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Compression-ignition engine fuelled with diesel and hydrogen engine acceleration process

The paper presents the results of research consisting in acceleration of a diesel engine powered by diesel and hydrogen. The test stand included a diesel engine 1.3 Multijet, hydrogen cylinders and measuring equipment. Empirical tests included engine testing at idle and at specified speeds on a chassis dynamometer, vehicle acceleration in selected gears from specified initial values of engine revolutions was also tested.. Selected parameters of the diesel fuel combustion and injection process were calculated and analyzed. The paper is a preliminary attempt to determine the possibility of co-power supply to diesel and hydrogen engines.

Key words: *hydrogen, compression-ignition engine, acceleration process, diesel fuel*

1. Introduction

Combating the greenhouse effect is the most important challenge facing humanity over the next decade. In the field of combustion engines, this is done by tightening the emission standards, increasing the combustion efficiency to maintain fuel economy and searching for new low-emission fuels. One of the possibilities of improving the parameters and pro-ecological properties of engines is the use of hydrogen as a fuel. In many publications the results of the research were presented, showing the benefits and possibilities related to the use of hydrogen as a fuel, among others, in the form of reduction of toxic exhaust gas components emission [1–4].

Hydrogen (H) is an alternative to traditional fuels and can be used to power automobiles in two ways:

– as a fuel in a traditional engine, which is the source of thermal energy,
– in fuel cells to generate energy to drive an electric motor [5, 6].

Hydrogen can be used as a stand-alone fuel or as an 'additive' to other fuels. It is characterized by favourable properties in relation to hydrocarbon fuels such as: no carbon, high combustion rate, wide flammability range. Hydrogen is currently considered to be the most environmentally friendly energy carrier and it is predicted that hydrogen will be the fuel of the future [2, 5]. It is assumed that in 2050, 20-25% of passenger transport will be serviced by vehicles powered by this gas [7, 8]. A separate issue is how to obtain hydrogen and the ecology of this process.

2. Research site and research methodology

2.1. Research site

The tests were carried out on a stand consisting of a diesel engine 1.3 MultiJet built in a Fiat Qubo vehicle meeting the Euro 5 standard, to which hydrogen was supplied from the cylinder to the inlet channel by means of wires. The technical data of the engine is presented in Table 1 into non-return valves. The pressure of hydrogen dosed was regulated by a valve and read on a manometer, and the flow rate was measured by means of a digital mass flow meter Vogtlin, located in the pipe directly supplying the gas to the system. Additionally, the test stand was extended by an external fuel supply system, which allows the vehicle engine to be supplied with other alternative fuels without the need to change the fuel in the main fuel tank every time. [9].

The INDIMICRO 602 system by AVL was used to indicate the engine in dynamic conditions. It included a computer with AVL software, AVL measuring module and AVL transmitter. The basic functions of this system include [9]:

– recording the pressure course inside the cylinder – using the AVL GH13P piezoeletric sensor installed in the glow plug nest of the first cylinder,
– recording of the crankshaft position signal,
– analysis of injection parameters – using an analogue signal of injector control after conversion into a digital signal.

The tests were carried out on Dynorace chassis dynamometer designed for two axle drive vehicles type DF4FS-HLS, consisting of a control system and a load generating system. The vehicle is shown on the chassis dynamometer in Fig. 1. The elements of the test stand are shown in Fig. 2.

Table. 1 Technical data of the test engine (1.3 MultiJet) [9]

Maximum power [KM]	75
Maximum power [kW]	55
Total capacity [cm^3]	1248
The number of cylinders	4
Diameter of a cylinder [mm]	69.6
Piston stroke [mm]	82
Rotations on neutral gear [rpm]	850 ±20
Maximum moment [Nm]	190
Maximum moment [kgm]	19.4
Rotational speed at maximum moment [rpm]	1500

Fig. 1. Research car, Fiat Qubo with engine 1.3 MultiJet

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Fig. 2. Research site: 1. The view inside the vehicle with research apparatus: computer with AVL software, measuring module AVL and AVL converter, 2. Hydrogen cylinder, 3. The view of the engine compartment with the hydrogen supply location

2.2. Research methodology

Tests were carried out to determine the effect of hydrogen addition (fed to the inlet channel) on the operating parameters of a CI motor. The measurements were carried out during the acceleration of the vehicle for two variants of operation, i.e. for diesel oil and for diesel oil with the addition of hydrogen fed to the engine intake system. The pressure in the combustion chamber, engine speed and fuel injection parameters were recorded. The hydrogen flow was set at 20 ln/min. Engine tests included engine idle and at specific rotational speeds of 2000 rpm, 2500 rpm, 3000 rpm, 3500 rpm, 4000 rpm in vehicle driving conditions on a chassis dynamometer. The vehicle was then loaded with rolling resistance forces. An additional variant of the tests was acceleration of the vehicle on a chassis dynamometer in gear II and IV from the initial engine speeds of about 840 rpm and 2000 rpm respectively.

The research cycle included the following steps:

1. temperature stabilisation of the motors
2. engine speed stabilisation as indicated in the table.
3. hydrogen flow stabilisation

3. Analysis of test results obtained

Table 2 shows the engine operating parameters diesel fuelled with diesel and hydrogen fuelled diesel at selected speeds. The values of acceleration lever position, fuel temperature, bus pressure, amount of injected fuel, charge pressure and air flow are presented.

The addition of hydrogen slightly reduces the amount of injected diesel fuel at most engine speeds. The difference is within the range from 0.31 to 0.75 mm^3/cycle. Detailed data are presented in Fig. 3.

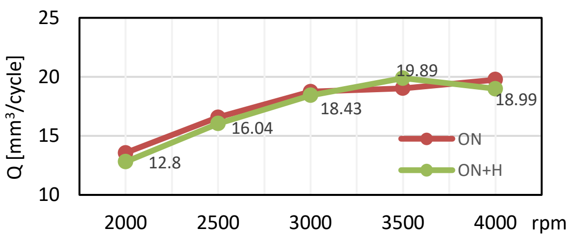


Fig. 3. Amount of injected fuel depending on the rotational speed at the supply of diesel and diesel with the addition of hydrogen

Table 2. Compression-ignition engine operating parameters

Engine operating parameters DF					
n_s [rpm]	2000	2500	3000	3500	4000
Position sensor for accelerator lever [%]	29	21	31	32	36
Fuel temperature sensor [°C]	48	48	48	48	48
Bus pressure sensor [bar]	614	704	834	946	1022
Injected quantity ON [mm^3/cycle]	13.55	16.57	18.74	19.03	19.76
Charge pressure sensor [mbar]	1241	1400	1542	2000	1664
Air flow meter [mg]	313	451	549	584	477
Motor operating parameters DF+ H at 20 ln/min flow rate					
Position sensor for accelerator lever [%]	2000	2500	3000	3500	4000
Fuel temperature sensor [°C]	21	30	37	42	39
Bus pressure sensor [bar]	39	39	40	40	40
Injected quantity ON [mm^3/cycle]	576	734	896	962	1014
Position sensor for accelerator lever [%]	12.84	16.04	18.43	20.3	18.99
Charge pressure sensor [mbar]	1279	1307	1639	1740	1643
Air flow meter [mg]	317	379	424	563	451

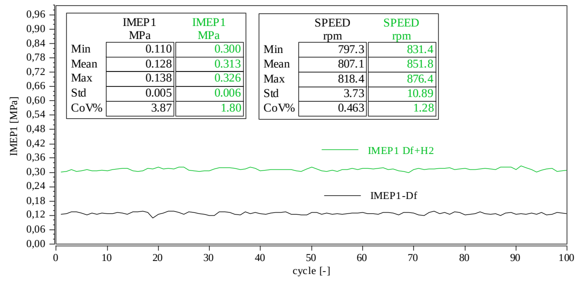


Fig. 4. Mean indicated pressure for 100 subsequent working cycles of the engine powered by diesel oil (black colour) and diesel oil and HHO (green colour) at idling speed; additionally, the tables show minimum, maximum, average values and standard deviation for mean indicator pressure (IMEP1) and engine speed

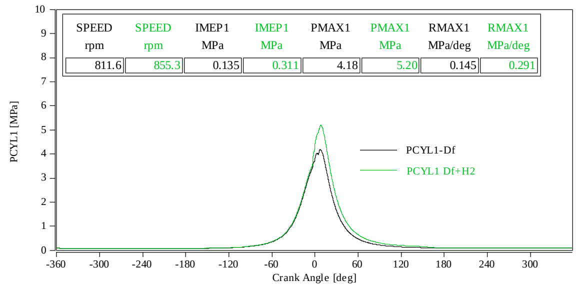


Fig. 5. Pressure inside the combustion chamber for idle operation, with diesel (black colour), diesel and H (green colour), additionally the table shows the average index pressure (IMEP1), maximum combustion pressure (PMAX1), maximum pressure rise speed (RMAX1) and engine speed (SPEED)

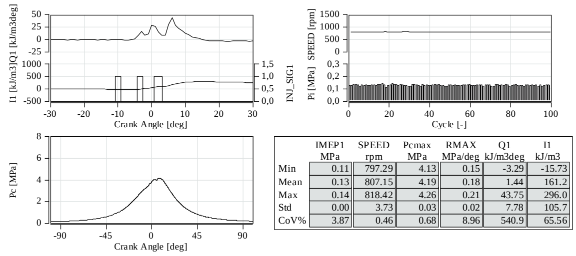


Fig. 6. Engine idle running with diesel supply; The courses of developing heat (Q1) and amount of developed heat (I1), mean indexed pressu-re (IMEP1) are presented

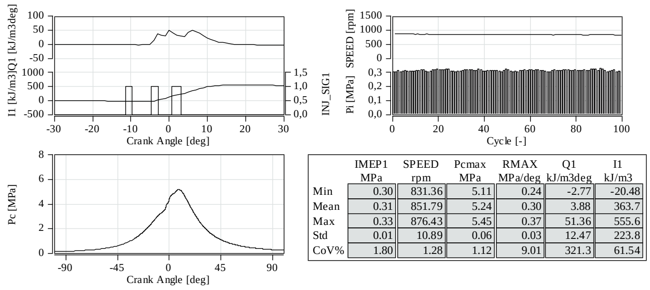


Fig. 7. Engine idle running, diesel fuelled, with the addition of hydrogen, The courses of developing heat (Q1) and amount of developed heat (I1), mean indexed pressure (IMEP1) are presented

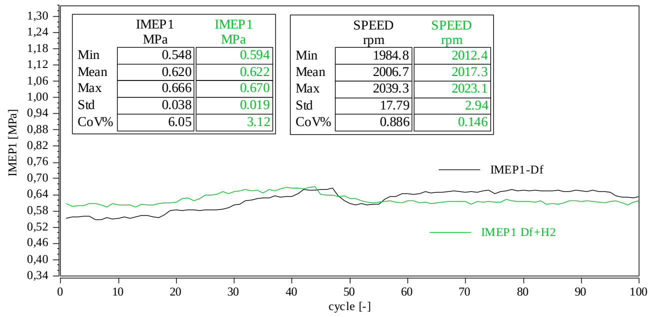


Fig. 8. Mean indicated pressure for 100 subsequent working cycles of the engine powered by diesel oil (black colour) and diesel oil and HHO (green colour), a vehicle driving with engine rotational speed of about 2000 rpm – gear 4; additionally, the tables show minimum, maximum, average and standard deviation for average indicator pressure (IMEP1) and engine speed

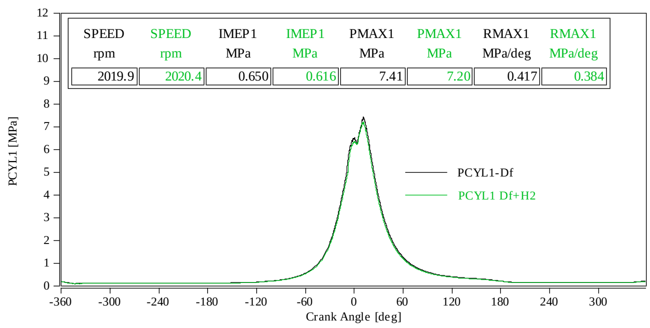


Fig. 9. Pressure inside the combustion chamber at engine speed about 2000 rpm – gear 4, at diesel fuel supply (black colour) and diesel oil and H (green colour), additionally the table shows average indexed pressure (IMEP1), maximum combustion pressure (PMAX1), maximum pressure rise speed (RMAX1) and engine speed (SPEED)

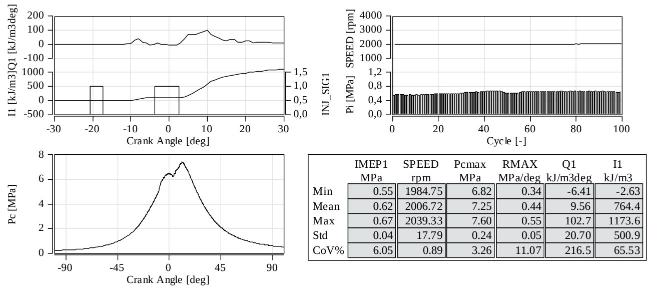


Fig. 10. A vehicle driving with engine rotational speed of about 2000 rpm in the fourth gear, with diesel fuel supply; The courses of developing heat (Q1) and amount of developed heat (I1), mean indicator pressure (IMEP1) are presented

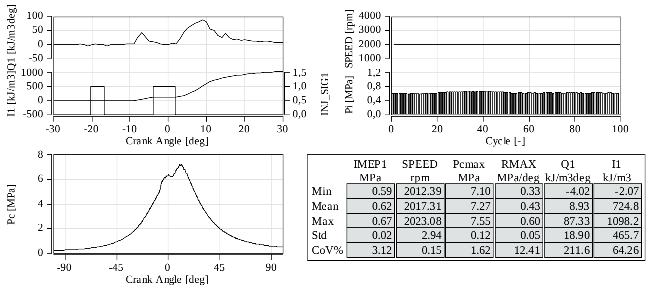


Fig. 11. A vehicle driving with engine rotational speed of about 2000 rpm in the fourth gear, with diesel fuel with the addition of hydrogen; The courses of developing heat (Q1) and amount of developed heat (I1), mean indicator pressure (IMEP1) are presented

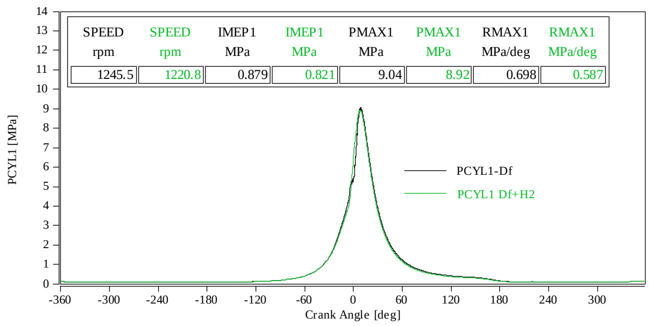


Fig. 12. Internal combustion chamber pressure during vehicle acceleration for second gear at engine speed 1245 rpm, for diesel (black colour) and diesel and H (green colour), in addition the table shows the mean index pressure (IMEP1), maximum combustion pressure (PMAX1), maximum pressure rise speed (RMAX1) and engine speed (SPEED)

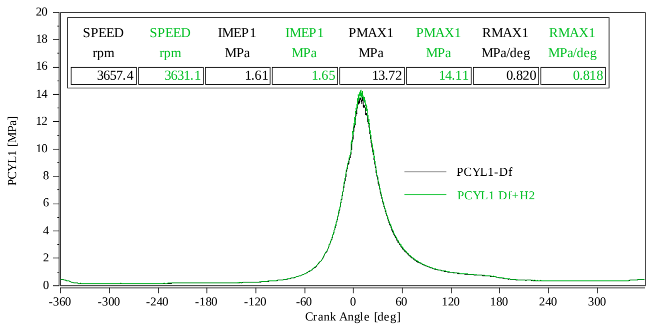


Fig. 13. Internal combustion chamber pressure during vehicle acceleration for second gear at engine speed 3657 rpm, for diesel (black colour) and diesel and H (green colour), in addition the table shows the average indicator pressure (IMEP1), maximum combustion pressure (PMAX1), maximum pressure rise speed (RMAX1) and engine speed (SPEED)

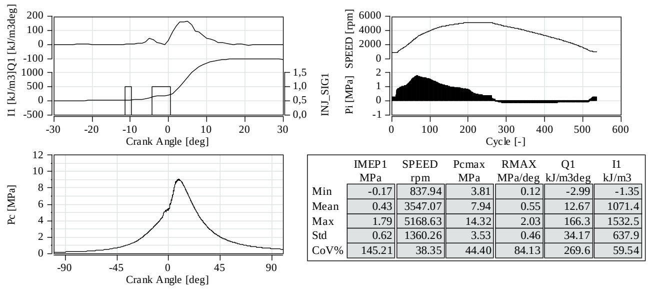
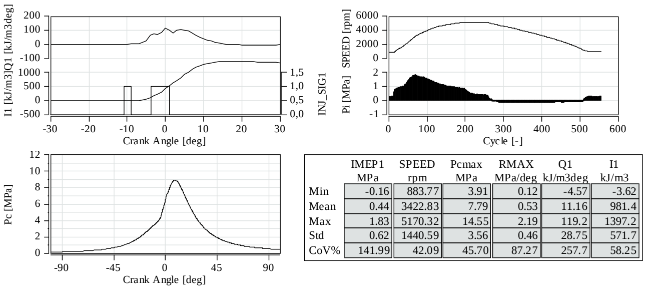


Fig. 14. The vehicle acceleration in the second gear with the throttle open at maximum, with diesel supply; The courses of developing heat (Q1) and amount of developed heat (I1), mean indexed pressure (IMEP1) are presented



	IMEP1 MPa	SPEED rpm	Pcmax MPa	RMAX MPa/deg	Q1 kJ/m3deg	I1 kJ/m3
Min	-0.16	883.77	3.91	0.12	-4.57	-3.62
Mean	0.44	3422.83	7.79	0.53	11.16	981.4
Max	1.83	5170.32	14.55	2.19	119.2	1397.2
Std	0.62	1440.59	3.56	0.46	28.75	571.7
CoV%	141.99	42.09	45.70	87.27	257.7	58.25

Fig. 15. The vehicle acceleration in the second gear with the throttle open at maximum, with diesel fuel with the addition of hydrogen; The courses of developing heat (Q1) and amount of developed heat (I1), mean indexed pressure (IMEP1) are presented

Figures 4 to 7 show the engine operating parameters at idling speed supplied with diesel (black colour), diesel and hydrogen (green colour). The tables show minimum, maximum, maximum, average and standard values for mean indexed pressure (IMEP1), maximum combustion pressure (PMAX1), maximum pressure rise speed (RMAX1) and engine speed (SPE-ED). In the range of average values of measured parameters it was found that the average value of average indexed pressure (from 100 consecutive cycles of engine operation) increased by about 144% when the engine was supplied with diesel and hydrogen at the same time. The maximum value of the average indexed pressure increased by 136% with simultaneous increase of the average engine speed. The addition of hydrogen also increases the maximal speed of pressure rise, the maximum value of the heat transfer rate and the amount of heat transfer coefficient. These parameters increase by 76%, 17% and 87% respectively in relation to the diesel supply. Figure 7 shows the course of pressure inside the combustion chamber at a speed of approx. 800 rpm. The maximum value of pressure inside the combustion chamber increased by approx. 24% in the case of ON+H engine power supply relative to ON power supply alone.

Figures 8 to 11 show the engine operating parameters for a vehicle travelling in fourth gear at engine speed of about 2000 rpm, supplied with diesel (black colour) and diesel and hydrogen (green colour). The value of the average pressure indexed in the case of diesel oil supply with the addition of hydrogen slightly decreased. The pressure inside the combustion chamber decreased by 2.8%. The addition of hydrogen to the combustion process also affects the reduction of the maximum heat discharge values and the amount of heat discharge, respectively by 17.5% and 6.9%.

Figures 12 to 13 show the engine operating parameters for a vehicle being driven in the second gear with the fuel delivery control unit open at the maximum speed of 1245 rpm and 3657 rpm, respectively, for diesel (black colour) and diesel oil and hydrogen (green colour) – the vehicle was loaded with rolling resistance and inertia resistance forces. It was noted that the maximum pressure inside the combustion chamber at a speed of 1245 rpm decreased by about 1.3%, and for 3657 rpm it increased by about 2.8% in the case of ON+H engine power supply relative to ON power supply alone. Additionally, it can be stated that the maximum values of the heat discharge course and the amount of heat discharge decreased by 28% and 8%, respectively, in relation to the diesel supply – Figs 14 and 15.

4. Conclusion

On the basis of the conducted research, the influence of the addition of hydrogen administered to the inlet system on the operation of a compression-ignition engine was evaluated. When the engine is simultaneously supplied with diesel oil and hydrogen added to the intake manifold, the average indexed pressure increased at idling speed by about 144% in relation to the supply with diesel oil only. The amount of heat produced, the maximum combustion pressure and the maximum rate of pressure rise also increased.

On the basis of the presented initial measurements it was stated that for the engine operating at idling speed, the addition of H affects the increase of engine parameters. For engine operating conditions other than idling, a decrease in heat output, heat output, pressure inside the combustion chamber and average indexed pressure was observed. In the course of the research, hydrogen expenditure was selected so that in all engine operating conditions it did not have an extremely negative impact on engine operation – so that there was no explosion of gas deposited in the intake manifold. The original maps of diesel fuel injection time control have not been modified. At present, it seems that hydrogen supplied to the intake manifold may influence the improvement of engine energy parameters, but in order for this influence to be safe and observable outside the idle gear, it is necessary to modify both the dose of hydrogen and the dose of diesel oil each time to the engine operating conditions. It should also be considered whether it would be possible to replace hydrogen with Brown HHO gas obtained from the on-board gas generator.

Nomenclature

CI	compression ignition
DF	diesel fuel
H	hydrogen
I1	amount of developed heat
IMEP	mean indicating pressure
ON	diesel
PMAX1	maximum combustion pressure
Q1	developing heat
RMAX1	maximum rate of increase of combustion pressure
SPEED	engine speed

Bibliography

[1] KRUCZYŃSKI, S., ŚLĘZAK, M., GIS, W. et al. Evaluation of the impact of combustion hydrogen addition operating properties of self – ignition engine. *Eksploatacja i Niezawodnosc – Maintenance and Reliability*. 2016, **18**(3), 343-347. https://doi.org/10.17531/ein.2016.3.4

[2] LEJDA, K. Wodór w aplikacjach do środków napędu w transporcie drogowym. Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów 2013.

[3] MERKISZ, J., IDZIOR, M., BAJERLEIN, M. et al. The impact of hydrogen in diesel fuel on the parameters of CI engine's performance. *Mechanika Czasopismo Techniczne*. 2012, 261-274.

[4] SURYGAŁA, J. Wodór jako paliwo. *Wydawnictwa Naukowo-Techniczne*. Warszawa 2008.

[5] GIS, W. Implementation of vehicles equipped with fuel cells and hydrogen refueling infrastructure in Europe. *Combustion Engines*. 2015, **162**(3), 782-787.

[6] WOŹNIAK, G., LONGWIC, R. Initial assessment of the course of combustion process in a diesel engine powered by diesel oil and Brown's gas. *IOP Conference Series Materials Science and Engineering*. 421, 042085. https://doi.org/10.1088/1757-899X/421/4/042085

[7] Raport Energetyka zrównoważona. www.feri.org.pl. Wodór. 2018.

[8] Automotive Industry Raport. www.pzpm.otg.pl.2018/2019

[9] LONGWIC, R., SANDER, P. The characteristics of the combustion process occurring under real operating conditions of traction. *IOP Conference Series Materials Science and Engineering*. **148**(1). https://doi.org/10.1088/1757-899X/148/1/012071

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