Test Stand Research on ICE Engine Powered by an Alternative Fuel

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Abstract. In the article presented were research results on effects of ignition advance angle change on shape of open and closed indicator graphs for a Honda NXH 110 engine powered by alternative fuels, i.e. E85, CNG, biogas and Pb95 petrol. Presented as well was the effect of ignition advance angle on mechanical power and torque figures produced by the engine. The research measurements were performed for engine under full load, on an engine test stand located at Faculty of Automotive and Construction Machinery Engineering, Warsaw university of Technology. Furthermore, the effects of ignition advance angle change on engine's indicated work was presented.

Keywords: Closed-loop pressure diagram · Ignition advance angle (IAA) Compressed natural gas (CNG) · Biogas · Indicated work

1 Introduction

Presently the climate package obligates European Union members to increase: the contribution of renewable energy sources (RES) in the energy of EU market (up to 27% from RES electricity generation structure in the timeframe till 2030 [1–8]), improve the efficiency of processing of the primary energy sources (up to 27% in the timeframe till 2030) and reduce carbon dioxide emission (up to 40% till 2030 as compared to the 1990 levels) [3, 4]. It should be emphasized that the climatic package [1] offers support for the balanced development of distributed generation devices and environmental friendly technologies [4–30]. Distributed generation devices include technologies which produce energy from Renewable energy sources (only electricity generation systems) and cogeneration systems (cogeneration systems in the literature [4] are well known as systems which could combine heat and power generation in the same process). Among different cogeneration systems we can mention i.e. gas engines which could be powered by an alternative fuels (e.g. CNG, LNG, biogas and other biofuels). Generally for micro-installations [4] and emergency power systems the low power combustion engines play a key role.

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In herein work a research study of a low power ICE engine (four stroke Honda NHX 110) powered with Pb95 unleaded gasoline, CNG, biogas and E85 has been presented.

The Sect. 2 presents the used test stand. In Sect. 3 experimental research results of conducted tests have been shown. Section 4 contains main conclusions from the research carried out.

2 Test Stand Description

In Fig. 1(a) the dynamometer test stand placed inside environmental chamber (Fig. 2c) has been presented. The test stand consists of the Honda NHX 110 four stroke internal combustion engine (Fig. 2d), an electrical motor/generator machine, the programmable controller (EMU/ECM – Engine Management Unit/Engine Control Management) [18] – Fig. 2(b), the measurement chain and the controlling system prepared in LabVIEW Software. The ICE engine was equipped with the three-way catalyst.

Moreover, the test stand had dynamometer where the torque was conveyed to the brushless DC electric motor/generator with fixed magnets, operating as a motor/generator). An electrical power was received by such components as the three–phase bridge rectifier (the main parameters: maximum voltage – 400 V, maximum current – 300 A), a transistor module, the resistor with the resistance value of 0.05 Ω, the brushless electrical motor with fixed magnets (the main parameters: resistance: 0.0004 Ω, supply voltage from 30 V to 70 V, rotational speed ratio 150 rpm/V of supply voltage, the maximum rotational speed, corresponding to the maximum supply voltage, it was equal 10500 rpm, power consumption for a motor operating without a load equals 13 A when powered with 20 V current). The transistor module was controlled by using a proprietary microchip controller [19]. The torque from the internal combustion engine's shaft was conveyed to the electric generator while using a drive belt with a toothed (timing) belt (the gear ratio between the ICE engine and an electrical machine was equal i = 1.42). The torque was measured by using L6 N tensometric meter (manufactured by Zemic). The rotation angle of the crankshaft was measured with using a digital 14bit absolute single–turn encoder. The encoder was communicated with the measurement board in SSI standard, it was having the clock frequency of 44.9 kHz, which ensured measurement precision of 0.5 CA for the rotational speed of 3800 rpm, respectively e.g. 1 CA for 7600 rpm.

In Sect. 3 the experimental research results performed at the discussed test stand (Fig. 1) have been presented.

3 Experimental Research Results

Experimental research was conducted for air–fuel equivalence ratio maintained at $\lambda = 1$. The temperature of intake air was equal 299 ± 2 K, the atmospheric pressure was identical for the all measurements, at 1009 hPa. The temperature of the coolant of

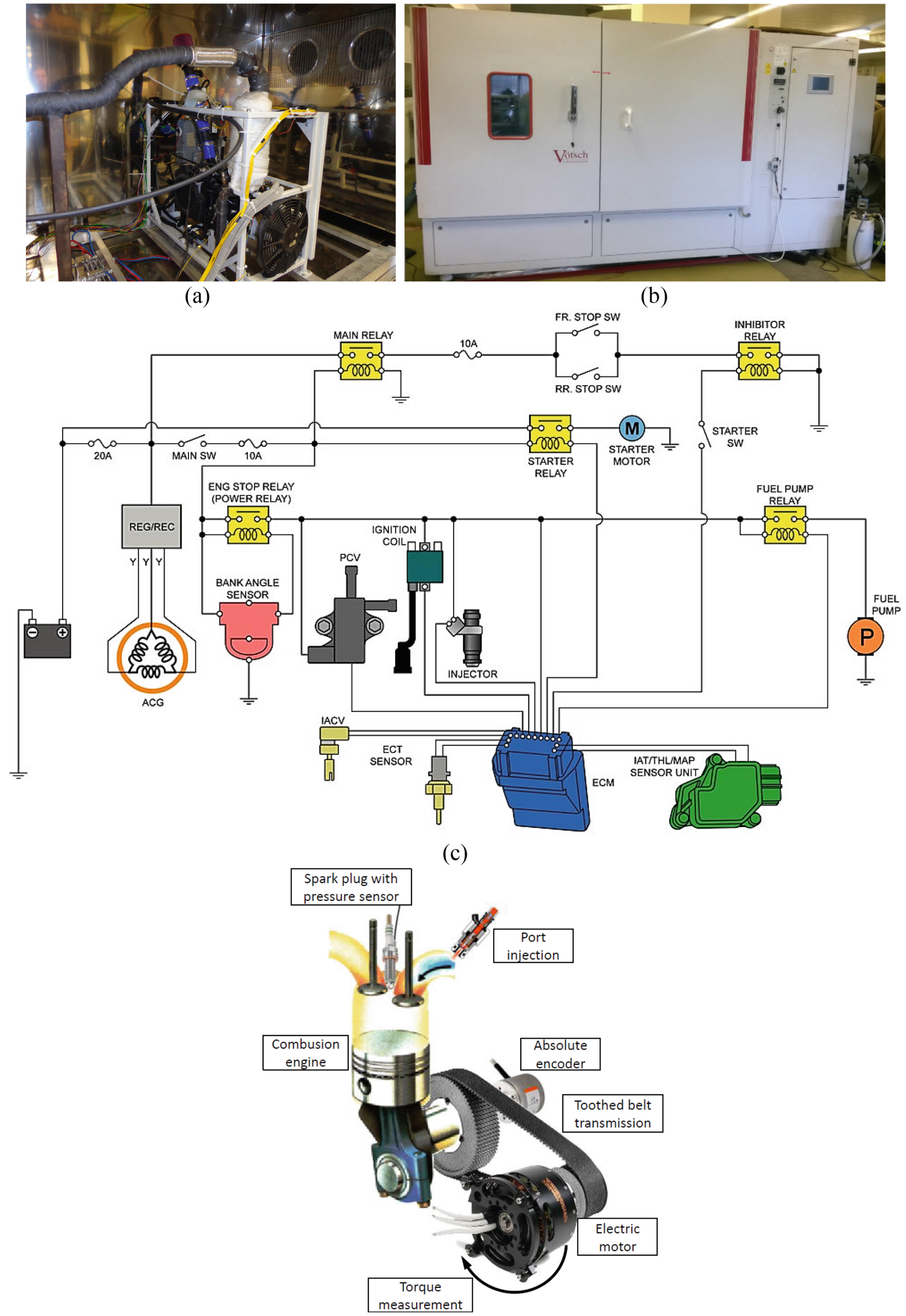

Fig. 1. (a) A photo of the test bench placed in the environmental chamber, (b) the environmental chamber, (c) diagram of the ICE engine with ECM, (d) general scheme of the test stand.

the ICE engine oscillated in the range of 363–368 K during all experiments. Moreover, the rotational speed was equal 4500 rpm (in accordance with the technical specification). For this rotational speed value the engine achieves maximum torque, the throttle was fully opened.

3.1 Opened Graphs of Indicated Pressure

In this subsection, the influence of ignition advance angle on the values of indicated and open pressure graphs for ICE HONDA NHX 110 engine fueled respectively with: unleaded Pb95 gasoline, CNG, biogas and E85, have been presented. In the case of gasoline and CNG, the tests were carried out for ignition advance angles from IAA = 10 to IAA = 40 before the Top Dead Center (TDC) position, with measurements taken with 10–degree increments. In the case of biogas, the tests were conducted for ignition advance angles from IAA = 20 to IAA = 40, and for E85 the experiment was conducted from IAA = 20 to IAA = 30 accordingly.

In Fig. 2, the influence of ignition advance angle on the open pressure diagram graphs for: IAA = 10 (Fig. 2a), IAA = 20 (Fig. 2b), IAA = 30 (Fig. 2c) and IAA = 40 (Fig. 2d) accordingly have been discussed. The Figs. 2(a–d) present several hundred consecutive working cycles for each ignition advance angle value.

Analysis of Figs. 2(a–d) shows, that for conducted measurements a major dispersion of results occurs at crankshaft angles corresponding to the beginning of combustion processes for all tested fuels. Based on results of statistical measures analysis (i.e.: skewness, kurtosis, standard deviation, coefficient of variation) presented in [24], it can be concluded that with the beginning of primordial combustion process [23] the value of probability density function decreases, the value of dispersion around the mean value increases and locally the coefficient of variation and skewness increase.

It is worth highlighting, that with increase of ignition advance angle, the maximum indicated pressure inside the cylinder increases (for IAA = 10 for unleaded Pb95 gasoline the maximum indicated pressure was 3.03 MPa, while for CNG it was equal to 2.42 MPa). Average torque for Pb95 at IAA = 10 at engine crankshaft was 8.24 Nm, while for CNG the average torque at engine crankshaft was 4.919 Nm (Fig. 5b). Start-up of the engine on biogas for IAA = 10 was not possible (the engine operated irregularly, misfiring was noticeable).

Observing the changes of indicated pressure inside the cylinder (Fig. 2) it is worth noting, that until the pressure changes depend mainly on air-fuel mixture compression, the process is highly repeatable, unlike when pressure changes are contributed mainly by the combustion process.

3.2 Closed-Loop Pressure Diagrams

The subsection presents the influence of the ignition advance angle on closed indicated pressure graphs of Honda NHX 110 ICE engine fueled with: Pb95, CNG, E85 and biogas, respectively.

Figure 2 presents closed graphs for the following ignition advance angle: IAA = 10 (Fig. 2a), IAA = 20 (Fig. 2b), IAA = 30 (Fig. 2c) and IAA = 40 (Fig. 2d).

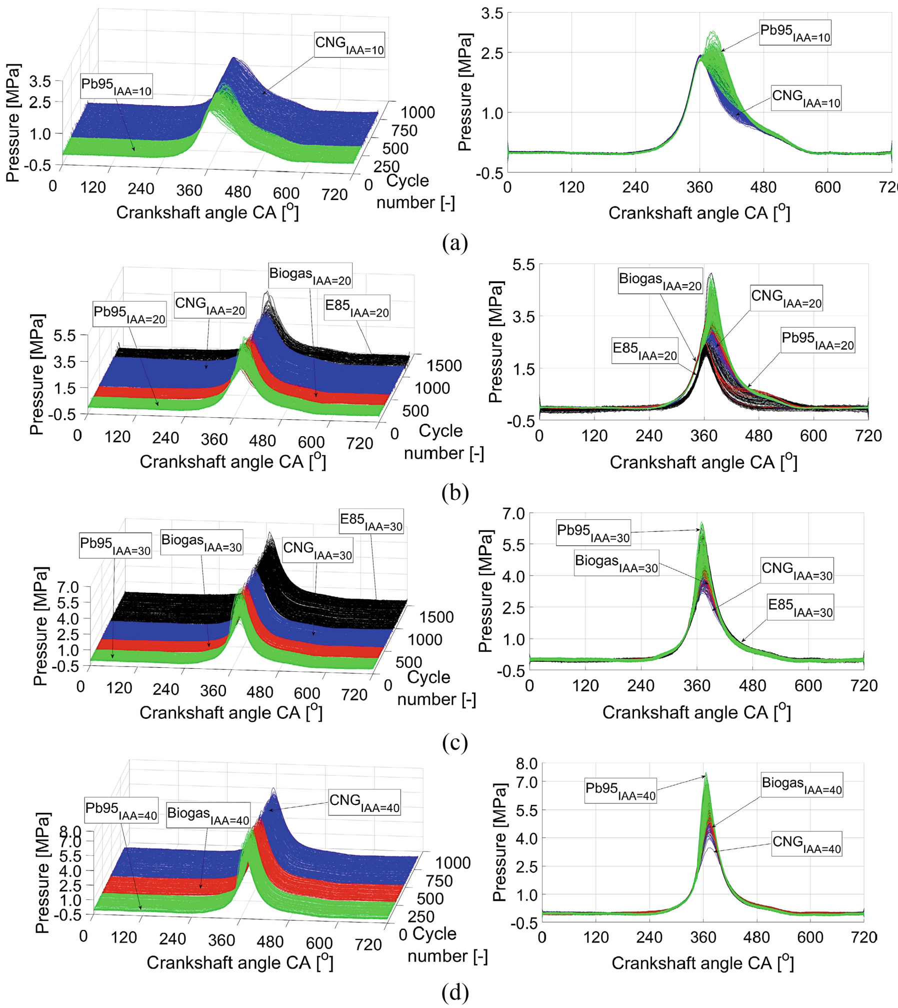

Fig. 2. Opened graphs of indicated pressure for: (a) IAA = 10, (b) IAA = 20, (c) IAA = 30, IAA = 40.

Analysis of Figs. 3(a–d) shows, that with increase of ignition advance angle, the average value of indicated pressure in the cylinder increases, which results in increased value of indicated work (Fig. 4.(a–d) – the area of indicated work increases.

3.3 Indicated Work Graphs

This subsection presents the influence of the ignition advance angle (from IAA = 10 to IAA = 40) on the values of indicated work for ICE Honda NHX 110 powered with: unleaded Pb95 gasoline, CNG and biogas, respectively.

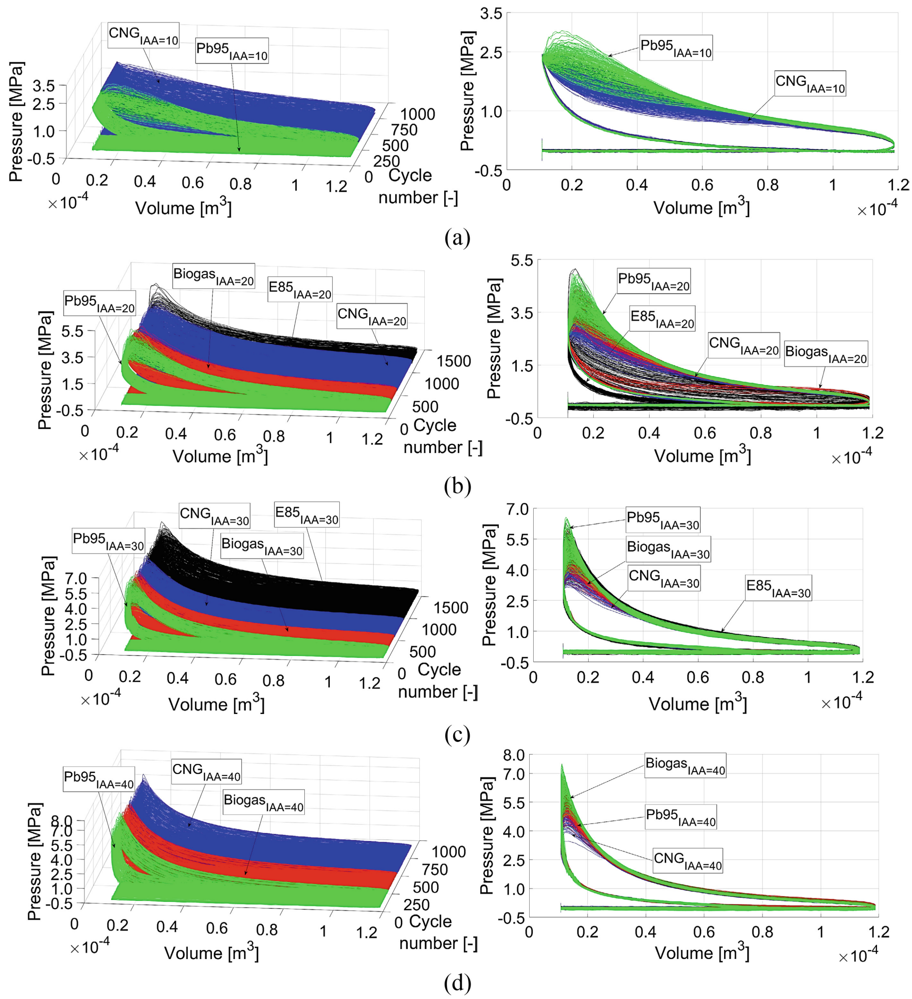

Fig. 3. Closed-loop pressure diagrams for: (a) IAA = 10, (b) IAA = 20, (c) IAA = 30, IAA = 40.

In Fig. 2(a) the indicated work curves for IAA = 10 have been illustrated. The maximum value was achieved for unleaded Pb95 gasoline, it was equal 177.5 J, while for CNG, and it was equal 161 J.

Figure 2(b) presents the indicated work values for IAA = 20 of ICE engine powered by: Pb95, CNG and biogas respectively. Highest value of indicated work occurred for Pb95, of value around 185 ± 3 J. However, highest amplitude of indicated work was noted for biogas, at 160 J (caused mainly by misfires).

Highest value of indicated work was achieved for IAA = 40 (Fig. 2d) for Pb95, the value of indicated work oscillated around 191.5 ± 3 J.

It is worth highlighting, that value of work performed (delivered) from IAA = 10 to IAA = 40 was at similar level for all fuels, at 17 ± 4 J – the intake process of fresh air-fuel mixture and exhaust are repeatable.

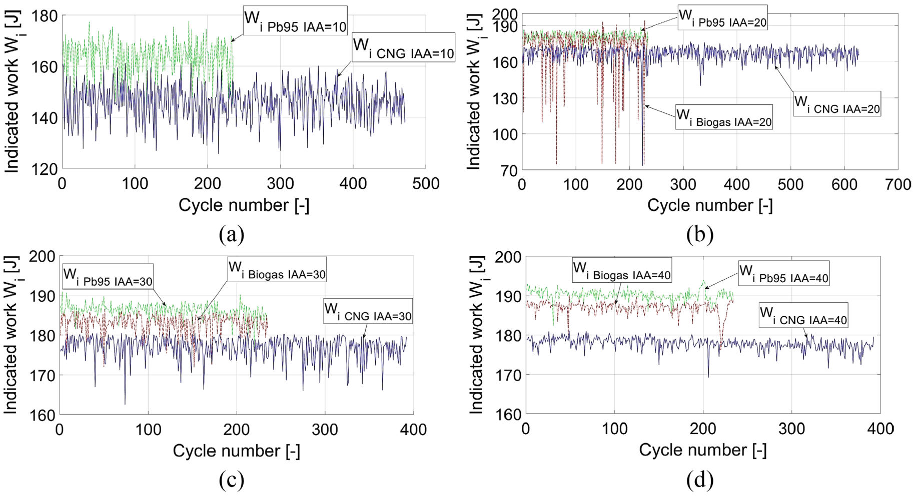

Fig. 4. The indicated work value for: (a) IAA = 10, (b) IAA = 20, (c) IAA = 30, (d) IAA = 40.

3.4 The Torque and Mechanical Power Graphs

In this subsection the experimental research results on the influence of ignition advance angle on the mechanical power value and the torque value of Honda NHX 110 fueled with CNG, biogas, E85 and Pb95 gasoline have been illustrated.

In Fig. 5(a) the influence of the ignition advance angle on the mechanical power value has been presented. The maximum mechanical power value was equal: 5.12 kW (unleaded Pb95 gasoline), 4.59 kW (E85) for IAA = 30 and for IAA = 40 (CNG – 3.658 kW and biogas – 3.73 kW).

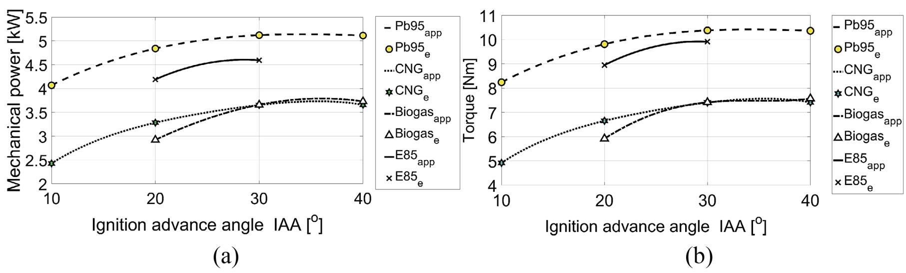

Fig. 5. The influence of ignition advance angle on: (a) the mechanical power value, (b) the torque value of the ICE Honda NHX 110 engine powered by: CNG, biogas, E85 and Pb95 gasoline.

Analysis of Fig. 5(b) proves that the highest value of the torque was achieved for the ignition advance angle of IAA = 30 (unleaded Pb95 gasoline – 10.38 Nm, CNG – 7.41 Nm and E85–9.91 Nm, respectively) and for IAA = 40 (biogas – 7.57 Nm), accordingly.

4 Conclusions

Based on the conducted experimental research it was stated that the increase of ignition advance angle is accompanied by both, increase of the maximum indicated pressure value and increase of indicated work value for all examined fuels. Highest value of indicated work was noted for ignition advance angle IAA = 40 for unleaded Pb95 gasoline, at value of around 190 ± 3 J (for IAA = 30 the value was about 188 ± 3 J). Therefore, it can be concluded, that differences between indicated work for IAA = 40 and IAA = 30 are not major, which is supported further by maximum power values (for IAA = 30 equal to 5.12 kW, while for IAA = 40 it was equal to 5.115 kW). Highest values of mechanical power and indicated work for CNG and biogas were noted for IAA = 40 (their values respectively: for CNG: $W_{i\ CNG}$ = 175 ± 6 J, mechanical power: 3.66 kW, while for Biogas: $W_{i\ Biogas}$ = 185 ± 6 J, mechanical power: 3.73 kW).

Based on conducted research and analysis of indicated pressure changes in the cylinder, it was concluded that until the pressure changes can be attributed mainly to exchange of mixture in the cylinder [23], the process can be considered as highly repeatable. When pressure changes begin to contributed by the combustion processes, the pressure changes become less repeatable. In order to determine the beginning and end of combustion, based on long-duration measurements with wide use of statistical measures [24], the authors suggest utilization of, i.e. probability density function for determination of mixture ignition delay in the cylinder.

The authors of the article currently conduct further research on Honda NHX 110 engine performance for alternative fuels, such as hydrogen and bio-derived fuels, in context of application of such engines as part of stationary distributed generation systems.

References

1. Directive 2009/28/EC of the council of 23 April 2009, on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC
2. Directive 2012/27/EU of the European Parliment and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC
3. EUCO 169/14 Conclusions. 23,24 October 2014. http://www.consilium.europa.eu/. Accessed 11 Nov 2017
4. Chmielewski, A., Gumiński, R., Mączak, J., Radkowski, S., Szulim, P.: Aspects of balanced development of RES and distributed micro–cogeneration use in Poland: case study of a mCHP with Stirling engine. Renew. Sustain. Energy Rev. **60**, 930–952 (2016)

5. Milewski, J., Szabłowski, Ł., Kuta, J.: Optimal control strategy of NG piston engine as a DG unit obtained by an utilization of artificial neural network. In: Power Engineering and Automation Conference (PEAM 2012), pp. 410–416. IEEE (2012)
6. Chmielewski, A., Gumiński, R., Radkowski, S., Szulim, P.: Aspects of support and development of distributed microcogeneration in Poland. Rynek Energii **5**, 94–101 (2014)
7. Milewski, J., Szabłowski, Ł., Kuta, J.: Control strategy for an internal combustion engine fuelled by natural gas operating in distributed generation. Energy Procedia **14**, 1478–1483 (2012)
8. Szabłowski, Ł., Milewski, J., Kuta, J., Badyda, K.: Control strategy of a natural gas fuelled piston engine working in distributed generation system. Rynek Energii **3**, 33–40 (2011)
9. Chmielewski, A., Gontarz, S., Gumiński, R., Mączak, J., Szulim, P.: Research on a micro cogeneration system with an automatic load–applying entity. In: Szewczyk, R., Zieliński, C., Kaliczyńska, M. (eds.) Challenges in Automation, Robotics and Measurement Techniques. Advances in Intelligent Systems and Computing, vol. 440, pp. 387–395. Springer, Cham (2016)
10. Małecki, A., Mydłowski, T., Dybała, J.: Badania wpływu zanieczyszczeń biopaliw na sprawność silnika ZI (Research on the impact of biofuels pollutants on the SI engine efficiency). Zeszyty Naukowe Instytutu Pojazdów **99**, 89–97 (2014). (In Polish)
11. Sendzikiene, E., Rimkus, A., Melaika, M., Makareviciene, V., Pukalskas, S.: Impact of biomethane gas on energy and emission characteristics of a spark ignition engine fuelled with a stoichiometric mixture at various ignition advance angles. Fuel **162**, 194–201 (2015)
12. Chmielewski, A., Gumiński, R., Radkowski, S., Szulim, P.: Experimental research and application possibilities of microcogeneration system with Stirling engine. J. Power Technol. **95**, 14–22 (2015)
13. Kukharonak, H., Ivashko, V., Pukalskas, S., Rimkus, A., Matijošius, J.: Operation of a spark-ignition engine on mixtures of petrol and N-butanol. Procedia Eng. **187**, 588–598 (2017)
14. Chmielewski, A., Gumiński, R., Maczak, J., Szulim, P.: Model–based research on a micro cogeneration system with Stirling engine. J. Power Technol. **96**, 295–305 (2016)
15. Nunes de Faria, M.M., Vargas Machuca Bueno, J.P., ElmasIAAlami Ayad, S.M.M., Pereira Belchior, C.R.: Thermodynamic simulation model for predicting the performance of spark ignition engines using biogas as fuel, Energy Conversion and Management (2017, in print)
16. Chmielewski, A., Gontarz, S., Gumiński, R., Mączak, J., Szulim, P.: Research study of the micro cogeneration system with automatic loading unit. In: Szewczyk, R., Zieliński, C., Kaliczyńska, M. (eds.) Challenges in Automation, Robotics and Measurement Techniques. Advances in Intelligent Systems and Computing, vol. 440, pp. 375–386. Springer, Cham (2016)
17. Małecki, A., Chmielewski, A., Mydłowski, T., Gumiński, R., Dybała, J.: Silniki spalania zewnętrznego w układach mikrokogeneracji (External combustion engines in micro-cogeneration systems). Zeszyty Naukowe Instytutu Pojazdów **98**, 147–156 (2014). (In Polish)
18. Mydłowski, T., Nader, S., Biskup, K., Jasiński, M.: Wykorzystanie urządzenia ECU Master EMU do sterowania silnikami z zapłonem iskrowym (Using the ECU Master EMU device to control spark ignition combustion engines). Zeszyty Naukowe Instytutu Pojazdów **86**, 125–129 (2011). (In Polish)
19. Małecki, A., Mydłowski, T., Dybała, J.: Stanowisko hamowniane do badań silników spalinowych o małych mocach (The engine dynamometer to test internal combustion engines with low power). Zeszyty Naukowe Instytutu Pojazdów **96**, 55–66 (2013). (In Polish)
20. Dybała, J., Mydłowski, T., Małecki, A., Bogdziński, K.: Dynamometer and test stand for low power internal combustion engine. Combust. Engines **162**, 996–1000 (2015)

21. Małecki, A., Mydłowski, T., Radkowski, S.: Przegląd uniwersalnych sterowaników do silników ZI (Review of programmable electronic fuel injection controllers). Zeszyty Naukowe Instytutu Pojazdów **93**, 93–101 (2013)
22. Pham, P.X., Vo, D.Q., Jazar, R.N.: Development of fuel metering techniques for spark ignition engines. Fuel **206**, 701–715 (2017)
23. Rychter, T., Teodorczyk, A.: Teoria silników tłokowych (The theory of piston engines), Wydawnictwo Komunikacji i Łączności WKŁ (2013). (In Polish)
24. Chmielewski, A., Gumiński, R., Mydłowski, T., Małecki, A., Bogdziński, K.: Operation tests of an engine supplied with alternative fuels, working as a distributed generation device. J. Power Technol. **97**, 1–10 (2017)
25. Chłopek, Z., Biedrzycki, J., Lasocki, J., Wójcik, P.: Assessment of the impact of dynamic states of an internal combustion engine on its operational properties. Eksploatacja i Niezawodnosc - Maintenance and Reliability **17**(1), 35–41 (2015)
26. Chmielewski, A., Gumiński, R., Mydłowski, T., Małecki, A., Bogdziński, K.: Model based research on ICE engine powered by an alternative fuels. In: Springer Proceedings in Mathematics & Statistics (In print)
27. Matuszewska, A., Owczuk, M., Zamojska-Jaroszewicz, A., Jakubiek-Lasocka, J., Orliński, P.: Evaluation of the biological methane potential of various feedstock for the production of biogas to supply agricultural tractors. Energy Convers. Manag. **125**, 309–3019 (2016)
28. Chmielewski, A., Gumiński, R., Mydłowski, T., Małecki, A., Bogdziński, K.: Research study of HONDA NHX 110 powered by an alternative fuel. In: 2nd International Conference on the Sustainable Energy and Environment Development – SEED 2017 IOP Conference Series: Energy and Enviromental Studies (2018, in print)
29. Lasocki, J., Kołodziejczyk, K., Matuszewska, A.: Laboratory-scale investigation of biogas treatment by removal of hydrogen sulfide and carbon dioxide. Pol. J. Environ. Stud. **24**(3), 1427–1434 (2015)
30. Chmielewski, A., Gumiński, R., Mydłowski, T., Małecki, A., Bogdziński, K.: Research on HONDA NHX 110 fueled with biogas, CNG and E85. In: 2nd International Conference on the Sustainable Energy and Environment Development – SEED 2017 IOP Conference Series: Energy and Enviromental Studies (2018, in print)