The effect of combustion of methyl hydroxide in the CI on toxic indicators is characteristic of changes in load and speed

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Abstract. It should be noted that the harmful substances emitted by manufacturing enterprises are concentrated over a huge radius in a certain area, and the EG of automobiles are distributed throughout the territory of the settlement. At the same time, cars pollute the atmosphere with hydrocarbons and NOx by 30%, carbon oxides by 90%. Under adverse conditions, toxic mists are formed in the surface layers of the atmosphere, the so-called smogs, which contain toxic components of EG - hydrocarbons and NOx. There are over 100 different components in the EG of automobile motors, most of which are toxic. The approximate composition of the EG of gasoline and CI motors. The reason for the formation of hydrocarbons CH is the heterogeneity of the composition of the combustible mixture in the combustion chamber of the motor, as well as the unevenness of temperature and pressure in its various parts. In some combustion zones, the fuel practically does not burn out, as the chain reaction of hydrocarbon oxidation breaks.

1. Introduction
All types of modern transport cause great damage to the biosphere, but road transport is the most dangerous for it. In the global balance of air pollution, the share of vehicles is 13.3%, but in cities it rises to 80%.

According to the Russian Ministry of Transport, the annual damage from negative environmental impacts resulting from the operation of vehicles is $ 45 billion.

At present, the reduction of atmospheric air pollution with toxic substances emitted by automobile transport is one of the most important problems facing humanity. There is only one way to solve it - the car should become environmentally friendly. An important place here belongs to neutralization systems that can several times reduce the toxicity of exhaust gases (EG). This explains the relevance of my chosen topic of essay [4-8].

Environmental pollution during the operation of internal combustion motors is associated with air pollution and is caused by emissions of nitrogen, carbon, sulfur, aldehydes and hydrocarbons, as well as suspended particles - aerosols. The basic principles for reducing harmful emissions from internal combustion motors are given in the work. Among them, the most effective EG purification system stands out.

The aim of the work was to find out how to neutralize harmful substances in EG. To this end, the following task was set: to consider ways to neutralize harmful substances in the system of gasoline and CI motors, as well as their implementation [9-12].
The effect of lead on blood is manifested in a decrease in the amount of hemoglobin and the presence of lead in the air causes serious damage to the digestive system, central and peripheral nervous system. In some combustion zones, the fuel practically does not burn out, as the chain reaction of hydrocarbon oxidation breaks. The reason for the formation of hydrocarbons CH is the heterogeneity of the composition mixture in the combustion chamber of the motor, as well as the unevenness of temperature and pressure in its various parts. In some combustion zones, the fuel practically does not burn out, as the chain reaction of hydrocarbon oxidation breaks.

Carbon monoxide is formed in gasoline motors during the combustion of air-fuel mixtures with some oxygen deficiency, as well as due to the dissociation of carbon dioxide that occurs at high temperatures. Under normal conditions, CO is a colorless, odorless gas; it is lighter than air and therefore can easily spread in the atmosphere. The mechanism of the toxic effect of CO is determined by the ability to convert part of the hemoglobin of blood into carboxyhemoglobin, which causes tissue respiration. Along with this, CO has a direct effect on tissue biochemical processes that entail a violation of fat and carbohydrate metabolism, vitamin balance, etc. The toxic effect of CO is also associated with its direct effect on the cells of the central nervous system. When exposed to humans, CO causes headache, dizziness, fatigue, irritability, drowsiness, pain in the heart. Acute poisoning is observed upon inhalation of air with a concentration of CO greater than 2.5 mg / l for 1 hour [18-24].

NOx in EG are formed as a result of the reversible oxidation of nitrogen by atmospheric oxygen under the influence of high temperatures and pressure in the motor cylinders. An increase in the maximum temperature of the working cycle and an excess of oxygen are the main factors contributing to the formation of NOx. As the EG cools and dilutes with air, nitric oxide turns into dioxide, etc.

Nitric oxide NO is a colorless gas, nitrogen dioxide NO2 is a reddish-brown gas with a characteristic odor. NOx, when ingested, combine with water. At the same time, they form compounds of nitric and nitrous acids in the respiratory tract. NOx irritate the mucous membranes of the eyes, nose, and mouth. Exposure to NO2 contributes to lung disease. Symptoms of poisoning manifest themselves only after 6 hours in the form of cough, suffocation, and increasing pulmonary edema is possible.

Of the total amount of harmful substances emitted into the atmosphere of large cities, the majority is automobile transport - 60%. Industrial enterprises emit 18%, power plants 13%, urban heating systems 6% and other sources 3%.

It should be noted that the harmful substances emitted by manufacturing enterprises are concentrated over a huge radius in a certain area, and the EG of automobiles are distributed throughout the territory of the settlement. At the same time, cars pollute the atmosphere with hydrocarbons and nitrogen oxides (NOx) by 30%, carbon oxides by 90%. Under adverse conditions, toxic mists are formed in the surface layers of the atmosphere, the so-called smogs, which contain toxic components of EG - hydrocarbons and NOx [13-17].

There are over 100 different components in the EG of automobile motors, most of which are toxic. The approximate composition of the EG of gasoline and CI motors.

The table shows that gasoline motors are more toxic than CI motors. The most toxic EG components of gasoline motors are: carbon monoxide (CO), (NOx), hydrocarbons (CnHm), and in the case of leaded gasoline, lead. Acreoline is also found in the EG, which enters the environment (especially when CI motors are run). It has the smell of burnt fats (with a content of more than 0.004 mg / l), causes irritation of the upper respiratory tract, as well as inflammation of the mucous membrane of the eyes.

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The reason for the formation of hydrocarbons CH is the heterogeneity of the composition mixture in the combustion chamber of the motor, as well as the unevenness of temperature and pressure in its various parts. In some combustion zones, the fuel practically does not burn out, as the chain reaction of hydrocarbon oxidation breaks.

A carcinogenic substance, dioxin (cyclic ether), which is a colorless combustible liquid, was found in the EG of a CI motor. Dioxins and related compounds are many times more toxic than poisons such as curare and potassium cyanide.

In the case of leaded gasolines, about 50% of the lead is deposited in the form of soot on motor parts and in the exhaust pipe, the remainder goes into the atmosphere. Lead is present in the EG in the form of tiny particles 1-5 microns in size, which are stored for a long time in the atmosphere. The concentration of lead in the atmosphere of the roadside is 2-20 times higher than in other places. The presence of lead in the air causes serious damage to the digestive system, central and peripheral nervous system. The effect of lead on blood is manifested in a decrease in the amount of hemoglobin and the destruction of red blood cells [25-33].

Over the long period of existence of the problem of automobile emissions and air pollution by them, many methods and methods have been developed to reduce the number of exhausts or reduce their
toxicity, and standards for toxicity of EG have been adopted. At present, measures are being developed and are being implemented to reduce atmospheric pollution by emissions of automobile motors, which include: improving motor designs and improving manufacturing quality, searching for new types of fuel, using various additives to him, the creation of power plants for cars that emit less harmful substances, the development of devices that reduce the content of harmful components in EG.

Practice has shown that at the same time it is impossible to achieve the level of exhaust toxicity required by the legislation of developed countries in the first three ways. Therefore, the use of alternative fuels has become widespread. In this case, toxic vapors coming out of the motor cylinders are neutralized before they are released into the atmosphere.

2. Experimental part

Figure 1 shows the effect of the use of methyl hydroxide on the of toxic components in the EG of a compression ignition (CI) motor 2H 10.5 / 12.0 at work with fuel injection angle (FIA), depending on the change in load at the rated speed of the crankshaft (n = 1800 min\(^{-1}\)) and the optimal installation values angle advances fuel injection [34, 35].

Analyzing the changes in the values of toxic components in the EG of a CI motor depending on the change in load at a rotational speed of n = 1800 min\(^{-1}\) and the optimal installation of the AAFI, the following can be noted. The NO\(_x\) in the EG during CI operation on methyl hydroxide with FIA is significantly lower than at work on diesel fuel (DF) in the entire range of load changes [36].

![Figure 1](image.png)

Figure 1. The effect of the use of methyl hydroxide with FIA of toxic components in the EG of a CI motor \(\Theta_{df} = 34^\circ\) and \(\Theta_m = 34^\circ\) depending on the change in load at \(n = 1800\) min\(^{-1}\).

- - CI process; - - - methyl hydroxide with firing DF.

So, at \(p_e = 0.127\) MPa, of NO\(_x\) in the EG decreases from 225 ppm during CI operation on DF to 215 ppm when operating on methyl hydroxide with FIA, or by 4.4%. At \(p_e = 0.55\) MPa, the decrease in the NO\(_x\) in the EG is even more significant. If during CI operation on DF the NO\(_x\) in EG is 420 ppm, then at the same load, but at work on methyl hydroxide with FIA, it is only 285 ppm. The decrease is 32.1%. At maximum loads (at \(p_e = 0.65\) MPa), the decrease is from 380 ppm during CI operation on DF to 250 ppm during CI operation on methyl hydroxide with FIA, or 34.2% [37-42].

The soot in the EG is significantly reduced when the CI motor runs on methyl hydroxide with FIA in the entire studied load range. So, at \(p_e = 0.127\) MPa, the soot in the EG decreases from 2.1 units on the bosch scale during CI operation on DF to 0.1 units on the bosch scale when operating CI on methyl hydroxide with FIA. At maximum loads (at \(p_e = 0.65\) MPa), the soot in the EG decreases from 6.5 units on the bosch scale at work on DF to 1.3 units on the bosch scale at work on diesel on methyl hydroxide with FIA, or 5 times [43-48].
Analyzing the of total hydrocarbons in the EG, the following regularities can be stated: the of CH₄ during CI operation on DF increases with increasing load, and at work on methyl hydroxide, the concentration of CH₄ decreases first and then increases and has values higher than at work on DF in the entire range loads. At pₑ = 0.127 MPa and CI operation on methyl hydroxide with FIA, the value of CH₄ in the EG is 0.28%, and at work on DF, it is 0.03%. Then, of CH₄ during the operation of a CI motor with methyl hydroxide with FIA decreases to 0.12% at pe = 0.47 MPa. The value of CH₄ at work on DF is 0.07%. Then, the value of CH₄ increases to 0.23% at pₑ = 0.65 MPa, while during CI operation on DF of CH₄ is only 0.19% [49-54].

It should also be noted that when a CI motor runs on methyl hydroxide with FIA, the CO in the EG increases at low and medium loads (up to pₑ = 0.55 MPa). When a CI motor runs on methyl hydroxide with FIA and pₑ = 0.127 MPa, the CO in the EG is 0.28%, and when operating on DF, it is 0.08%. There is an increase of 3.5 times. However, with an increase in the load, the CO during operation on methyl hydroxide in the CI EG decreases and at a value of pₑ = 0.55 MPa it is compared with the values of the CO in the EG during CI operation on DF and amounts to 0.21%. With a further increase in the load, the CO in the EG during CI operation on methyl hydroxide with FIA is lower than the CO during CI operation on DF and at pₑ = 0.65 MPa is 0.35% against 0.48%, respectively. The decrease is 27% [55].

This is because the total hydrocarbons and carbon monoxide are products of incomplete combustion and that the increase in their percentage in the EG is affected by the deterioration of the combustion process at low loads due to overpopulation of the mixture due to ignition by the ignition DF. As a result, at low loads, the process of propagation of the flame front and the entire combustion process as a whole proceeds more “sluggishly”, contributing to the incomplete combustion of fuel and, as a result, to the deterioration of effective efficiency [56-58].

The CO₂ in the EG of a CI motor 2H 10.5 / 12.0 when the load changes does not depend much on the type of fuel and varies almost according to one dependence, although the CO₂ values for CI run on methyl hydroxide with FIA over the entire range are higher than the CO₂ in the EG for CI operation on DF and grow from 1.8% at pₑ = 0.127 MPa to 4.6% at pₑ = 0.65 MPa, while during CI operation at DF under the same loads, the CO₂ in the EG is 0.8% and 4.0% respectively. There is an increase of 2.25 times and by 15%, respectively [59].

Figure 2 shows the effect of the use of methyl hydroxide with FIA on the of toxic components in the EG, depending on the change in the rotational speed of the 2H 10.5 / 12.0 CI motor when operating on various types of fuel. An increase in the rotational speed is accompanied by an increase in emissions of the total amount of toxic components in the CI EG, except for NOₓ, of which decreases.

As can be seen from the graphs, a CI motor run on methyl hydroxide with FIA is characterized by a decrease in the NOₓ in the EG relative to the CI motor when operating on DF at all studied speed conditions. So, if in a CI motor at work on DF, of NOₓ in the EG decreases from 480 ppm at a speed of n = 1200 min⁻¹ to 375 ppm at n = 2000 min⁻¹, then in a CI motor run on FIA, of NOₓ decreases, respectively, from 310 ppm to 255 ppm. In percentage terms, this decrease at n = 1200 min⁻¹ is 35.4%, and at n = 2000 min⁻¹ it is 32.0% [60].

This is due, obviously, primarily to the fact that when a CI motor runs on methyl hydroxide, due to the particular chemical composition of methyl hydroxide (the chemical formula of methyl hydroxide is CH₃OH) and the chemistry of the combustion process, the formation of fast NOₓ is predominant, replacing the formation of NOₓ in the overall balance the formation of NOₓ obtained by the thermal mechanism, or the so-called thermal NOₓ, which cannot but affect the overall decrease of NOₓ in the EG. The soot in a CI EG changes during CI operation on CI motors from 3.7 units on the bosch scale at n = 1200 min⁻¹ to 6.8 units on the bosch scale at n = 2000 min⁻¹, and when the CI is run on methyl hydroxide with FIA - from 0.65 units on the bosch scale at n = 1200 min⁻¹ to 1.05 units on the bosch scale at n = 2000 min⁻¹.
The soot in the EG with an increase in the rotational speed from 1200 to 2000 min\(^{-1}\) increases by 83.7% when the CI motor is run on DF and increases by 61.5% when the CI motor is run on methyl hydroxide with FIA. The soot in the EG at a speed of \(n = 1200\) min\(^{-1}\) decreases from 3.7 units on the bosch scale for a CI motor run on DF to 0.65 units on the bosch scale for a CI motor run on CI motor with FIA. There is a decrease of 5.7 times. The soot in the EG at \(n = 2000\) min\(^{-1}\) for a CI motor run on DF is 6.8 units on the bosch scale, and for a CI motor run on methyl hydroxide with FIA, the soot is reduced to 1.05 units on the bosch scale. This decrease at \(n = 2000\) min\(^{-1}\) occurs 6.5 times. The CH\(_{x}\) in the EG of a CI motor changes during operation on DF from 0.35\% at \(n = 1200\) min\(^{-1}\) to 0.10\% at \(n = 2000\) min\(^{-1}\), and at work on methyl hydroxide with FIA, from 0.10\% at \(n = 1200\) min\(^{-1}\) to 0.21\% at \(n = 2000\) min\(^{-1}\). The decrease in CH\(_{x}\) at \(n = 1200\) min\(^{-1}\) is 71.4\%. The increase in the CH\(_{x}\) at \(n = 2000\) min\(^{-1}\) is 110.0\%. The CO in the EG of a CI motor changes during operation on DF from 0.49\% at \(n = 1200\) min\(^{-1}\) to 0.29\% at \(n = 2000\) min\(^{-1}\). When a CI motor runs on methyl hydroxide with FIA, the CO in the EG is 0.24\% at \(n = 1200\) min\(^{-1}\), and then increases to 0.27\% at \(n = 2000\) min\(^{-1}\). The CO in the EG when operating on methyl hydroxide CI with FIA at \(n = 1200\) min\(^{-1}\) decreases from 0.49\% to 0.24\%, and at \(n = 2000\) min\(^{-1}\) it decreases from 0.29\% to 0.27\%, or 51\% and 6.9\%, respectively. The CO\(_{2}\) in the EG changes during CI operation on DF from 3.6\% at \(n = 1200\) min\(^{-1}\) to 3.8\% at \(n = 2000\) min\(^{-1}\). When a CI motor runs on methyl hydroxide with FIA, the CO\(_{2}\) in the EG changes from 3.9\% at \(n = 1200\) min\(^{-1}\) to 4.6\% at \(n = 2000\) min\(^{-1}\). The increase in CO\(_{2}\) in the EG during the operation of a CI motor with methyl hydroxide with FIA is 8.3\% at \(n = 1200\) min\(^{-1}\) and 21.0\% at \(n = 2000\) min\(^{-1}\).

3. Conclusion

Thus, with the supply of 93\% methyl hydroxide and 7\% ignition DF, the following results are possible: a decrease in the NO\(_{x}\) in the EG during CI operation on methyl hydroxide with FIA is from 35.4\% at \(n = 1200\) min\(^{-1}\) to 32\% at \(n = 2000\) min\(^{-1}\); a decrease in the soot in the EG when a CI motor runs on methyl hydroxide with FIA occurs 5.7 times at \(n = 1200\) min\(^{-1}\) and 6.5 times at \(n = 2000\) min\(^{-1}\); a decrease in the CO in the EG during the operation of a CI motor with methyl hydroxide with FIA is from 51\% at \(n = 1200\) min\(^{-1}\) to 6.9\% at \(n = 2000\) min\(^{-1}\); the increase in CO\(_{2}\) in the EG when the CI motor runs on methyl hydroxide with FIA is from 8.3\% at \(n = 1200\) min\(^{-1}\) to 21.0\% at \(n = 2000\) min\(^{-1}\); a decrease in the of CH\(_{x}\) in the EG during CI operation on methyl hydroxide with FIA is 71.4\% at \(n = 1200\) min\(^{-1}\), an increase in the of CH\(_{x}\) is 110.0\% at \(n = 2000\) min\(^{-1}\).
References

[1] Anfilatov A A and Chuvashev A N 2020 Journal of Physics: Conf. Series 1515 042048
[2] Likhanov V A and Lopatin O P 2020 IOP Conf. Series: Earth and Environmental Science 421 072018
[3] Anfilatov A A 2020 Journal of Physics: Conf. Series 1515 042049
[4] Likhanov V A, Lopatin O P and Yurlov A S 2019 Journal of Physics: Conf. Series 1399 055026
[5] Likhanov V A, Kozlov A N and Araslanov M I 2020 IOP Conf. Series: Materials Science and Engineering 734 012211
[6] Likhanov V A and Rossokhin A V 2020 IOP Conf. Series: Materials Science and Engineering 862 062047
[7] Lopatin O P 2020 IOP Conf. Series: Earth and Environmental Science 421 072019
[8] Likhanov V A and Lopatin O P 2020 Journal of Physics: Conf. Series 1515 052002
[9] Likhanov V A and Lopatin O P 2020 IOP Conf. Series: Materials Science and Engineering 862 062014
[10] Anfilatov A A and Chuvashev A N 2020 IOP Conf. Series: Materials Science and Engineering 862 062064
[11] Likhanov V A and Skryabin M L 2019 IOP Conf. Series: Earth and Environmental Science 315 032045
[12] Likhanov V A and Rossokhin A V 2019 Journal of Physics: Conf. Series 1399 044038
[13] Likhanov V A and Lopatin O P 2018 IOP Conf. Series: Materials Science and Engineering 457 012011
[14] Kopchikov V N and Fominykh A V 2020 Journal of Physics: Conf. Series 1515 042028
[15] Likhanov V A and Anfilatov A A 2020 IOP Conf. Series: Materials Science and Engineering 862 032048
[16] Lopatin O P 2020 IOP Conf. Series: Materials Science and Engineering 862 062087
[17] Devetyarov R R 2020 IOP Conf. Series: Materials Science and Engineering 862 062072
[18] Likhanov V A and Lopatin O P 2020 IOP Conf. Series: Materials Science and Engineering 734 012202
[19] Anfilatov A A and Chuvashev A N 2020 IOP Conf. Series: Materials Science and Engineering 862 062069
[20] Likhanov V A, Lopatin O P and Yurlov A S 2020 IOP Conf. Series: Materials Science and Engineering 734 012208
[21] Romanyuk V, Likhanov V A and Lopatin O P 2018 Theoretical and Applied Ecology 3 27-32
[22] Anfilatov A A and Chuvashev A N 2020 IOP Conf. Series: Materials Science and Engineering 862 032055
[23] Marchuk A, Likhanov V A and Lopatin O P 2019 Theoretical and Applied Ecology 3 080-6
[24] Anfilatov A A and Chuvashev A N 2020 Journal of Physics: Conf. Series 1515 022035
[25] Likhanov V A and Lopatin O P 2020 Journal of Physics: Conf. Series 1515 042019
[26] Skryabin M L and Likhanov V A 2019 Journal of Physics: Conference Series 1399 044063
[27] Lopatin O P 2020 IOP Conf. Series: Materials Science and Engineering 862 062025
[28] Likhanov V A and Lopatin O P 2019 Journal of Physics: Conf. Series 1399 055016
[29] Skryabin M L and Likhanov V A 2020 IOP Conf. Series: Materials Science and Engineering 734 012075
[30] Chuvashev A N and Chuprakov A I 2020 IOP Conf. Series: Materials Science and Engineering 862 062089
[31] Likhanov V A and Lopatin O P 2017 Thermal Engineering 64(12) 935-44
[32] Skryabin M L 2020 IOP Conf. Series: Earth and Environmental Science 421 072012
[33] Lopatin O P 2020 Journal of Physics: Conf. Series 1515 042021
[34] Devetyarov R R and Chuvashev A N 2020 Journal of Physics: Conf. Series 1515 042080
[35] Likhanov V A and Lopatin O P 2019 Ecology and Industry of Russia 23(9) 60-5
[36] Likhanov V A and Anfilatov A A 2020 IOP Conf. Series: Materials Science and Engineering
[37] Skryabin M L 2020 Journal of Physics: Conf. Series 1515 042107
[38] Likhanov V A and Anfilatov A A 2020 IOP Conf. Series: Materials Science and Engineering 862 032044
[39] Chuvashov A N and Chuprakov A I 2020 IOP Conf. Series: Materials Science and Engineering 862 062083
[40] Anfilatov A A and Chuvashov A N 2020 Journal of Physics: Conf. Series 1515 042052
[41] Lopatin O P 2020 Journal of Physics: Conf. Series 1515 042009
[42] Lopatin O P 2020 Journal of Physics: Conf. Series 1515 052004
[43] Chuvashov A N, Chuprakov A I and Anfilatov A A 2020 IOP Conf. Series: Materials Science and Engineering 734 012184
[44] Likhanov V A and Rossokhin A V 2020 IOP Conf. Series: Materials Science and Engineering 734 012207
[45] Likhanov V A and Lopatin O P 2020 Journal of Physics: Conf. Series 1515 042008
[46] Likhanov V A and Lopatin O P 2018 Ecology and Industry of Russia 22(10) 54-9
[47] Likhanov V A and Rossokhin A V 2018 IOP Conf. Series: Materials Science and Engineering 457 012007
[48] Likhanov V A and Lopatin O P 2019 Journal of Physics: Conf. Series 1399 055020
[49] Chuvashov A N and Chuprakov A I 2019 Journal of Physics: Conf. Series 1399 055085
[50] Likhanov V A and Rossokhin A V 2020 IOP Conf. Series: Materials Science and Engineering 862 062046
[51] Anfilatov A A 2020 Journal of Physics: Conf. Series 1515 042098
[52] Likhanov V A, Lopatin O P and Vylegzhanin P N 2020 IOP Conf. Series: Materials Science and Engineering 862 062074
[53] Lopatin O P 2020 IOP Conf. Series: Materials Science and Engineering 734 012199
[54] Kozlov A N, Anfilatov A A and Chuvashov A N 2019 Journal of Physics: Conf. Series 1399 055051
[55] Rossokhin A V and Anfilatov A A 2020 IOP Conf. Series: Materials Science and Engineering 862 062065
[56] Anfilatov A A and Chuvashov A N 2020 Journal of Physics: Conf. Series 1515 042077
[57] Chuvashov A N and Chuprakov A I 2020 Journal of Physics: Conf. Series 1515 042094
[58] Likhanov V A, Rossokhin A V and Devetyarov R R 2020 Journal of Physics: Conf. Series 1515 042064
[59] Anfilatov A A and Chuvashov A N 2020 IOP Conf. Series: Materials Science and Engineering 862 032052
[60] Skryabin M L and Grebnev A V 2020 Journal of Physics: Conf. Series 1515 052052
[61] Likhanov V A and Lopatin O P 2020 IOP Conf. Series: Materials Science and Engineering 862 062027
[62] Likhanov V A, Lopatin O P and Vylegzhanin P N 2020 IOP Conf. Series: Materials Science and Engineering 862 062078
[63] Likhanov V A and Lopatin O P 2020 IOP Conf. Series: Materials Science and Engineering 862 062033
[64] Skryabin M L 2020 Journal of Physics: Conf. Series 1515 04283
[65] Likhanov V A, Kopchikov V N and Fominykh A V 2020 Journal of Physics: Conf. Series 1515 042026