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Technology Development for Using Hydrogen Obtained from Hydrogen Sulfide Taken from the Black Sea Bottom as an Alternative Fuel in the Internal Combustion Engines of Vehicles

Field/Specialty: 0407 Engineering/Transport

The Author's Abstract

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General description of work

Topicality of research. In the modern era, the intense development of the energy and transport sectors places mankind before serious energy and environmental problems. As the population of the Earth has increased, energy demands have grown as well, leading to a reduction in the existing fossil fuel resources, whose world reserves might become scarce in the near future. Currently, there is shortage of 4 million barrels of oil in the world every day and by the year 2050, it is expected that under the conditions of modern consumption, its reserves will be depleted or disappear.

Technical progress based on traditional energy, along with a number of positive sides, has also a negative impact on the environment and causes global climate change.

The main source of environmental pollution is the processes occurring in the internal combustion engine of vehicle, since the complicated heat and mass exchange processes occur between the engine cylinder and the atmosphere, and combustion products contain more than 200 different types of substances, most of which are poisonous. Among them, particularly notable are: carbon monoxide (CO), carbon dioxide (CO_2), various hydrocarbons (C_XH_Y), nitrogen and sulfur oxides; lead compounds; solid matters in the form of soot; heavy metals and so on. In addition, $14{,}5 \cdot 10^{18}$ kJ of heat is transmitted to the Earth's atmosphere, which causes dislocation of the so-called heat balance and contributes to an increased risk of global warming.

These problems attest to the fact that the question of increasing the motor transport fuel efficiency and environmental safety is very relevant, therefore, any activity ensuring the motor transport fuel efficiency and an increase in environmental safety is of great practical and social importance.

Among the numerous well-known measures to improve the vehicle's environmental performance, particularly effective is to seek ways to use alternative fuels. Environmentally and economically, one of the promising fuels of the future is hydrogen, which is the most abundant element in the universe and much of it is present on the Earth as water. The prospect of using hydrogen as a fuel for motor transport is due to its environmental purity, infinite deposits, renewability and the excellent thermal properties.

Combustion products of in engines converted to run on hydrogen do not contain compounds, such as engine hydrogen converted to hydrogen, soot particles, lead, etc. However, the environmental problem is the reduction of nitrogen oxides. Hydrogen as a motor transport fuel has some positive and negative properties as discussed in this doctoral thesis.

Goal of research. The goal of the dissertation is to develop a method of extracting hydrogen sulfide-containing aqueous solution from the deep waters of the Black Sea and to separate methane and hydrogen from it by using membrane technology. The goal of the next step is to analyze theoretical and experimental studies on the use of hydrogen in the internal combustion engines as a fuel. This means that the purpose of the work is to develop a common cycle of using hydrogen in the internal combustion engines, which was obtained according to technology of its separation from hydrogen sulfide-containing aqueous solutions extracted from the deep waters of the Black Sea.

○ ***This work was supported by Shota Rustaveli Georgian National Science Foundation (SRNSFG) [DP 2016_5. Organization and management of transport processes].***

Research methods. Theoretical and experimental research methods are used in this works. Theoretical research was used to determine the parameters of traffic flow in order to assess the environmental impacts and logistical management of environmental safety in urban conditions. Based on the membrane separation method of gaseous mixtures, there were selected the local natural zeolites - unprocessed zeolite from Dzegvi village, zeolite from Khekordzula village processed by N_i, and synthetic cationite KY-2-8, and it has been established that they can be used as a high-effective adsorbing agent for hydrogen sulfide existing in the deep-sea waters. The composition of combustion products was determined experimentally by methodology developed according to the EURO standard requirements, and there was used gas analyzer Multitest 211 manufactures in Italy.

The novelty of research findings. There was developed a common cycle of extracting the hydrogen sulfide-containing aqueous solution from the Black Sea waters and obtaining hydrogen by membranous technologies and using it as a fuel, which was studied experimentally.

Based on the experimental data, a methodology has been developed that will allow us for determining, in each individual case, the ratio of hydrogen and gasoline in the mixture, which will ensure a high level of the working process.

Experimental data have shown that the most effective adsorbing agents for hydrogen sulfide existing in the deep waters of the Black Sea as aqueous solution are of local natural zeolites (unprocessed clinoptilolite from Dzegvi village and zeolite from Khekordzula village processed by N_i) and synthetic cationite KY-2-8. Synthetic zeolite CaA is also characterized by high adsorbing capacity towards methane, while methane is not adsorbed at all on cationite KY-2-8.

The methodology was developed to calculate the environmental damage (in GEL) of harmful substances emitted during operation of vehicle gasoline + hydrogen and natural gas + hydrogen fuel. Based on this methodology, the socio-economic effect obtained by improving the vehicle's environmental performance (compared to the baseline) was calculated.

Practical bearing. The 21st century is the century of hydrogen energy. Georgia is among the countries that do not have fossil oil and gas deposits. Therefore, extraction and use of non-traditional sources of energy, including hydrogen, in motor transport or other energy machinery will solve our country's energy and economic problems. Hence, the scheme proposed in this work for extracting hydrogen sulfidefrom the Black Sea deep waters and its separation by using membrane technology (obtaining methane and hydrogen) has practical value, since hydrogen and methane accumulated in the special gas carriers can be used both in motor transport and in thermal power stations for power generation and household consumption. Experimental research points once again to the environmental benefits of using hydrogen as a fuel of motor transport as compared to other types of fuel, and this is a kind of recommendation for adapting this type of the vehicle fleet to this type of fuel.

On overview of work. Presentations on the results of dissertation paper were made at the following conference and forums:

1. ১The scientific-practical workshops on transport-related issues held at the Department of Transport and Civil Engineering of Akaki Tsereteli State University, ATSU, Kutaisi, 2014–2016.
2. III Georgian-Polish International Scientific-Practical Conference Transport Bridge Europe-Asia”. Kutaisi, 24-26.10.2017.

3. IV Georgian-Polish International Scientific-Practical Conference Transport Bridge Europe-Asia”. GTU, Tbilisi, 8-11.10.2018.
4. V International Scientific-Practical Conference “Energy: Regional Problems and Development Opportunities”, ATSU, Kutaisi, 25-26.10.2018.
5. International Scientific-Technical Conference trans&MOTAUTO’17. Burgas, Bulgaria, 24-27.06.2017.
6. Conference on Transport Sciences Győr 2019, Széchenyi István University, Győr, Hungary.
7. International Scientific-Technical Conference trans&MOTAUTO’19. Varna, Bulgaria, 17-21.06.2019.

Published materials. On dissertation materials, there have been published 10 scientific papers, including 5 papers in high-rated journals registered in the ERIH PLUS databsses, which have been recommended by the Dissertation Council of the Faculty of Technical Engineering of ATSU.

The volume and structure of dissertation. Dissertation is divided into four chapters, and includes 22 tables, 36 drawings, 2 diagras list of 80 references. Disertation comprises 140 printing pages.

Content of work

The first chapter is devoted to the analysis of literature sources that analyze the impact of the transport system on the ecosystem and ways to adress it. There is also assessed the impact of traffic flow on environmental conditions of the South Caucasus region and logistical management of environmental safety of transport in urban areas.

At the present stage, the environmental situation in the world in a number of regions, including Georgia is very tense, because transportation of raw materials and finished products and meeting the increased demands for passenger transportation are impossible without development of the transport system, in which, one of the leading role is being played by motor transport, which is developing by leaps and bounds both in terms quality and quantity. To date, the world vehicle fleet has exceeded one billion (more than 1.2 million vehicles in Georgia) and the length of motorways is 11.5 million km.

The movement of individual vehicles on motorways may not have a significant impact on the environment and ecosystem, but there is a different situation when considering the traffic flow in terms of cargo and passenger transport.

The amount of harmful substances emitted by vehicles flow on a given section of motorway (kg/h·km) is determined by the formula:

$$Y = \sum_{i}\sum_{j}\sum_{K} W_j \cdot P_{Ki} \cdot N_a \qquad (1)$$

where W_i – quantity of any component or fuel consumption during the period of run g/km;

P_{Ki} – the likelihood of falling into the traffic flow of K group vehicle when moving at a *i*-velocity range;

N_a – traffic flow intensity, v/h.

Particular attention should be paid to the rational management of the mobility of vehicles of the categories of M_1 and M_2 in major cities. (M_1 and M_2 represent the category of passenger vehicles in the range of up to 2500 kg and 2500-5000 kg of gross vehicle weight. However, in the case of M_1 category, the number of passengers does not exceed eight, while in the case of M_2 category, this number is more than eight).

Given the fact that the major share of traffic flow in major cities and districts towns is undertaken by vehicles from the categories of of M_1 and M_2, it is easy to imagine the role of these types of objects in terms of environmental pollution. It is estimated that in the case of average annual mileage, 70-80% of urban pollution falls on vehicles from this category.

In the Caucasus, as well as in many other regions throughout the world, environmental problems are most pressing, including: pollution of the atmosphere, water resources and soil. In the city of Tbilisi, about 276,500 tons of harmful substances are released into the atmosphere per year, of which 83.3% is motor transport. The mass of the exhaust substances in the atmosphere in Kutaisi is 76 200 tons, and 168 700 tons of harmful substances are emitted in the atmosphere in Rustavi City.

The prospect of using hydrogen as a fuel for motor transport is due to its environmental safety, infinite deposits, renewability and excellent thermal properties. In addition, as a fuel, it can be stored in a compressed, liquefied, or bonded state. However, it can be obtained directly from vehicle.

Therefore, along with other alternative sources, the prospects of using hydrogen in the internal combustion engines of vehicles are being actively discussed, since hydrogen energy actually means the country's energy independence.

The second chapter dwells on studying environmental problems of the Black Sea and the process of obtaining hydrogen sulphide from its deep waters. It also discusses some methods of extracting and separating gaseous mixtures from the depths of the Black Sea. This chapter also provides an overview of the theoretical and experimental processes of the membrane process for obtaining hydrogen from hydrogen sulfide.

Today, one of the main problems in determining the environmental status of the Black Sea is the presence of methane and hydrogen sulfide in the lower layers of water, whose content increases annually due to the pollution.

Marine environmental studies have shown that the vital characteristics of the Black Sea are steadily deteriorating as the hydrogen sulfide-containing zone occupies 87% of all water (Fig. 1), which constitutes a serious threat to both humans and life in general. If we don't do anything to prevent these processes, the Black Sea can be poisoned by hydrogen sulfide, which will change the chemical composition of water, and consequently, impoverish the flora and fauna of the sea.

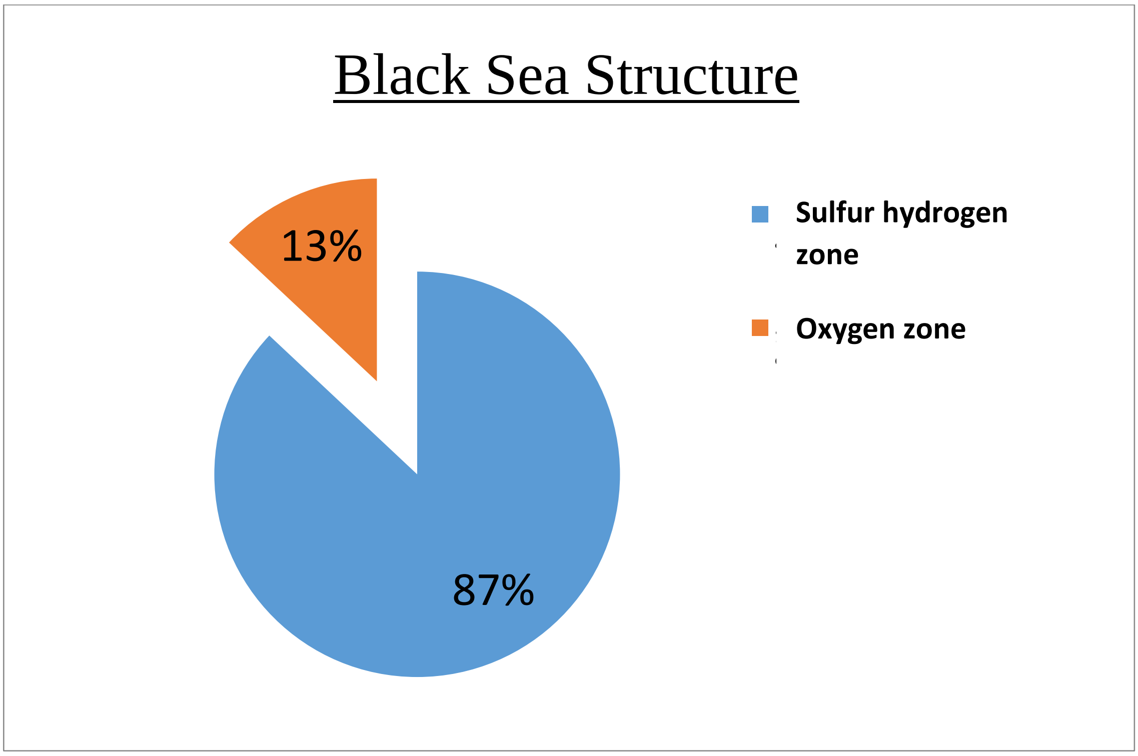

Fig. 1. The Black Sea structure (hydrogen sulfide-containing zone, osygen-containing zone).

Among methods of extracting hydrogen sulfide from the Black Sea waters, particular mention should be made of as follows:

After initial pumping of water by a solid vertical channel pump, it is possible to obtain a gas-water in the sea due to a pressure difference of hydrostatic pressure at the level of a lower section of the channel the gas-liquid mixture inside the channel at the same level. At this time, there is no need for additional energy to extract hydrogen from the hydrogen sulfide aqueous solution from the depth to the surface, due to the so-called gas-filter effect.

Membrane separation methods for gaseous mixtures have been rapidly developed in recent times, allowing for extracting hydrogen sulfide from the seawater directly at the depths. In this respect, the methods of ion-exchange and selective sorption used in polymeric membranes, which are based on the property of semipermeable hydrophobic membranes to conduct gas and retain water.

The method of extracting hydrogen sulfide from the deep waters of the Black Sea using the normal pipeline, and of further dividing it into the elements, is based on the extraction of water containing H_2S from the depths of the natural reservoirs, which is due to a pressure difference existing between the sea surface and the receiving area.

Membrane and sorption methods are effective for separating and dividing the gaseous mixtures extracted from the Black Sea deep waters.

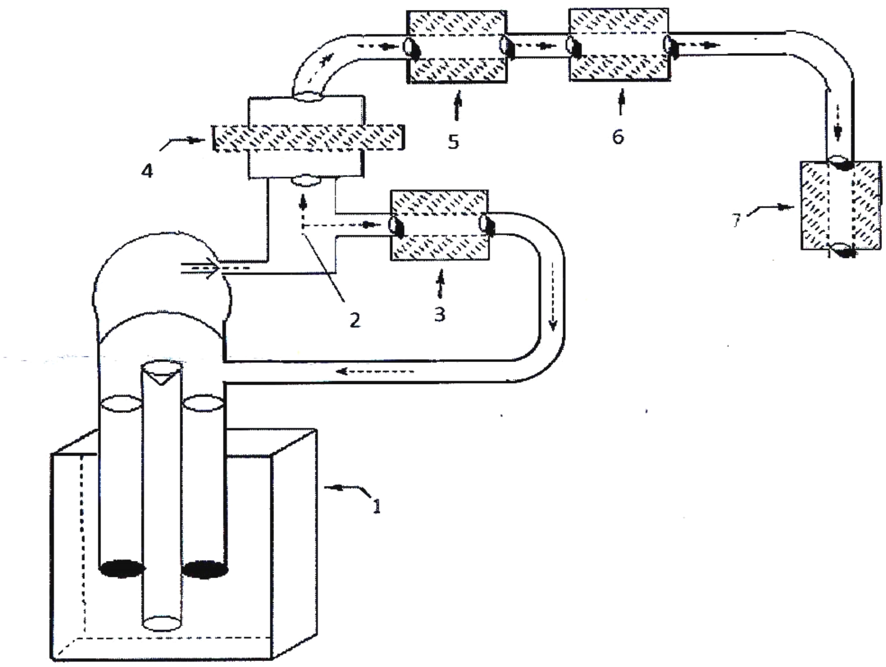

Fig. 2. The separating and dividing scheme of the gaseous mixtures from the Black Sea deep water using the membrane technologies and sorbtion methods.

1. The devcice for pumping water from the seabed.
2. Water pumped from the seabed with a mixture of gases (H_2;CH_4;K^+;NH_4^+; H_2S)
3. Zeolitic module for adsorption of $K^+$and NH_4^+;
4. Membrane module for separating the gas mixtures (H_2;CH_4;H_2S) from water;
5. Membrane module for adsorption of hydrogen;
6. Membrane-zeolitic module for adsorption of methane;
7. Membrane-zeolitic module for adsorption of hydrogen sulfide.

With a view to extracting hydrogen sulfide from the seawater by method of adsorptive concentration, studies were carried out using clinoptilolite of local origin from Khelkordzula village modified by N_i and by natural unprocessed clinoptilolite from Dzegvi village and zeolite from Khelkordzula village, and in addition, use was also made of synthetic zeolite cationite KY-2-8.

As the test samples, there were used natural sulfur-containing waters from Khobi and Tsaishi in western Georgia. In addition, the hydrogen sulfide content in water from Khobi was 4,76÷6,8 mg/l pH=9,65, while in water from Tsaishi, the hydrogen sulfide content was 20,22÷22,1 mg/l pH=8,85.

Table 1.

Adsorption of hydrogen sulfides hydrogen sulfide-containing water from Khobi with zeolites (Co=5,1 mg/lH_2S, Vo=250 ml; m=40 g)

№	Name of zeolites	pH after the experiment	Retention time	H_2S concentration in water after adsorption, c; mg/l	The adsorption value, α; mg/g	The quality of extracting H_2S, E; %
1	Zeolite modified by N_i from Khekordzula village	3,15	48	0,68	0,0276	86,7
2	Unprocessed zeolite from Dzegvi village	8,5	48	2,55	0,0164	50
3	Cationite KY-2-8	2,1	48	0,68	0,0276	86,7

At the next stage of research, there was studied the adsorption kinetics of H_2S on modified zeolite, unprocessed clinoptilolite and synthetic cationite KY-2-8 from the sulfur-containing water with different concentrations of H_2S. At the same time, 0.5 g of selected species of zeolite was placed in test waters of equal volume. Water analysis on H_2S content is performed every 15 minutes.

Table 2.

The adsorption of hydrogen sulfide modified by zeolite from the sulfur-containing water from Tsaishi (Co=20,2 mg/l H_2S, Vo=50 ml; m=0,5 g)

№	Retention time, min.	H_2S concentration in water after adsorption, mg/l	The adsorption value, mg/g	The quality of extracting H_2S, E
1	15	4,76	1,55	76,5
2	30	4,25	1,60	78,9
3	45	4,25	1,60	78,9
4	60	4,25	1,60	78,9
5	75	4,25	1,60	78,9
6	90	4,25	1,60	78,9

The summarized results of the experiments are shown in Table 3, while the adsorption rate of hydrogen sulfide at room temperature (25 °C) is shown in Figure 3.

Table 3.

The quality of extracting H_2S (E%) from the sulfur-containing natural water from Tsaishi(Co=22,1 mg/l).

Clinoptilolite	Time t, min					
	15	30	45	60	75	90
Cationite KY - 2 – 8	76,2	80,5	82,8	82,8	82,8	82,8
Zeolite modified by N_i from Khekordzula village	76,43	78,96	78,96	78,96	78,96	78,96
Unprocessed zeolite from Dzegvi village	14,71	19,91	24,43	27,15	27,6	28,05

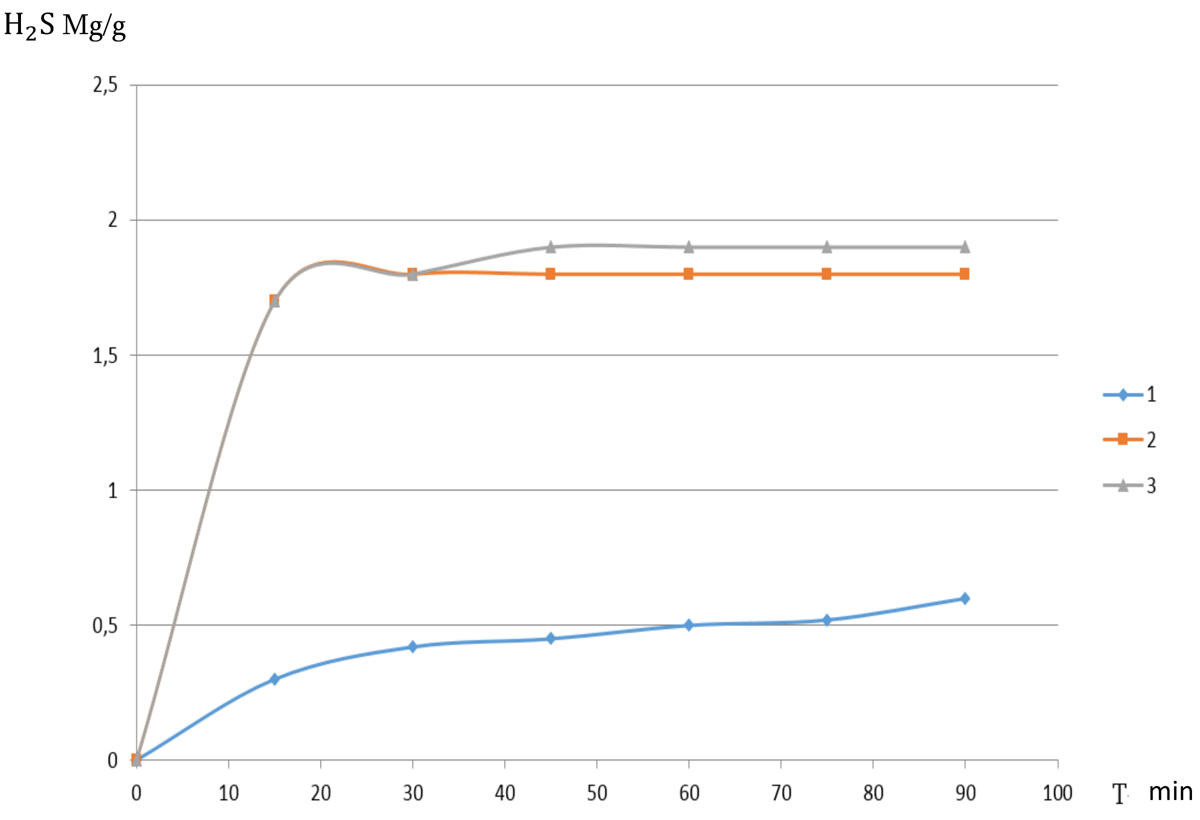

Fig. 3. The adsorption rate of hydrogen sulfide on zeolites (25°C)

1. Unprocessed clinoptilolite from Dzegvi village;
2. Zeolite modified by N_i Khekordzula clinoptilolite;
3. Cationite KY-2-8.

Based on our research, we can conclude that zeolites of local origin and synthetic cationite KY-2-8 can be used as a highly efficient adsorbing agent towards H_2S of hydrogen sulfide existing in the Black Sea deep waters.

The third chapter is devoted to the analysis of theoretical and experimental studies of the use of hydrogen as an alternative fuel in the internal combustion engines.

The energy-environmental parameters of the internal combustion engines are highly dependent on the type of fuel used, and an objective assessment of these parameters can be made through the analysis of the thermodynamic parameters of duty cycle. To this end, we calculate the theoretical cycles for both gasoline and the gas+hydrogen mixture at different ratios in a wide range of the excess air coefficient (α), when varying the compression degree (ε).

The increase in the amount of hydrogen in the mixture increases the speed of the combustion process, reducing the duration of combustion and increasing the heat removal rate. In particular, the increase in the mass transport rate of hydrogen within 0÷0,1 limits at a maximum temperature, increases the heat release coefficient from 0.772 to 0.807. The mean indicated pressure and indicated efficiency reache a maximum value when the hydrogen content in the mixture is within 0.03 ÷ 0.04.

Based on the experimental data, we have developed a methodology that will allow us determining, in each specific case, the ratio of hydrogen and gasoline in the mixture, which ensures the implementation of a working process at a high level. In this case, we can determine the minimum amount of gasoline that will ensure the smooth course of regardless of the mixture impoverishment.

This methodology is based on the determination of the amount of heat energy released during the combustion process, which is calculated in the given case by the formula:

$$Q = \beta \cdot G_{gn} \cdot H_{ug} = G_g \cdot H_{ug} + G_w \cdot H_{uw} \qquad (2)$$

where G_{gn} - is gasoline consumption without the addition of hydrogen; G_w - hydrogen flow rate as the additive; G_g - gasoline consumption after the addition of hydrogen; H_{ug} and H_{uw} - the lowest heat of combustion of gasoline and hydrogen; β - the coefficient of gasoline reduction in case of adding and from the following expression:

$$\beta = \frac{G_g \cdot H_{ug} + G_w \cdot H_{uw}}{G_{gn} \cdot H_{ug}} = \frac{G_g + K \cdot G_w}{G_{gn}} \qquad (3)$$

Where $K = \frac{H_{uw}}{H_{ug}} = 2{,}73$

The analysis of this expression shows that β is a dimensionless coefficient and all its values can be experimentally determined, when G_w=0 and β=1. Figure 4. Illustrates the change in the β coefficient on the excess air coefficient (α).

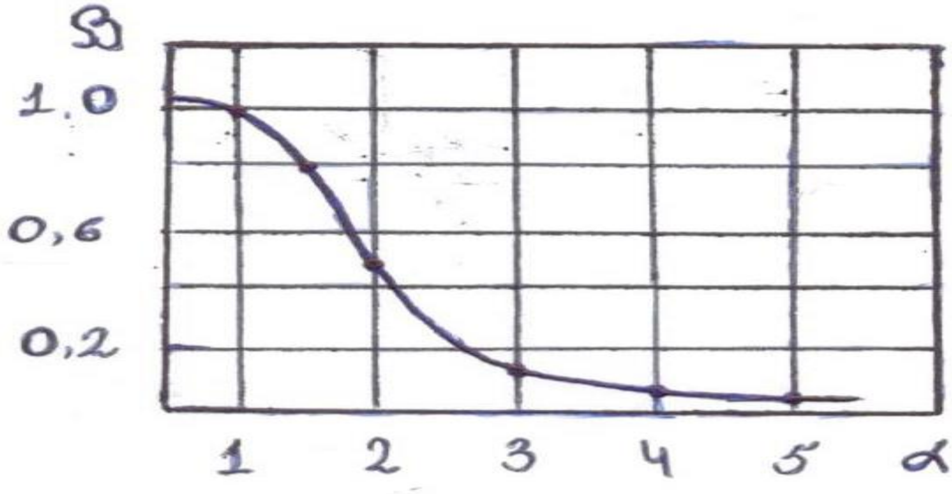

Fig. 4. The dependence of the dimensionless coefficient β on the excess air coefficient

The goal of our research is to measure the environmental characteristics of vehicle while operating on different types of fuel (gasoline, natural gas, hydrogen+gasoline, hydrogen+natural gas) and make relevant conclusions and recommendations.

To carry out research, the gas analyzer Multitest 211 that we used is intended for determining the concentrations of various toxic compounds in combustion products of power-generating units of the transport devices running on gasoline or gaseous fuel. The device operates in both static and dynamic modes. Instruction for using the device and for measuring work was drawn in accordance with the requirements of UNR 10893:2000 standards.

The goal of the experimental study is to analyze the environmental characteristics of vehicles running on traditional fuels (gasoline) and natural gas, as well as on gas+hydrogen, natural gas+hydrogen.

At the first stage of the research, we selected as a subject the MERCEDES-BENZ/ML 320 car, which runs mostly on gasoline and is converted to natural compressed gas. Based on the experimental research methodology, when operating in idle mode of engine (n=700 min^{-1}), for the cases of both gasoline and natural gas, we have measured values of CO, CO_2, HC, O_2, NO_X and α and (showing the excess air coefficient). In both cases, the identity of engine's thermal mode is maintained (the coolant temperature is 90 °C). The same measurements were carried out when working in loading modes of n=2000 min^{-1} and n=3000 min^{-1}. In all three cases, the test was repeated several times and the difference between the values was negligible. The measurement results are shown in Figure 5.

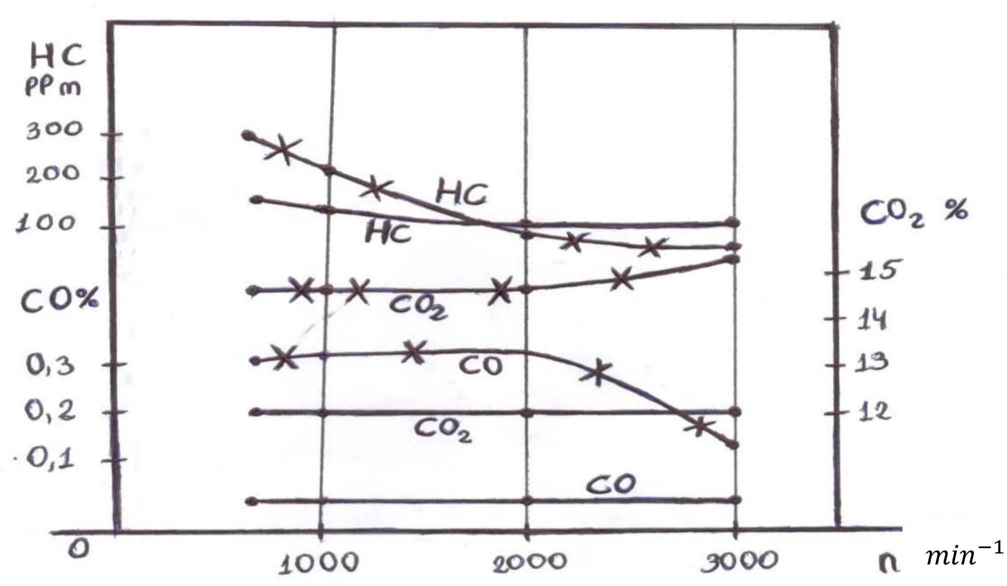

Fig. 5. Analysis of combustion products of the MERCEDES-BENZ/ML 320 car with the dependence on the engine speed

gasoline **--X----X----X----X--** natural gas ————————

For the comparative analysis, we carried out the same measurements for a stationary engine (gas-24) in the test-bench conditions, particularly at idling speeds n=700 min^{-1}, n=2000 min^{-1} and n=3000 min^{-1},when operating on both gasoline and natural compressed gas. The data are presented in Table 4.

Table 4.

Analysis of combustion products for gasoline-powered engine and engine converted to natural gas with the dependence on the engine speed

Type of fuel	CO%	CO_2%	HC/ppm	O_2	Λ
n=700 min^{-1}					
Gasoline	2,45	8,4	470	7,3	1,332
Natural gas	0,05	4,5	443	11,28	2,38
n=2000 min^{-1}					
Gasoline	2,48	8,6	426	8,2	1,441
Natural gas	0,06	4,9	450	12,3	2,52
n=3000 min^{-1}					
Gasoline	2,46	8,9	402	9,1	1,63
Natural gas	0,06	5,2	455	12,8	2,56

The analysis of research shows that in the case of the MERCEDES-BENZ/ML 320 car running on gasoline, the value of carbon dioxide (CO) decreases from 0,31 to 0,14 with the increase in the rotation frequency, while the value of CO_2 increases from 14,7 to 15,3. This indicates that the combustion process occurring in the cylinder is complete, since the amount of oxygen consumed decreases from 0.5% to 0.05%. As for hydrocarbon HC, its value is reduced from 288 ppm to 58 ppm. Nitrogen oxides are not found in combustion products, which is typical for gasoline-powered engines.

In the case of the same car running on compressed natural gas, the change in carbon and carbon dioxide in combustion products does not actually depends on the engine speed, and the HC value drops from 140 ppm to 70 ppm. Accordingly, the amount of oxygen consumed varies within 0,05÷0,25.

The main objective of the study is to explore the possibilities of using hydrogen in motor transport and to analyze the environmental characteristics of both traditional gasoline and natural gas and gasoline+hydrogen, natural gas+hydrogen during conversion. To carry out these studies, we have chosen the MITSUBISHI/OUTLANDER car with the capacity of liters V_l=3. The car is equipped with a base fueling system (light fuel injection), a compressed gas fueling system and the device that adds hydrogen to main fuel while the engine is running. Engine operation on these systems is regulated by a switching device placed in the car’s interior.

Table 5.

Analysis of combustion products of the MITSUBISHI/OUTLANDER car with the dependence on the crankshaft speed and the type of fuel

type of fuel	CO%	CO_2%	HC/ppm	O_2%	Λ
n=700 min^{-1}					
gasoline	0,01	14,0	1	0,03	1,001
gasoline + hydrogen	0,01	15,1	1	0,06	1,002
natural gas	0	11,6	37	0,39	1,021
natural gas + hydrogen	0	11,5	31	0,36	1,02
n=2000 min^{-1}					
gasoline	0,02	13,8	3	0,3	1,001
gasoline + hydrogen	0,01	15,2	0	0,02	1,01
natural gas	0	11,7	23	0,34	1,019
natural gas + hydrogen	0	11,6	23	0,32	1,018
n=3000 min^{-1}					
Gasoline	0,02	13,6	0	0	1,001
gasoline + hydrogen	0,01	15,2	0	0,02	1,001
natural gas	0	11,6	10	0,21	1,012
natural gas + hydrogen	0	11,7	9	0,20	1,011

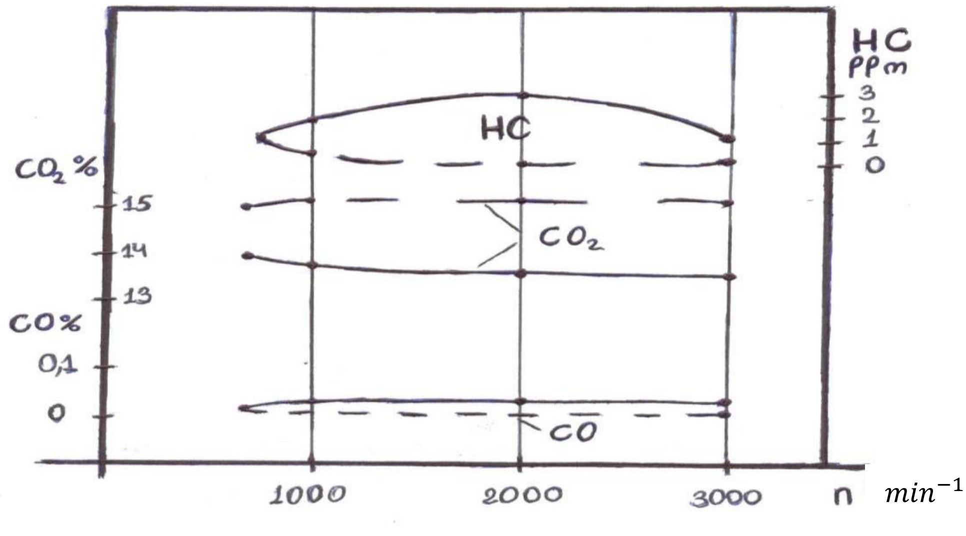

Fig. 6. The environmental characteristics of the MITSUBISHI/OUTLANDER car running on gasoline and gasoline+hydrogen with the dependence on the engine speed
gasoline __________ gasoline + hydrogen __ __ __ __ __

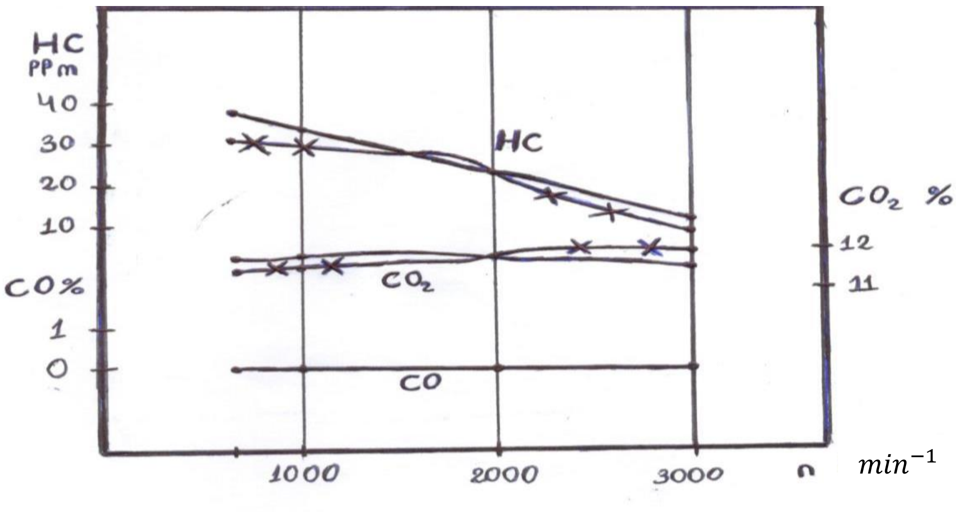

Fig. 7. **The environmental characteristics of the MITSUBISHI/OUTLANDER car running on natural gas and natural gas+hydrogen with the dependence on the engine speed**
natural gas __________ natural gas + hydrogen –**X----X----X----X—**

Consider first the engine running in idle mode (n=700 min^{-1}). In the case of engines running both on gasoline and gasoline+hydrogen engines, the CO values are the same in both cases, and the value of HC does not change as well, however, in the other case CO_2 increases, which is explained by the corresponding increase in the amount of oxygen involved in the combustion process (O_2 increases from 0,03 % to 0,06%) and the carbon oxidation process is improving. That means that the addition of hydrogen to traditional fuel in the idle mode does not have a significant effect on the components such as CO and HC.

In the same regime, when using compressed gas and natural gas+hydrogen as a fuel, the value of CO in combustion products is not recorded at all, but in the other case, there is a slight decline in the values of CO, HC and O_2.

If we compare the engine operation in both modes on gasoline and natural gas, in the second case, the values of CO and CO_2 are significantly lower as compared to gasoline-powered engines, however HC is significantly higher, which is typical for engines running of gaseous fuel.

With the engine running in loading mode (n=2000 min^{-1}), when gasoline and gasoline+hydrogen are used as fuel, in the second case, the values of CO and HC are noticeably lower than in the the first case, however, there is a certain increase increase in CO_2, indicating improvement in the combustion process. In the same mode, when using natural gas and natural gas+hydrogen, the value of CO in combustion products is not recorded at all, the value of HC value is the same, however in the first case, there is recorded a slightly higher value of CO_2. The analysis of data of engine running on gasoline and natural gas in the same mode, shows that there is a significant increase in HC when using natural gas, in the cases, the gasoline-powered engine is far worse. In addition, by adding hydrogen to natural gas, the environmental characteristics of the engine do not change actually, although there is the increase in the engine power by 10-12%.

Thus, the analysis of esearch shows that as compared to base fuel (gasoline), the use of natural gas and hydrogen as alternative fuels significantly reduces the amount of toxic compounds in combustion products, which indicates once again the prospect of introducing hydrogen energy in vehicles.

The fourth chapter analyses the methodology for calculating the socio-economic damage caused by harmful substances emitted into the environment, as well as the socio-economic effects obtained by decline in them.

To make decision on planning and carrying out environmental activities, a preliminary economic analysis ashould be made, which involves comparison and analysis of environmental and socio-economic outcomes. The socio-economic effect reflects simultaneously both the social and economic outcomes achieved through the implementation of environmental measures and measured in value terms. For example, the decline in the incidence of diseases,on the one hand, improves human health, and on the other hand, increases the time spent on work.

The socio-economic damage (GEL/year) caused by harmful compounds emitted into the environment by motor transport can be calculated based on the following formula:

$$Y= j\sigma fM \qquad (4)$$

where j is a constant value, and it depends on the year of manufacture of vehicle. For vehicles manufactured before 2005 j=2,4, while for vehicles manufactured after 2005, j=2,0.

f- the dimensionless value and for motor transport f=10.

σ - a relative indicator of the threat of atmospheric air pollution, and it is selected from the table.

M- the annual mass of harmful substances released by vehicle into the environment calculated by the formula:

$$M = \sum_{1}^{n} A_i m_i \qquad (5)$$

It is impossible to undertake environmental measures without a preliminary economic analysis. This means that the costs of environmental measures must be in line with the environmental and economic outcomes achieved. The evaluation criteria for measures undertaken are indicators such as improving the well-being of the population, reducing the risk of disease, physical and mental development of person, increased productivity and so on.

The annual socio-economic effect of reducing toxic compounds in exhaust gases is calculated by the formula for a particular type of vehicle engine:

$$E = \left[C \cdot \left(\frac{B_{ex}}{B_b} \cdot \frac{P_1 + E_n}{P_2 + E_n} - 1\right) + E_k + Z - X\right] \cdot N \qquad (6)$$

Let us calculate the socio-economic effect obtained by improving the environmental characteristics of vehicle using this methodology. Based on the calculation, we obtained that the use of alternative fuels (gasoline+hydrogen) in comparison to traditional fuel causes a reduction of environmental damage by one car by 0.32 l /t · km. In our case, the social effect from a single engine is GEL 72.3, which in terms of 1000 cars has a social effect of GEL 72 300 per year.

General conclusions and recommendations

1. At present, the environmental situation in many regions throughout the world, including Georgia, is very tense, which is directly related to the rapid growth in the number of transport systems.
2. The main source of environmental pollution is the processes occurring in the internal combustion engine of vehicle, since combustion products contain more than 200 different types of substances, most of which are poisonous. Among them, particularly notable are: carbon monoxide (CO), carbon dioxide (CO_2), various hydrocarbons (C_XH_Y), nitrogen and sulfur oxides; lead compounds; solid matters in the form of soot; heavy metals and so on. The air pollution is proportional to the intensity motor transport traffic flow.
3. Considering that Georgia is a transit region, special attention should be paid to the assessment of unfavorable environmental phenomena caused by transport-related pollution. The solution to this problem requires the establishment of a single system of nature protection and management in the immediate vicinity of motorways in the light of modern environmental monitoring requirements.
4. One of the real opportunities to improve the economic and environmental performance of vehicles, in particular motor transport, is to seek alternative energy sources, since they are of great practical and social importance today.
5. The prospects for improving the economic and environmental characteristics of vehicles, in particular motor transport, is hydrogen energy, since hydrogen is the Earth's most abundant element and much of it is present on Earth as water.

   The prospect of using hydrogen as a fuel for motor transport is due to its environmental safety, infinite deposits, renewability and excellent thermal and "engine" properties. In addition, as a fuel, it can be stored in a compressed, liquefied, or bonded state. However, it can be obtained directly from vehicle.
6. The creation of reliable, efficient and environmentally friendly hydrogen-powered energy generating equipment is essential for the transition to hydrogen energy. At present, studies on hydrogen-powered internal combustion engines are being carried out in large car companies, such as BMW, HONDA, GM (GENERAL MOTORS), FORD Corporation, MAZDA and so on. In this doctoral thesis, we have conducted research on using hydrogen as an additive to traditional fuel in terms of analysis of changes in environmental parameters.
7. There was developed a common full cycle of extracting hydrogen sulfide from the Black Sea basin, its separation from aqueous solution, with a view to obtaining hydrogen and methane from it by membrane technology and using it as a fuel in the internal combustion engine.
8. With a view to extracting hydrogen sulfide from the seawater by method of adsorptive concentration, studies were carried out using clinoptilolite of local origin from Khekordzula village modified by N_i and by natural unprocessed clinoptilolite from Dzegvi village and zeolite from Khekordzula village, and in addition, use was also made of synthetic zeolite cationite KY-2-8. As the test solutions, there were used natural sulfur-containing waters from Khobi and Tsaishi in western Georgia. The experimental data show that modified zeolites and synthetic cationite are characterized by a large range of hydrogen sulfide adsorption. The relatively low

adsorption capacity is exhibited by unprocessed clinoptilolite from Dzegvi village, and besides, the influence of the time factor on the adsorption process is also significant.

9. With a view to analyzing thermodynamic parameters of the internal combustion engine duty cycle, there were calculated the theoretical cycles for both gasoline and the gas+hydrogen mixture at different ratios in a wide range of the excess air coefficient (α), when varying the compression degree (ε). A methodology has been developed that allows us for determining the ratio of gasoline and hydrogen in the mixture, which, when operating in any engine mode, ensures the normal development of the combustion process in the cylinder of engine.

10. To carry out research, we used the gas analyzer Multitest 211 manufactured in Italy, which works in both static and dynamic modes.

At the first stage of the research, we selected as a subject the MERCEDES-BENZ/ML 320 car, which runs mostly on gasoline and is converted to natural compressed gas. Based on comparative analysis, we can conclude that for the research subject, natural gas is more environmentally friendly option than gasoline.

The analysis of research shows that basic fuel efficiency is estimated at 10-12%, and besides, there is a significant decline in the amount of toxic compounds in combustion products that points once again to the prospects for introducing hydrogen energy.

11. Use of alternative fuel (gasoline+hydrogen), as compared to traditional fuel, reduces the environmental damage caused by one car. In our case, the social effect from a single engine is GEL 72.3, which in terms of 1000 cars has a social effect of GEL 72 300 per year.

12. The analysis of the results of research allows us for concluding that hydrogen energy in motor transport is appropriate both for solving environmental problems and for improving the socio-economic situation of the country. Hydrogen extraction and energy development are the future of our country.

Doctoral student Bachana Markelia has authored and co-authored scientific publications (a total of 9 publications)

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