Investigation of nitrogen oxides in the cylinder of a gas-diesel engine

V A Likhanov and O P Lopatin

Department of thermal engines, automobiles and tractors, Vyatka State Agricultural Academy, October prospect, 133, Kirov, 610017, Russian Federation

E-mail: nirs_vsaa@mail.ru

Abstract. The paper presents the results of studies of the volume content and mass concentration of nitrogen oxides in the cylinder of a diesel engine running on a gas-diesel process. At the same time, the fuel supply through the gas-diesel process was carried out in the following proportions: natural gas -80%, diesel fuel - 20%. According to the results of the research, a reliable reduction in the content of nitrogen oxides in the cylinder of a diesel engine running on a gas-diesel process was noted.

With the application of modern toxicity requirements for diesels, the emission limits for one of the most toxic components of exhaust gases – nitrogen oxides (NOx) are being tightened. The concentration of nitrogen oxides in the air more than 0.008% causes pulmonary edema and is a threat to human life. The concentration of nitrogen oxides in diesel exhaust gases significantly exceeds 0.1% [1-6].

The volume content (rNOx) and mass concentration (cNOx) of NOx in the diesel cylinder when running on natural gas, depending on the change in the angle of rotation of the crankshaft (r.c.s.) for setting the fuel injection advance angle Θinj=7º to the upper dead point (UDP) are shown in figure 1.

The maximum value of the volume content of NOx in the cylinder when running a diesel on diesel fuel at n=2400 min⁻¹ and pₑ=0.947 MPa (figure 1a) is 892 ppm, the maximum mass concentration is 1.284 g/m³ at an angle of r.c.s. φ=14.5º after UDP. The volume content of nitrogen oxides in the cylinder at the time of opening the exhaust valve at an angle of r.c.s. φ=130.0º after UDP is 684 ppm with a mass concentration of cNOx=0.984 g/m³ [7-15].

The maximum value of the volume content of NOx in the cylinder when the diesel is running on natural gas at n=2400 min⁻¹ and pₑ=0.947 MPa is 941 ppm, the maximum mass concentration is cNOx=1.355 g/m³ at the r.c.s. angle φ=15.5º after TDC. The volume content of nitrogen oxides in the cylinder at the time of opening the exhaust valve is φ=130.0º r.c.s. after UDP is 570 ppm with a mass concentration of cNOx=0.820 g/m³. The difference between the maximum values of the volume content and the mass concentration of NOx in the diesel cylinder when operating on diesel fuel and natural gas is 5.5%. The decrease in the volume content and mass concentration of NOx in the diesel cylinder when operating on natural gas at φ=130.0º r.c.s. after UDP is 17% [16-22].

To compare the concentration of nitrogen oxides in the diesel cylinder when switching from diesel fuel to natural gas, consider the values of the volume content and mass concentration of nitrogen oxides in the cylinder for a constant volume of the cylinder, that is, for the same position of the crankshaft. At the position of the crankshaft corresponding to the angle φ=14.5º r.c.s. after UDP when
working on diesel fuel $r_{NO_x}=892$ ppm, $c_{NO_x}=1.284$ g/m$^3$. When switching to natural gas, $r_{NO_x}=937$ ppm, $c_{NO_x}=1.349$ g/m$^3$. The difference between the volume content and the mass concentration of nitrogen oxides in the diesel cylinder when operating on natural gas at $\varphi=14.5^\circ$ r.c.s. after UDP is 5.0%.

![Figure 1](image1.png)

**Figure 1.** The volume content and mass concentration of nitrogen oxides in the cylinder of a 4CHN 11.0/12.5 diesel engine with charge air cooling depending on the change in the angle of r.c.s. at $\Theta_{inj}=7^\circ$: a - $n=2400$ min$^{-1}$; b - $n=1700$ min$^{-1}$; – diesel fuel; - - gas-diesel fuel.

The maximum value of the volume content of nitrogen oxides in the cylinder when the diesel engine is running on diesel fuel at $n=1700$ min$^{-1}$, $p_e=1.036$ MPa (figure 1b) is 913 ppm, the maximum mass concentration is 1.314 g/m$^3$, at $\varphi=8.0^\circ$ r.c.s. after UDP. The volume concentration of nitrogen oxides in the cylinder at the time of opening the exhaust valve is $\varphi=130.0^\circ$ r.c.s. after UDP is 703 ppm with a mass concentration of $c_{NO_x}=1.012$ g/m$^3$ [23-28].

![Figure 2](image2.png)

**Figure 2.** The volume content and mass concentration of nitrogen oxides in the cylinder of a 4CHN 11.0/12.5 diesel engine with charge air cooling depending on the change in the angle of r.c.s. at $\Theta_{inj}=9^\circ$: a - $n=2400$ min$^{-1}$; b - $n=1700$ min$^{-1}$; – diesel fuel; - - gas-diesel fuel.
The maximum value of the volume content of nitrogen oxides in the cylinder when the diesel engine is running on natural gas at \( n=1700 \text{ min}^{-1} \), \( p_e=1.036 \text{ MPa} \) is 957 ppm, the maximum mass concentration is \( 1.378 \text{ g/m}^3 \), at \( \varphi=9.5^\circ \text{ r.c.s.} \) after UDP the volume concentration of nitrogen oxides in the cylinder at the time of opening the exhaust valve \( \varphi=130.0^\circ \text{ r.c.s.} \) after UDP is 603 ppm, at a mass concentration of \( c_{\text{NO}_x}=0.868 \text{ g/m}^3 \). The difference between the maximum values of the volume content and the mass concentration of nitrogen oxides in the diesel cylinder when operating on diesel fuel and natural gas is 4.8%. The decrease in the volume content and mass concentration of nitrogen oxides in the diesel cylinder when operating on natural gas at \( \varphi=130.0^\circ \text{ r.c.s.} \) after UDP is 14.0%.

For comparability of indicators of nitrogen oxides in the diesel cylinder during the transition from diesel fuel to natural gas, consider the volume content and mass concentration of nitrogen oxides in the cylinder for a constant volume of the cylinder. At the position of the crankshaft corresponding to \( \varphi=8.0^\circ \text{ r.c.s.} \) after UDP when working on diesel fuel \( r_{\text{NO}_x}=913 \text{ ppm}, c_{\text{NO}_x}=1.314 \text{ g/m}^3 \). When switching to natural gas, \( r_{\text{NO}_x}=885 \text{ ppm}, c_{\text{NO}_x}=1.274 \text{ g/m}^3 \). Differences in the volume content and mass concentration of nitrogen oxides in a diesel cylinder when operating on a natural gas pipeline \( \varphi=8.0^\circ \text{ r.c.s.} \) after UDP it is 3.0% [29-32].

The volume content and mass concentration of \( \text{NO}_x \) in the diesel cylinder when running on natural gas, depending on the change in the angle r.c.s. for setting the fuel injection advance angle \( \Theta_{\text{inj}}=9^\circ \) to the UDP are shown in figure 2. The considered dependencies for \( \Theta_{\text{inj}}=7^\circ \) are also valid for the angle \( \Theta_{\text{inj}}=9^\circ \). The analysis of the graphs presented in figure 2 shows similar dependencies of the flow of the curves at \( \Theta_{\text{inj}}=7^\circ \), but it should be noted only their difference in absolute values.

The volume content and mass concentration of nitrogen oxides in the diesel cylinder when running on natural gas, depending on the change in the angle of the r.c.s. at optimal values \( \Theta_{\text{inj}} \) to UDP are shown in figure 3.

![Figure 3](image)

**Figure 3.** The volume content and mass concentration of nitrogen oxides in the cylinder of a 4CHN 11.0/12.5 diesel engine with charge air cooling depending on the change in the angle of r.c.s. at optimal values \( \Theta_{\text{inj}} \): a - \( n=2400 \text{ min}^{-1} \); b - \( n=1700 \text{ min}^{-1} \); – diesel fuel; – – - gas-diesel fuel.

The dependences of the volume content and mass concentration of nitrogen oxides at the optimal angles \( \Theta_{\text{inj}} \), shown in figure 3, are similar to those previously considered.

The studies of the volume content of \( r_{\text{NO}_x} \) and \( c_{\text{NO}_x} \) mass concentration of nitrogen oxides in the cylinder of diesel engine with charge air cooling was a reduction of nitrogen oxides in the result of the use of natural gas and confirmed a good agreement with the theoretical calculations of the volume
content and mass concentration of nitrogen oxides in experimental studies. The difference between theoretical calculations and experimental data did not exceed 5%.

References
[1] Torres-Jimenez E, Jerman M S, Gregorc A et al. 2011 Fuel 90(2) 795-802
[2] Lazarev E and Lomakin G 2014 WIT Transactions on Ecology and the Environment 190(1) 677-83
[3] Luksho V A, Kozlov A V, Terenchenko A S and Grinev V N 2018 International Journal of Mechanical Engineering and Technology 9 1385-95
[4] Lang Y-H, Li G-L, Wang X-M and Peng P 2015 Marine Pollution Bulletin 90(1-2) 129-34
[5] Likhanov V A and Lopatin O P 2018 IOP Conf. Series: Materials Science and Engineering 457 012011
[6] Bauer C, Hofer J, Simons A, Althaus H-J and Del Duce A 2015 Applied Energy 157 871-83
[7] Yadava S and Maitra S S 2017 Global Nest Journal 19 533-39
[8] Likhanov V A and Lopatin O P 2019 Journal of Physics: Conf. Series: Materials Science and Engineering 1399 055016
[9] Sivakumar M, Ramesh kumar R, Syed Thathagir M H and Shanmuga Sundaram N 2018 Renewable Energy 116 518-26
[10] Kozlov A N, Anfilatov A A and Chuvashiev A N 2019 Journal of Physics: Conf. Series 1399 055051
[11] Cai J, Gao S, Zhu L, Jia X, Zeng X and Yu Z 2017 Journal of Environmental Science and Health. Part A: Toxic/Hazardous Substances and Environmental Engineering 52(13) 1226-32
[12] Likhanov V A and Lopatin O P 2019 Journal of Physics: Conf. Series 1399 055020
[13] Dzhallilova S and Erofeev V 2017 Key Engineering Materials 743 394-7
[14] Ahmad I 2016 Journal of Pure and Applied Microbiology 10 95-102
[15] Likhanov V A, Lopatin O P and Yurlov A S 2019 Journal of Physics: Conf. Series 1399 055026
[16] Kordulis C, Gousi M, Kordouli E, Lycourghiotis A and Bourikas K 2016 Applied Catalysis B: Environmental 181 156-96
[17] Shatrov M G, Sinyavski V V, Dunin A Y, Shishlov I G, Vakulenko A V and Yakovenko A L 2018 International Journal of Engineering and Technology 7 288-95
[18] Likhanov V A and Lopatin O P 2020 IOP Conf. Series: Earth and Environmental Science 421 072018
[19] Santos C E D, Silva J D, Gomes L P, Zinani F and Wander P 2015 Renewable Energy 80 331-7
[20] Zhilenkov A A and Efremov A A 2017 IOP Conference Series: Materials Science and Engineering 10 012043
[21] Lopatin O P 2020 IOP Conf. Series: Earth and Environmental Science 421 072019
[22] Rivero J C S, Navarro-Pineda F S, Eastmond-Spencer A and García J B 2016 Sustainability 8(12) 1316
[23] Sinyavskii V V, Alekseev I V, Ivanov I Y, Bogdanov S N and Trofimenko Y V 2017 Pollution Research 36 686-92
[24] Likhanov V A and Lopatin O P 2017 Thermal Engineering 64(12) 935-44
[25] Fasihi M, Bogdanov D and Breyer C 2015 ISES Solar World Congress 2015 Conference Proceedings 1333-52
[26] Gonzalez-Salazar M A, Venturini M, Poganietz W-R, Finkenrath M and Leal M R 2017 Renewable and Sustainable Energy Reviews 73 159-77
[27] Likhanov V A and Lopatin O P 2019 Ecology and Industry of Russia 23(9) 60-5
[28] Melbert A A, Shaposhnikov Y A, Mashensky A V and Voinash S A 2019 Journal of Physics: Conference Series 1399 012011
[29] Chuvashiev A N and Chuprakov A I 2019 Journal of Physics: Conf. Series 1399 055085
[30] Likhanov V A and Lopatin O P 2018 Ecology and Industry of Russia 22(10) 54-9
[31] Skryabin M L 2020 IOP Conf. Series: Earth and Environmental Science 421 072012
[32] Chen W, Pan J, Liu Y, Fan B, Liu H and Otchere P 2019 Applied Energy 176 453-67