Initial assessment of the course of combustion process in a diesel engine powered by diesel oil and Brown’s gas

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Abstract. Application of water electrolyzer generating Brown’s gas as an additional source of supplying diesel engine was assessed in this article. Water, due to its slight conductivity must have been enriched with appropriate hydroxides. By-product of combustion of Brown’s gas is water vapour. Laboratory site consisted of: hydrogen generator, diesel engine 1,3 Multijet and apparatus for assessment of combustion process. The course of selected parameters of process of functioning of diesel engine of a vehicle with double supply – diesel oil and Brown’s gas. Empirical research were conducted in the conditions of static engine work. AVL – Indi Micro 602 was applied to indicate the engine. Selected parameters of combustion process were analysed. If application of the electrolyzer will be justified, the works on analysis of its energy balance and its control will be continued.

1. Introduction

The basic source for the drive of internal combustion engines are still fuels based on the deposits of oil. Oil resources are limited. In addition, instability of prices of petroleum-derived fuels and environmental issues force to look for new ecological sources of energy. One of the way to reduce CO₂ emission is application of fuels that do not contain coal, for example, hydrogen. The product of combustion of hydrogen is water. Hydrogen (H) is an alternative to traditional fuels and can be applied to drive motor vehicles in two ways, as a fuel in the traditional engine, which is consumed in the engine chamber, or in the fuel cells to generate energy driving electric engine [1,6]. The product of combustion of hydrogen in the presence of oxygen is water vapour, which can be liquefied and applied again in the electrolyzer. Hydrogen may be applied as an independent fuel or as an addition to other fuels, it has special properties with reference to hydrocarbon fuels such as lack of coal, high speed of combustion, broad combustibility range. Nowadays, it is treated as the most proecological energy carrier and it is predicted that hydrogen will be fuel of the future. Due to high temperature of self-ignition, hydrogen may not be applied directly to supply diesel engines. This problem does not refer to Brown’s gas (HHO) [2,4,5,8]. Initial research on the possibility of using Brown’s gas as an additional fuel supplying diesel engine were presented in the article.

2. Brown’s gas and its application

Brown’s gas (the so-called fourth form of water) described for the first time by Australian scientist, Yull Brown has been known for years. Primal source of generated energy is water, that is, splitting of water into particles of hydrogen and oxygen and avoiding explosion to form gas. Brown’s gas, having...
chemical formula HHO is fulminant, colourless, odourless, mixture of hydrogen and oxygen in volumetric proportion 2:1. Brown’s gas is obtained as a result of electrolysis of water, in accordance with chemical reaction below [3]:

$$2\text{H}_2\text{O} \rightarrow 2\text{H}_2\uparrow + \text{O}_2\uparrow$$

Brown’s gas is generated in the so-called HHO generators. This gas is applied in car engines to adapt the vehicle to use water as an additional source of energy. The engine is powered by the mixture of hydrogen and oxygen obtained in the process of electrolysis. By-product of combustion is water vapour. Water, due to its slight conductivity must be enriched with appropriate acids or salts. Sodium hydroxide or potassium hydroxide are the most frequent solutions [3,9]. There are many research results showing the capabilities resulting from application of HHO gas in a combustion process, mainly, reduction of exhaust emission or increased efficiency of combustion and life of the engine [10,11,12,13].

3. Research site and research methodology

Diesel engine 1.3 Multijet built in Fiat Qubo was the subject of the research. Technical data of the engine are presented in table 3.1. This engine meets the norm Euro 5. The research were conducted in static conditions while driving the research vehicle in real road traffic. AVL Indi Micro 602 with built-in signal amplifier, cooperating with four analogue input channels and two digital inputs was applied to indicate the engine. The basic functions of this system include [7]:

- registering the course of pressure inside the cylinder – with the use of a piezoelectric sensor AVL GH13P mounted in the socket of the heater plug of the first cylinder,
- signal recording informing about the location of the crankshaft,
- analysis of the parameters of injection – with the use of an analogue signal of controlling the injector after conversion into digital signal.

| Table 3.1. Technical data of research diesel engine (1.3 Multijet) |
|---------------------------------------------------------------|
| 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 (rot/1’) | 850 ± 20 |
| Maximum moment (Nm) | 190 |
| Maximum moment (kgm) | 19.4 |
| Rotational speed at maximum moment (rot/1’) | 1500 |

Figure 3.1. shows the research site that consisted of: HHO generator (the details of structure of the generator were shown on figure 3.2) installed in Fiat Qubo, engine of the vehicle with Brown’s gas charging, computer with AVL software, measuring module AVL and AVL converter. Brown’s gas from generator was charged directly to inlet system of the engine. Mixture of HHO was obtained from the electrolyzer, which was powered by the accumulator for the whole experiment. About 25 g of KOH (potassium hydroxide) was added to 800 ml of distilled water. About 40% of hydrogen from one-litre sample of gas was obtained. The measurements were conducted with the use of diesel oil, and then with diesel oil and powering by HHO gas, which was charged to the inlet collector. The pressure in the combustion chamber, engine rotational speed and parameters of fuel injection were registered. The research were conducted while driving the vehicle on the even, smooth surface of asphalt expressway.
Engine rotational speed was maintained at the level of: 2000 rot/min, 2500 rot/min, 3000 rot/min, 3500 rot/min, 4000 rot/min.

**Figure 3.1.** Mobile research site: 1. HHO generator installed in the car, 2. The view of the engine chamber with a place where generator was mounted, 3. The view inside the vehicle with research apparatus: computer with AVL software, measuring module AVL and AVL converter 4. Research car, Fiat Qubo with engine 1.3. MultiJet

**Figure 3.2.** Applied HHO generator:
1. Wires, 2. PWM regulator, 3. Switch, 4. Transmitter 12V/60A, 5. DC amper shunt, 6. Main fuse, 7. Digital ammeter, 8. Electrolyzer, 9. WRBD – water tank with the stube pipes, 10. Dehumidifier with a sensor of electrolyte level, 11. Gas filter, 12. Sensor MAF/MAP 13. One-way valves, 14. Fuel intake.
4. Analysis of research results

The figures from 4.1 to 4.5 show the courses of mean indicated pressure for 1000 subsequent working cycles of the engine powered by diesel oil (black colour) and diesel oil and HHO (green colour). In addition, the tables show minimum, maximum, average values and standard deviation for mean indicated pressure (IMEP1), maximum combustion pressure (PMAX1), maximum speed of pressure rise (RMAX1) and engine rotational speed (SPEED). These graphs refer to the vehicle driving on the even and smooth asphalt surface of expressway with engine rotational speed of 2000 rot/min, 2500 rot/min, 3000 rot/min, 3500 rot/min and 4000 rot/min. Within the scope of average values of measured parameters, it was found that when the engine is powered both by diesel oil and HHO, mean indicated pressure and maximum pressure in a combustion chamber increase. Moreover, slight increase in maximum speed of combustion pressure rise was observed. The average values of average indicated pressure for the majority of rotational speeds was increasing by about 20% when HHO was applied. The highest increase was registered at 3000 rot/min – about 80%. However, this result requires further tests and verifications. Moreover, maximum speed of pressure rise increased by a few per cent. Figure 4.6 shows the course of pressure inside the combustion chamber with engine rotational speed of about 2540 rot/min (similar rotational speeds for registered cycles with powering by ON and ON+HHO) at constant speed (600 engine working cycles), powered by diesel oil (black colour) and diesel oil and HHO (green colour). In addition, table shows the angle of occurrence of combustion commencement and pressure at that time. It was found that HHO addition has not impact on the angle of combustion commencement and occurrence of injection angle of the first dose of diesel oil (fig. 4.7). Therefore, self-ignition delay angle is similar. HHO addition affects the growth of maximum combustion pressure. After application of HHO addition and initiation of combustion, the course of developing heat and amount of developed heat increased – fig. 4.8. The angle of occurrence of maximum combustion pressure increased, as well as the values of average indicated pressure.

Figure 4.1. Mean indicated pressure for 1000 subsequent working cycles of the engine powered by diesel oil (black colour) and diesel oil and HHO (green colour), real traction conditions of the vehicle driving with engine rotational speed of about 2000 rot/min on the even and smooth asphalt surface. In addition, the tables show minimum, maximum, average values and standard deviation for mean indicated pressure (IMEP1), maximum combustion pressure (PMAX1), maximum speed of pressure rise (RMAX1) and engine rotational speed (SPEED)
Figure 4.2. Mean indicated pressure for 1000 subsequent working cycles of the engine powered by
diesel oil (black colour) and diesel oil and HHO (green colour), real traction conditions of the vehicle
driving with engine rotational speed of about 2500 rot/min on the even and smooth asphalt surface. In
addition, the tables show minimum, maximum, average values and standard deviation for mean
indicated pressure (IMEP1), maximum combustion pressure (PMAX1), maximum speed of pressure
rise (RMAX1) and engine rotational speed (SPEED).

Figure 4.3. Mean indicated pressure for 1000 subsequent working cycles of the engine powered by
diesel oil (black colour) and diesel oil and HHO (green colour), real traction conditions of the vehicle
driving with engine rotational speed of about 3000 rot/min on the even and smooth asphalt surface. In
addition, the tables show minimum, maximum, average values and standard deviation for mean
indicated pressure (IMEP1), maximum combustion pressure (PMAX1), maximum speed of pressure
rise (RMAX1) and engine rotational speed (SPEED).
Figure 4.4. Mean indicated pressure for 1000 subsequent working cycles of the engine powered by diesel oil (black colour) and diesel oil and HHO (green colour), real traction conditions of the vehicle driving with engine rotational speed of about 3500 rot/min on the even and smooth asphalt surface. In addition, the tables show minimum, maximum, average values and standard deviation for mean indicated pressure (IMEP1), maximum combustion pressure (PMAX1), maximum speed of pressure rise (RMAX1) and engine rotational speed (SPEED).

Figure 4.5. Mean indicated pressure for 1000 subsequent working cycles of the engine powered by diesel oil (black colour) and diesel oil and HHO (green colour), real traction conditions of a vehicle driving with engine rotational speed of about 4000 rot/min on the even and smooth asphalt surface. In addition, the tables show minimum, maximum, average values and standard deviation for mean indicated pressure (IMEP1), maximum combustion pressure (PMAX1), maximum speed of pressure rise (RMAX1) and engine rotational speed (SPEED).
Figure 4.6. Pressure inside the combustion chamber with engine rotational speed of about 2540 rot/min registered in traction conditions of a vehicle – driving at constant speed (600 engine working cycles), powered by diesel oil (black colour) and diesel oil and HHO (green colour), the table shows the angle of occurrence of combustion commencement and pressure at that time.

| Crank Angle [deg] | PCYL1 [MPa] | PCYL1 [MPa] |
|-------------------|-------------|-------------|
|                   | 2,600       | 6,004       |
|                   | 6,414       |             |

Figure 4.7. The course of digital signal of injection with engine rotational speed of about 2540 rot/min registered in traction conditions of a vehicle – driving at constant speed (600 engine working cycles), powered by diesel oil (black colour) and diesel oil and HHO (green colour), the table shows the angle of injection commencement.

| X INJ_SIG1 INJ_SIG1 |
|---------------------|
| deg                 |
| -41,258             |
| 0,000               |
| 0,000               |
Figure 4.8. The courses of developing heat (Q1) and amount of developed heat (I1) with engine rotational speed of about 2540 rot/min calculated for traction conditions of a vehicle – driving at constant speed (600 engine working cycles), powered by diesel oil (black colour) and diesel oil and HHO (green colour)

5. Conclusions
The impact of adding Brown’s gas HHO on the functioning of the diesel engine was assessed. Initial research allow to suppose that HHO system may be easily integrated with existing engine system. When the engine was powered both by diesel oil and HHO, the average indicated pressure was increasing for every rotational speed – by about 20% on average in comparison with powering only by diesel oil. The amount of developed heat, maximum combustion pressure and maximum speed of pressure rise also increased. The angle of occurrence of combustion commencement remained unchanged. Based on presented initial measurements, it was found that for the engine working on neutral gear, HHO addition decreases concentration of carbon dioxide and carbon monoxide. It has been observed that the amount of nitric oxides increases with increase of rotational speed. The research concerned gas emission behind the catalyst. A significant issue related to the use of gas generator is the control of the intensity of HHO impact, as we as concentrations and types of electrolyte – the research on this issue will be conducted in the future.

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