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FUELLING COMPRESSION IGNITION ENGINE BY MINERAL DIESEL FUEL MIXTURE WITH SYNTHETIC HYDROCARBONS

ZASILANIE SILNIKA O ZAPŁONIE SAMOCZYNNYM MIESZANINAMI MINERALNEGO OLEJU NAPĘDOWEGO Z SYNTETYCZNYMI WĘGLOWODORAMI

WINCENTY LOTKO[1], KAMIL ŁODYGOWSKI[2]
Kazimierz Pulaski University of Technology and Humanities in Radom

Summary

This article presents aspects related to usage of prospective bio-mixture, which consists of mineral diesel fuel and synthetic hydrocarbons, as a new component of fuel, in order to fulfill the requirements of the National Index Target. Research on the new formula of the fuel was conducted on new-generation, compression ignition engine quipped with common rail fuel injection. Research was conducted in conditions of external velocity performance analysis specifications for defined rotational speed of crankshaft and at full load. Two mixtures of fuel consisting of 5% and 10% (vol/vol) synthetic hydrocarbons were used in the experiment. Synthetic fuel is a result of catalytic conversion of bio-ethanol into hydrocarbons mixture which is realized according to ETG technology. The resultant oil fraction is a mixture of hydrocarbons which mix at any ratio with petroleum hydrocarbons, entirely free of benzene, alcohols, sulfur, phosphorus and metals. The aim of performing the ecological

[1] Kazimierz Pulaski University of Technology and Humanities in Radom, The Faculty of Mechanical Engineering, Machine and Vehicles Operation Institute, Al. Bolesława Chrobrego 45, 26-600 Radom, Poland

[2] Kazimierz Pulaski University of Technology and Humanities in Radom, The Faculty of Mechanical Engineering, Machine and Vehicles Operation Institute, Al. Bolesława Chrobrego 45, Radom, Poland; e-mail: kamil.lodygowski@tlen.pl

analysis of the compression ignition engine running on fuel with synthetic addition, was registering the concentration of toxic exhaust (among others HC, CO, NO_x) and gases regarded as greenhouse gases (CO_2) during the study. Fuels with synthetic addition were found to be less damaging to the environment in comparison to conventional ones, while increasing engine power.

Keywords: biofuel, synthetic fuel, internal combustion engine

Streszczenie

W artykule przedstawione zostały zagadnienia związane z zastosowaniem perspektywicznej biomieszaniny składającej się z mineralnego oleju napędowego oraz syntetycznych węglowodorów, jako nowego składnika paliw motorowych, celem spełnienia wymagań NCW (Narodowy Cel Wskaźnikowy). Badania nad nową formułą paliwa zostały zrealizowane na nowej generacji silniku o zapłonie samoczynnym wyposażonym w zasobnikowy układ zasilania typu common rail. Badania wykonane były w arunkach prędkościowych charakterystyk zewnętrznych dla określonych wartości prędkości obrotowych wału korbowego i pełnych obciążeń. W eksperymencie użyto dwóch mieszanin paliwa zawierającego 5% oraz 10% (vol/vol) węglowodorów syntetycznych. Paliwo syntetyczne jest wynikiem procesu katalitycznej konwersji bioetanolu do mieszaniny węglowodorów, realizowanego według technologii ETG. Otrzymana frakcja olejowa jest mieszaniną węglowodorów mieszającą się w dowolnym stosunku z węglowodorami ropopochodnymi, całkowicie pozbawioną benzenu, alkoholi, siarki, fosforu i metali. Celem dokonania analizy ekologicznej silnika spalinowego o zapłonie samoczynnym zasilanym paliwem z dodatkiem syntetycznym podczas badań było rejestrowane stężenie toksycznych składników spalin (m. in. HC, CO, NO_x) oraz gazów uznawanych za cieplarniane (CO_2). Wykazano, że paliwa z dodatkiem syntetycznym cechują się mniejszą degradacją środowiska przy jednoczesnym wzroście mocy silnika w stosunku do zastosowania konwencjonalnych paliw.

Słowa klucze: biopaliwa, paliwa syntetyczne, silniki spalinowe

1. Introduction

Despite its numerous flaws, internal combustion engine still prevails as the power source for motor vehicles. Today the key determinant in development studies on internal combustion engines is their ecological aspect, i.e. reducing emission of harmful substances to the minimum possible [6].

Research on usage of alternative fuels for internal combustion engines, for instance [2] [3] [4] [5], is constantly conducted. Tests were carried out on fuels such as: liquefied petroleum gas (LPG), natural gas (CNG and LNG), vegetable oils and their esters, as well as alcohol fuels (methanol, ethanol, butanol).

Synthetic fuels are characterized by less negative environmental impact than petroleum fuels. Obtaining long-chain aliphatic hydrocarbons, which are raw materials for production of motor fuel, has been the subject of development studies and research for a long time. Research in this field is constantly conducted in domestic and foreign research centers.

Use of a mixture consisting of synthetic fuels and mineral diesel fuel is justified especially in the economic aspect. Production of synthetic fuels is more expensive, and as a result, less profitable on a large scale.

Use of synthetic additives in fuel contributes to reduction of harmful impact on natural environment. When compared to mineral diesel fuel, synthetic fuel comprises much smaller and simpler molecules. Such structure contributes to their more complete and cleaner combustion. Splitting of small molecules emits less intermediate compounds which cause the presence of adverse substances in exhaust gases [1, 7].

The article presents results of a study on fuelling the compression ignition engine AVL 5402 with mixtures of diesel fuel with synthetic carbohydrates obtained by the ETG technology. They are referenced to the case of fuelling the same engine by diesel fuel obtained by processing crude oil and available in gas stations. In order to analyze the influence of the addition of compression ignition combustion engine on improving its environmental performance, concentrations of harmful exhaust elements (HC, CO, NO_x, SO_2), greenhouse gases (CO_2) and fuel consumption were registered.

2. Selected fuel physical and chemical properties

During the research, combustion engine AVL was working according to velocity performance specifications and was fuelled by three types of fuel: diesel fuel compliant with the PN-EN 590:2011 standard and mixtures of mineral diesel fuel with synthetic carbohydrates.

Fuels used in the research were composed using the following volume fraction of components mixed at the ratio (%V/V) with mineral diesel fuel:

- 95% ON + 5% SYNON – identified as 5SYNON
- 90% ON + 10% SYNON – identified as 10SYNON

Those mixtures were clear, without sediment. They were stored for a few days in a room temperature and showed no signs of delamination.

Diesel fuel was produced by Polski Koncern Naftowy Orlen S.A. It was a carbohydrate fuel dedicated to fuelling high speed compression ignition engines, in which the content of FAME methyl esters of fatty acids was up to 7% of the volume (%V/V). It was characterized by low content of aromatic hydrocarbons, low content of solid impurities and increased cetane number [8]. Another fuel used in the study was synthetic fuel. Synthetic hydrocarbons are remains of separation, in the temperature of up to 210 ^oC, of naphtha fraction from the liquid product of catalytic conversion of alcohols into hydrocarbons mixture, realized according to ETG technology, which was developed by EKOBENZ Sp. z o.o. in Lublin (patent P.408081 pending). The process of converting ethanol was conducted in temperature between 270 - 350^{o}C under pressure of 2 MPa with use of aluminosilicate type catalyzer. The obtained oil fraction is a collection of hydrocarbons, mixing at any ration with petroleum hydrocarbons, entirely free from benzene, alcohol, sulfur, phosphorus and metals.

Table 1 shows a comparison of selected physical and chemical properties of fuels, which were the subject of the study. Defining basic physical and chemical properties of fuels was done by means of laboratory tests according to specified standards.

Table 1. Basic physical and chemical properties of motor fuels used in the study

Fuel	Net calorific value [MJ/kg]	Ignition temperature [ºC]	Cetane indicator [-]	Carbon residue %(m/m)	Density [kg/m³]	Viscosity [mm²/s]
Diesel fuel	42,91	63	51	0,19*	842	2,48
5SYNON	42,84	64	50	0,16*	844	2,48
10SYNON	42,80	62	49	0,11*	845	2,49

3. Test bench

The research was conducted on engine test bench in the Vehicle and Machine Operation Institute of the University of Technology and Humanities in Radom. The test bench was equipped with a AVL 5402 single cylinder compression ignition engine and exhaust component analysis system.

Figure 1 presents the test bench. The tested engine was a single cylinder compression ignition unit with a common rail system of fuel injection. The common rail system enabled to examine fuelling the engine with multiple fuel injections in a work cycle. The control system enabled to divide the fuel dose and to adjust the angle of injection in a wide range. Technical specification is presented in Table 2.

4. Research methodology

All measures were done for external velocity performance analysis for selected rotation speeds of crankshaft. At every sampling point the engine worked at full load (full dosing of fuel).

The engine had the nominal settings of fuel injection pressure value (180 MPa) and the angle of dynamic start of fuel pumping α_{dpt} according to the engine control map, which was designed for the needs of this study. In addition, apart from measuring consumption of fuel using volumetric technique, the amount of CO, CO_2, NO, NO_x, HC, SO_2 in exhaust was registered during the study.

Fig 1. General view of test bench

Table 2. Technical specification of AVL 5402 engine

Parameter	Value
Number and arrangement of cylinders	1-cylinder, vertical
Diameter of cylinder [mm]	85,01
Piston stroke [mm]	90
Cylinder capacity [cm^3]	511
Compression ratio	17,5
Engine type	5402 AVL
Number of valves in one cylinder	4
Pressure in Common Rail [MPa]	180
Fuel injector system	directly to cylinder
Fuel injector system type	Common Rail - Bosch
Exhaust gas recirculation valve	closed
Charge	none

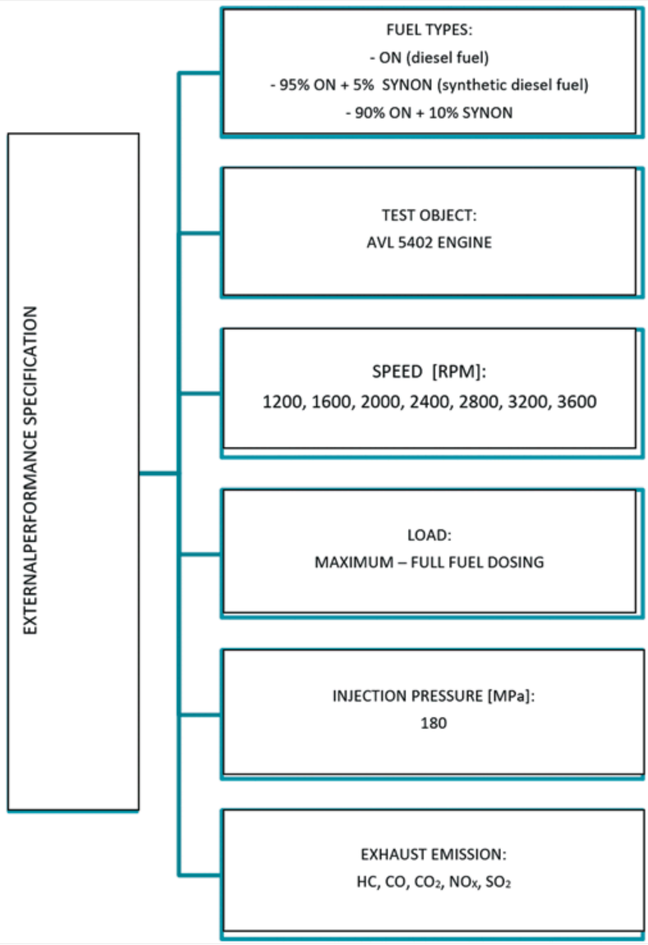

Fig. 2. Chart presenting the scope of performed research

5. Research results and discussion

Figures 3 and 4 show respectively the effective power and torque which the examined engine achieved with particular fuel types. In comparison to mineral fuel, a power increase (up to 5% for 10SYNON) can be seen for fuels with synthetic additive.

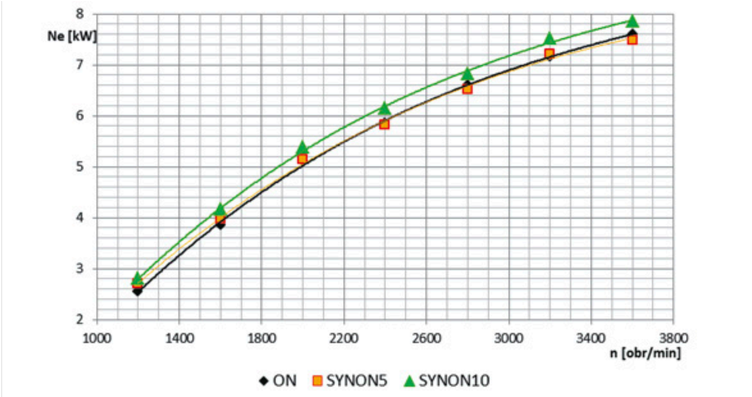

Figure 3. Comparison of effective power of AVL engine fuelled by mineral diesel fuel and mixtures of diesel fuel with synthetic diesel fuel, working at full load

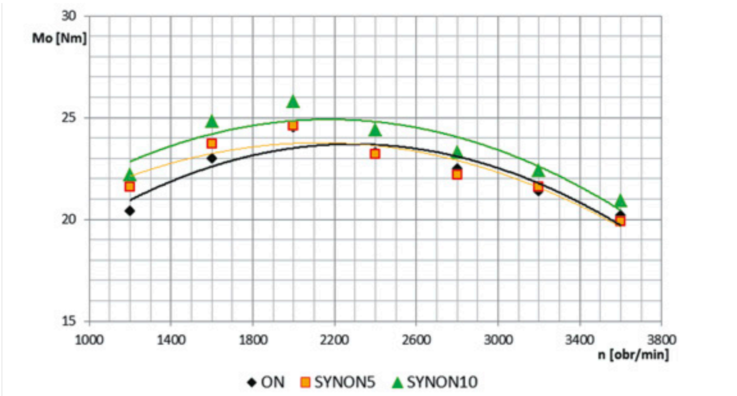

Figure 4. Comparison of torques of an AVL engine running on mineral diesel fuel and the mixture of diesel fuel and synthetic diesel fuel, working at full load

Values of CO, CO_2, HC, NO_x and SO_2 in exhaust were registered at preparation of external performance specification. Recorded study results are presented below in form of diagrams. Fuel composition, in this case the addition of synthetic hydrocarbons, was found to have a considerable impact on emission level of particular components.

Carbon dioxide (CO_2), carbon monoxide (CO) and not fully combusted carbohydrates C_mH_n i aldehydes C_mH_nO (indicated with the common symbol HC) are among the products of incomplete combustion which occurs in the real combustion engine.

The increase in concentration of carbon dioxide with the increased proportion of synthetic fuel is the result of different composition of carbohydrates comprising the fuel. Concentration of carbon dioxide in exhaust increases with the amount of synthetic fuel used (up to 9% in fuelling the 10 SYNON engine), which indicates more complete combustion of mixture in cylinder. Lower concentration of non-combusted hydrocarbons in the cylinder also confirms the previous finding (Fig. 7).

Concentration of carbon monoxides in exhaust gases emitted by compression ignition engines is very low due to the fuel combustion in excessive air. However, the emission may increase as a result of disturbance of combustion process caused by inappropriate physical and chemical properties of the fuel. Analysis of the diagram in the Figure 6 shows that in case of the tested fuels there are no significant changes in concentration of carbon monoxide in exhaust, which confirms that physical and chemical properties of used fuels are appropriate.

Diagrams presented in the Figure 7 show the relation between the concentration of accumulated incompletely combusted HC carbohydrates and the rotary speed of engine crankshaft. Exhaust of the engine fuelled by 10 SYNON was found to show a decrease in HC concentration by more than 40%, compared to fuelling by mineral diesel fuel.

Generation of nitric oxide is caused by the sudden process of oxygen atoms bonding with nitrogen in high temperatures. With the increased proportion of synthetic fuel, the nitric oxide concentration in exhaust decreased by 20% (NO) and by 17% (NO_x) for 10 SYNON in relation to ON (Fig. 8), which indicated lower temperature of flame during combustion.

Sulfur dioxide SO_2 is a result of contamination of fuel with sulfur. Thanks to enforcing the limitation of sulfur content by PN-EN 590 standard, diesel fuel combustion no longer emits as much sulfur oxides into the atmosphere as before. Synthetic fuels, due to their composition, emit less sulfur dioxide into the atmosphere, which is shown in the diagram in the Figure 9.

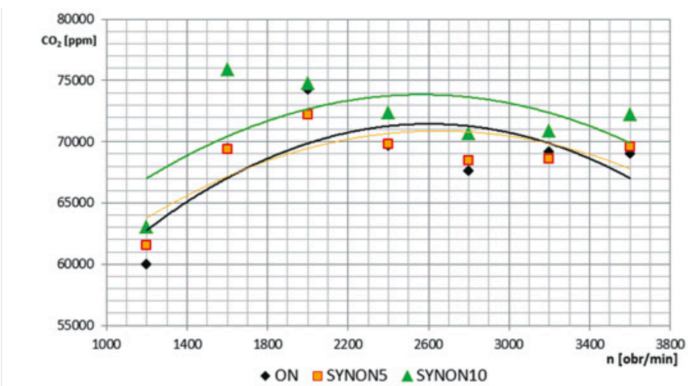

Fig. 5. Comparison of CO_2 concentration in exhaust from AVL engine which is fuelled by mineral diesel fuel and the mixtures of diesel fuel with synthetic hydrocarbons, working at full load

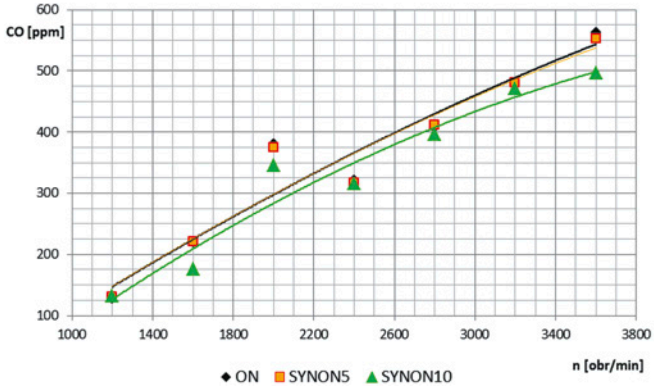

Fig. 6. Comparison of CO concentration in exhaust of AVL engine fuelled by mineral diesel fuel and mixtures of diesel fuel with synthetic hydrocarbons, working at full load

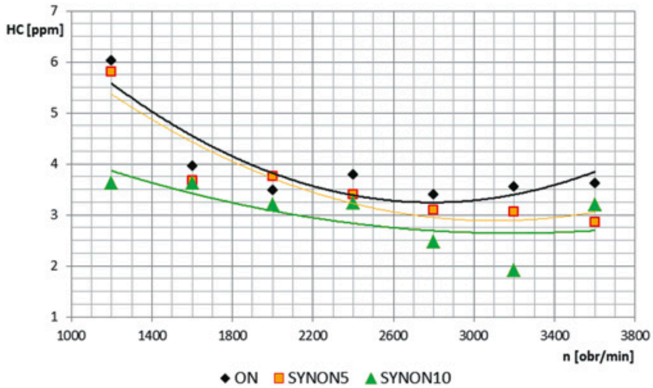

Fig. 7. Comparison of HC concentration in exhaust of AVL engine fuelled by mineral diesel fuel and mixtures of diesel fuel with synthetic hydrocarbons, working at full load

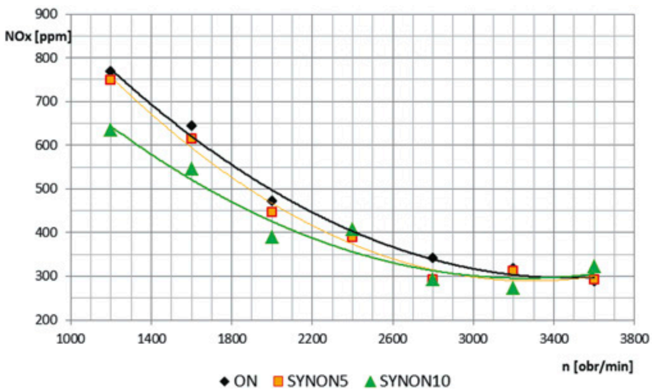

Fig. 8. Comparison of NO_x concentration in exhaust of AVL engines fuelled by mineral diesel fuel and mixtures of diesel fuel with hydrocarbons, working at full load

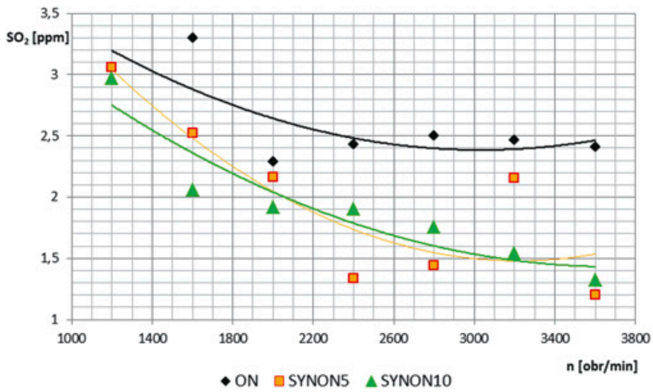

Fig. 9. Comparison of SO_2 concentration in exhaust of AVL engines fuelled by diesel fuel and mixtures of diesel fuels with synthetic hydrocarbons, working at full load

6. Conclusions

Conducted tests and analysis of results led to the following conclusions:

1. The conducted study confirmed that mixtures of mineral diesel fuel with synthetic hydrocarbons can be used to fuel compression ignition engines.
2. An increase of power and torque by 5% was found in engines fuelled by the new kind of fuel.
3. Adding even small (10% v/v) dose of synthetic fuel leads to decrease of carbon monoxide concentration (up to 12%), sulfur oxides (up to 45%), hydrocarbons (up to 40%) as well as nitrogen oxides (up to 17%) in exhaust.
4. It was shown that fuel mixed with synthetic hydrocarbons can be considered as an eco-fuel.
5. Use of new kind of fuel can be beneficial not only in the ecological aspect, but also for the economic sector.
6. Obtained results justify the need for conducting further research enabling assessment of ecological parameters of engines running on these fuels.

The above mentioned conclusions are the basis for drawing the general conclusion: fuelling of compression ignition engine by the new kind of fuel (mixture of mineral diesel fuel with synthetic hydrocarbons) has a positive impact on increasing power and torque of an engine, while decreasing the concentration of toxic components in exhaust.

The full text of the article is available in Polish online on the website http://archiwummotoryzacji.pl.

Tekst artykułu w polskiej wersji językowej dostępny jest na stronie http://archiwummotoryzacji.pl.

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