DOI: https://doi.org/10.15407/pmach2019.02.070

UDC 621.43

PROSPECTS OF USING HYDROGEN MICROADDITION TO IMPROVE DIESEL ENGINE ECOLOGICAL INDICATORS

Andrii M. Avramenko
an0100@ukr.net
ORCID: 0000-0003-1993-6311

Anton M. Lievtierov
dppp@ipmach.kharkov.ua
ORCID: 0000-0001-5308-1375

Valerii M. Bhantsev
ORCID: 0000-0003-0661-1040

Nataliia Yu. Hladkova
ORCID: 0000-0002-8043-4890

Vira M. Kirieieva
ORCID: 0000-0002-7532-1760

A. Podgorny Institute of Mechanical Engineering Problems of NASU,
2/10, Pozharsky str., Kharkiv, 61046, Ukraine

The problem of environmental degradation in megapolises, particularly because of the toxicity of the exhaust gases of transport engines, requires an integrated solution. The peculiarity of the processes of mixture formation and combustion in diesel engines is the presence of local areas, rich in fuel or air. This results in incomplete diesel fuel combustion and contributes to the formation of toxic and mutagenic-carcinogenic compounds. Exhaust gases from diesel engines contain solid particles (SPs) that, due to their developed surface, are carriers of mutagenic-carcinogenic compounds. A very important factor affecting the completeness of fuel combustion in the cylinder of an internal combustion engine (ICE) is the intensive heat exchange between the walls of the combustion chamber and the working fluid. As a result, a relatively cold gas wall layer occurs. In this layer, the unburned hydrocarbons C_nH_m reside, and SPs are formed. The microaddition of hydrogen to the incoming charge makes it possible to significantly reduce the thickness of the "cold" layer due to the intensification of the combustion process in the ICE cylinder and near-wall areas. The generation and use of hydrogen, on board a vehicle, as a microaddition to normal engine fuel is justified as follows. First, the activation of combustion processes in the engine cylinder and, accordingly, fuel combustion completeness increase, which helps reduce the level of mass emissions of SPs and unburned hydrocarbons with the exhaust gases from ICEs. Secondly, such an approach makes it possible to reduce the level of load on the regular exhaust gas neutralization systems of modern vehicle engines, and increase the reliability of their work and their resource. The design of the on-board small-size electrolyzer and its control algorithm are developed. Comprehensive motor studies of the influence of hydrogen microadditions to diesel fuel on the effective 1Ch 8.5 / 11 diesel engine performance and the toxicity of its exhaust gases were carried out. Experimental studies show that with hydrogen microadditions, owing to an increase in fuel reactivity and combustion completeness, carbon monoxide emissions and smoking at the exhaust are reduced by 5–6% and 20%, respectively, with practically no unburned hydrocarbons present. The use of the proposed design and algorithm of the on-board electrolyzer operation will significantly reduce the level of toxicity of the exhaust gases from vehicle ICEs with minimal energy consumption for the functioning of the system.

Keywords: *on-board electrolyzer, hydrogen, micro-additions, diesel engine, environmental indicators.*

Introduction

The problems and prospects of using hydrogen as a fuel for internal combustion engines (ICE) are dealt with by many scientists in different countries of the world, with A. Podgorny Institute of Mechanical Engineering Problems of NASU being a pioneer in this field [1, 2].

The increase of the effectiveness of hydrogen generation systems is one of priority research directions. The current level of the energy consumption of stationary systems for generating hydrogen is 3.7–3.9 kWh per 1 m^3 of hydrogen [3, 4].

Today, the problems of using alternative fuels for ICEs receive much attention in almost all developed countries. This is forced by the situation with energy resources in the world, namely the reduction in the reserves of petroleum-based fuel. Each country chooses its own way in overcoming energy problems and reducing the level of toxicity of exhaust gases (EG) from ICEs, choosing those raw materials and alternative fuels that most closely correspond to the resource and economic features of the country. In the United States, for example, the Ronn motor company [5, 6] deals with the development of hydrogen generation systems on board a vehicle. Thus, according to company reports, the use of on-board electrolysers allows reducing the level of toxicity of EGs from different ICEs by an average of 10–12%.

Publication Analysis

One of the promising areas of engine development is not only the use of alternative fuels, such as lower alcohols (methanol, bioethanol, butanol), natural and associated petroleum gases, vegetable oils of specially grown crops, hydrogen, etc., but also various additions to normal motor fuel. First of all, studies are carried out with the aim of replacing or partially replacing the main type of fuel for manufactured cars without making significant structural changes to their engine, as well as for studying the possibilities of combining and using them as additives. At the same time, the effect of such a replacement on the environment is assessed.

Of all the alternative fuels, hydrogen should be singled out separately. The addition of hydrogen to normal fuel is not only capable of replacing the energy potential of a part of gasoline or diesel fuel. Hydrogen has a high diffusion rate, which determines its ability to form a homogeneous mixture in the combustion chamber in a very short period of time [7]. In addition, the fact that the mass specific heat of hydrogen combustion is about 3 times higher than that of gasoline [8–10] remains very significant.

When hydrogen is burning, the thickness of the flame extinguishing zone (the near-wall layer where no oxidizing processes take place) is about 5 times less than that of hydrocarbon fuels. This proves the high efficiency of hydrogen influence on the kinetics of mixture combustion in the whole volume [11]. Accordingly, the completeness of fuel combustion increases, and the emission of toxic substances decreases, which leads to a significant decrease in the level of harmful emissions of unburned hydrocarbons and solid particles, as well as carbon and nitrogen oxides.

Canadian Hydrogen Energy Company developed and patented a system for injecting hydrogen into the ICE intake manifold, referred to as Hydrogen Fuel Injection (HFI) System [12].

The operational principle of the HFI technology is based on the fact that the electrolysis apparatus, which consumes energy from the vehicle's on-board electrical network, decomposes distilled water and sends the released hydrogen and oxygen to the engine intake manifold. The amount of hydrogen entering the diesel engine is very insignificant, but such a microaddition increases the completeness of diesel fuel combustion, thereby changing the pattern of propagation of the flame front in engine cylinders. This is exactly what contributes to increasing the efficiency of a diesel engine and the overall combustion of traditional fuels.

The HFI system can work with any engine (diesel, gasoline, gas). Large American companies engaged in freight transport, upgrade their heavy vehicles, with the economy of operating costs per vehicle being more than $ 700 per month [13]. Also, the operation of an ICE with hydrogen added to normal fuel allows reducing carbon formation on the combustion chamber walls and has a positive effect on the economic performance and the ICE life [14, 15].

The above review clearly shows that the development and fine-tuning of on-board hydrogen generation systems to improve ICE performances is a promising area of research.

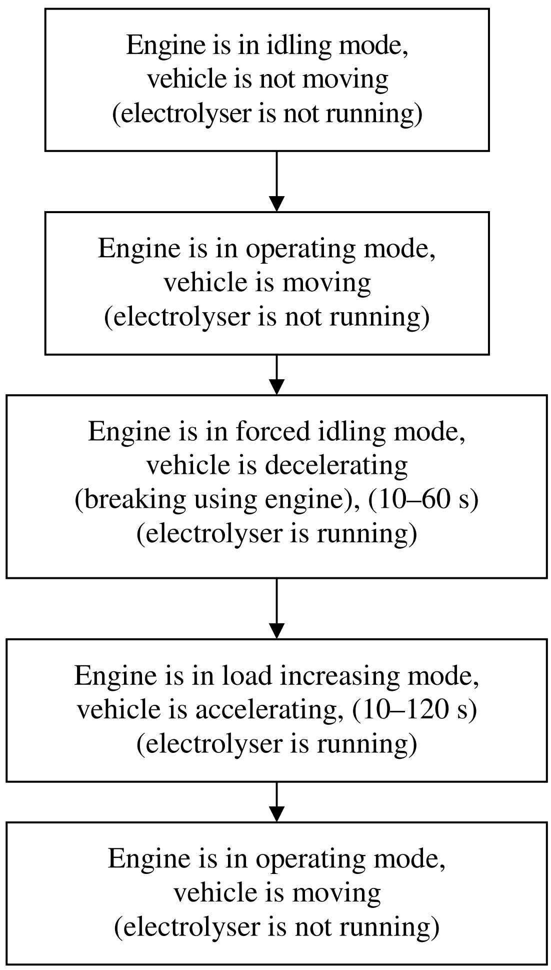

Fig. 1. Operation algorithm of a vehicle electrolyzer

Purpose and Objectives of the Study

The purpose of this study is to reduce the level of emissions of harmful substances from the EGs of a transport diesel engine through using hydrogen microadditions to normal fuel.

To achieve this goal, the work addressed the following tasks:

– to conduct a literature review on hydrogen generation systems aboard a vehicle;

– to develop both an on-board electrolyzer and an algorithm for its operation;

– to carry out motor studies of the effect of hydrogen microadditions to normal fuel on the energy-ecological indicators of a diesel engine;

– to draw conclusions and make recommendations for using hydrogen microadditions to improve ICE environmental performances.

Main Study Results

The object of the study is the environmental indicators of a diesel engine operating on normal and diesel fuels with hydrogen microadditions. A brief technical specification of a 1Ch 8.5/11 diesel engine is given below.

Cylinder diameter D=85 mm
Piston stroke S=110 mm
Number of cylinders z=1
Rated power Ne=4.5 kW
Crankshaft rotation speed n=1500 min^{-1}

The operation algorithm of the vehicle power plant with an electrolyzer integrated into the engine power supply system is shown in Fig. 1.

In the existing systems [5, 12], the on-board electrolyzer usually operates continuously from the moment the ICE starts until the moment it stops, which leads to increased energy consumption for hydrogen and oxygen generation, and, ultimately, in terms of the ratio of fuel consumption to the toxicity of EGs, is low effective.

The proposed algorithm of the situational functioning of the electrolyzer (depending on the engine load mode) allows minimizing the energy consumption for hydrogen generation and reducing the toxicity of EGs.

The schematic diagram of the engine unit with an electrolyzer is shown in Fig. 2.

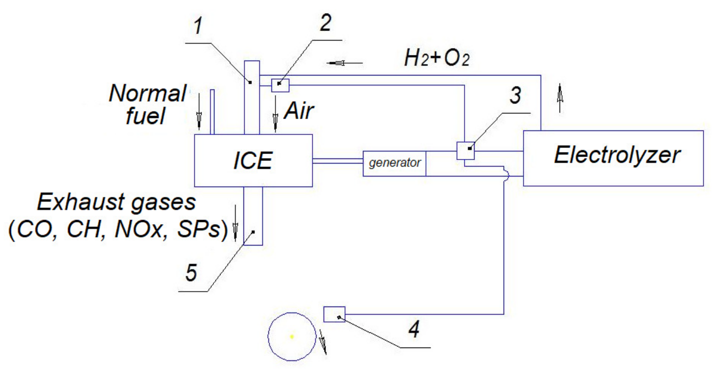

Fig. 2. Schematic operation diagram of an electrolyzer in the vehicle engine power supply system:
1 – intake manifold; 2 – MAP/MAF sensor; 3 – electroyzer control unit; 4 – speed sensor; 5 – exhaust manifold

The results of the motor studies of the effect of hydrogen microadditions on the ecological indicators of a diesel engine are shown in Fig. 3.

Energy consumption for generating hydrogen for the mode under study was 0.2 kWh.

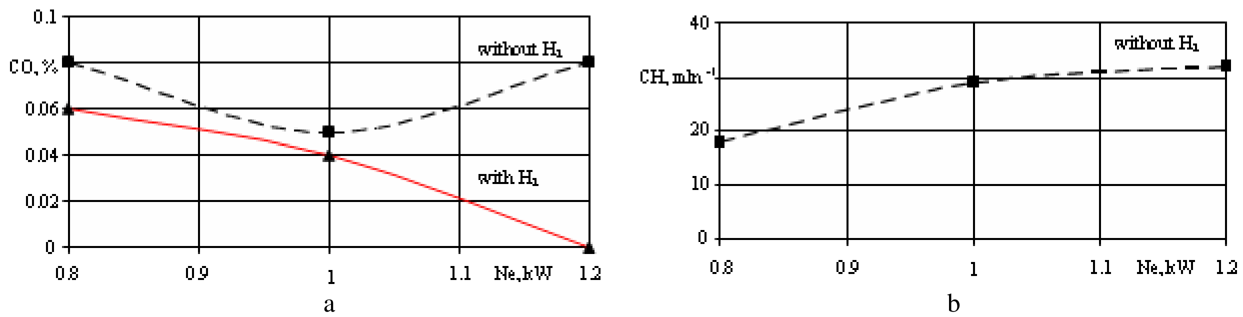

Fig. 3. Characteristics of the EG toxicity of a 1Ch 8.5 / 11 diesel engine:
– – – – –■– – – – – – operation on normal fuel; ——▲—— – operation on fuel with H_2 microaddition

The curves of carbon monoxide emission dependence from the engine load indicate the following. When the engine is running on normal diesel fuel, with an increase in load from 0.8 to 1 kW, the level of carbon monoxide emission (Fig. 3, a) decreases from 0.08 to 0.05%, and then there is a steady increase in the emission of this toxic component with EGs. The content of CO in the EGs of the engine operating on normal diesel fuel with H_2 microaddition decreases steadily with increasing load, reaching a zero value. The nature of the emission of unburned hydrocarbons (Fig. 3, b) with the diesel engine EGs is due to high-quality power control, i.e. at low load conditions, the air excess factor in the fuel-air mixture α is large (up to six in idling mode), and with an increase in load, the share of fuel in the mixture increases, and α decreases to 1.2–1.4, the amount of unburned hydrocarbons increases and mainly depends on the thickness of the near-wall layer. This is confirmed by the emission curve of CH, when the engine is running on normal diesel fuel. Hydrogen microadditions to diesel fuel make it possible to practically exclude the emission of CH with the EGs of a diesel engine (Fig. 3, b).

Such a method seems to be particularly effective in improving the toxicity characteristics of vehicle ICEs, since the greatest intensity of formation of toxic components in the combustion products takes place in the transient processes of the cycle of a piston engine, which, due to the characteristics of the model of vehicle operation, constitute a significant proportion of the engine running time.

Conclusions

According to the results of the study, the following can be noted:

– the use of on-board hydrogen generation systems to improve the environmental and resource indicators of ICEs is a promising area of research;

– the developed original design of the on-board electrolyzer and the algorithm of its work in the vehicle is characterized by its minimal energy capacity;

– the motor studies of the 1Ch 8.5/11 diesel engine toxicity characteristics showed that the microaddition of hydrogen (up to 1% of energy content) to normal diesel fuel can significantly reduce the level of carbon monoxide emissions and eliminate unburned hydrocarbons from the composition of EGs;

– the modification of motor fuels by hydrogen microadditions thereto can be recommended as an effective means of improving the energy-ecological characteristics of vehicle ICEs.

References

1. Podgornyy, A. N. (1978). *Vodorod – toplivo budushchego* [Hydrogen, the fuel of the future]. Kiyev: Naukova dumka, 133 p. (in Russian).
2. Podgornyy, A. N., Varshavskiy, I. L., & Priymak, A. I. *Vodorod i energetika* [Hydrogen and energy]. Kiyev: Naukova dumka, 144 p. (in Russian).
3. Solovey, V., Zipunnikov, M., Shevchenko, A., Vorobjova, I., & Kotenko, A. (2018). Energy effective membrane-less technology for high pressure hydrogen electro-chemical generation. *French-Ukrainian J. Chemistry*, vol. 6, no. 1, pp. 151–156. https://doi.org/10.17721/fujcV6I1P151-156
4. Solovey, V., Nguyen Tien Khiem, Zipunnikov, M., Shevchenko, A. (2018). Improvement of the membrane – less electrolysis technology for hydrogen and oxygen generation. *French-Ukrainian J. Chemistry*, vol. 6, no. 2, pp. 73–79. https://doi.org/10.17721/fujcV6I2P73-79
5. URL: https://www.ronnmotorgroup.com/
6. URL: https://www.vox.com/energy-and-environment/2018/2/16/16926950/hydrogen-fuel-technology-economy-hytech-storage
7. Fomin, V. M. & Platunov, A. S. (2011). *Vodorod kak khimicheskiy reagent dlya sovershenstvovaniya pokazateley raboty avtomobilnogo dvigatelya s NVB* [Hydrogen as a chemical reagent for improving the performance of an automobile engine with GDI]. *Transport na alternativnom toplive – Alternative Fuel Transport*, no. 4 (22), pp. 30–39 (in Russian).
8. Pevnev, N. G. & Ponamarchuk, V. V. (2015). *Analiz svoystv vodoroda s tselyu vozmozhnosti yego primeneniya v kachestve dobavki k osnovnomu toplivu* [Analysis of the properties of hydrogen with the aim of its possible use as an addition to the main fuel]. In *Progressive technologies in transport systems.* Paper presented at the Proceedings of the XII International Scientific and Practical Conference. Orenburgb: Orenburg State University, pp. 304–309 (in Russian).
9. Peretrukhin, S. F., Brizitskiy, O. F., Kirillov, V. A., Kuzin, N. A., & Kozlov, S. I. (2010). *Bortovoy generator sintez-gaza dlya DVS s iskrovym zazhiganiyem* [An onboard synthesis gas generator for spark ignition internal combustion engines]. *Transport na alternativnom toplive – Alternative Fuel Transport*, no. 5 (17), pp. 68–74 (in Russian).

10. Matskerle, Yu., Ivanova, V. B., & Benediktova, A. R. (1987). Sovremennyy *ekonomichnyy avtomobil* [The modern economical car]. Moscow: Mashinostroyeniye, 320 p. (in Russian).
11. Smolenskaya, N. M., Smolenskiy, V. V., & Shaykin, A. P. (2009). *Vliyaniye dobavki vodoroda na protsess goreniya v benzinovykh dvigatelyakh s iskrovym zazhiganiyem* [Influence of the addition of hydrogen on the combustion process in gasoline engines with spark ignition]. In *Progress of vehicles and systems.* Paper presented at the Proceedings of the IV International Scientific Conference. Volgograd: Volgograd State Technical University, pp. 247–248 (in Russian).
12. Gilchrist, S. & Rand, T. (2019). Hydrogen fuel injection to improve engine efficiency the practical beginning of the hydrogen economy. Canada: Canadian Hydrogen Energy Company, 15 p. URL: http://nha.confex.com/nha/2007/recordingredirect.cgi/id/196 (Accessed: 30.05.2019).
13. *Vodorod, kak prisadka k standartnomu toplivu DVS. Prosto dobav vody* [Hydrogen, as an additive to standard engine fuel. Just add water]. *Avtomobil'noye i gazovoye oborudovaniye – Automotive and gas equipment*: official website, URL: http://carscomfort.ru/dvs/vodorod-v-dvs.html (Accessed: 30.05.2019) (in Russian).
14. Kudryash, A. P., Marakhovskiy, V. P., & Kaydalov, A. A. (1989). *Teoreticheskiye i eksperimentalnyye issledovaniya sgoraniya vodoroda v dizele* [Theoretical and Experimental Studies of the Combustion of Hydrogen in a Diesel Engine]. *Voprosy atomnoy tekhniki i tekhnologii. Seriya yadernaya tekhnika i tekhnologii – Problems of Atomic Science and Technology. Series: Nuclear technology and technology*, iss. 2, pp. 48–50 (in Russian).
15. Marakhovskiy, V. P. & Kaydalov A. A. (1992). *Vodorodnyy dizel* [Hydrogen diesel]. *Avtomobilnaya promyshlennost – Automotive industry*, no. 2, pp. 17–19 (in Russian).

Received 12 March 2019

Перспективи застосування мікродомішок водню для поліпшення екологічних показників дизельного двигуна

Авраменко А. М., Лєвтєров А. М., Бганцев В. М., Гладкова Н. Ю., Кірєєва В. М.

Інститут проблем машинобудування ім. А.М. Підгорного НАН України,
61046, Україна, м. Харків, вул. Пожарського, 2/10

Проблема погіршення екологічної ситуації у мегаполісах, в тому числі й через токсичність відпрацьованих газів транспортних двигунів, потребує комплексного вирішення. Особливістю процесів сумішоутворення та згоряння в дизельних двигунах є наявність локальних зон, багатих паливом або повітрям. Це призводить до неповного згоряння дизельного палива та сприяє формуванню токсичних та канцерогенно-мутагенних сполук. Викиди дизельних двигунів містять тверді частинки, які завдяки розвиненій поверхні є носіями канцерогенно-мутагенних сполук. Дуже важливим чинником, що впливає на повноту згоряння палива в циліндрі двигунів внутрішнього згоряння (ДВЗ), є інтенсивний теплообмін між стінками камери згоряння та робочим тілом. Внаслідок цього виникає відносно холодний пристінний прошарок газу. В цьому прошарку залишаються незгорілі вуглеводні C_nH_m *та формуються тверді частинки. Додавання мікродомішок водню до свіжого заряду дозволяє значно зменшити товщину "холодного" прошарку за рахунок інтенсифікації процесу згоряння у циліндрі ДВЗ та пристінних ділянках. Генерування на борту автомобіля та використання водню як мікродомішки до штатного палива двигуна обґрунтовується таким. Підвищується активація процесів згоряння у циліндрі двигуна та, відповідно, збільшується повнота згоряння палива, що сприяє зниженню рівня масових викидів твердих частинок та незгорілих вуглеводнів з відпрацьованими газами ДВЗ. Крім того, такий підхід дозволяє знизити рівень навантаження на штатні системи нейтралізації відпрацьованих газів ДВЗ сучасних транспортних засобів, підвищити надійність їхньої роботи та збільшити ресурс. Розроблено конструкцію бортового малогабаритного електролізера та алгоритм його керування. Проведено комплексні моторні дослідження впливу мікродомішок водню до дизпалива на ефективні показники дизеля 1Ч 8,5/11 та токсичність його відпрацьованих газів. За даними результатів експериментальних досліджень встановлено, що під час додавання мікродомішок водню, за рахунок підвищення реакційної здатності та повноти згоряння палива забезпечується зменшення рівня викидів оксиду вуглецю на 5–6% й на 20% димності відпрацьованих газів за практично повної відсутності незгорілих вуглеводнів. Використання запропонованої конструкції та алгоритму роботи бортового електролізера дозволить суттєво знизити рівень токсичності відпрацьованих газів транспортних ДВЗ за мінімальних енерговитрат на функціонування системи.*

Ключові слова: *бортовий електролізер, водень, мікродомішки, дизельний двигун, екологічні показники.*

Література

1. Подгорный А. Н. Водород – топливо будущего. Киев: Наук. думка, 1978. 133 с.
2. Подгорный А. Н., Варшавский И. Л., Приймак А. И. Водород и энергетика. Киев: Наук. думка, 1984. 144 с.
3. Solovey V., Zipunnikov M., Shevchenko A., Vorobjova I., Kotenko A. Energy Effective Membrane-less Technology for High Pressure Hydrogen Electro-chemical Generation. *French-Ukrainian J. Chemistry*. 2018. Vol. 6. No. 1. P. 151–156. https://doi.org/10.17721/fujcV6I1P151-156
4. Solovey V., Nguyen Tien Khiem, Zipunnikov M., Shevchenko A. Improvement of the Membrane – less Electrolysis Technology for Hydrogen and Oxygen Generation. *French-Ukrainian J. Chemistry*. 2018. Vol. 6. No. 2. P. 73–79. https://doi.org/10.17721/fujcV6I2P73-79
5. URL: https://www.ronnmotorgroup.com/
6. URL: https://www.vox.com/energy-and-environment/2018/2/16/16926950/hydrogen-fuel-technology-economy-hytech-storage
7. Фомин В. М., Платунов А. С. Водород как химический реагент для совершенствования показателей работы автомобильного двигателя с НВБ. *Транспорт на альтернативном топливе.* 2011. № 4(22). С. 30–39.
8. Певнев Н. Г., Понамарчук В. В. Анализ свойств водорода с целью возможности его применения в качестве добавки к основному топливу. *Прогрессивные технологии в транспортных системах:* тр. конф. 2015. С. 304–309.
9. Перетрухин С. Ф., Бризицкий О. Ф., Кириллов В. А., Кузин Н. А., Козлов С. И. Бортовой генератор синтез-газа для ДВС с искровым зажиганием. *Транспорт на альтернативном топливе*. 2010. № 5(17). С. 68–74.
10. Мацкерле Ю., Иванова В. Б., Бенедиктова А. Р. Современный экономичный автомобиль. М.: Машиностроение, 1987. 320 с.
11. Смоленская Н. М., Смоленский В. В., Шайкин А. П. Влияние добавки водорода на процесс горения в бензиновых двигателях с искровым зажиганием. *Прогресс транспортных средств и систем:* тр. конф. 2009. С. 247–248.
12. Gilchrist S., Rand T. Hydrogen fuel injection to improve engine efficiency the practical beginning of the hydrogen economy. Canada: Canadian Hydrogen Energy Company, 15 p. URL: http://nha.confex.com/nha/2007/recordingredirect.cgi/id/196 (Дата обращения: 30.05.2019)
13. Водород, как присадка к стандартному топливу ДВС. Просто добавь воды. Автомобильное и газовое оборудование: официальный сайт. URL: http://carscomfort.ru/dvs/vodorod-v-dvs.html (Дата обращения: 30.05.2019)
14. Кудряш А. П., Мараховский В. П., Кайдалов А. А. Теоретические и экспериментальные исследования сгорания водорода в дизеле. *Вопр. атом. техники и технологии. Сер. ядер. техника и технологии.* 1989. Вып. 2. С. 48–50.
15. Мараховский В. П., Кайдалов А. А. Водородный дизель. *Автомоб. пром-сть.* 1992. № 2. С. 17–19.