ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0012.2861

COMBUSTION OF MIXTURE OF DIESEL FUEL WITH GASOLINE IN A COMPRESSION IGNITION ENGINE

Wojciech Tutak, Arkadiusz Jamrozik

Czestochowa University of Technology
Faculty of Mechanical Engineering and Computer Science
Armii Krajowej Av. 21, 42-201 Czestochowa, Poland
tel.:+48 34 3250555, fax: +48 34 3250507
e-mail: tutak@imc.pcz.pl

Abstract

Paper presents results of experimental investigation of combustion process of diesel-gasoline blend in compression ignition direct injection engine. The researches were conducted for constant load of engine at constant rotational speed. Operating parameters of engine powered with diesel-gasoline blend were at the same level as for engine powered by pure diesel fuel. The preliminary study was conducted using CFD modelling. Based on encouraging modelling results preliminary experimental research was carried out. It turned out that it is possible to co-burning diesel with the gasoline as a blend. A mixture of 20, 40 and 60% of gasoline with diesel was used. It was concluded that an increase in gasoline fraction in blend causes delay of start of the combustion process. The homogeneity of the fuel-air mixture was improved due to longer ignition delay, which is accompanied by higher values of pressure rise rate. With 20 and 40% of gasoline fraction causes higher peak pressure compared to reference fuel-burning ware obtained. Up to 40% of gasoline fraction, the BSFC was kept at the same level as for reference fuel. It was observed that with the increase in gasoline fraction up to 40% NOx emission increased as well. Based on the carried out tests it can be stated that it is possible to co-burn gasoline with diesel in a compression ignition engine while maintaining the invariable engine operating parameters and exhaust emissions.
Keywords: *combustion, engine, diesel, gasoline, combustion phases*

1. Introduction

Compression ignition engines are responsible for large harmful emission, which contributes to the increase in the greenhouse effect. These engines are still used in various machines and cars due to relatively high efficiency and reliability. Currently are conducted researches on the use of alternative fuels to power these engines [1-3]. In the available literature in are works on the use of gasoline as a fuel for powering an auto ignition engine. Of course, this is not a typical alternative fuel; it is still oil-based fuel, although alternative to diesel oil.

In practice, there are two ways of co-combustion of more than one fuel in CI engine. The first way is to produce a blend of diesel fuel with other fuel and then bring the mixture to the engine, using a typical supply system for a diesel engine. The biggest difficulty is that large percentages of alternative fuel do not form a stable mixture with diesel fuel. Blends are not stable and separate in the presence of trace amounts of water. In such a power system, it is difficulty to change the ratio of diesel/other fuel. The second way is dual fuel mode in which fuels are delivered to engine separately [4, 5]. Conventional fuel for CI engine is delivered by direct injection system and alternative fuel is injected into intake port. The ignition process is controlled by the injected dose of diesel fuel [20]. This requires the addition of an injector, along with a separate fuel tank, lines and control system.

In the paper [6] authors conducted experimental and simulation study to improve the fuel efficiency of compression ignition engine using a gasoline-diesel blended fuel. The blended fuel was directly injected into the cylinder with various blending ratios. Combustion and emission characteristics were investigated to describe the effects of gasoline ratio on fuel blend. Authors showed that the advantages of gasoline-diesel blend fuel combustion in CI engine, high thermal efficiency and low emission. They stated that the increase in gasoline fraction in blend causes increase in ignition delay (ID) and maximum pressure rise rate. The biggest advantage was decreasing soot emission up to 90% compared to the conventional diesel fuel. Effect of gasoline fraction in blend with diesel fuel on combustion parameters were investigated and presented by authors of paper [7]. They used pure diesel and its blend with 10%, 20%, 30% and 40% gasoline at an engine constant speed under 10%, 50% and 100% loads. Authors stated that the ignition delay time is extended by increasing the ratio of gasoline in blend fuels. The increase in ignition delay had diverse effects on engine performance for different engine loads. At low load, pure diesel condition achieves a better performance; in contrast, a better performance could be realized by blend fuels at medium and high loads, though a slightly higher NOx emission level [7]. Authors of paper [8] presented results of combustion effect of gasoline/diesel blended fuel composed of diesel fuel with gasoline as additives in volume basis, on combustion, fuel economies, and exhaust emissions. The results indicated that with the fraction of gasoline increasing in blends, the ignition delay was increased and the combustion phasing was retarded with the common injection timing. Additionally they stated that this led to a significant increase of premixed burning phase, which was in favour of smoke reduction; although, too much gasoline might be adverse to fuel consumption [6, 7]. An optimum combustion phasing was identified, leading to a higher thermal efficiency and better-premixed combustion with blended fuels. Authors of the paper [9] investigated the auto-ignition processes in RCCI combustion conditions, using gasoline and diesel as low and high reactivity fuels using dual-fuel mode. As the diesel/gasoline fuel ratio was reduced, the ignition delay increased extending the mixing time and the first combustion stage was lowered while the second one was enhanced [10]. The combustion phasing of co-combustion of diesel and gasoline blend was investigated and presented in the paper [11]. Authors also stated that ID increases with the gasoline content in the blend, and generally increases the premixed phase of combustion process. The combustion duration (CD) was not noticeably changed. The change in injection timing affected combustion phasing but not ignition delay directly. Emission characteristics of gasoline-diesel fuel were investigated by authors [12]. They stated that that changes in fuel composition and engine parameters affect ignition delay and global equivalence ratio, which are closely tied to HC and CO emissions, respectively. The methods that extend ignition delay, such as increasing EGR rate, increasing gasoline proportion in fuel blends, or reducing intake pressure, cause increased HC emissions. In contrast, for most cases, CO emissions are dominated by global equivalence ratio, which is mainly adjusted by EGR and intake pressure.

The motivation of the undertaken tests was to check what percentage of gasoline in blend with diesel fuel is accepted by CI engine. In the literature, there are works dealing with this issue but in my opinion, this problem should be developed.

2. Test stand and setup

In the study used the 1-cylinder direct injection natural aspired compression ignition engine. Tests conducted at a constant full load and angle of fuel injection and constant rotational speed equal to 1500 rpm. Detailed engine specifications are presented in Tab. 1. The engine was air-cooled. A piezoelectric pressure sensor was installed in the cylinder head for measurement of the in-cylinder pressure. Fuel consumption was determined on the basis of volumetric measurement equipment. All the experiments were performed at steady state condition by stabilizing the engine operating conditions for 5-10 min depending on the operating conditions. During the tests recorded 200 consecutive engine cycles with resolution 1 deg of CA. It was recorded simultaneously: rotational speed of engine, air, and fuel consumption, air temperature, fuel temperature, exhaust gas temperature, ambient temperature, and pressure.

The study was conducted on the test bench, which included the following elements:

- test engine 1CA90 adapted for a multi-fuels powering,

- exhaust gas analyser: THC, CO, CO_2, O_F – Bosch BEA 350: THC: range 0-9999 ppm vol. accuracy: 12 ppm vol; NO_X: range 0-5000 ppm accuracy: 10 ppm; CO: range 0-10 %vol. accuracy: 0.06% vol; CO2: range 0-18% vol. accuracy: 0.4% vol; O_F: range 0-22% vol. accuracy: 0.1% vol; λ: range 0.5-9.999 accuracy: 0.01.

Tab. 2. Main engine parameters

Parameter	Value
Number of cylinders	1
Displacement volume	0.573 dm^3
Bore	90 mm
Stroke	90 mm
Compression ratio	17:1
Rated power	7 kW
Crankshaft rotational speed	1500 rpm
Injection pressure	21 MPa

Indication system:

- digital measurement system for acquisition and analysis of fast changing data,
- measuring system for fuel and air consumption.

Digital measurement system for data acquisition:

- piezoelectric pressure transducer, Kistler 6061 SN 298131, sensitivity: ±0.5%,
- charge amplifier, Kistler 5011B, linearity of FS <±0.05%,
- data acquisition module, Measurement Computing USB-1608HS – 16 bits resolution, sampling frequency 20 kHz,
- computer PC,
- crank angle encoder, resolution 360 pulses/rev.

In Tab. 2 are presented fuels parameters. Normal diesel fuel and 95-octane gasoline were used.

Tab. 2. Fuels properties

Parameter	Gasoline	Diesel
Cetane number	-	51
Octane number	95	0
Autoignition temperature [°C]	340-350	254 – 300
Density w 15°C [kg/m^3]	737	835
Viscosity at 40°C [mm^2/s]	0.6 – 1.0	2.72
Lower heating value [MJ/kg]	43	42.5
Heat of evaporation [kJ/kg]	315 – 350	270 – 375
Stoichiometric air-fuel ratio	14.5	14.7

The heat release is determined on the basis of the recorded in-cylinder pressure data according to piston position. The basis for this analysis is the first low of the thermodynamics and the equation of state. After some simplification, it is determined well-known equation for dQ/dφ:

$$\frac{dQ}{d\varphi} = \frac{1}{\kappa - 1}\left[\kappa p \frac{dV}{d\varphi} + V \frac{dp}{d\varphi}\right], \tag{1}$$

where:
κ – the ratio of specific heats,
V – the cylinder volume,
p – in cylinder pressure.

The instantaneous cylinder volume is determined on the basis of engine geometry. During the analysis not taken into account crevice effect, heat transfer, medium change by injection of fuel that the determined dQ/dφ is termed as the net heat release rate.

The character of compression-ignition engine operation is substantially affected by the pressure rise rate. Parameter dp/dφ indicating the performance of the engine is the indicated mean effective pressure, which is determined on the basis of the instantaneous pressure in the cylinder [19]. Indicated mean effective pressure is one of the factors to characterize combustion engine work in terms of opportunities for reaching desirable high performance.

Instabilities in engine operation concern the combustion process in its macro-scale and can be measured and expressed by the coefficient of variation of indicated mean effective pressure (COV_{IMEP}). In these researches, this factor was determined on the basis of 200 consecutive cycles. The COV_{IMEP} is determined by computing the IMEP from consecutive engine work cycles. It was defined as:

$$COV_{IMEP} = \frac{\sigma_{IMEP}}{(IMEP)_{mean}} \cdot 100, \tag{2}$$

where:
σ_{IMEP} – standard deviation of IMEP.

The mean IMEP was calculated as:

$$(IMEP)_{mean} = \frac{\sum_{i=1}^{i=200} IMEP_i}{200}, \tag{3}$$

where:
i – number engine cycle.

The COV_{IMEP} is directly related to the combustion stability.

3. Results

The preliminary study was conducted using CFD method. Model AVL Fire was used for preliminary tests of the possibility of using diesel-gasoline mixture to power the compression ignition engine [13]. For this purpose, the computational mesh of the combustion chamber was made and after the verification of the model conducted a study.

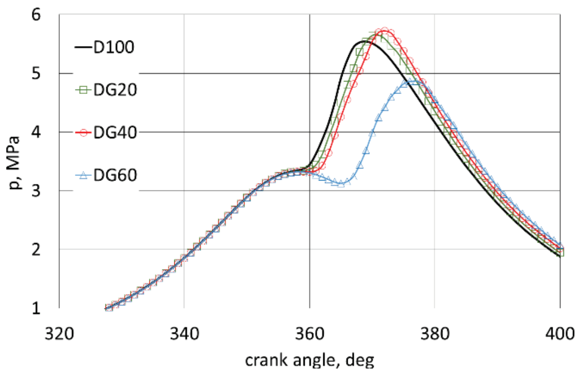

Fig. 1. Pressure traces for preliminary studies – modelling

On the basis of preliminary studies of investigation of gasoline fraction in diesel fuel mixture on combustion process in compression ignition engine concluded that it is possible to co-combustion of these both fuels as blend. Based on results determined the maximum fraction of gasoline in fuels mixture which ensures the correctness of the combustion process for test engine.

In the next order, experimental studies were carried out. The tests of the engine powered by the diesel fuel and gasoline mixture were carried out every 20% v/v.

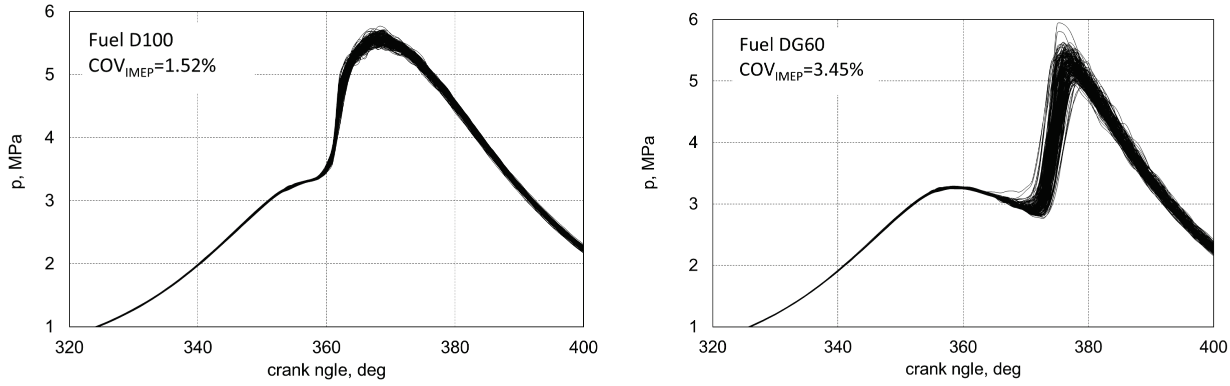

Fig. 2. Cycle variation for engine powered by pure diesel fuel and mixture DG60

Due to similar heating values of both fuels, the energy value of the mixture did not significantly change. In case of burning diesel fuel, the COV_{IMEP} was equal 1.52% and for 60% of gasoline fraction it increased only to 3.45%. The limit fraction of gasoline in mixture was one that which causes clearly visible during the research the uniqueness of the engine cycles (Fig. 2). For IC engine operation, it would be ideally if each successive cycle the same were. This would ensure a very smooth engine running.

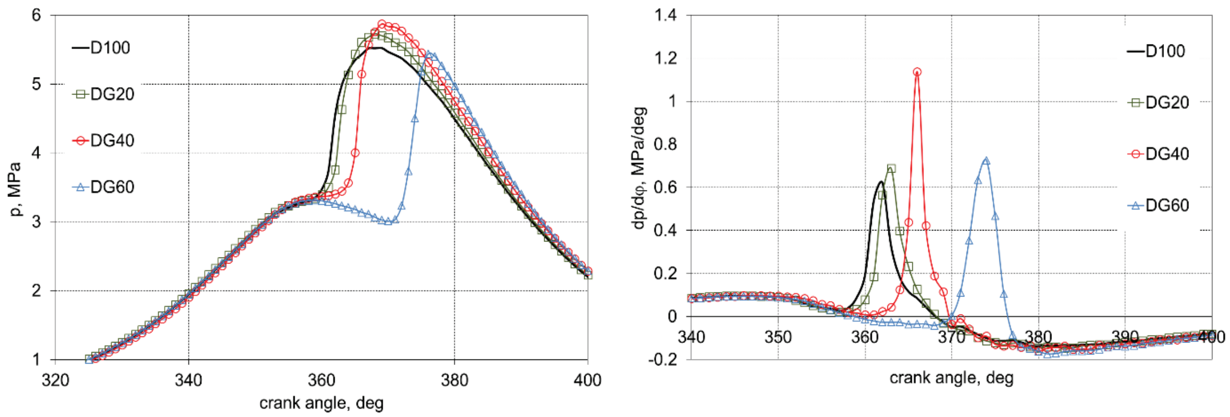

Fig. 3. Pressure curses and pressure rise rate

In Fig. 3 are presented pressure and pressure rise rate for analysed cases. On the basis of presented data can be concluded that the increase in gasoline fraction in blend, the combustion process is initiated later [18]. The homogeneity of the fuel-air mixture was improved due to longer ignition delay, which is accompanied by higher values of pressure rise rate. With 20 and 40% of gasoline fraction causes higher peak pressure compared to reference fuel burning.

With the higher considered gasoline fraction, he combustion process was significantly delayed and peak pressure was equal to value received with diesel fuel burning. Analysing rate of pressure rise it is visible that 40% of gasoline fraction in mixture causes too high value of dp/dφ, which exceeded 1 MPa/deg. The measurement error of IMEP is δ_{IMEP}=2.1% and error of BSFC is δ_{BSFC}=4%.

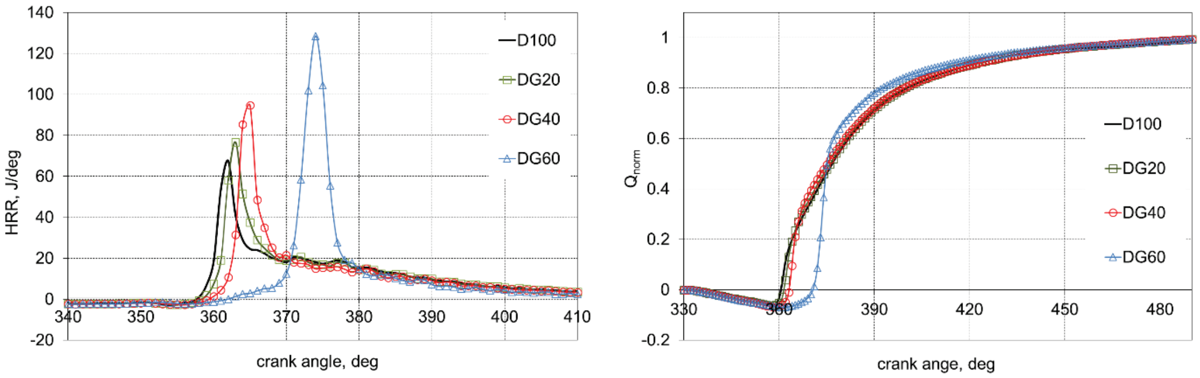

Fig. 4. Heat release rate and normalised heat release

In Fig. 4 are presented results of heat release analysis. With the increase in gasoline fraction in mixture, observed increase in maximum value of heat release rate and this peak value was placed for larger values of degree of CA after TDC. Gasoline participation in burned mixture caused a shorter time of occurrence of the kinetic combustion phase but it shortened the time of occurrence of the kinetic combustion phase, whereas this phase was faster. More fuel was burned in kinetic combustion phase. Up to 40% of gasoline fraction the BSFC was kept at the same level as for reference fuel burning and was equal to 230 g/kWh. In case of 60% of gasoline fraction, the BSFC increased significantly up to 265 g/kWh. It was among others due to higher cycle variation.

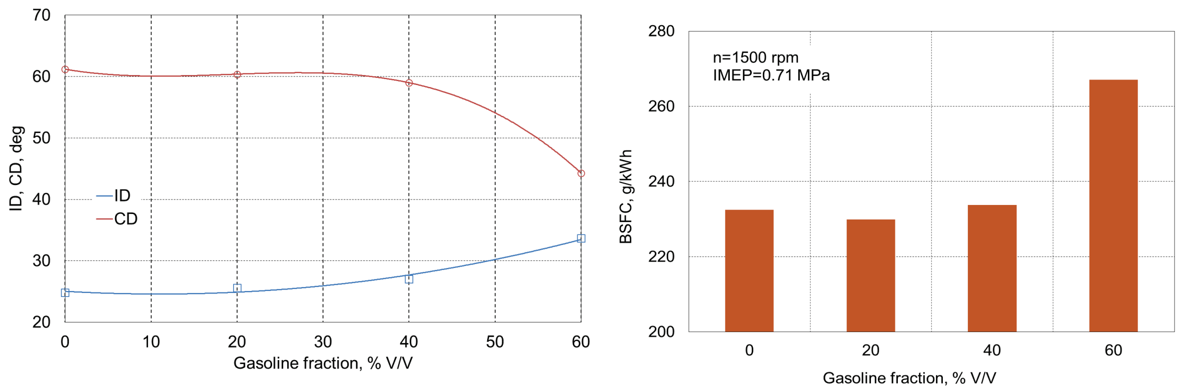

Fig. 5. Combustion phases and brake specific fuel consumption

Analysing the combustion phases, it can be concluded that with the increase in the fraction of gasoline in the fuels mixture, the ignition delay increases mainly due to the poor properties of the auto-ignition of gasoline. Additionally it can be stated that with gasoline participation in blend the combustion duration decreased.

In Fig. 6 are presented results of exhaust gas analysis for various gasoline fraction in fuels mixture. It was observed that with the increase in gasoline fraction up to 40% NOx emission increased as well. It was due to increase in ignition delay, low cetane number of gasoline, which causes rapid combustion process with higher temperature. The cetane number is an important fuel property for diesel engines [14]. It has an influence on engine start ability, emissions, peak cylinder pressure, and combustion noise. Formation of nitrogen oxides is strongly dependent on the in-cylinder temperature, the oxygen concentration, and the residence time of the gases at high temperatures [15].

Nitrogen oxides formation rate in the combustion chamber of an internal combustion engine is due to high temperature in the combustion chamber during premixed combustion phase [16, 17]. Premixed combustion phase can be decreased by injection strategy, which can reduced the temperature. Lower temperature in the combustion chamber causes lower thermal efficiency of the engine and in addition, this can result in increased soot emissions. The THC emissions depend on the combustion quality, engine load, and physical properties of the fuel. There are different mechanisms that affect THC emission in the compression ignition engine. The lowest value of THC emission obtained for 20% of gasoline fraction. It was lower than obtained for engine powered by pure diesel fuel. For two larger fractions of gasoline in mixture THC, emission was higher in comparison with reference fuel burning. CO formation in engines is strongly connected with combustion quality, and tends to increases with insufficient oxygen and incomplete combustion. It is well known from the literature [15], the CO emissions increase especially for fuel-rich mixtures.

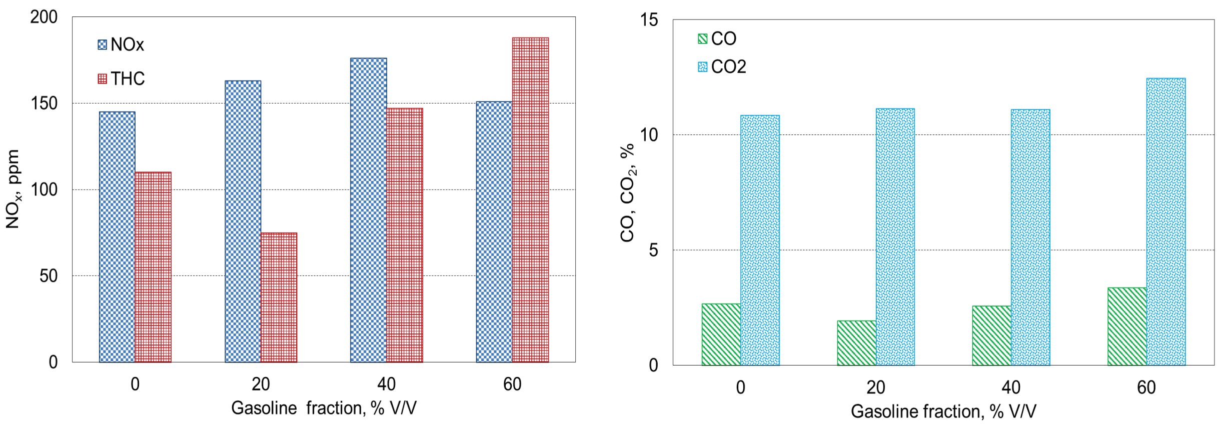

Fig. 6. Emission characteristics

CO emission was kept at the same level and the differences were in range of measurement errors. The highest values of THC and CO emission were associated with an incorrect combustion process and the expressive uniqueness of subsequent engine cycles.

4. Conclusion

The combustion and emissions characteristics of the compression ignition engine powered by diesel-gasoline blend had been investigated experimentally, and the main conclusions are drawn as following:

- with 40% of gasoline fraction in blend obtained the highest value of pressure rise rate exceeding 1 MPa/deg,
- with the increase in gasoline fraction in mixture observed increase in maximum value of heat release rate and peak value was placed for larger values of degree after TDC,
- up to 40% of gasoline fraction the BSFC was kept at the same level as for reference fuel and was equal to 230 g/kWh,
- with the increase in gasoline fraction up to 40% NOx emission increased,
- the lowest value of THC obtained for 20% gasoline fraction in fuels blend.

Based on the carried out tests it can be stated that it is possible to co-burn gasoline with diesel in a compression ignition engine while maintaining the invariable engine operating parameters and exhaust emissions. However, further work is needed to attain a combustion concept useful for the whole engine operating range.

Acknowledgements

The authors would like to express their gratitude to AVL LIST GmbH for providing an AVL FIRE software under the University Partnership Program.

References

[1] Tutak, W., *Bioethanol E85 as a fuel for dual fuel diesel engine*, Energy Conversion and Management, 86, pp. 39-48, 2014.

[2] Jamrozik, A., *The effect of the alcohol content in the fuel mixture on the performance and emissions of a direct injection diesel engine fueled with diesel-methanol and diesel-ethanol blends*, Energy Conversion and Management, 148, pp. 461-476, 2017.

[3] Jamrozik, A., Tutak, W., Pyrc, M., Gruca, M., Kočiško, M., *Study on co-combustion of diesel fuel with oxygenated alcohols in a compression ignition dual-fuel engine*, Fuel, 221, pp. 329-345, 2018.

[4] Luft, S., *A dual-fuel compression ignition engine – distinctive features*, Combustion Engines, 141/2, 33-39, 2010.

[5] Stelmasiak, Z., *Application of alcohols to dual – fuel feeding the spark-ignition and self-ignition engines*, Polish Maritime Research, 3(83), Vol. 21, 86-94, 2014.

[6] Seokhwon, L., Joonho J., Sungwook P., *Optimization of combustion chamber geometry and operating conditions for compression ignition engine fueled with pre-blended gasoline-diesel fuel*. Energy Conversion and Management, 126, pp. 638-648, 2016.

[7] Li, J., Yang, W. M., An, H., Chou, S K., *Modeling on blend gasoline/diesel fuel combustion in a direct injection diesel engine*. Applied Energy, 160, pp. 777-783, 2015.

[8] Jiakun, Du, Wanchen Sun, Liang Guo, Senlin Xiao, Manzhi Tan, Guoliang Li, Luyan Fan, *Experimental study on fuel economies and emissions of direct-injection premixed combustion engine fueled with gasoline/diesel blends*, Energy Conversion and Management, 100, pp. 300-309, 2015.

[9] Benajes, J., Molina, S., García, A., Belarte, E., Vanvolsem, M., *An investigation on RCCI combustion in a heavy duty diesel engine using in-cylinder blending of diesel and gasoline fuels*, Applied Thermal Engineering, 63, pp. 66-76, 2014.

[10] Jamrozik, A., Tutak, W., Gruca, M., Pyrc, M., P*erformance, emission and combustion characteristics of CI dual fuel engine powered by diesel/ethanol and diesel/gasoline fuels*, Journal of Mechanical Science and Technology, Vol. 32, No. 6, pp. 2947-2957, 2018.

[11] Wei Jet Thoo, Arman Kevric, Hoon Kiat Ng, Suyin Gan, Paul Shayler, Antonino La Rocca, *Characterisation of ignition delay period for a compression ignition engine operating on blended mixtures of diesel and gasoline*. Applied Thermal Engineering, 66, pp. 55-64, 2014.

[12] Han, D., Ickes, A. M., Bohac, S. V., Huang, Y., Assanis, D. N., *HC and CO emissions of premixed low-temperature combustion fuelled by blends of diesel and gasoline*. Fuel, 99, pp. 13-19, 2012.

[13] AVL Fire Manual: Combustion 2013. AVL List GmbH Hans-List-Platz 1, A-8020 Graz, Austria.

[14] Kuszewski, H., Jaworski, A., Lejda, K., Ustrzycki, A., Woś, P., *The study of derived cetane number for ethanol-diesel blends*, Combustion Engines, 162(3), 928-932, 2015.

[15] Heywood, J. B., *Internal Combustion Engine Fundamental*, 2nd ed. McGraw-Hill, 2003.

[16] Barik, D. Murugan, S., *Simultaneous reduction of NOx and smoke in a dual fuel DI diesel engine*, Energy Conversion and Management 84, pp. 217-226, 2014.

[17] Pyszczek, R., Schmalhorst, C., Teodorczyk, A., *Numerical investigation on diesel combustion and emissions with a standard combustion model and detailed chemistry*, Combustion Engines, 162(3), 19-33, 2015.

[18] Jankowski, A., *Chosen problems of combustion processes of advanced combustion engine,* Journal of KONES, Vol. 20, No. 3, pp. 203-208, Warsaw 2013.

[19] Kowalski, M., Jankowski, A., *Research performance of novel design of diesel engine,* Journal of KONES Powertrain and Transport, Vol. 24, No. 4, pp. 99-108, Warsaw 2017.

[20] Kowalski, M., Jankowski, A., *Research Performance of Novel Design of Diesel Engine* Journal of KONES, Vol. 24, No. 4, pp. 99-108, Warsaw 2017

Manuscript received 18 January 2018; approved for printing 18 June 2018