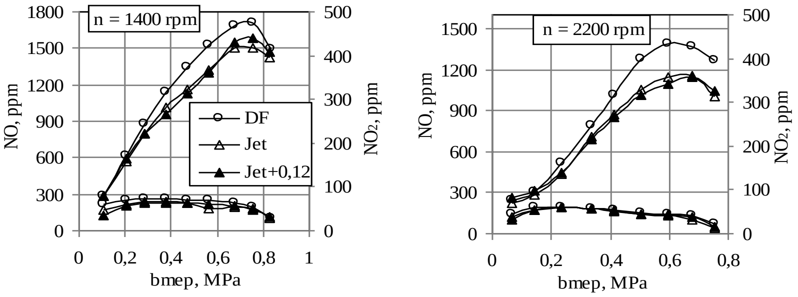

Fig. 3. The nitric monoxide NO and nitrogen dioxide NO_2 emissions produced from fuels DF, JF and JF+0.12vol% as a function of engine load (bmep) for 1400 rpm (a) and 2200 rpm (b) speed

3 pav. Azoto viendeginio NO ir dvideginio NO_2 emisijos, pagamintos iš degalų DF, JF ir JF+0.12vol%, priklausomybė nuo nuo variklio apkrovos (bmep), dirbant 1400 min^{-1} (a) and 2200 min^{-1} (b) sūkiais

As Fig. 3 shows, when using the jet fuel JF and JF+0.12vol% the maximum nitric monoxide NO emissions decreased by 11.5% and 7.0% at speed of 1400 rpm, and 17.1% and 17.3% at rated 2200 rpm speed in comparison with respective 1705 ppm and 1389 ppm emanating from the normal diesel. The reduced NO emissions match pretty well with the lower maximum cylinder gas pressures (Fig. 1) and, hence, temperatures that plays essential role in the NO_x production [7]. In contrast to NO emissions, the amounts of nitrogen dioxide NO_2 did not change greatly, neither with the use of jet F-34 fuel, nor with the addition of the cetane improver into jet F-34 fuel. As a result, by the replacement of the diesel fuel with aviation F-34 fuel the total NO_x emissions as a sum of both NO and NO_2 species reduced significantly.

The reduced NO_x (Fig. 3), CO (Fig. 4), HC (Fig. 5) emissions and smoke opacity of the exhausts (Fig. 6) suggest real environmental advantages. All these advantages could be beneficially utilised by using the aviation fuel F-34 on the battlefield for land-based military aircrafts, vehicles, and equipment powered by the diesel engines. Better emissions obtained in considered studies differ actually from those measured on a single-cylinder heavy duty common-rail diesel engine fuelled with fuel JP-8, where NO and NO_x emission were higher with both unburned carbons HC and carbon monoxide CO pollutants practically unaffected by the addition of every type of biodiesel in the JP-8 fuel. In that case, significant changes in harmful emissions were accompanied by slightly higher the volumetric fuel consumption under heavy loads due to addition of 50vol% sunflower oil and/or olive oil biodiesel into aviation JP-8 fuel [2].

The replacement of traditional diesel fuel by a lighter jet F-34 fuel did not lead actually to big CO emissions changes when operating within the range of low-to-medium loads at speed of 1400 rpm (Fig. 4 a). The positive role of using F-34 fuel for diesel engine powering comes into effect when operating under medium-to-high loads, where the maximum CO emissions produced from aviation JF and JF+0.12vol% fuels were reduced by 39.3% and 16.8% compared to 4988 ppm emanating at fully opened throttle from the normal diesel. After transition to high speed of 2200 rpm, the CO emissions produced by the engine were increased on average from 45.9% (DF) to 103.2% (JF) compared to those 286 ppm and 315 ppm measured under low and medium loads at 1400 rpm speed. Because of incomplete combustion, the advantages gained by using the jet F-34 fuel at low 1400 rpm speed disappeared markedly and the CO emissions produced from jet JF and JF+0.12vol% fuels sustained over the entire load range at more or less the same level as that of the normal diesel. However, when operating under high load and rated speed of 2200 rpm, the CO emissions became correspondingly 2.5% and 3.0% higher with regard to the normal diesel.

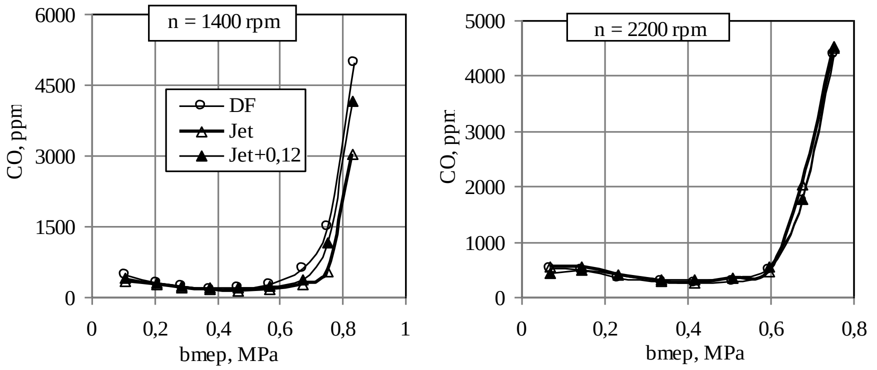

Fig. 4. Dependencies of carbon monoxide CO emissions on engine load (bmep) at 1400 rpm (a) and 2200 rpm (b) speed

4 pav. Anglies viendeginio CO emisijos priklausomybės nuo variklio apkrovos (bmep), dirbant 1400 min^{-1} (a) ir 2200 min^{-1} (b) sūkiais

Experimental investigation conducted at the laboratories of National Technical University of Athens and Hellenic Air Force Academy, with the main scope to evaluate the use of JP-8 aviation fuel as a full substitute for diesel fuel, revealed that JP-8 fuel combustion significantly affects some basic operating parameters of both types of engines (DI and IDI) compared to standard diesel operation. The scientists determined that the full substitution of diesel fuel with JP-8 affects positively, i.e. reduces the values of the carbon monoxide concentration while it seems to have a negligible influence on the concentration of nitrogen oxide emissions for both types engine. On the other part, the operation of each types of engine with the jet JP-8 fuel seems to affect seriously the values of the unburned hydrocarbons and soot emission concentrations compared to the respective values observed under normal diesel operation [8].

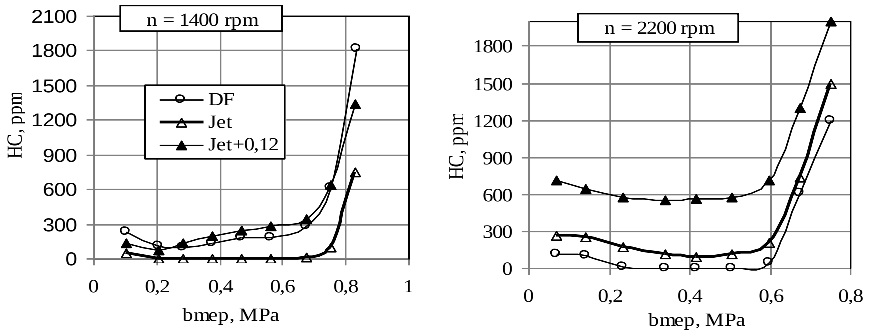

Fig. 5. Emissions of unburned hydrocarbons HC as a function of engine load (bmep) at 1400 rpm (a) and 2200 rpm (b) speed

5 pav. Nesudegusių angliavandenilių HC emisijos priklausomybės nuo variklio apkrovos (bmep), dirbant 1400 min^{-1} (a) ir 2200 min^{-1} (b) sūkiais

Because of having similar origin and nature the HC pollutants change with the increasing load (bmep) the same way as the CO emissions. Replacement of the diesel fuel with the jet F-34 fuel noticeably reduced the HC emissions over the intire range of loads at speed of 1400 rpm (Fig. 5 a). When running the engine on aviation fuel under medium load at low 1400 rpm speed, the HC emissions reduced nearly to the zero level. The HC emission produced from military F-34 fuel were 78.3% lower for the low load and 58.8% lower for the high load compared to 230 ppm and 1820 ppm emanating from the normal diesel. When using the treated F-34 fuel, the HC emissions proceede ambiguously with load, i.e. emissions changed from the level being 43.5% lower to 55.6% higher level compared to the normal diesel operating under low-to-medium loads. Finally, the reduction up to 26.4% with regard to the normal diesel fuel achieved for the HC emissions after transition to high load. Promising HC emissions results monitored mainly at the low speed of 1400 rpm changed to be more complicated after engine speed increased to 2200 rpm (Fig. 5 b). Emissions of hydrocarbons HC produced from jet JF fuel and treated JF+0.12vol% fuel continued at higher levels over the whole load range. Finally, the HC emissions produced from neat jet fuel JF and treated JF+0.12vol% fuel were increased to the maximum of 1500 ppm (25.0%) and 2000 ppm (66.7%) compared to the normal diesel (1200 ppm) running under high load.

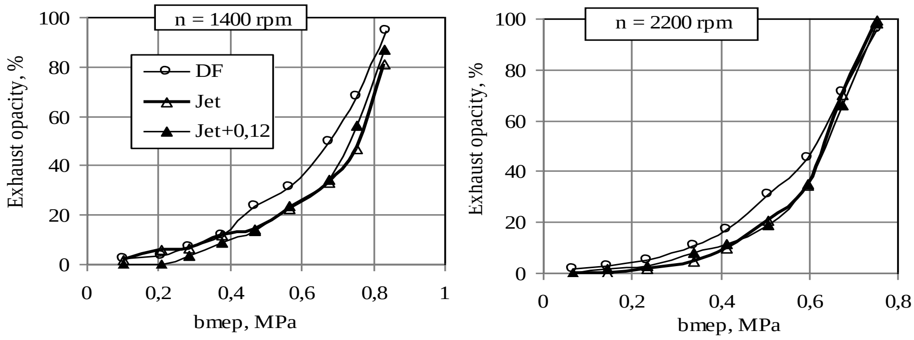

Fig. 6. Smoke opacity of the exhausts as a function of engine load (bmep) at 1400 rpm (a) and 2200 rpm (b) speed

6 pav. Deginių dūmingumo priklausomybės nuo variklio apkrovos (bmep), dirbant 1400 min^{-1} (a) ir 2200 min^{-1} (b) sūkiais

The graphs in Fig. 6 show the smoke related advantages to be utilised beneficially by using in the diesel engine jet F-34 fuel and F-34 fuel treated with 012vol% of the cetane improver. By using of military aviation fuels for land-based diesel engine powering the smoke opacity could be decreased over the whole load range at the low speed of 1400 rpm (Fig. 6 a). The smoke opacity produced from the tested jet fuels sustained at correspondingly 14.6% and 8.1% lower levels than that critically increased to 94.9% for the engine running on commercial diesel fuel. At rated speed of 2200 rpm, the smoke opacity further relatively decreased due to the use of jet F-34 fuel and treated F-34 fuel under low-to-medium loads (Fig. 6 b). However, the positive effect of using military jet JF and JF+0.12vol% fuels has disappeared gradually with the increase in engine load, so that black smoke generated from the normal diesel, F-34 fuel and treated F-34 fuel scaled up to the highest 95.8%, 99.6% and 98.2% levels.

Conclusions

1. The autoignition delay for the jet F-34 fuel was 0.84^o (10.1%) and 1.12^o (11.0%) longer compared to 8.34^o and 10.22^o measured for the fully loaded normal diesel running at speeds of 1400 rpm and 2200 rpm. The addition into jet F-34 fuel 0.12vol% of 2-ethylhexyl nitrate the cetane number (48.5) improved and, as a result, the autoignition delay decreased by nearly 1.29^o (15.5%) over the all load range at speed of 1400 rpm. At 2200 rpm speed, the effect of using the cetane improver was negligible, and the autoignition delays 10.22^o (DF) and 10.25^o (JF+0.12vol%) coincided actually when operating under the high (100%) load.
2. The peak cylinder pressure generated from jet JF and JF+0.12vol% fuels lowered by 4.3% and 2.8% at speed of 1400 rpm, and 2.5% and 5.7% at rated 2200 rpm speed compared to 86.6 MPa and 82.5 MPa of the normal diesel. Treated jet F-34 fuel suggests the cylinder pressure gradients lower for the all loads at speed of 2200 rpm with the maximum value reduced by 9.4% compared to that 15.9 bar/deg of the normal diesel.
3. When running DI diesel engine on aviation F-34 fuel, the fuel mass consumption per unit of energy developed depends on engine load and speed. At speed odf 1400 rpm the minimum bsfc for jet F-34 fuel decreased by 4.8% compared to the reference value of 249.5 g/kWh, whereas at rated speed of 2200 rpm the bsfc was 2.7% higher than, 251.8 g/kWh, of the normal diesel. The addition 0.12vol% of the cetane improver 2-ethylhexyl nitrate into jet F-34 fuel does not affect greatly the brake specific fuel consumption of the engine.
4. The biggest achievement to be utilised in practice by the use of jet F-34 fuel in military land-based vehicles can be linked with significantly lower NO and NO_x emissions. Nitric monoxide NO produced from jet JF and JF+0.12vol% fuels reduced by 11.5% and 7.0% at speed of 1400 rpm, and 17.1% and 17.3% at 2200 rpm speed compared to respective 1705 ppm and 1389 ppm of the normal diesel. Maximum NO_2 emissions were similar to those of 73.8 ppm and 59.4 ppm generated by the normal diesel at speeds of 1400 rpm and 2200 rpm.
5. The use the jet fuel F-34 in the diesel engine allows effective control on harmful CO, HC emissions and smoke opacity, i.e. the maximum values of considered pollutants relatively decreased by 39.3%, 58.8%, and 14.6% at speed of 1400 rpm. After transition to speed of 2200 rpm, the positive effect gained by the use of the treated jet JF+0.12vol% fuel vanished and maximum CO and HC emissions increased by 3.0% and 66.7% compared to the normal diesel.

To support NATO Single Fuel Policy (SFP) and actualise important logistical advantages military F-34 (JP-8) fuel can be recommended for direct injection diesel engines powering in land–based military aircraft, vehicles and equipment because this kerosene based aviation fuel is economically attractive, environmental friendly and suggests smoother performance of the engine.

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Gvidonas Labeckas, Stasys Slavinskas, Valentina Vilutienė

REAKTYVINIŲ DEGALŲ PANAUDOJIMAS DYZELINIAME VARIKLYJE

Santrauka

Straipsnyje pateikiama normaliais 95vol% (klasė C) dyzeliniais degalais + 5vol% RME (DF), reaktyviniais F-34 degalais (JF) ir apdorotais cetano priedais (JF+0.12vol%) F-34 degalais maitinamo keturtakčio, keturių cilindrų, tiesioginio įpurškimo dyzelinio variklio darbo efektyvumo ir pagrindinių deginių emisijos komponentų palyginamoji analizė. Tyrimų tikslas yra ištirti galimybę reaktyvinius F-34 degalus panaudoti antžeminės karinės technikos tiesioginio įpurškimo dyzeliniuose varikliuose ir išstudijuoti reaktyvinių F-34 degalų ir 0.12vol% 2-ethylhexyl nitrato cetano priedais apdorotų reaktyvinių F-34 degalų įtaką savaiminio užsiliepsnojimo periodo trukmei, degimo procesui, variklio darbo efektyvumui ir deginių emisijos rodikliams.

Reaktyviniais JF ir JF+0.12vol% degalais maitinamas variklis išvysto maksimalų dujų slėgį cilindre 4.3% ir 2.8% mažesnį, esant 1400 min^{-1} sūkiams, ir 2.5% bei 5.7%, esant sūkiams 2200 min^{-1}, palyginti su 86.6 MPa ir 82.5 MPa normalaus dyzelinio variklio išvystomu slėgiu. Pasėkoje apdorotais reaktyviniais degalais maitinamas variklis veikia minkščiau ir, esant vardiniams 2200 min^{-1} sūkiams, maksimalus dujų slėgio padidėjimas cilindre sumažintas 9.4% palyginti su 15.9 barų/^{o} normalaus variklio naudojimo atveju. Minimaliosios lyginamosios degalų sąnaudos (bsfc) reaktyvinių degalų F-34 ir priedais apdorodų F-34 degalų sumažėjo 4.8% ir 3.5% esant 1400 min^{-1} sūkiams ir padidėjo 2.7% ir 3.7%, esant 2200 min^{-1} sūkiams, palyginti su 249.5 g/kWh ir 251.8 g/kWh normalaus variklio sąnaudomis.

Maximali NO emisija, panaudojus reaktyvinius degalus JF ir JF+0.12vol%, sumažėjo 11.5% ir 7.0%, esant 1400 min^{-1}, ir 17.1% bei 17.3%, esant 2200 min^{-1} sūkiams, palyginti su 1705 ppm ir 1389 ppm sklindančių iš normalaus dyzelinio variklio. Maksimalios CO emisijos taip pat sumažėjo 39.3% ir 16.8% palyginti su 4988 ppm, kurias skleidžia normalus dyzelinis variklis, veikiantis 1400 min^{-1} sūkiais. Variklio sūkius padidinus iki 2200 min^{-1}, ekologinis reaktyvinių degalų F-34 naudojimo efektas sumažėjo iki minimumo ir CO emisija plačiame apkrovų diapazone išliko beveik nepakitusi ir padidėjo 2.5% ir 3.0%, atitinkamai, palyginti su maksimalia (100%) apkrova veikiančio dyzelinio variklio emisija. Nesudegusių angliavandenilių HC emisija taip pat buvo 78.3% ir 58.8% mažesnė, dirbant maža ir maksimalia apkrova palyginti su 230 ppm ir 1820 ppm sklindančių iš normalaus dyzelinio variklio, veikiančio 1400 min^{-1} sūkiais. Deginių dūmingumas reaktyvinių degalų JF ir JF+0.12vol% naudojimo atveju visame apkrovų diapazone išliko mažesnis ir jo maksimaliosios reikšmės santykinai sumažėjo 14.6% ir 8.1% palyginti su 94.9% 1400 min^{-1} dažniu veikiančiu dyzeliniu varikliu. Variklio eksperimantiniai bandymai parodė, kad kariniai F-34 degalai, kaip potencialus tradicinių dyzelinių degalų pakaitalas, yra ekologiškai švaresni ir siūlo geresnę degalų ekonomiją bei mažesnius kenksmingos emisijos kiekius, įskaitant NO, NO_2, NO_x, CO, HC ir deginių dūmingumą.

Dyzelinis variklis, reaktyviniai degalai, savaiminis užsiliepsnojimas, degimas, degalų sąnaudos, deginių emisija, dūmingumas

Г. Лабяцкас, С. Славинскас

ПРИМЕНЕНИЕ РЕАКТИВНОГО ТОПЛИВА В ДИЗЕЛНОМ ДВИГАТЕЛЕ

Резюме

В статье анализируются рабочие показатели и эмиссия отработавших газов четырехтактного, четырёхцилиндрового, дизельного двигателя работающего поочередно на нормальном 95vol% (класс С) + 5vol% RME дизельном топливе (DF), также реактивном F-34 топливе (JF) и топливе F-34 обработанном цетанновой присадкой (JF+0.12vol%). Целью работы являлось исследование возможности применения военного реактивного топлива F-34 в наземных дизельных двигателях с непосредственным впрыскиванием и изучение влияния реактивного топлива F-34 и цетанновой присадкой (0.12vol%) обработанного топлива F-34 на период самовоспламенения, сгорание, рабочие показатели двигателя и эмиссию отработавших газов.

В случае применения реактивного топлива JF и JF+0.12vol% максимальное давление газов в цилиндре уменьшилось на 4.3% и 2.8% при частоте вращения 1400 мин$^{-1}$, и 2.5% и 5.7% при частоте вращения 2200 мин$^{-1}$ по сравнению с соответствующими показателями 86.6 MPa и 82.5 MPa базового двигателя. На реактивном топливе дизельный двигатель работал более мягко при частоте вращения 2200 мин$^{-1}$ и максимальный прирост давления в цилиндре уменьшился на 9.4% по сравнению с нормальным двигателем (15.9 бар/^{o}). При работе на реактивном топливе F-34 и цетанновой присадкой обработанном F-34 топливе эффективный удельный расход топлива (bsfc) уменьшился на 4.8% и 3.5%, и увеличился на 2.7% и 3.7% при частоте вращения 2200 мин$^{-1}$ по сравнению с нормальным 249.5 г/кВт и 251.8 г/кВт расходом дизельного топлива.

При работе двигателя на реактивном топливе JF и JF+0.12vol% максимальная NO эмиссия оказалось меньшей на 11.5% и 7.0% при частоте вращения 1400 мин$^{-1}$, и на 17.1% и 17.3% при частоте вращения 2200 мин$^{-1}$ по сравнению с соответствующей 1705 ppm и 1389 ppm эмиссией производимой дизельным топливом. Максимальная CO эмиссия также уменьшилось на 39.3% и 16.8% по сравнению с 4988 ppm, производимыми нормальным дизельным двигателем при частоте 1400 мин$^{-1}$. На номинальной 2200 мин$^{-1}$ частоте вращения, экологический эффект от применения реактивного топлива F-34 уменьшился до минимума и CO эмиссия в широком диапазоне нагрузок практически не изменилось и увеличилось на 2.5% и 3.0%, соответственно, по сравнению с дизельным двигателем работающем на полной (100%) нагрузке. Эмиссия несгоревших углеводородов HC также была на 78.3% и 58.8% меньшей при малой и полной нагрузке по сравнению с 230 ppm и 1820 ppm производимыми нормальным двигателем при частоте вращения 1400 мин$^{-1}$. Дымность отработавших газов от реактивного топлива JF и JF+0.12vol% оказалось меньшей во всем нагрузочном диапазоне, и её наибольшие значения уменьшились на 14.6% и 8.1% по сравнению с 94.9% производимыми дизельным двигателем при частоте 1400 мин$^{-1}$. Экспериментальные исследования показали, что реактивное F-34 топдиво, как потенциальный заменитель традиционного дизельного топлива, является экологически более чистым и обеспечивает лучшую экономию топлива при меньших выбросах вредных веществ, включая NO, NO_2, NO_x, CO, HC и дымность отработавших газов.

Дизельный двигатель, реактивное топливо, самовоспламенение, сгорание, удельный расход топлива, эмиссия и дымность отработавших газов