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EVALUATION OF PROCESS EFFICIENCY OF GASEOUS PRODUCTS COMBUSTION WHILE SELECTIVE CATALYTIC REDUCTION SYSTEM IN GAS PUMPING UNITS WITH GAS TURBINE DRIVE USED

Abstract: *The purpose of the study is to conduct an analysis of the main methods of cleaning gas turbine emissions and the analysis of ensuring the efficient operation of the selective catalytic reduction system. There was calculation of the required catalyst volume and reagent consumption made to ensure the efficient operation of the selective catalytic reduction system. According to the results obtained, it can be concluded that as the Low-Pressure Turbine Gas Pumping Unit rotational speed increases, the purification efficiency increases when ammonium hydroxide is used as a reagent and decreases when carbamide is used as a reagent. The efficiency of cleaning off gases from nitrogen oxides was obtained when using the Selective Catalytic Reduction system in a mode from 0.5 to the nominal operating mode for all types of reagent.*

Keywords: *selective catalytic reduction, gas pumping unit, effective system operation, reagent, carbamide; ammonium hydroxide, oxides*

1. Introduction

Minimizing the negative impact of energy systems on the environment, reducing the technogenic impact on the ecosystem is one of the key tasks on today's agenda. The improvement of gas transportation technologies is an integrated task to the development of advanced approaches to diagnostics, monitoring and control environmental (Petrochenkov, 2015).

Pollution of the environment by toxic combustion products of organic fuels is one of the most important problems of modern thermal energy. Currently there is a tightening of the concentration of harmful substances in the exhaust gases of the gas pumping unit (GPU). Thus, in particular, according to environmental policy, the concentration of NO_x oxides in combustion products should not exceed 30 mg/m^3. Known work in which the technologies of combustion of oxides are considered: combustion systems were specifically developed to reduce NO_x emissions with a primary focus on natural gas as the primary fuel. Over time, the development of these combustion systems has demonstrated the capability to operate on gaseous fuels with a much wider range heating values (Cho, 1994), operating experience of selective catalytic reduction (SCR) systems for denitrification of flue gas in chemical process industries (CPI) and petroleum refinery heaters and boilers, gas turbine systems, and coal-fired stream, SNOX

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process is a catalytic process for the combined. removal of sulfur oxides and nitrogen oxides from flue gases produced by a coal-fired boiler (Durrani, 1994).

However, at the moment, not a single GPU of domestic production can ensure compliance with such standards. The use of promising gas turbine engines operating with a low-emission combustion chamber as a GPU drive will achieve compliance with the standards for newly developed units focusing on oxy-coal combustion processes and differences when compared with atmospheres enriched in N_2 (Fernández-Miranda et al., 2016), thermodynamic and kinetic aspects of arsenic substances in flue gas (Du et al, 2016), power plants with electrostatic precipitator (ESP) and wet flue gas desulfurization (FGD) scrubber (Senior et al., 2015). But, nevertheless, this will not solve the problems associated with the excess of NO_x emissions in combustion products of a colossal amount of GPUs, which are in use the zeolite catalysts with high internal surface areas, uniform pore systems, considerable ion-exchange capabilities, and satisfactory thermal stabilities are herein addressed for the corresponding depollution processes (Zhang et al., 2016); this report addresses nitrogen oxides (NO_x) controls for new cement kilns and focuses specifically on staged combustion in the calciner (SCC), selective noncatalytic reduction (SNCR), and selective catalytic reduction (SCR) as processes for the control of NOx. Practices and controls that are incorporated in normal operating processes for cement kilns will also be discussed (Neuffer & Laney, 2007).

Thus, there is a need to find a universal method for reducing the concentration of NOx in combustion products of gas turbine drives on both newly developed and in-service GPUs. One such method is to use a selective catalytic reduction (SCR) system as part of the GPU. This method is widely used to clean smoke and exhaust gases from NO_x with an efficiency of up to 90% (Chupka & Licata, 2013).

Modern experience shows that it is impossible to consider any equipment (especially electrical equipment) regarding only the issue of its operation (Buzanowski, 2011), "disconnected" from the issue of its design, during which the main criteria, reliability indicators, operating modes and other aspects that have to be operated during operation were laid down (Miyamoto et al., 1982).

Thus, there are known solutions for designing gas turbine power plants based on an aviation gas turbine engine (Yi et al., 2000; Ilyushin et al., 2021; Kavalerov et al., 2015) that generate electric and thermal energy. It is known from these works that in conditions of distributed generation, the use of autonomous power supply sources in parallel network operation creates the problem of reducing the operational characteristics of the GPU, such as available electrical power, energy efficiency and the quality of electricity. The decrease in GPU performance can be explained by the new emerging properties of the whole system in which they operate. It is necessary to expand the set of acceptable solutions for the implementation of various methods and algorithms for controlling automatic control systems, taking into account territorial, technological and other operating conditions and factors. (Balakin et al., 2022).

A significant amount of time and effort when starting a GTU is spent on installation, adjustment, preparation of test programs, calibration of sensors, etc. There is a well-known literature on the diagnosis of gas turbines. Such diagnostic methods should take into account the nonlinear behavior of the engine, measurement uncertainty, simultaneous malfunctions and a limited number of measurements on the stand. The modes of manual and automatic programmable loading of free shafts of GTU turbines, as well as providing all the necessary conditions for control and acceptance tests of gas turbine installations, are carried out during load tests (Jansohn, 2013; Breeze, 2016). Approaches to HIL modeling are considered in investigations. Full-featured stands are used, among other things, for engines converted for the needs of pumping gas through main gas pipelines and for the needs of small-scale power generation.

2. Overview of the main methods of cleaning gas turbine emissions

2.1. Dry suppression (DLN) of nitrogen oxides

The DLN system is a two-stage combustion chamber with preliminary mixing of fuel and air. Such a system can operate on both gaseous and liquid fuels.

The system includes four main components: a fuel injection system, a flame tube, a Venturi nozzle and a central section of the flame tube. These components are combined into a common structure and form two stages of the dry suppression chamber. In the pre-preparation mode of the fuel mixture, the first stage serves to thoroughly mix the fuel with the air and obtain a homogeneous poor, unburned fuel-air mixture for supplying it to the second stage.

Pre-mixing of fuel and natural gas and combustion of the fuel-air mixture depend on the load of the plant:

- mode I (primary): fuel ignition occurs, gas turbine speed (GT) is set, operation under a load equal to 20% of the nominal one. The mixture of air and fuel enters only the burners of the first stage, where the fuel burns;
- mode II (depleted): GT operates in a load interval equal to 20÷39% of the nominal. The mixture of air and fuel is supplied to both stages of the compressor station (CS) and combustion is carried out in two stages;
- mode III (secondary): GT operation at a load equal to 40% of the nominal. The mixture of air and fuel enters only the second stage of the compressor station, where it burns;
- mode IV (pre-mixing): GT operation in the load interval of 41-100% of the nominal. The mixture of air and fuel is supplied to both stages of combustion chamber, but combustion occurs only in its second stage, where all fuel burns.

An automatic transition from burning natural gas to burning liquid fuel is possible (Salilew et al., 2021). Special flame detectors monitor combustion in the first and second stages of the DLN system. Spark plugs are not retracted during operation, as it is necessary to re-ignite the fuel in the first stage at high loads.

First section of fuel-air mixture preparation is limited by wall of first stage of dry suppression chamber and front cone of Venturi nozzle. The latter prevents the return casting of hot gases from the second to the first stage of the DLN system.

The efficiency of the dry suppression chamber varies depending on the load. Control of calibrated valve separates fuel for operation at specified point determined by design ignition temperature. The schematic diagram of the gas fuel supply and distribution system in the dry suppression chamber.

A feature of the DLN system is that this cleaning method can only be used in the next generation GT, which provided for its presence at the design stage.

2.2. Selective non-catalytic reduction (SNCR)

The method of selective non-catalytic recovery (SNCR) has become widespread in the world energy sector and is used in Russia at thermal power plants. In this method, ammonia or urea is added to the flue gases, which reduce NO to molecular nitrogen. Avoiding the use of a catalyst significantly reduces the cost of the process.

The method is applied in the temperature range of about 850 to 1100 ° C and is described by the gross reaction

$$4NO+4NH_3+O_2 \text{–>} 4N_2 + 6H_2O$$

At lower temperatures, the reaction proceeds too slowly, and at higher temperatures, the reaction begins to compete

$$4NH_3+5O_2 \text{–>} 4NO+6\ H_2O$$

The main difficulty in applying this method is associated with the need to ensure a very homogeneous mixing of the reagent with flue gases precisely in a given temperature window and staying in it for 200-500 ms.

2.3. Selective catalytic reduction (SCR)

Selective catalytic reduction is the most effective means of reducing NO_x emissions. The use of catalysts makes it possible to repeatedly increase the effect of non-catalytic reduction of nitrogen oxides, reduce reagent costs, significantly reduce the process temperature and increase the stability of the purification system (Johnson, 2014).

The cleaning efficiency in the case of using this method reaches over 90% (Timko et al., 2010). Combined with dry suppression technology, it ensures that the lower limit of environmental standards for NO_x (20 mg/m^3) is met. A schematic view of the SCR system is shown in Figure 1.

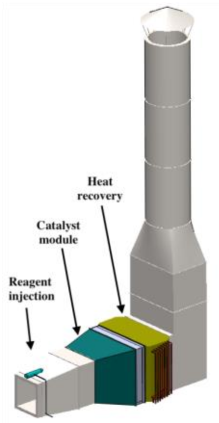

Figure 1. Schematic representation of SCR system

Catalytic gas cleaning is represented by chemical processes of reduction with reducing gas to the simplest components. The final product of the reaction is safe components - water vapors, carbon dioxide, nitrogen (Napolitano et al., 2022).

The reducing agent (reagent) is injected into the flue gas stream upstream of the catalyst. Near the surface of the catalyst, reducing reactions occur with varying degrees of intensity, as a result of which nitrogen oxides are converted to molecular nitrogen. The feed rate and flow rate of the reagent are determined by the NOx concentration at the inlet and outlet of the purification system.

In case of ammonia being a reagent, its injection is carried out mainly by blowing a mixture of air with previously evaporated and mixed anhydrous ammonia, less often - by injecting an aqueous ammonia solution directly into the stream.

If urea solution is used as a reagent, its injection is carried out mainly by direct injection into the flue gas stream or by preliminary gasification and decomposition of urea to obtain an ammonia-gas mixture.

The SCR system consists of the modules installed in the GPU exhaust duct and additional modules for its operation, located on the unit site (Figure 2).

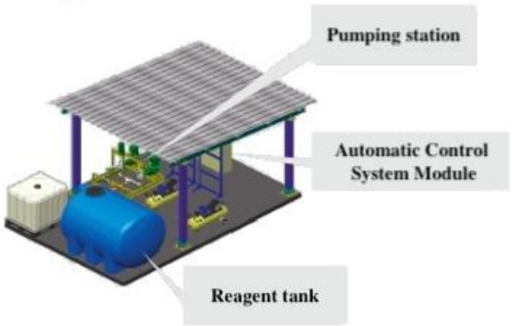

Figure 2. Additional modules of SCR system

The reducing agent is injected into the flue gas stream at the catalyst inlet. NO_x conversion occurs on the catalyst surface by one of the following basic reactions.

With ammonia as reducing agent:

$$4NO + 4NH_3 + O_2 <-> 4N_2 + 6H_2O$$

$$6NO_2 + 8NH_3 <-> 7N_2 + 12H_2O$$

With urea as reducing agent:

$$4NO + 2(NH_2)2CO + 2H_2O + O_2 <-> 4N_2 + 6H_2O + 2CO_2$$

$$6NO_2 + 4(NH_2)2CO + 4H_2O <-> 7N_2 + 12H_2O + 4CO_2$$

The feed rate and flow rate of the reducing reagent are determined by the NO_x concentration at the inlet and outlet of the purification system (Holmer et al., 2022).

Catalysts for SCR plants are catalysts in the form of:

- honeycomb ceramic blocks;
- plate elements.

Honeycomb ceramic catalysts were most widely used (Figure 3). Basically, these catalysts are produced by extrusion of a homogeneous catalyst mass, the channels have a square cross-section of various sizes (Kim et al., 2020)

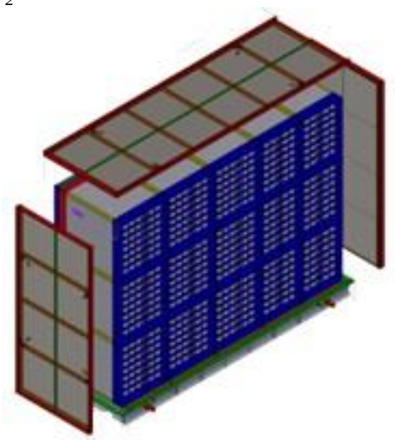

Figure 3. Design of catalyst

Thanks to the use of catalysts in the purification process, the consumption of the reagent is reduced, the neutralization temperature of nitrogen oxides is significantly reduced, and the purification efficiency exceeds 90% (Sala et al., 2017).

When installing SCR after GPU, it is important not only to select the reagent and catalyst correctly, but also to comply with the following technical conditions:

- determine economic feasibility: reduce exhaust gas temperature by dilution with air or use a catalyst for high temperatures (Koebel & Strutz, 2003);
- ensure uniform distribution of temperature, reagent vapor concentration and NO_x when the gas stream enters the catalyst units (Kim et al., 2022);
- ensure minimum back pressure in the system;
- take into account the specifics of the GPU operation in relation to the electric power system (under different load relief (overload) modes).

Only in case of simultaneous fulfillment of the above three conditions, the SCR system will be an effective solution for neutralizing nitrogen oxides.

2.4. Characteristics of the gas turbine.

For turbines in the system of driven gas turbine plants (GTP), the dependence is determined:

$$\sigma_t = f(\pi_t; T_g)$$

where □$_t$ - gas flow rate through turbin; □$_t$ - degree of expansion, T_g - gas temperature;

At the same time, the speed of rotation of the turbine has little effect on its throughput. Graphically, this dependence is a family of parabolas built on the basis of turbines adopted in the theory of dependence. Instead of T_g, it is more convenient to use the □□□□T_g/T_v, where T_v coefficient, where T_v is the air temperature. Knowing the relative pressure losses along the ξ_{tp} path and the flow ratio of the σ_t and compressor turbines □$_k$ the characteristics of the turbine and compressor can be combined using the expression:

$$\pi_t = \pi_k(1 - \xi_{tp} \cdot 7)$$

$$\sigma_t = \sigma_к + \sigma_{mon} - \sigma_{ox} - \sigma_{yt}$$

formula □$_{mon}$ - mass flow rate of fuel, □$_{ox}$ - mass flow rate of air for cooling, □$_{yt}$ - mass flow rate of leaks, □$_{tp}$ - in pressure loss along the path. The amount of heat transferred in the generator in variable mode depends on the method of gas-turbine unit control, which affects the change in the temperature interval between the gas after the turbine and air after the compressor. The control method means the effect on the control factors to maintain the specified controlled parameters (N_e - effective power of the gas-turbine unit, n - rotation speed, T_g - temperature of combustion products, π_k - degree of pressure increase in the compressor), etc.

The main control factor is the fuel supply, but changing the geometry of the compressor or turbine can also be used. In addition to the gas-turbine unit characteristics discussed above, the gas turbine manufacturers provide for each new type of unit, and then, according to experimental data, a universal characteristic of the axial compressor, a characteristic of the gas-turbine unit operating modes, a dependence of power and air flow on compressor revolutions, a dependence of pressure behind the compressor and between turbines on compressor revolutions, a dependence of power shaft power, a dependence of temperature on power, etc (Petrochenkov, 2013). It should be borne in mind that all listed dependencies are processed by plants according to the readings of instruments with an increased accuracy class and that tests are carried out with a clean blade apparatus of the axial compressor and turbine at nominal clearances of the linear part (Petrochenkov et al., 2018).

One of the main parameters determining the operating mode of the gas turbine is the available power of the C_n drive, where □□ is a coefficient to take into account the dependence of the available power on the speed of the axial compressor.

Based on the studies, the total dependence of available power (N_{pac}) on relative revolutions (C_n) and air temperature (t_v):

$$N_{pac} = N_{nom} \cdot \mathrm{A} - \alpha_2 \cdot \tau$$

$$\mathrm{A} = \alpha_{00} + \alpha_{10} \cdot \bar{n} + \alpha_{20} \cdot \bar{n}^2 + \alpha_{01} \cdot t_v + \alpha_{02} \cdot t_v[t_v] + \alpha_{11} \cdot \bar{n} \cdot t_v$$

□□ □ factor to take into account the dependence of available power on the speed of rotation of the axial compressor;
□□□□ factor to take into account the change in the available power of the GTU at disconnection of the ambient air temperature T_v from the nominal temperature equal to 288 K;
□□ □ factor to take into account the drop in the available capacity of the GPU during the overhaul period;
□□□□ the time, months that have passed since the last repair of the GTU.
Of particular importance is the grade. drive, since it is he who appears in the expressions for calculating the total energy costs. In work (Salilew et al., 2021), it is assumed that the main factors affecting the efficiency of GTU is the load factor and relative revolutions.

It is also necessary to take into account the energy accumulation in the rotating masses of the rotors of the two-shaft gas turbine plant, the dynamics of which are described by the equations of the turbocharger rotor and the free turbine (FT).

$$A_{DI} = K_{DI} \cdot (A_{DIZ} - A_{DI}),$$
$$G_T = K_{GT} \cdot A_{DI},$$
$$n_{TS} = K_{NTS} \cdot G_T,$$
$$n_{TK} = \frac{(n_{TS} - n_{TK})}{T_{NTK}},$$
$$N_E = K_{NE} \cdot n_{TK},$$
$$\left(\frac{3{,}14}{30}\right)^2 \cdot J_\Sigma \cdot n_{CT} \cdot \frac{dn_{CT}}{dt} = 1000(N_E - N_G)$$

A_{DI} – angle of gas metering unit rotation;
A_{DIZ} – preset angle of gas metering unit rotation;
G_T – fuel consumption;
n_{TK} – turbocharger rotor speed;
n_{CT} – free turbine rotor speed;
n_{TS} – turbocharger rotor speed by static characteristic;
J_Σ – total moment of inertia of the free turbine reduced to the shaft;
T_{NTK} – time constant of turbocharger rotor;
N_E – available power of free turbine;
N_G – power consumption of free turbine;
K_{DI}, K_{GT}, K_{NTS}, K_{NE} – coefficients.

This algorithm will make it possible to obtain output characteristics and proceed to the development of the test bench system for automatic control of SCR (Petrochenkov & Mishurinskikh, 2021). During the process, the bench control system should calculate the value of the reagent amount supply depending on the GTU revolutions, as well as determine the most effective reagent to reduce nitrogen oxide emissions into the atmosphere.

3. Calculation of required catalyst volume and reagent consumption to ensure efficient operation of the SCR system

The initial data on the qualitative and quantitative composition of exhaust gases of the Ural GPU-16 were adopted in accordance with the data of the developer of the GPU and are given in Table 1.

Table 1. Composition of exhaust gases downstream the free turbine GTU-16P at Tn= + 15 ° C.

GTU operating mode, % of rated power	100	50
Air-fuel ratio	3.53	4.72
Composition of exhaust gases at standard air humidity (volume %):		
O_2	14.35	15.90
N_2	75.55	76.10
CO_2	2.88	2.17
H_2O	7.22	5.83
Content of harmful substances, to 15% O_2, mg/m^3, not more than:		
NO_x	180	137
CO	47	128
SO_x	0.3	
Total flow temperature, ° C	486.6	404.8
Gas consumption, kg/s	55.38	42.92

The design values of the required catalyst volume, the specific consumption of the reagent for the 100% and 50% power modes of the GPU operation (AdBlue liquid – 32.5% aqueous solution of urea), the dependence of the design value of hydraulic resistance on the area of the catalytic reactor are given in Tables 2 and 3.

Table 2. Calculated Catalyst Volume and Reagent Flow (100 % of GTU power).

Parameters	Value	Units of measure
Exhaust gas mass flow rate	55.38	kg/s
Exhaust gas temperature	486.6	° C
Pressure	101,350	Pa
NO_x concentration	180	mg/m^3
CO concentration	47	mg/m^3
Molar mass of exhaust gases	28.3128	g/mol
Universal gas constant	8.314	$m^2 * kg/(s^2 \cdot K \cdot mol)$
Density of hot exhaust gases	0.454372039	kg/m^3
Exhaust gas volumetric flow under normal conditions	45.95850622	m^3/s
Volume flow rate of hot exhaust gases	121.8824999	m^3/s
Mass flow NO_x	21.93884999	g/s
Mass flow rate of CO	5.728477497	g/s
Reagent mass flow rate	18.20924549	g/s
Minimum catalyst volume required	18	m^3
Reagent mass flow rate	65.55328377	kg/h

Table 3. Calculated Catalyst Volume and Reagent Flow (50 % of GTU power).

Parameters	**Value**	**Units of measure**
Exhaust gas mass flow rate	42.92	kg/s
Exhaust gas temperature	404.8	° C
Pressure	101,350	Pa
NO_x concentration	137	mg/m^3
CO concentration	128	mg/m^3

Molar mass of exhaust gases	28.4002	g/mol
Universal gas constant	8.314	$m^2 * kg/(s^2 \cdot K \cdot mol)$
Density of hot exhaust gases	0.510779627	kg/m^3
Exhaust gas volumetric flow under normal conditions	35.61825726	m^3/s
Volume flow rate of hot exhaust gases	84.02841013	m^3/s
NO_x Mass Flow	11.51189219	g/s
Mass flow rate of CO	10.7556365	g/s
Reagent mass flow rate	9.554870516	g/s
Minimum catalyst volume required	10	m^3
Reagent mass flow rate	34.39753386	kg/h
Reagent mass flow rate	825.5408126	kg/day

3.1. Reagent Selection Features

In SCR systems, a solution of carbamide or ammonia is used as a reagent (Table 4).

Table 4. Reagent selection.

Ammonia (NH_3)	**Industrial urea solution**
more effective than carbamide	no risk of catalyst contamination
requires lower capital expenditures	safe and non-toxic
easy to operate	easy to maintain
has no additional process stages	has no risks associated with transportation, unloading and storage
reduces the likelihood of corrosion and contamination of equipment	
more effective than carbamide	
requires lower capital expenditures	

As a reducing agent, an aqueous solution of carbamide (or an aqueous solution of urea) is widely used in selective catalytic reduction systems of nitrogen oxides. Its most common variety is AdBlue, which is produced according to the ISO 22241 standard of 32.5% high-purity urea and 67.5% demineralized water.

3.2. Summary of SCR system at Ural GPU-16

Subsequently, the data from the above results were approximated in order to build a dependence on the efficiency of the SCR system in three test modes for different reagent consumption.

Figures 4,5,6 show the dependencies of the concentration of nitrogen oxides in total (in terms of NO_x) before and after the SCR system in various test modes when the reagent flow rate is changed by injection into the GPU exhaust gases.

It was established that 100% efficiency of purification of off-gases from nitrogen oxides using the SCR system is observed at 0.5 of nominal value at all reagent flow rates and at 0.75 of nominal value at low reagent flow rates (0.32-0.36 l/min). At the same time, the required concentration level after the SCR system of 50 mg/m^3 (i.e., a concentration of 43-48 mg/m^3 at a reagent flow rate of 0.47-0.48 l/min) was reached in the test mode of 0.75 of the nominal value.

At the mode equal to the nominal, effective operation of the SCR system is observed with an increase in reagent consumption up to 0.8-1.0 l/min. NO_x concentrations (iv. 15% O_2 in flue gases) up to 50 mg/m^3.

A total of 17 series of measurements of nitrogen oxides in the composition of exhaust gases were performed and processed. Measurements were performed while monitoring the composition of the off-gases before and after the SCR system, except for two series of measurements performed without reagent supply.

When comparing the test data, it was established:

- at the mode of 0.5 of the nominal value and the reagent consumption of 0.78 l/min, the concentration of nitrogen oxides in total in terms of NO_x after the SCR system was 0, which corresponds to 100% efficiency of the exhaust gas purification system;
- in the mode of 0.75 of the nominal value and reagent flow rate in the range from 0.395 and 0.89 l/min, the concentration of nitrogen oxides in total after the SCR system varied from 4 to 42 mg/m^3, which amounted to 48-96 % of the efficiency of the exhaust gas purification system;
- in the 0.9-1.0 mode of the reagent rating and flow rate in the range of 0.49-1.03 l/min, the concentration of nitrogen oxides after the SCR system varied in the range of 6-25 mg/m^3, which corresponds to 85-96% of the efficiency of the exhaust gas purification system.

The results of the data indicate the confirmation of 100% efficiency of purification of off-gases from nitrogen oxides when using the SCR system at the mode of 0.5 of the nominal value at all reagent flow rates. At the same time, there is a direct dependence of efficiency (up to 100%) with an increase in reagent consumption.

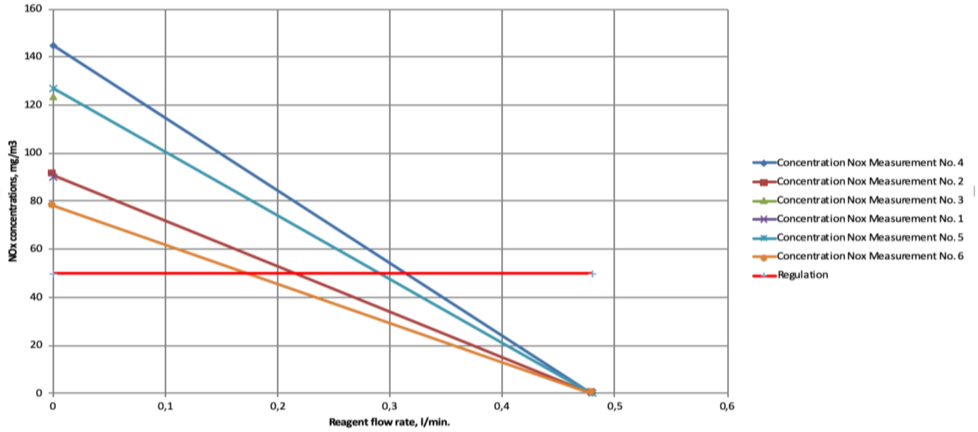

Figure 4. Concentration of nitrogen oxides in total (before and after the SCR system in 0.5 of the nominal operating mode)

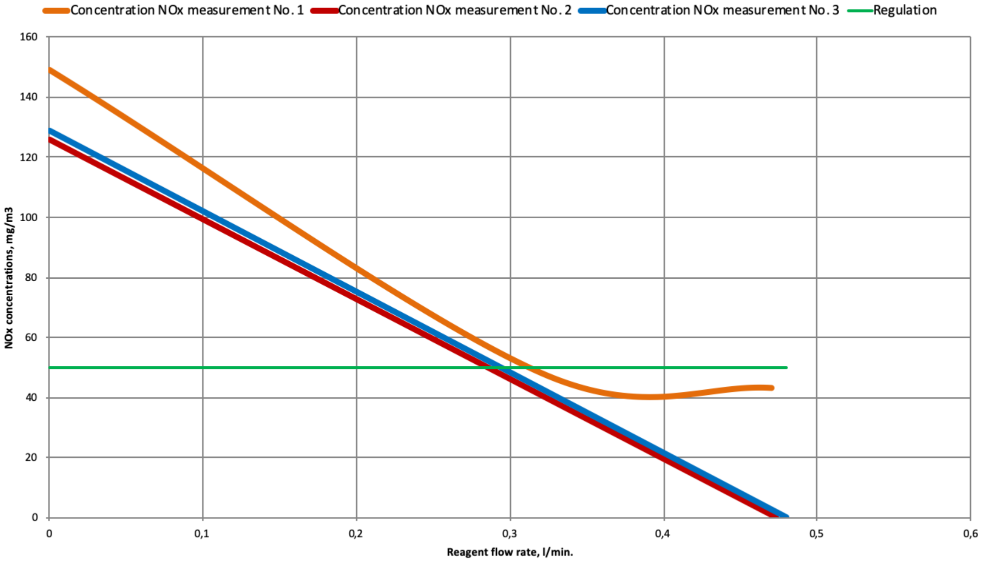

Figure 5. Concentration of nitrogen oxides (before and after the SCR system is 0.8 of the nominal operating mode)

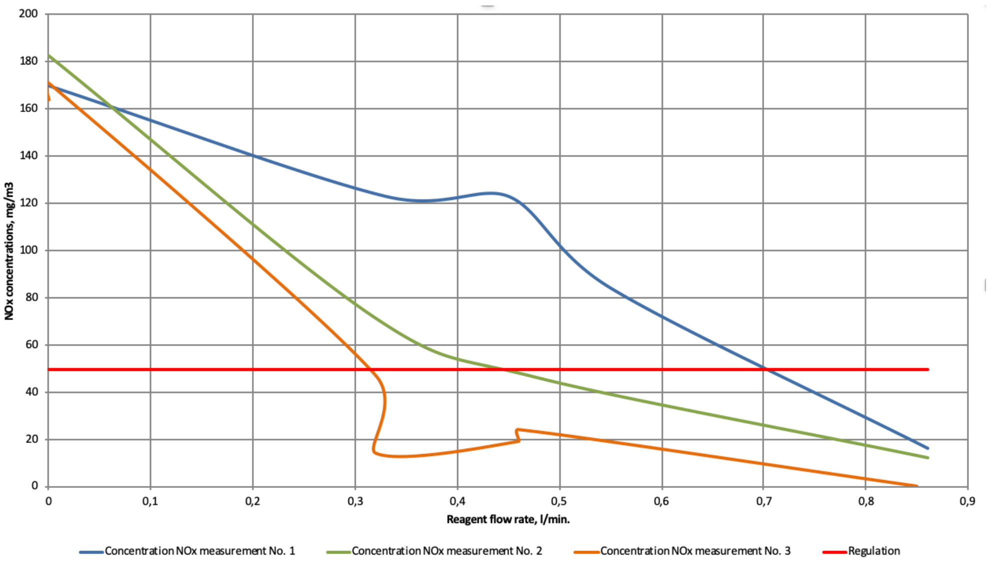

Figure 6. Concentration of nitrogen oxides (before and after the SCR system in nominal operation mode)

1. At GPU LPT rotation speed of 3799-4200 (0.5 of nominal) rpm, the purification efficiency when used as a reagent "urea" is 5.3% higher compared to when used as a reagent "ammonia water."

2. At GPU LPT rotation speed of 4500 (0,75 of nominal) rpm, the purification efficiency when used as a reagent "ammonia water" is 5.3% higher compared to when used as a reagent "urea."

3. At GPU LPT rotation speed of 5000-5010 (nominal) rpm, the purification efficiency when used as a reagent "ammonia water" is increased by 23.6% compared to when used as a reagent "urea."

4. Conclusion

In general, according to the results obtained, it can be concluded that as the GPU LPT rotational speed increases, the purification efficiency increases when ammonia water is used as a reagent and decreases when urea is used as a reagent.

In the process of current study, the need to develop the following algorithm for supplying the reagent by a signal from the automatic control system to the inlet to the nozzle assemblies has been proved: fine spraying of the reagent takes place through the nozzle system, small droplets of the reagent are picked up by the flow of exhaust gases and move towards the catalyst inside the exhaust system of the GPU. As the droplets move through the diffuser, the liquid evaporates, hydrolyzes and thermalizes. Simultaneously with the above-described process, a fan is activated to allow part of the flue gases to flow through the gas duct-thermalizer. Due to the heat of the flue gases, small droplets of the reagent evaporate, which ensures the supply of a mixture of flue gases with the reagent to the exhaust path of the gas compressor through the distribution manifold of the thermally insulated reagent.

5. Discussion

The next stage of the research will be investigating the factors affecting the efficiency of the process of combustion of gaseous products in the gas pumping unit. Then develop an algorithmic control of the concentration of nitrogen oxides in gaseous products in the gas pumping unit and methods for controlling the combustion process of gaseous products. The next stage of research verifies the algorithmic and software of the automatic control system for the supply of reagent to the inlet to the nozzles to reduce the amount of polluting emissions.

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