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Artūras KERŠYS
Dalius KALISINSKAS
Saugirdas PUKALSKAS
Andrius VILKAUSKAS
Robertas KERŠYS
Rolandas MAKARAS

INVESTIGATION OF THE INFLUENCE OF HYDROGEN USED IN INTERNAL COMBUSTION ENGINES ON EXHAUST EMISSION

BADANIE WPŁYWU WODORU STOSOWANEGO W SILNIKACH SPALINOWYCH NA EMISJĘ SPALIN

This article deals with the possibility to use hydrogen in gasoline and diesel engines. Hydrogen production in a vehicle and hydrogen generators mounted in a vehicle are overviewed. Under operation of the hydrogen generator electrical current changes with temperature, to stabilize current the current pulse generator is used. Modifications of an intake manifold were made in order to supply hydrogen to an engine. For this purpose a special universal plate to evenly mix the hydrogen with fuel mix was made designed. The experimental and rig tests were performed. The rig tests were carried out at constant 2200 rpm. It was found that smokiness, in both cases decreases with an additional deployment of hydrogen. Other indicators of the exhaust gas using the hydrogen in case of the rig tests are worse. A possible cause of negative influence is an excessive amount of hydrogen, which releases at 25 A current.

Keywords: *hydrogen, fuel, exhaust gas, energetic.*

Przedstawiony artykuł dotyczymożliwości wykorzystania wodoru w silnikach benzynowych i wysokoprężnych. Omówiono wytwarzanie wodoru w pojeździe oraz w generatorach wodoru zamontowanych w pojeździe.W trakcie funkcjonowania generatorawodoru prąd elektryczny zmienia się wraz z temperaturą; w celu stabilizacji prądu stosuje się generator impulsów prądowych. Aby dostarczyć wodór do silnika dokonano modyfikacji kolektora dolotowego. Do tego celu zaprojektowano specjalną uniwersalną płytę do równomiernego mieszania wodoru z mieszanką paliwową.Przeprowadzono próby eksperymentalne i próby na stanowisku badawczym. Próby na stanowisku badawczym prowadzono przy stałej prędkości obrotowej 2200 rpm. Stwierdzono, że zadymienie w obu przypadkach zmniejsza się wraz z dodatkowym wykorzystaniem wodoru. Inne wskaźniki spalin przy wykorzystaniu wodoru w przypadku badań na stanowisku badawczym wypadają mniej korzystnie. Możliwą przyczyną tego negatywnego oddziaływania jest nadmierna ilość wodoru, który uwalnia się w obecności prądu o wartości 25 A.

Słowa kluczowe: *wodór, paliwo, spaliny, energetyczny.*

1. Introduction

The high degree of the world's dependency on energy related with the expected future depletion of the worldwide petroleum reserves has led to big efforts in search for alternative energy sources such as nuclear, geothermal, biomass source etc. Alcohols, biomass based fuels, either single or blended with conventional petroleum based fuels are the most important alternative fuels for internal combustion engines [1].

Ecological environment and pollution is one of many problems solved in vehicles production that cause the rice of ecological requirements. Now we have standard Euro V [16]. The previous detailed investigations [7, 10] demonstrate than regulation of fuel supply system is not simple according to exhaust emission parameters like CO, HC, and O_2, and the air-fuel ratio is not homologous to these parameters. The outer characteristics, power and torque of internal combustion engines, are associated with ecological requirements by decreasing their limit values, because we cannot adjust performance of the fuel supply system to optimal characteristics when ecological requirements should be satisfied. Ecological requirements create special difficulties when solving the problem of alternative fuels using in internal combustion engines. The analysis of environment pollution is very complicated, because many factors have an influence on exhaust emission contents [14].

The Problem of energy resources is the theme considered with growing attention every year on a world scale. Crisis shaking economy of the whole planet motivates to deal with the issue of energy resources much deeper. Vehicle manufacturers are more often talking about alternative energy resources and alternative cars: electro-mobiles, bio-fuel-driven engines, hydrogen internal combustion aggregates. The greatest vehicle manufacturers invest hundreds of millions into the investigation of a hydrogen engine. Specialists make predictions that hydrogen is almost an inexhaustible resource, without any pollution of environment; just we need to improve hydrogen extraction ways [9 – 11].

Efficiency of an internal combustion engine is improved by fuel enrichment with hydrogen. This is achieved by hydrogen injection into fuel mixture in the intake manifold [4, 8].

With hydrogen used as an additive for traditional fuels, characteristics of an internal combustion engine become higher, i.e. engine power increases, fuel consumption and concentration of dangerous additives in exhaust decrease.

2. Hydrogen extraction and use in vehicles

During water electrolysis chemically-associated elements dissociate as electric current flows along them.

When water is subject to electrolysis

$$2H_2O(s) \rightarrow 2H_2(d) + O_2(d) \quad (1)$$

electric current flows through water, which dissociates into oxygen and hydrogen gas. Oxygen emits at anode and hydrogen emits at cathode on electrolysis element Fig. 1 [2].

$$H_2O \rightarrow 2H^+ + 1/2O_2 + 2e^- \quad (2)$$

$$2H^+ + 2e^- \rightarrow H_2 \quad (3)$$

To conduct these reactions under normal conditions required potential difference between anode and cathode is equal to 1,229 V. During the process all 100% of electric power is not converted into chemical energy of hydrogen. Energy loss appears so as ions transmitting electricity have heate water [4].

A hydrogen generator is used to produce hydrogen in a car Fig. 2. The Generator is filled with distilled water. Required amount of the water is refilled from a reservoir. Electrolysis reaction goes in a hydrogen generator. Electrodes obtain electrical charge from a battery in a car. To achieve more efficient hydrogen emission calcium hydroxide powder is added into the distilled water. Emitted hydrogen by pipe goes to the engines intake manifold. Then it mixed with air gets into cylinders of the engine. Fuel mixture enriched with hydrogen burns out faster and more evenly. The engine runs more silently and evenly, gas going out from the silencer is almost scentless and there is detectable a little dampness [7, 13].

Faraday's law is applied to evaluate efficiency of the hydrogen

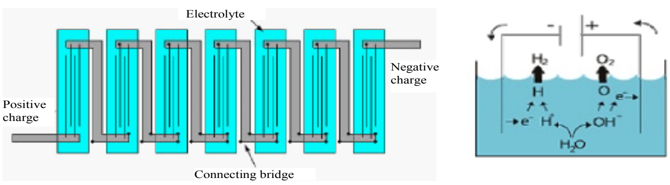

Fig. 1. Principal scheme of water electrolysis [3]

generator of the system and following to that law it is possible to calculate the volume of hydrogen emitted [4].

$$V_{H_2gen} = \frac{R \cdot I \cdot T \cdot t}{F \cdot p \cdot z} \quad (4)$$

where R – universal gas constant (R=8,31J/mol K); I – current strength; T – ambient temperature; t – time; F – Faraday's constant (F=96485 C/mol); p – ambient pressure; z – amount of electrons, flowing along circuit to form one molecule: $z(H_2) = 2$, $z(O_2) = 4$.

Calculation of a hydrogen generator showed that with 25 A current hydrogen gas extractions is 1.88 l per minute. From one liter of water 1860 liters of hydrogen are extracted. Power of the hydrogen generator at the voltage of 13.8 V and the current of 25 A is equal to 345 W. Vehicle engine losses are 0.34 kW.

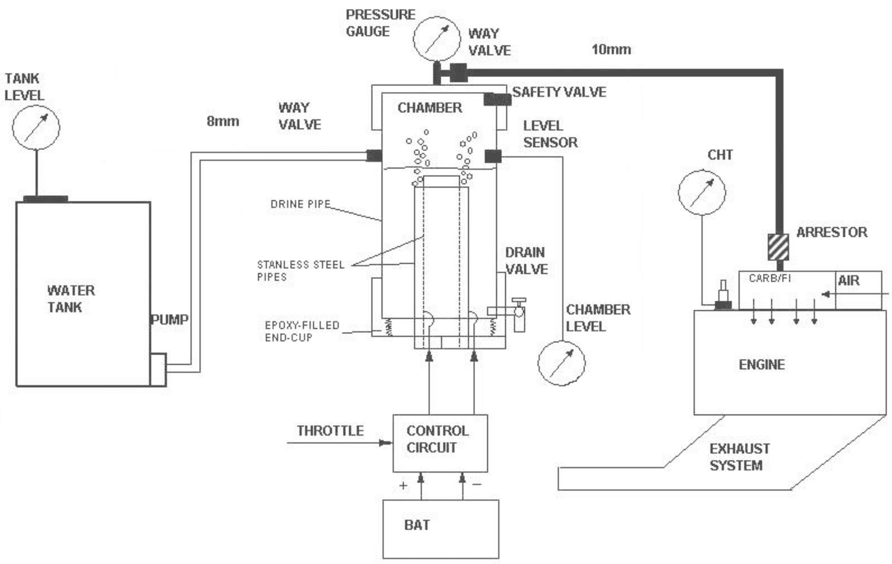

Fig. 2. Scheme of hydrogen generator

3. Influence of hydrogen used in ICE on fuel consumption and exhaust emission

In order to evaluate exhaust emission of an internal combustion engine an investigation has been performed. We chose for experiments popular three vehicles with gasoline internal combustion engines and three vehicles with diesel internal combustion engines in Lithuania. The working capacities of these engines are from 1500 to 2200 cm^3 and the power from 60 to 89 kW (Table 1).

Table 1. Technical data of tested engines

Row. Nr.	Engine name	Fuel type	Year of manufacture	Power, kW	Working capacity, cm^3
1	Type 1	Gasoline	1986	89	2000
2	Type 2	Gasoline	1985	66	1800
3	Type 3	Gasoline	1987	63	1500
4	Type 4	Diesel	1995	70	2200
5	Type 5	Diesel	1997	60	1700
6	Type 6	Diesel	1998	81	1900

A hydrogen generator (model R130V12, H2 - 130 l/h) is mounted in engine compartment. It has to meet safety requirements. If the engine does not run, the generator does not have to switch. A hydrogen generator is connected through relay.

Generator exciting voltage of winding is used to relay connection, so as voltage in it appears only when the engine is running, thus until an engine does not run, hydrogen generator does not work, as well, Fig.3.

In order to avoid overheating of hydrogen generator, thermo-relay is mounted within it, which disconnects exciting voltage of switching relay, until hydrogen generator gets cool.

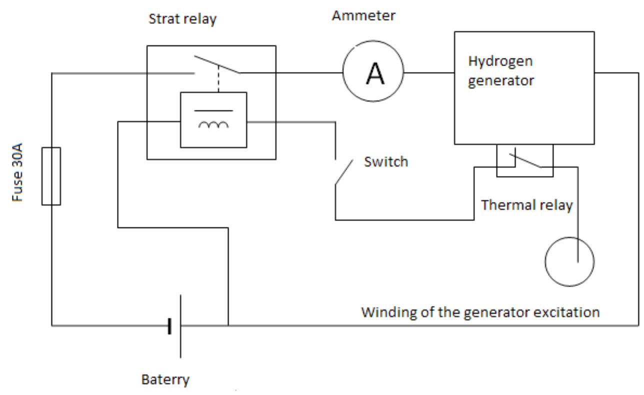

Fig.3. Electrical scheme of connection a hydrogen generator into circuit

For mixture of hydrogen the air intake system was modified. For this purpose the universal plate was constructed. This helped to mix hydrogen with the intake air (Fig.4).

It is noted that under operation of the hydrogen generator, it is practically impossible to maintain constant current, and the electrolyte starts to heat up. In case of cold electrolyte the current is too low, and under operation of the hydrogen generator, it grows too much. To solve the problem the current pulse generator was used (CPG). The installed universal plate is shown in Fig. 5.

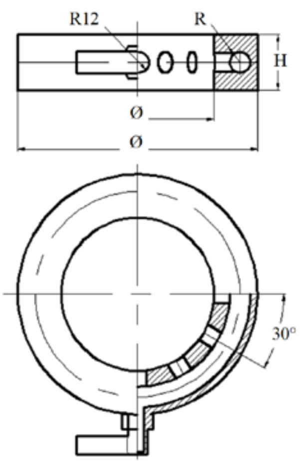

Fig.4. Universal plate

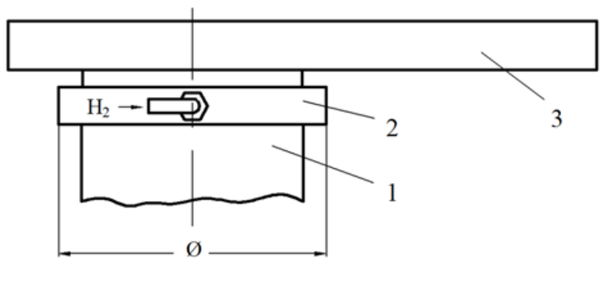

Fig.5. The installed universal plate: 1 – intake manifold; 2 – constructed plate;3 – box of air filter

The principle of CPG operation are often cut offs of the circuit what is characterized by frequency (Hz), that is, how many times per second the circuit was cut off. This allows more efficient use of the car power. It is also possible to get varying amount of exhaust gas with changing capacity, which depends on the current.

For measuring of exhaust gases, the engine diagnostic stands CORGHI GAS 810 +NO_x and BEA 460 which belongs to Transport Engineering Department of Kaunas University of Technology was chosen.

Fig. 6 shows the content of vehicle gasoline hydrocarbons (HC) at different engine modes. Fig. 6 shows that at low engine speeds the exhaust gas hydrocarbon content is more than at the higher speed. In addition, after the filing of hydrogen, the hydrocarbon content in the exhaust gases is reduced.

One of possible reasons is the oxidation of hydrocarbons. During explosion the flame spreads at high speed, so fuel burns better. The petrol engine working at low revolutions emits more hydrocarbons into environment than at higher revolutions. Reduction of hydrocarbon emission is observed when the fuel burns with hydrogen. By increasing the engine speed, the difference decreases and at maximum revolutions the hydrogen addition does not affect the exhaust gas composition.

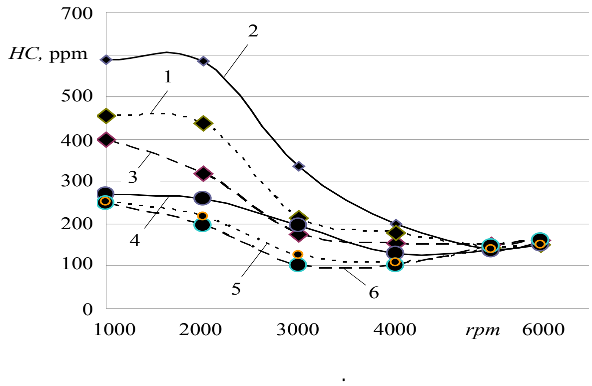

Fig. 6. Hydrocarbons of gasoline and gasoline with hydrogen: 1 – Type 3 gasoline; 2 – Type 1; gasoline; 3 – Type 2 gasoline; 4 – Type 1 (gasoline+ H_2); 5 – Type 3 (gasoline+H_2); 6 – Type 2 (gasoline+H_2)

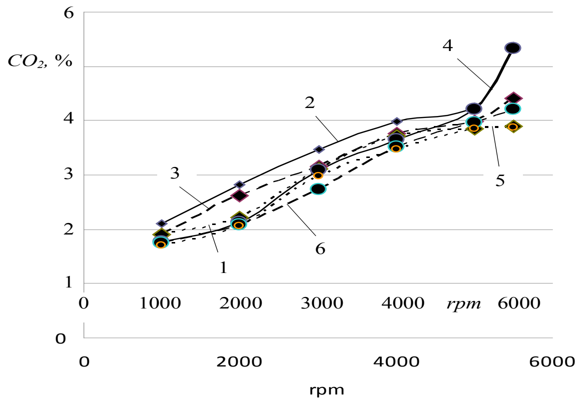

Fig. 7. Carbon dioxide of gasoline and gasoline with hydrogen: 1 – Type 3 gasoline; 2 – Type 1 gasoline; 3 – Type 2 gasoline; 4 – Type 1 (gasoline+ H_2); 5 – Type 3 (gasoline+H_2); 6 – Type 2 (gasoline+H_2)

With increasing revolutions the valve opening time is shorter, and at the same time, the amount of air entering the cylinder is lower, which results in worse fuel combustion. Hydrogen feeding promotes better combustion of the mixture up to 3500 rpm. The best effect is the appearance at lower and medium engine speeds.

Fig. 7 shows emissions of carbon dioxide (CO_2) at different engine modes. Fig. 7 shows that the amount of CO_2 in the exhaust gas

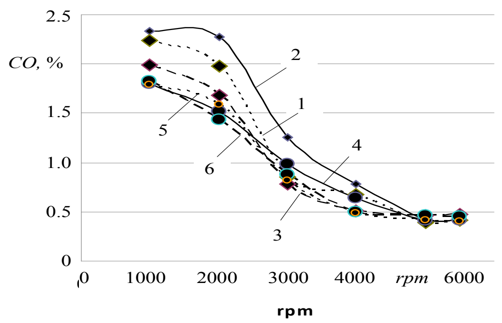

Fig. 8. Carbon monoxide of gasoline and gasoline with hydrogen: 1 – Type 3 gasoline; 2 – Type 1 gasoline; 3 – Type 2 gasoline; 4 – Type 1 (gasoline+ H_2); 5 – Type 3 (gasoline+H_2); 6 – Type 2 (gasoline+H_2)

increases as the engine speeds. CO_2 exhaust reduction is observed after the filing of additional hydrogen.

Fig. 8 shows emissions of carbon monoxide (CO) at different engine modes. In Fig. 8 it is shown that the maximum amount of CO in the exhaust gas is at lower engine speed.

CO is formed at high combustion temperatures and oxygen deficiency. Therefore, the fuel is oxidized not to the end. CO is reduced by about 14% when the fuel is burning along with the hydrogen. During engines operation at high revolutions hydrogen does not have any effect on the exhaust gas composition. Speeds decrease with increasing CO content. In case of further hydrogen the amount of CO in the exhaust gases further reduces.

Soot formation process in the local fuel oversaturated areas is during hydrocarbon pyrolysis, where according to the complex multi-level mechanism the fuel molecules break down and decompose. Smokiness of the diesel engines is more dependent on the chemical composition of the fuel, i.e. amount of aromatic hydrocarbons and the fuel ketene number, diffusion processes taking place in the chamber, complicated mechanism of the formation of soot particles and their combustion rate.

Fig. 9 shows the soot content of diesel vehicles with different engine speeds. The graph 9 shows that the soot content increases with engine speeds. The maximum amount of soot emissions is at the maximum engines speed. In case of addition of hydrogen, carbon black is reduced. The effect is due to the hydrogen, the fuel burns better, therefore, there is less emissions of soot.

Fig. 10 shows NO_x of the diesel vehicles, at different engine speeds. The graph 10 shows that the minimum amount of NO_x in the exhaust gases is at low engine speeds. With increasing engine speeds NO_x increases, but at the speeds higher than 3000 rpm NO_x stabilizes. Lower combustion temperature results in less NO_x.

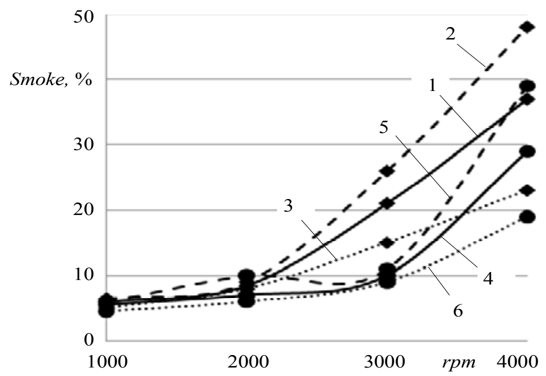

Fig.9. The soot content of diesel vehicles at different engine speeds: 1 – Type 4 diesel; 2 – Type 5 diesel; 3 – Type 6 diesel; 4 – Type 4 (diesel+ H_2); 5– Type 5 (diesel+H_2); 6 – Type 6 (diesel+H_2)

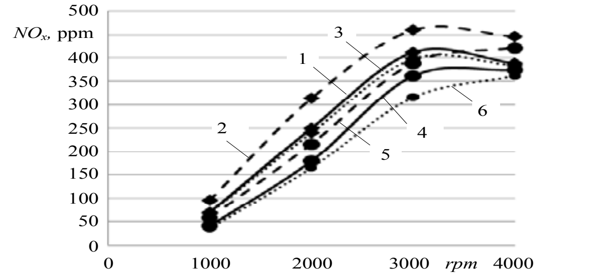

Fig.10. NO_x of the diesel vehicles at different engine speeds: 1 – Type 4 diesel; 2 – Type 5 diesel; 3 – Type 6 diesel; 4 – Type 4 (diesel+ H_2); 5 – Type 5 (diesel+H_2); 6 – Type 6 (diesel+H_2)

When the intake valve opens, low pressure area, formed in the cylinder, is quickly filled with the air of atmospheric pressure. This compressed air binds to the fuel hydrocarbons (HC) and provides a basis for combustion, pushing the piston and creating the engine power.

During compression the piston begins to rise, the molecules of air and fuel due to their mutual friction heat up. Absorbing heat the molecules expand.

With the further going up of the piston, pressure in the cylinder continues to increase, so the friction between the molecules is also increasing, leading to the further increase in temperature, and further expanding of the molecules.

Absorbing heat, molecules of hydrocarbon break down into hydrogen and carbon, and oxygen molecules (O_2) decompose into two separate oxygen atoms. When the fuel is ignited one atom of the oxygen oxidizes (combines with them) two hydrogen atoms and creates water and two oxygen atoms with one carbon atom create carbon dioxide. With increasing oxidation, the newly formed water and carbon dioxide creates an additional pressure, which the engine turns into useful power that allows rotating crankshaft to drive a car. While the combustion chamber temperature remains below 2300 degrees Fahrenheit, nitrogen molecules remain inert, this means that they do not split into separate nitrogen atoms and do not bind to other gases. However, reaching 2300 degrees nitrogen molecules decompose and bind to oxygen to form NO_x compounds. Concentration of NO_x is less at lower engine's revolutions. With engine speed greater than 3000 rpm addition of hydrogen has much lower effect on NO_x formation.

One of the possible reasons is that the gas volume generated by hydrogen generator is too low when the engine is running at the speed higher than 3000 rpm.

To realize the analysis of impact of hydrogen gas on the diesel engine rig tests were carried out in the laboratory of Internal combustion engines of Automobile transport department of Vilnius Gediminas

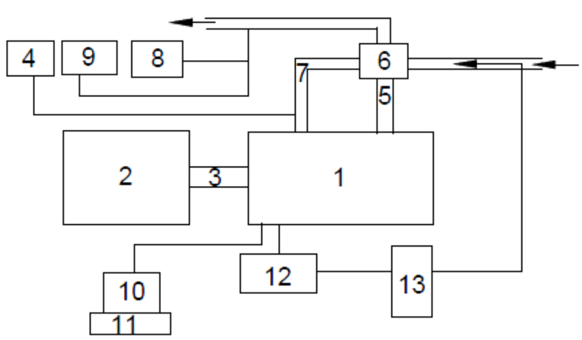

Fig. 11. Rig test structure: 1 – internal combustion diesel engine; 2 – dynamometer load КИ 5543; 3 – power takeoff; 4 – HD 2304,0 Pressure Meter; 5 – exhaust manifold; 6 – turbo-compressor; 7 – intake manifold; 8 – smoke meter AVL DiCom 465; 9 – gas analyzer AVL DiCom 4000; 10 – fuel tank; 11 – scale for diesel consumption; 12 – battery; 13 – hydrogen generator.

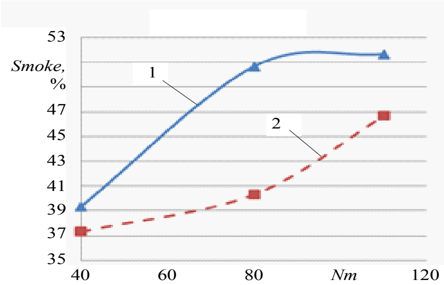

Fig.12. The soot content of diesel vehicles at different engine speeds (2200 rpm): 1 – diesel; 2 – diesel+ H_2

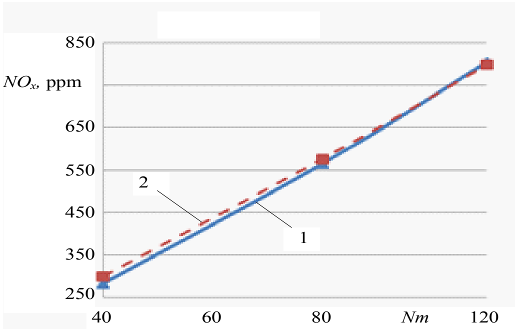

Fig. 13. NO_x of the diesel vehicles at different engine speeds (2200 rpm): 1 – diesel; 2 – diesel+H_2

Technical University (VGTU), using four-strokes diesel engine 1.9 TDI 66 kW, dynamometer load KI-5543, gas analyser AVL DiCom 4000, smoke meter AVL DiCom 465 and electronic scale SK-5000 to measure fuel consumption (Fig. 11).

Tests with both diesel and additional hydrogen were carried out three times. From the results obtained averages were derived and dependencies plotted.

Measurements were performed at the constant speed 2200 rpm, with variable load (40, 80 and 110 Nm). Fuel consumption with the additional hydrogen is slightly higher and at the load of 110 Nm both with diesel fuel and the additional deployment of hydrogen it does not change.

One of the reasons of the fuel consumption increase is possibly required the additional energy to go electrolysis in the hydrogen generator. The cause of the possible negative affect is an excessive amount of hydrogen, which is released at 25 A current. At higher currents the hydrogen generator is more heated, and the intensity of the heat causes an additional water steam. Therefore, it is appropriate to establish a suitable electric current, at which reduction in fuel consumption is to be derived. With additional use of hydrogen the smokiness decreases from 5% to 20% throughout the entire load mode (Fig. 12).

NO_x amount increases with load. NO_x amount at low and medium loads, with additional use of hydrogen increases by 2–5%. At the load higher than 80 Nm, NO_x amount varies slightly. One of the possible causes is the increasing NO_x emissions due to the increased combustion temperatures Fig. 13. At the load higher than 80 Nm the hydrogen does not affect the amount of NO_x.

4. Conclusion

Having the results of investigation, the following was concluded:

1. The investigation established that the hydrogen addition to traditional fuels did not have significant impact on fuel consumption – at certain engine operating modes the fuel consumption with hydrogen additive increases.
2. CO is formed at high temperature, and oxygen deficiency. Therefore, the fuel is oxidized not completely. CO is reduced to 20% when the fuel combusts along with the hydrogen, CO reduction is due to the fact that there is no carbon in the supplied hydrogen-oxygen mixture. Hydrocarbon (C_xH_y) exposed in the atmosphere to the sunlight reacts with nitrogen oxides to form the main component of smog, ozone O_3. The introduction of hydrogen promotes better combustion of the mixture in the wider range of revolutions. Therefore, fewer hydrocarbons (42%) are discharged into the environment and probability less ozone is formed.
3. NO_x reacting with water forms nitric acid. At the sunlight NO_x reacts with other active components of atmosphere, commonly with hydrocarbons, and as the result of complex reactions photochemical oxidants (including ozone) are formed. These highly unstable combinations damage plants and irritate human respiratory and vision organs. It is important to reduce amount of NO_x in the exhaust gas. Mixing of the combustible mixture with the hydrogen reduces combustion temperature; therefore, environmental pollution is less (to 28%).
4. With applying the hydrogen CO_2 reduces by 1–5%. CO_2 amount in the atmosphere causes so called „greenhouse effect", therefore it is very important to reduce its amount.
5. The results of rig tests performed vary from the road test ones. In case of road testing it is difficult to define the human factor, which is to be regarded as the main decisive factor causing the difference between the results obtained.
6. The results show that the hydrogen gas in an internal combustion engine in different engine operating ranges result in positive energy and environmental performance, therefore, it is appropriate to continue the research, finding the optimal adjustable engine parameters and amount of hydrogen gas provided.

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Artūras KERŠYS, Ph.D., D.Sc., Assoc. Prof.
Dalius KALISINSKAS, Ph.D.
Department of Transport Engineering
Kaunas University of Technology
Kęstučio str., 27-220 Kaunas, Lithuania
E-mails: arturas.kersys@ktu.lt, dalius.kalisinskas@ktu.lt

Saugirdas PUKALSKAS, Ph.D., D.Sc., Assoc. Prof.
Department of Automobile Transport
Vilnius Gediminas Technical University
J. Basanavičiaus str., 28, Vilnius, Lithuania
E-mail: Saugirdas.pukalskas@vgtu.lt

Andrius VILKAUSKAS, Senior Researcher
Mechatronics Centre for Research, Studies and Information
Kaunas University of Technology
Kęstučio str., 27-206 Kaunas, Lithuania
E-mail: andrius.vilkauskas@ktu.lt

Robertas KERŠYS, Ph.D., D.Sc., Assoc. Prof.
Rolandas MAKARAS, Ph.D., D.Sc., Assoc. Prof.
Department of Transport Engineering
Kaunas University of Technology
Kęstučio str., 27-217 Kaunas, Lithuania
E-mails: robertas.kersys@ktu.lt , rolandas.makaras@ktu.lt