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Provision of carbon-free emission of exhaust gases on vehicles

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Abstract. The paper analyzes foreign and domestic research on reducing emissions of harmful substances and greenhouse gases from exhaust gases. The provision of carbon-free emissions of exhaust gases in motor vehicles has been studied. Ways for further research on environmental safety and energy efficiency of vehicles are given.

1 Introduction

The Decree of the President of the Republic of Uzbekistan dated July 10, 2020 No. PP4779 “On additional measures to improve the energy efficiency of the economy and reduce the dependence of sectors of the economy on fuel and energy products by attracting available resources” approved a roadmap “to improve energy efficiency and save fuel and energy resources at large energy-intensive enterprises of branches of the economy”. Paragraph 15 of this roadmap sets the task to “develop a long-term National Strategy for the Development of Hydrogen Energy” [1,2].

The use of hydrogen as a fuel for internal combustion engines has been known for a long time. For example, in the 1920s, the option of using hydrogen as an additive to the main fuel for internal combustion engines of airships was studied, which made it possible to increase their flight range.

The use of hydrogen as a fuel for internal combustion engines is a complex problem that includes a wide range of issues:
- the possibility of converting modern engines to hydrogen;
- study of the working process of engines when working on hydrogen;
-determination of the optimal ways to regulate the working process to ensure minimal toxicity and maximum fuel efficiency;
-development of a fuel supply system that ensures the organization of an effective workflow in the cylinders of the internal combustion engine;
- development of efficient methods of hydrogen storage on board vehicles;
- ensuring the environmental efficiency of the use of hydrogen for internal combustion engines;
-providing the possibility of fueling and accumulating hydrogen for engines [3].

The solution of these issues has a variant level, however, the general state of research on this problem can be considered as a real base for practical application of hydrogen. This is confirmed by practical tests, research of variant engines running on hydrogen. For example, Mazda makes a bet on hydrogen rotary piston engine.

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The research in this area is characterized by a wide range of options for using hydrogen for external and internal mixing engines, using hydrogen as an additive, partially replacing fuel with hydrogen, and running the engine on hydrogen alone.

New transport engines developed to date include electric propulsion systems and internal and external combustion thermal engines with unconventional operating processes. The latter include stratified piston engines, gas turbines, steam and rotary engines, and Stirling engines. Some of these engines, in particular Stirling engines, may in principle make it possible to create a low-toxic vehicle using conventional fuels that will meet future stringent regulations [4,5,6].

Recently, a large number of foreign research centers of engine-building firms carry out research aimed at saving fuel and replacing traditional liquid hydrocarbon fuels with new types of.

The transition of transport to hydrogen fuel would solve the environmental problems of large cities once and for all. However, such a transition faces a number of challenges, including:
- the need for enormous energy costs to produce hydrogen by electrolysis of water;
- the need to use special sealed containers for storage and transportation of hydrogen, because it has a high permeability due to the small size of its molecules.

The need for a developed network of filling stations in every settlement and along major highways: hydrogen is the lightest and least dense gas, so a car with a hydrogen engine will have to refuel much more often than cars with gasoline and diesel engines.

One way to use hydrogen in vehicles is to burn it in the internal combustion engine. This approach is used by BMW and Mazda. Japanese and German engineers see this as an advantage.

Only the hydrogen fuel system adds weight to the car, while in fuel-cell cars the increase (fuel cells, fuel system, electric motors, current converters, powerful batteries) significantly exceeds the "savings" from removing the internal combustion engine and its mechanical powertrain.

The loss in usable space is also less in a car with a hydrogen engine (although the hydrogen tank in both cases eats up part of the trunk).

This loss could be reduced to zero if we make a car (with an internal combustion engine) that consumes only hydrogen. But this is where the main trump card of the Japanese and German researchers comes in.

BMW and Mazda propose to retain the ability to drive on gasoline (by analogy with the currently widespread dual-fuel cars "gasoline/gas").

Such an approach, according to the idea of car builders, will facilitate the gradual transition of vehicles to hydrogen-only power.

Meanwhile, mass production and mass sales of fuel cell vehicles will be severely limited by the small number of such fueling stations for a long time. Yes, and the cost of fuel cells is still high.

In addition, conversion of conventional combustion engines to hydrogen (with appropriate settings) not only makes them cleaner, but also increases thermal efficiency and improves operational flexibility.

The fact is that hydrogen has a much wider range of proportions of its mixing with air, compared to gasoline, at which combustion of the mixture is possible.

And hydrogen burns more completely, even near the walls of the cylinder, where in gasoline engines usually remains unburned mixture [7, 8, 9].

2 Methods

Transition of transport, industry and households to hydrogen combustion is a way to radically solve the problem of air protection from pollution by oxides of carbon, nitrogen, sulfur and hydrocarbons.

Transition to hydrogen technology and use of water as the only source of raw materials for hydrogen production cannot change not only the water balance of the planet, but also the water balance of its separate regions.

In the future, during the transition to hydrogen technology, such sources of hydrogen production, except for solid fuel, will be mostly eliminated. Water will be used as the main source of raw materials. As a source of energy for water decomposition - nuclear energy in its various forms (heat, electricity) and energy of water, wind in the form of electrical energy, solar radiation energy.

Electrolysis of water has been carried out in industrial practice for a long time and is widely described in the literature. Significant efforts are now being made in industrial science to harness the inexhaustible energy of solar radiation to decompose water. These include the use of photolysis cells to decompose water, solar cells to generate electricity with its subsequent use in the electrolysis of water. The main problem that is solved here is to conduct under the direct influence of solar energy a series of photochemical reactions with the target purpose of decomposition of water to hydrogen oxygen. The essence of the problem is to select biological systems that will use solar energy to decompose water.

The only exhaust gas from the combustion of hydrogen is water vapor, which enters the natural natural water cycle. It is known that hydrogen can be obtained from water again by electrolysis. This closed cycle, which is the basis of the idea of hydrogen energy, allows us to call hydrogen one of the most environmentally friendly fuels.

3 Results and Discussion

The Economic Commission for Europe at the United Nations (UNECE) in cooperation with leading European firms has developed the Auto-Oil program for all types of vehicles, on the basis of which emission and noise standards were further developed, based on scientific advances, technological production capabilities, the need to protect the environment at the lowest cost to society for their implementation. This direction is planned to be carried out as a part of the overall UNECE program "Clean Air for Europe". [10].

Standards in the field of emissions and noise for motor vehicles by special directive documents are gradually introduced in the territory of the European Union (EU). The dynamics of their development provides for the introduction in 2005 of norms of emissions and noise, outstripping the corresponding norms of standards of the USA and Japan [11]. In 1997, the EU consisted of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland. Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.

Mandatory implementation of these standards in the EU has led to a qualitative change in the structure of the fleet of trucks and passenger vehicles and increased the potential of the European road transport market. Consider the GHG emission standards for the following conditional market sectors.

In 1982, the ECE-R49 Regulations were introduced in Western Europe, regulating emission standards for diesel engines installed on trucks of this class with a GVW ≥ 3500 kg. Starting from 1993, the requirements for GHG emissions are sharply tightened (Table 1) [12].

Table 1. Emission norms (ECE-R49/02 cycle).

Stage	Term of introduction	Standard index [25]	Emission norms, g/(kWh)			
			NO_x	CO	HC	PM
-	1982	ECE-R49	18,0	14,0	3,5	-

Continuation of Table 1.

Stage	Term of introduction	Standard index [25]	Emission norms, g/(kWh)			
			NO_x	CO	HC	PM
A	1993	EURO I	8,0	4,5	1,1	0,36
B	1996	EURO II	7,0	4,0	1,1	0,15

Note. NO_x - nitrogen oxides (in particular NO, NO_2, N_2O_5,…); CO - carbon monoxide (carbon monoxide); HC - hydrocarbonates (international designation of gaseous hydrocarbons); PM is a symbol for "solid" particles (soot - up to 50%, sulfates - up to 20%, heavy hydrocarbons - up to 30%).

In accordance with the ECE-R49 / 02 Rules in Europe, for fine-tuning and testing transport diesel engines, a single 13-stage stationary cycle was adopted: idle mode, 5 modes at maximum torque revolutions (at 10, 25, 50, 75 and 100% load), idle mode, 5 modes at rated power speed (at 100, 75, 50, 25 and 10% load), idle mode. The diesel engine operating time in each mode is 10 minutes and is distributed as follows: 1 minute - to change the mode, 8 minutes - to organize the mode, 1 minute - to measure the exhaust gas composition [13, 16].

In December 1997, UNECE accepted a cue to consider a proposal to develop environmental standards for this class of diesel engines with increased test cycles (Tables 2 and 3) [12, 16].

Table 2. Emission (ESC cycle) and smoke (ELR test) standards.

Stage	Term of introduction	Standard index [25]	Emission norms, g/(kWh)				Smoke
			NO_x	CO	HC	PM	
A	2000	EURO III	5,0	2,1	0,66	0,1/0,13*	0,8
B1	2005	EURO IV	3,5	1,5	0,46	0,02	0,5
B2	2008	EURO V	2,0	1,5	0,46	0,02	0,5
C (EEV) **	Under consideration		2,0	1,5	0,25	0,02	0,15

* For diesel engines with cylinder displacement Vh < 0,75 l and nominal crankshaft speed, $n_{\text{ном}}$>3000 min-1.

**EEV (Enhanced Environmentally Friendly Vehicles) - "environmentally friendly" cars for use in areas with high levels of air pollution.

Table 3. Emission norms (ETC cycle).

Stage	Term of introduction	Standard index [25]	Emission norms, g/(kWh)				
			NO_x	CO	NMHC	PM*[1]	CH_4*[2]
A	2000	EURO III	5,0	5,45	0,78	0,16/0,21*[3]	1,6
B1	2005	EURO IV	3,5	4,0	0,55	0,03	1,1

Continuation of Table 3.

Stage	**Term of introduction**	**Standard index [25]**	**Emission norms, g/(kWh)**				
			NO_x	CO	NMHC	PM*[1]	CH_4*[2]
B2	2008	EURO V	2,0	4,0	0,55	0,03	1,1
C (EEV)	Under consideration		2,0	3,0	0,40	0,02	0,65

Note. NMHC - hydrocarbons formed during the combustion of non-methane (diesel) fuel; CH_4 - methane (natural gas).
*[1] Not applicable to gas-fired diesel engines in stage A and stages B1 and B2.
*[2] Only for diesel engines running on natural gas.
*[3] For diesel engines with cylinder displacement V_h < 0,75 l and nominal crankshaft rotation speed, $n_{\text{ном}}$>3000 мин$^{-1}$.

ESC (European Steady [state] Cycle) - The European Steady Cycle is conducted on 13 main and three additional diesel operating modes. The ESC cycle has been designed to take into account the real-world operating modes of diesels in heavy-duty vehicles (HDVs). The twelve main modes are defined for the three test crankshaft speeds: $n_A = 0{,}5 n_{\text{ном}}$; $n_A < n_B < n_C$; $n_C = 0{,}7 n_{\text{ном}}$ and four load levels: 25, 50, 75 and 100 % M by the external speed characteristic, respectively, for each test crankshaft speed. The diesel engine is tested in 13 main (test) modes, starting with idling (4 min), and then in 12 modes under load (2 min each) in a certain sequence, during which the emissions of exhaust gases are measured.

The European stationary cycle is conducted on 13 main and three additional diesel operation modes. The ESC cycle has been designed to take into account the real-world operating modes of diesels in heavy-duty vehicles (HDVs). The 12 main modes are defined for three test crankshaft speeds: ; ; and four load levels: 25, 50, 75 and 100 % M by external speed characteristic, respectively, for each test crankshaft speed. The diesel engine is tested at 13 basic (test) modes, beginning with idle running (4 min), and then at 12 modes under load (2 min each) in a certain sequence, during which emissions of exhaust gases are measured.

During the certification test, emission measurements are made at three additional diesel operation modes, chosen at random in the control area $(n_A...n_C)-(0{,}25...1{,}0)\grave{I}$. In additional operating modes, the emission NO_x should not be more than 10% of the emission NO_x obtained by interpolation over four adjacent test modes, provided that the standard is met as a whole (see Table 2) [12].

ELR (European Load Response [test]) - The European load acceptance cycle is carried out at the frequencies n_A, n_B and n_C the ESC cycle and additionally at a freely selectable frequency in the control region. First, the diesel engine operates at 10% load at a frequency of . The controlled frequency is then changed to a specific value in a wide open range and the load applied to the diesel should keep the crankshaft speed approximately constant. This operation is repeated twice at all four frequencies of the diesel engine (at a frequency, the initial load may be slightly higher than 10%). The final value of opacity, calculated from the average values of opacity at frequencies n_A, n_B and n_C, should be below the standard value (see Table 2).

The average haze value at a frequency shall not exceed by more than 20% the highest haze value measured at the frequencies and or exceed by more than 5% the standard value. Any of these conditions is essential.

ETC (European Transient Cycle) - A European transient cycle lasting 1800 s consists of three successive continuous phases of loading a diesel engine on a stand, simulating dynamic modes when a car moves along city streets, rural roads and highways [12].

According to the degree of harmfulness of the impact of exhaust gas emissions, CO is taken as the standard, the effect of which on the human body is most fully studied. Using the data of [14], it is possible to compile the following proportional series of coefficients for the relative aggressiveness of toxic components of exhaust gases (the value of the coefficient K_{PM} for solid particles is taken from soot).

$$K_{\text{CO}} : K_{\text{HC}} : K_{\text{NO}_x} : K_{\text{PM}} = 1 : 3{,}16 : 41{,}1 : 41{,}1 \cdot \quad (1)$$

Using this series, it is easy to show the progress of European standards for HDV vehicles in reducing the harmful effects of exhaust gas emissions on the human body. According to the degree of harmful effects, the equivalent CO emission standard for each component can be determined as the product of the relative aggressiveness coefficient and the corresponding value of the standard (see Tables 2 and 3). For example, the CO equivalent emission standard for nitrogen oxides can be defined as follows.

$$Э_{\text{NO}_x} = K_{\text{NO}_x} \cdot \text{NO}_x \quad (2)$$

Then, for each standard, the total standard equivalent to SD can be calculated using the formula.

$$Э_{\Sigma} = Э_{\text{NO}_x} + Э_{\text{PM}} + Э_{\text{CO}} + Э_{\text{HC}} \cdot \quad (3)$$

The calculation results are given in Table. 4.

Table 4. CO equivalent emission standards for HDV, g/(kWh)

Terms of introduction	**Standard index**	**$Э_{NOx}$**	**$Э_{PM}$**	**$Э_{CO}$**	**$Э_{HC}$**	**$Э_{\Sigma}$**
1993	EURO I	328,8	14,8	4,5	3,5	$Э_{I}$ = 351,6
1996	EURO II	287,7	6,2	4,0	3,5	$Э_{II}$ = 301,4
2000	EURO III	205,5	4,1	2,1	2,1	$Э_{III}$ = 213,9
2005	EURO IV	143,9	0,8	1,5	1,5	$Э_{IV}$ = 147,7
2008	EURO V	82,2	0,8	1,5	1,5	$Э_{V}$ = 86,0

Figure 1 shows a diagram illustrating the general development of European legislation to reduce the harmful effects on humans of exhaust gas emissions from diesel engines installed on HDV vehicles (the equivalent standard $Э_{\Sigma} = 351{,}6$ g/(kWh) is taken as 100% CO equivalent).

Light trucking. For their implementation, vehicles with a capacity of up to 6 passengers inclusive are used: cars, minibuses (with an engine capacity of $iV_h \leq 3$ l) and other passenger cars with a gross weight of GVW ≤ 2500 kg [15]. In accordance with Directive 96/44/EC, these vehicles are subject to the following exhaust gas emission standards (Table 5).

Table 5. Emission standards for cars and minibuses (<6 passengers, GVW ≤ 2500 kg), g/km

Cycle	Emission designation	EC 93-EURO I [16]	EC 96-EURO II [16]	
		Petrol = Diesel	Petrol	Diesel IDI/DI
ECE + EUDC	$HC+NO_x$	0,97 (1,13)	0,5	0,7/ 0,9
	CO	2,72 (3,16)	2,2	1.0
	PM*	0,14 (0,18)	-	0,08/0,1

Note. Standards for serial production are given in brackets. * For vehicles with diesel engines.

After 80,000 km of run, exhaust gas emissions must not exceed the following standards: 1.2 g / km - for all controlled components for cars with gasoline engines and 1.1 g / km (CO); 1.0 g/km (HC+NO); 1.2 g/km (PM) - for cars with diesel engines [17].

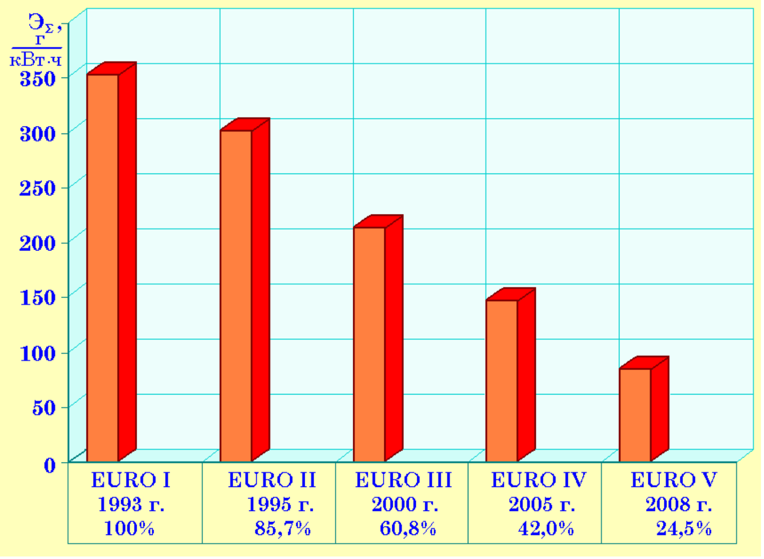

Fig.1. Development of European legislation to reduce diesel exhaust emissions for HDV vehicles.

Fine-tuning and testing of small engines is carried out as part of the respective vehicles on roller stands according to the new European driving cycle NEDC [16] or ECE + EUDC or MVEG - A [15]), which consists of two main parts (Fig. 2).

ECE (UNECE) CITY CYCLE (urban cycle): length 4.052 km; duration 820 s; maximum speed 50 km/h; average speed 18.7 km/h. The urban cycle includes an idling mode for 40 s after the engine is started and four identical single loading cycles lasting 195 s each. EUDC (special urban cycle): length 6.955 km; duration 400 s; maximum speed 120 km/h.

Fig.1. Development of European legislation to reduce diesel exhaust emissions for HDV vehiclesA package of new European environmental standards for passenger and light commercial vehicles was published on December 28, 1998 [12,16]. In table. 6 shows the emission standards for cars with small-capacity gasoline and diesel engines of sectors II-IV of the trucking market.

Table 6. Emission standards for passenger (M) and light commercial (N1) vehicles. (Directive 98/69/EC, annex 1, paragraph 5.3.1.4). g/km

Category	Class	RW, кг	CO	HC	NO_x	HC+NO_x	PM*1
A (2000) M*2	-	Все	2,3/0,64	0,20/-	0,15/0,50	-/0,58	0,05
A (2000) N1*3 (EURO III, [16])	I	RW≤1305	2,3/0,64	0,20/-	0,15/0,50	-/0,56	0,05
	II	1305<RW≤1760	4,47/0,80	0,25/-	0,18/0,65	-/0,72	0,07
	III	RW>1760	5,22/0,95	0,29/-	0,21/0,78	-/0,86	0,10
B (2005) M*2	-	Все	1,0/0,50	0,10/-	0,08/0,25	-/0,30	0,025
B (2005) N1*3 (EURO IV, [16])	I	RW≤1305	1,0/0,50	0,10/-	0,08/0,25	-/0,30	0,025
	II	1305<RW≤1760	1,81/0,63	0,13/-	0,10/0,33	-/0,39	0,04
	III	RW>1760	2,27/0,74	0,16/-	0,11/0,39	-/0,46	0,06

Note. RW is the recommended gross vehicle weight. The numerator indicates the emission standards for gasoline engines, the denominator - for diesel engines.
*1 For compression ignition (diesel) engines.
*2 Passenger vehicles with gross weight up to and including 2500 kg.
*3 Including category M vehicles over 2500 kg gross vehicle weight.

Compared to the EURO I and EURO II standards (see Table 4), Directive 98/69 / EC, adopted as a law, regulates more stringent standards for exhaust gas emissions A (2000) = EURO III and B (2005) = EURO IV for passenger and light commercial vehicles (LCV) in the European Union, clarifies gross weight values for each class of LCV vehicles and the existing ECE+EUDC test cycle, introduces new additional types of certification tests. Let's briefly review the main ones.

Type I test - type I test (test cycle for determining emissions at the outlet of a car muffler). Emissions measurements are carried out according to the established test cycle (see Fig. 2), excluding measurements during the first 40 s of engine idling.

Type IV test - test of the 4th type (determination of evaporating emissions). New procedure with higher and longer thermal loads to more accurately simulate the engine's thermal limit. The limit value for evaporative emissions is 2 g per test of this type.

Type VI test - type 6 test (cold start). The new test at negative temperature (-7 0C) is carried out only according to the urban cycle (see Fig. 2). Maximum permissible levels of emissions: for CO 15 g/km, for NS 1.8 g/km.

In parallel with the development of standards for harmful emissions, the possibility of reducing emissions of CO2 is being considered, since its accumulation in the atmosphere together with methane CH4 and other polyatomic gases leads to the development of the "greenhouse effect" on Earth. According to the agreements reached between the UNECE and the automotive industry of Western Europe, the following average CO2 emission standards for passenger cars have been determined: 1995 - 180 g/km; 1998 - 140 g/km; 2005 - 120 g/km [16,17,18].

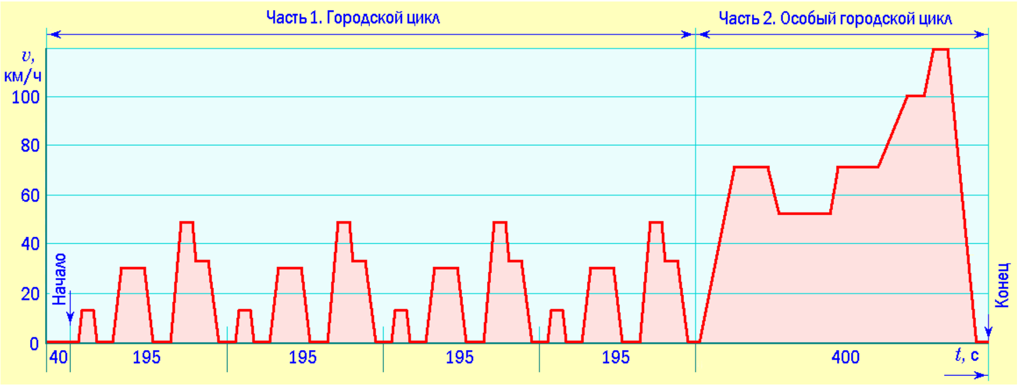

Fig.2. ECE/EG-Test vehicle testing program for exhaust gas emissions.

To this end, the United Nations Economic Commission for Europe, together with leading European companies, has developed the Auto-Oil program for all types of vehicles. On the basis of this program, standards for GHG emissions were formulated based on scientific achievements, technological capabilities of production, the need to protect the environment at the lowest cost for society for their implementation. This direction is planned to be carried out as an integral part of the overall UNECE program "Clean Air for Europe" [12].

At present, in our country and abroad, work is being carried out within the framework of the "Environmentally Clean Transport - Green Car" program to expand the use of cars with combined power plants, which reduce CO2 emissions by 25-35% and electric vehicles in the conditions of their operation in cities, and also an intersectoral program for the phased introduction of hydrogen energy in the transport sector. The latter implies the creation of an infrastructure for the use of hydrogen in transport, which will require significant financial investments and in the long term should be completed by 2030.

Hydrogen applications in which the traditional internal combustion engine is replaced by a power plant based on hydrogen fuel cells. Taking into account a number of the above-described for benzapyrene and stringent requirements for the emission of particulate matter only from the exhaust gases of errors in the adoption of legislative measures, it is necessary to bear in mind the fact that with a full transition to the use of hydrogen, H2O-water will be released from the exhaust gases, almost 9 kg per each kg of H2. Naturally, in the future, the actual large-scale use of hydrogen obtained from water will not increase the volume of water in the world's oceans, as happens with the combustion of hydrogen-containing methane.

Figure 3 shows a schematic diagram of a hydrogen electrolyzer [14,15].

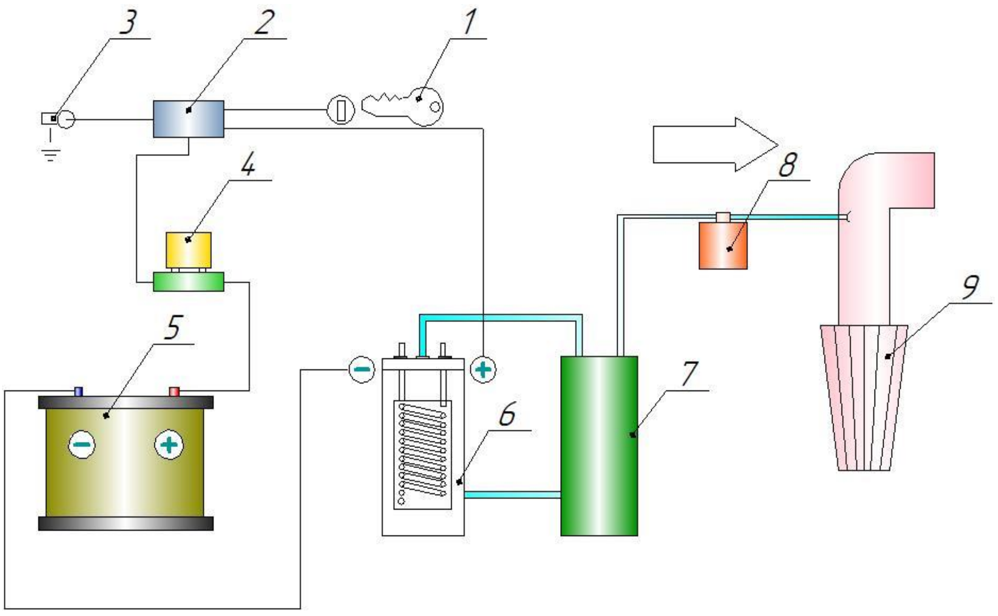

Fig. 3. Schematic diagram of the hydrogen electrolyzer. 1-key, 2-relay, 3-ground, 4-fuse, 5-battery, 6-HNO generator, 7-reservoir, 8-drier, 9-air filter.

4 Conclusions

Based on the analysis of the work of foreign and domestic studies on the reduction of emissions of harmful substances and greenhouse gases from exhaust gases, as well as from other vehicle systems, it is necessary to objectively conduct further research on environmental safety and energy efficiency of vehicles:
a) develop a comprehensive method for an objective assessment of the environmental safety of vehicles;
b) on the basis of the selected set of methods, conduct comparative studies of environmental and economic indicators and energy efficiency of vehicles with traditional internal combustion engines (ICE), with combined power plants.

References

1. Postanovleniye Prezidenta Respubliki Uzbekistan ot 10 iyulya 2020 goda № Q-4779 «Uvelicheniye energoeffektivnosti ekonomiki i snizheniye zavisimosti ekonomicheskikh sektorov v toplivno-energeticheskikh produktakh»
2. Postanovleniye Prezidenta Respubliki Uzbekistan ot 22 avgusta 2019 goda № PP-4422 «Ob uskorennykh merakh po povysheniyu energoeffektivnosti otrasley ekonomiki i sotsial'noy sfery, vnedreniyu energosberegayushchikh tekhnologiy i razvitiyu vozobnovlyayemykh istochnikov energii»
3. M.L.Varshavskiy, R.V. Maloye, *Kak obezvredit' otrabotavshiye gazy avtomobilya* (Transport, 1968)
4. A.S. 1455008 /SSSR/ Dvigatel' vnutrennego sgoraniya /AltPI im. I.I. Polzunova: avt. izobreteniye S.V. Novoselov, A.L. Novoselov, V.A. Sinitsyn, M.E. Bryakotin.- zayavl. 23.03.87, № 4258070/25-06, opubl. B.I. № 4 (1989)

5. Y. Kojima, et al., International Journal of Hydrogen Energy **27**, 10 (2002)
6. Ye. K .Lyutikova, YU. I. Kiryukhin, L. L. Antonova, K. V. Fedyshina, D. I. Samoylov, CH. G. Motlokh, V. N. Fateyev, «Razrabotka stoykikh k SO elektrokatalizatorov dlya tverdopolimernykh toplivnykh elementov»//Mezhdunarodnaya konferentsiya «Elektrokataliz v elektrokhimicheskoy energetike»: Tez.dokl. –M., (2003)
7. A. A. Vatul'yan, S. A. Glagovskiy, L. K. Petrov, Ye.V. Shatrov, *Konstruktsii sovremennykh dizeley dlya legkovykh i malotonnazhnykh gruzopassazhirskikh avtomobiley* (Tsniiteiavtoprom, 1987)
8. R. Kroyssenbrunner, *Kontseptsiya dizelya s nizkoy emissiyey vrednykh veshchestv i nizkim raskhodom topliva na primere dvigatelya firmy AVL «LEADER»*. Doklad na simpoziume firmy AVL List GmbH (Moskva, 1995)
9. Emissions standarts passenger cars world-wide (Delphi Technical Centre Luxembourg, 1997).
10. *Nelegkiy vybor Yevropy* (Biznes Unk, 4, 1996)
11. M. Egert, W. Cartellieri, U. Veit, R Walter, *Latest design and development aspects of engines for light commercial vehicles to meet futuer emission limits* (FISI- TA World Automotive Congress, 1998)
12. Pravila OON №49 «Yedinoobraznyye predpisaniya, kasayushchiyesya podlezhashchikh prinyatiyu mer po ogranicheniyu vybrosov zagryaznyayushchikh gazoobraznykh veshchestv i tverdykh chastits iz dvigateley s vosplameneniyem ot szhatiya, prednaznachennykh dlya ispol'zovaniya na transportnykh sredstvakh, a takzhe vybrosov zagryaznyayushchikh gazoobraznykh veshchestv iz dvigateley s prinuditel'nym zazhiganiyem, rabotayushchikh na prirodnom gaze ili szhizhennom neftyanom gaze i prednaznachennykh dlya ispol'zovaniya na transportnykh sredstvakh», 13.08.2008 g. Ye/YESE/324, Ye/YESE/trans/505
13. A.P. Kulchitsky, *Toxicity of automobile and tractor engines* (Vladimir: VlGTU, 2000)
14. J Ismatov, F Matmurodov, A Kholikov, A Abdullaev, J Djalilov, U Muhammadiyev, Journal of Physics: Conference Series **2131** (2021)
15. J. Ismatov, F. Matmurodov, J. Khakimov, J. Djalilov, IOP Conf. Series: Earth and Environmental Science **1112** (2022)
16. M. E.Weisblum, AAI Journal. **3**, 68 (2011)
17. V. N. Lukanin, Yu.V. Trofimenko, *Industrial and transport ecology* (Higher school, 2003)
18. V. F. Kutenev, B.V. Kisulenko, Yu.V. Shute, *Environmental safety of vehicles with internal combustion engines* (Ecology, Engineering, 2009)