The effect of methyl hydroxide ignition in CI motor on the volumetric upkeep of nitrogen oxides in exhaust gases

A A Anfilatov and A N Chuvashev
Department of thermal engines, Vehicles and tractors, Vyatka State Agricultural Academy, 610017, Kirov, October prospect, 133, Russian Federation

E-mail: anfilatov001@mail.ru

Abstract. This article presents the results of the education of output values of the volumetric upkeep of NOx in the EG. There are three ways of education of NOx, differing in the method of origin. The education of NOx can occur in the flame front, in which clusters of atomic oxygen and hydroxyl radical are observed, which are several orders of magnitude higher than the equilibrium ones in the zone of ignition products. The calculated data on the education of NOx in the CI motor cylinder by two reactions of the chain mechanism and the reaction of the bimolecular mechanism by equilibrium clusters in the zone of ignition products are in good agreement with the experimental ones.

1. Introduction

Nitrogen monoxide (NO) is a colorless, odorless, poorly soluble gas in water. It accounts for more than 90% of all NOx formed during high-temperature ignition. If the cluster is in the range of 10 to 50 ppm, it is not a highly toxic irritant.

Nitrogen dioxide (NO2) is a gas that is noticeable even at a low cluster: it has a brownish-reddish color and a special pungent odor. At a cluster of more than 10 ppm, it is a strong corrosive substance and strongly irritates the nasal cavity and eyes. At a cluster of more than 150 ppm, causes bronchitis, and over 500 ppm, pulmonary edema, even if the exposure lasted only a few minutes [1-4].

Nitrogen monoxide NO, which is present in urban air, can spontaneously convert to nitrogen dioxide NO2 during photochemical oxidation.

There are three ways of the education of NOx, differing in the method of origin, but not in chemical composition: thermal NOx (thermal NOx), fast NOx (fast NOx); fuel NOx (fuel NOx) [5-7].

Thermal NOx, which make up the majority, are formed at high temperatures (T> 1500 K) and under the condition of a high oxygen cluster during the oxidation of atmospheric nitrogen during ignition. Thermal oxides are formed during the ignition of gaseous fuels (natural gas and liquefied petroleum gas) and fuels that do not contain substances containing nitrogen.

Fast NOx are formed when atmospheric nitrogen is bound by hydrocarbon particles (radicals) that are present in the flare zone. This method of oxide education proceeds at a very high speed (hence their name; fast). The education of fast oxides primarily depends on the cluster of radicals in the root of the torch. With an oxidizing flame (ignition occurs with an excess of oxygen), their contribution is insignificant, but when burning enriched mixtures and during low-temperature ignition, their share can reach 25% of the total upkeep of NOx [8-12].
Fuel NOx are formed during the oxidation of nitrogen-containing substances present in the fuel in the flare zone. The cluster of fuel oxides can reach considerable sizes if the upkeep of nitrogen-containing substances in the fuel exceeds 0.1% by weight. As a rule, this applies only to liquid and solid fuels.

The proportion of fast NOx is more or less constant, while the proportion of fuel NOx increases when burning fuels with a higher molecular weight. In this case, the fraction of thermal NOx decreases [13-17].

The main difference between burning gaseous fuels and burning liquid fuels, from the point of view of NOx, is that in the latter nitrogen is in the form of nitrogen-containing compounds. Nitrogen causes the education of NOx oxides, which contribute significantly to the total NOx upkeep.

As for fuel NOx, the nitrogen contained in the fuel in the reducing medium cannot be converted into harmful NOx, but into simple and safe molecular nitrogen N2. To do this, in some areas of the torch, it is necessary to create fuel-rich zones and conditions for the recovery process. For example, in the ignition area, 80% of the total amount of ignition-supporting air is first supplied together with 100% of the fuel, and then the remaining 20% of the ignition air (additional air) is supplied [18-24].

In recent years, it has been suggested that the education of nitric oxide can occur in the flame front, in which there are clusters of atomic oxygen (O) and hydroxyl radical (OH), which are several orders of magnitude higher than the equilibrium in the zone of ignition products. However, for ignition conditions in CI motors, in the cylinders of which the temperature of the ignition products during ignition also increases as a result of "preloading" of the burnt charge elements, the education of NO in the flame front does not significantly affect the total emission of N.

The calculated data on the education of NO in the CI motor cylinder by two reactions of the chain mechanism (via O and N) and the reaction of the bimolecular mechanism by the equilibrium clusters of O2 and O in the zone of ignition products are in good agreement with experimental ones. This also confirms that mainly NO in the CI motor cylinder is formed in the zone of ignition products by the thermal mechanism (when operating on fuels without nitrogen compounds) [25-29].

2. Experimental part

Work on the conversion of a 2H 10.5 / 12.0 compression ignition (CI) motor to methyl hydroxide using. Studies on the effect of methyl hydroxide use showed the results of changes in the output values and the volume upkeep of NOx in the exhaust gas (EG) [30-35].

Figure 1, a shows graphs of the effect of the use of methyl hydroxide in CI motor with various setting of fuel injection angle (FIA) on the volumetric upkeep of \( r_{\text{NOx}} \), NOx in the EG calculated from the experimental data obtained at the nominal CI motor speed \( n = 1800 \text{ min}^{-1} \), taken at \( \Theta_{\text{fl}} \) (30 ... 38°) and \( \Theta_{m} \) (30 ... 38°).

If at the optimal values of the setting FIA \( \Theta_{\text{fl}} = 34^\circ \) and \( \Theta_{m} = 34^\circ \), the volumetric upkeep of \( r_{\text{NOx}} \) in the EG of CI motor is 313 ppm, then with a larger value of \( \Theta_{m} = 38^\circ \), the volumetric upkeep of \( r_{\text{NOx}} \) in the EG of CI motor increases and amounts to 374 ppm. When \( \Theta_{m} = 30^\circ \), the volumetric upkeep of \( r_{\text{NOx}} \) is 326 ppm [36-39].

The curves of changes in the values of the volumetric upkeep of \( r_{\text{NOx}} \) of NOx in the CI motor EG, obtained with the setting of FIA \( \Theta_{\text{fl}} = 30^\circ \) and different injection angles of methyl hydroxide \( \Theta_{m} \), show that with the setting of the FIA of \( \Theta_{m} \) equal to 34° and 30°, the volumetric upkeep of \( r_{\text{NOx}} \) of NOx in the EG of the CI motor is respectively 335 ppm and 316 ppm.

Graphs of changes in the values of the volumetric upkeep of \( r_{\text{NOx}} \) of NOx in the EG of CI motor, obtained with the setting of FIA \( \Theta_{\text{fl}} = 38^\circ \) and different angles of injection of methyl hydroxide \( \Theta_{m} \), show that with the setting of the FIA of \( \Theta_{m} \) equal to 38°, 34° and 30°, the volumetric upkeep of \( r_{\text{NOx}} \) of NOx in the EG CI motor is 334 ppm, 299 ppm and 323 ppm respectively. It can be seen from the graph that, with an increase in the FIA \( \Theta_{m} \), the volumetric upkeep of \( r_{\text{NOx}} \) of NOx in the diesel EG changes according to a complex dependence [40-46].
Figure 1. The effect of the use of methyl hydroxide in CI motor, depending on various setting of FIA, on the volume upkeep of NO\textsubscript{x} in the EG: at n = 1800 min\textsuperscript{-1} and p\textsubscript{e} = 0.585 MPa, q\textsubscript{cd} = 6.6 mg / cycle.

Figure 2. The effect of the use of methyl hydroxide in CI motor, depending on various setting of FIA on the volumetric upkeep of NO\textsubscript{x} in the EG calculated from the experimental data obtained at the CI motor speed (n = 1400 min\textsuperscript{-1}), taken at Θ\textsubscript{df} (30 ... 38º) and Θ\textsubscript{m} (30 ... 38º) [47-52].

If, at the optimal values of the setting FIA (Θ\textsubscript{df} = 34º and Θ\textsubscript{m} = 34º), the volumetric upkeep of r\textsubscript{NOx} of NO\textsubscript{x} in the EG of the CI motor is 328 ppm, then with a larger value of Θ\textsubscript{m} = 38º, the volumetric upkeep of r\textsubscript{NOx} in the EG of the CI motor increases and amounts to 385 ppm. When Θ\textsubscript{m} = 30º, the volumetric upkeep of r\textsubscript{NOx} of NO\textsubscript{x} is 337 ppm.

The values of the volumetric upkeep of r\textsubscript{NOx} of NO\textsubscript{x} in the EG of the CI motor, obtained with the setting of FIA Θ\textsubscript{df} = 30º and different angles of injection of methyl hydroxide Θ\textsubscript{m}, show that with the setting of the high-temperature carbon dioxide of Θ\textsubscript{m} equal to 34º and 30º, the volumetric upkeep of r\textsubscript{NOx} NO\textsubscript{x} in the EG of the CI motor is, respectively, 346 ppm and 330 ppm [53-59].
Graphs of changes in the values of the volumetric upkeep of $r_{NOx}$ of NO$_x$ in the EG of CI motor, obtained with the setting of FIA $\Theta_{df} = 38^\circ$ and different angles of injection of methyl hydroxide $\Theta_m$, show that with the setting of the FIA of $\Theta_{df}$, $38^\circ$, $34^\circ$ and $30^\circ$, the volumetric upkeep of $r_{NOx}$ of NO$_x$ in the EG CI motor is 344 ppm, 310 ppm and 334 ppm respectively. It can be seen from the graph that, with an increase in the FIA $\Theta_m$, the volumetric upkeep of $r_{NOx}$ of NO$_x$ in the CI motor EG changes according to a complex dependence [60-65].

3. Conclusion

By experimental studies and by calculation, the values of the upkeep of the calculated volumetric upkeep of $r_{NOx}$ of NO$_x$ in the EG of CI motor are determined depending on the change in the rotational speed. The decrease in $r_{NO}$ calculation at $n = 1200$ min$^{-1}$ is from 528 ppm when CI motor is running on diesel oil to 341 ppm when working on methyl hydroxide, i.e. by 35.4%. At $n = 2000$ min$^{-1}$, the decrease in $r_{NOx}$ calculation is from 412 ppm when running on diesel oil to 280 ppm when working on methyl hydroxide, or by 32.0%.

References

[1] Likhanov V A and Lopatin O P 2018 IOP Conf. Series: Materials Science and Engineering 457 012011
[2] Romanyuk V, Likhanov V A and Lopatin O P 2018 Theoretical and Applied Ecology 3 27-32
[3] Lopatin O P 2020 IOP Conf. Series: Materials Science and Engineering 862 062087
[4] Anfilatov A A and Chuvashev A N 2020 IOP Conf. Series: Materials Science and Engineering 862 062064
[5] Marchuk A, Likhanov V A and Lopatin O P 2019 Theoretical and Applied Ecology 3 080-6
[6] Anfilatov A A and Chuvashev A N 2020 Journal of Physics: Conf. Series 1515 022035
[7] Likhanov V A and Lopatin O P 2019 Journal of Physics: Conf. Series 1399 055016
[8] Skryabin M L and Likhanov V A 2020 IOP Conf. Series: Materials Science and Engineering 734 012075
[9] Likhanov V A and Lopatin O P 2019 Journal of Physics: Conf. Series 1399 055020
[10] Chuvashev A N and Chuprakov A I 2019 Journal of Physics: Conf. Series 1399 055085
[11] Likhanov V A and Rossokhin A V 2020 IOP Conf. Series: Materials Science and Engineering 862 062046
[12] Likhanov V A, Lopatin O P and Yurlov A S 2019 Journal of Physics: Conf. Series 1399 055026
[13] Anfilatov A A and Chuvashev A N 2020 Journal of Physics: Conf. Series 1515 042048
[14] Likhanov V A and Lopatin O P 2020 IOP Conf. Series: Earth and Environmental Science 421 072018
[15] Anfilatov A A and Chuvashev A N 2020 IOP Conf. Series: Materials Science and Engineering 862 062069
[16] Anfilatov A A 2020 Journal of Physics: Conf. Series 1515 042049
[17] Lopatin O P 2020 IOP Conf. Series: Earth and Environmental Science 421 072019
[18] Likhanov V A, Kozlov A N and Araslanov M I 2020 IOP Conf. Series: Materials Science and Engineering 734 012211
[19] Likhanov V A and Rossokhin A V 2020 IOP Conf. Series: Materials Science and Engineering 862 062047
[20] Likhanov V A and Lopatin O P 2017 Thermal Engineering 64(12) 935-44
[21] Skryabin M L 2020 IOP Conf. Series: Earth and Environmental Science 421 072012
[22] Lopatin O P 2020 Journal of Physics: Conf. Series 1515 042021
[23] Likhanov V A and Lopatin O P 2020 Journal of Physics: Conf. Series 1515 052002
[24] Likhanov V A and Lopatin O P 2020 IOP Conf. Series: Materials Science and Engineering 862 062014
[25] Chuvashev A N and Chuprakov A I 2020 IOP Conf. Series: Materials Science and Engineering 862 062089
[26] Kopchikov V N and Fominykh A V 2020 *Journal of Physics: Conf. Series* **1515** 042028
[27] Likhanov V A and Anfilatov A A 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 032048
[28] Anfilatov A A and Chuvash A N 2020 *Journal of Physics: Conf. Series* **1515** 042052
[29] Lopatin O P 2020 *Journal of Physics: Conf. Series* **1515** 042009
[30] Devetyarov R R and Chuvash A N 2020 *Journal of Physics: Conf. Series* **1515** 042080
[31] Likhanov V A and Lopatin O P 2019 *Ecology and Industry of Russia* **23**(9) 60-5
[32] Chuvash A N, Chuprakov A I and Anfilatov A A 2020 *IOP Conf. Series: Materials Science and Engineering* **734** 012184
[33] Likhanov V A and Rossokhin A V 2020 *IOP Conf. Series: Materials Science and Engineering* **734** 012207
[34] Likhanov V A and Lopatin O P 2020 *Journal of Physics: Conf. Series* **1515** 042008
[35] Lopatin O P 2020 *Journal of Physics: Conf. Series* **1515** 052004
[36] Chuvash A N and Chuprakov A I 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062083
[37] Likhanov V A and Lopatin O P 2020 *Journal of Physics: Conf. Series* **1515** 042019
[38] Skryabin M L and Likhanov V A 2019 *Journal of Physics: Conference Series* **1399** 044063
[39] Likhanov V A and Anfilatov A A 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 032050
[40] Skryabin M L 2020 *Journal of Physics: Conf. Series* **1515** 042107
[41] Likhanov V A and Anfilatov A A 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 032044
[42] Likhanov V A and Lopatin O P 2018 *Ecology and Industry of Russia* **22**(10) 54-9
[43] Likhanov V A and Rossokhin A V 2018 *IOP Conf. Series: Materials Science and Engineering* **457** 012007
[44] Likhanov V A and Skryabin M L 2019 *IOP Conf. Series: Earth and Environmental Science* **315** 032045
[45] Likhanov V A and Rossokhin A V 2019 *Journal of Physics: Conf. Series* **1399** 044038
[46] Likhanov V A and Lopatin O P 2020 *IOP Conf. Series: Materials Science and Engineering* **734** 012202
[47] Likhanov V A, Lopatin O P and Yurlov A S 2020 *IOP Conf. Series: Materials Science and Engineering* **734** 012208
[48] Lopatin O P 2020 *IOP Conf. Series: Materials Science and Engineering* **734** 012199
[49] Kozlov A N, Anfilatov A A and Chuvash A N 2019 *Journal of Physics: Conf. Series* **1399** 055051
[50] Rossokhin A V and Anfilatov A A 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062065
[51] Anfilatov A A and Chuvash A N 2020 *Journal of Physics: Conf. Series* **1515** 042077
[52] Anfilatov A A 2020 *Journal of Physics: Conf. Series* **1515** 042098
[53] Likhanov V A, Lopatin O P and Vylegzhanin P N 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062074
[54] Likhanov V A, Kopchikov V N and Fominykh A V 2020 *Journal of Physics: Conf. Series* **1515** 042026
[55] Chuvash A N and Chuprakov A I 2020 *Journal of Physics: Conf. Series* **1515** 042094
[56] Anfilatov A A and Chuvash A N 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 032052
[57] Likhanov V A, Rossokhin A V and Devetyarov R R 2020 *Journal of Physics: Conf. Series* **1515** 042064
[58] Skryabin M L and Grebnev A V 2020 *Journal of Physics: Conf. Series* **1515** 052052
[59] Likhanov V A and Lopatin O P 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062027
[60] Skryabin M L 2020 *Journal of Physics: Conf. Series* **1515** 04283
[61] Likhanov V A and Lopatin O P 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062033
[62] Likhanov V A, Lopatin O P and Vylegzhanin P N 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062078
[63] Lopatin O P 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062025
[64] Anfilatov A A and Chuvashev A N 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 032055
[65] Devetyarov R R 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062072