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ANALYSIS OF GREENHOUSE GAS EMISSIONS INTO ATMOSPHERIC AIR FROM OIL AND GAS PRODUCTION FACILITIES

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The sectors of the national economy have experienced the devastating impact of Russian aggression in Ukraine. The adaptability to challenges during the full-scale war has allowed enterprises in the oil and gas sector to maintain a positive dynamic. Currently, oil and gas companies emit a significant amount of greenhouse gases. Despite wartime conditions, these companies are paying attention to ensuring Ukraine's fulfillment of its international and European integration commitments in the field of climate change mitigation. Ensuring the effective functioning of enterprises is a key objective of environmental policy. The construction of new oil and gas wells will enhance the country's energy potential. However, oil and gas wells pose environmental threats both during technological processes and in emergency situations. Therefore, analyzing greenhouse gas emissions throughout the well's life cycle is highly relevant. The purpose of this study is to analyze greenhouse gas emissions into the atmosphere at various stages of the well life cycle. To achieve this aim, the following research objectives were formulated: to analyze greenhouse gas emissions during the drilling and abandonment stages of wells and to identify measures for their reduction. The object of the study is oil and gas wells located at an industrial site. The subject of the study is greenhouse gas emissions. An analysis of total greenhouse gas emissions during the life cycle was conducted. Combustion products from diesel fuel used by drilling rig engines are the primary sources of impact on the atmospheric air during drilling and abandonment. These stages of the well life cycle account for a significant portion of greenhouse gas emissions. Organized sources of greenhouse gas emissions during the drilling and abandonment stages were considered. Gross emissions of greenhouse gases into the air during the drilling and abandonment of three wells of varying depth and drilling cycle duration were calculated. It has been determined that the enterprise's greenhouse gas emissions pose no risk to the health of personnel. *Key words:* well life cycle, greenhouse gases, environment, emission sources, combustion products, drilling process.

Аналіз викидів парникових газів у атмосферне повітря нафтогазовидобувними об'єктами. Кривенко Г.М.
Галузі вітчизняної економіки відчули на собі руйнівну силу російської агресії в Україні. Адаптивність до викликів в умовах повномасштабної війни дозволила підприємствам нафтогазової галузі зберегти позитивну динаміку. На даний час підприємства нафтогазової галузі викидають значну кількість парникових газів. Незважаючи на військовий стан нафтогазові компанії приділяють увагу забезпеченню виконання Україною її міжнародних та євроінтеграційних зобов'язань у сфері боротьби зі зміною клімату. Гарантування ефективного функціонування підприємств є головним завданням екологічної політики. Спорудження нових нафтогазових свердловин дасть змогу покращити енергетичний потенціал держави. Але нафтогазові свердловини створюють загрозу навколишньому середовищу як при технологічних процесах, так і під час аварійних ситуацій. Отже, аналіз викидів парникових газів під час життєвого циклу свердловини є актуальним. Метою даної роботи є аналіз викидів парникових газів у атмосферне повітря на етапах життєвого циклу свердловини. Для досягнення поставленої мети були сформульовані наступні задачі досліджень: аналіз викидів парникових газів на етапах буріння та ліквідації свердловин та заходи щодо їх мінімізації. Об'єктом дослідження є нафтогазові свердловини на промисловому майданчику. Предмет досліджень: викиди парникових газів. Проведено аналіз сумарних викидів парникових газів під час життєвого циклу. Продукти згорання дизельного палива двигунів бурової установки є джерелами впливу на повітряне середовище при бурінні та ліквідації свердловини. На ці етапи життєвого циклу свердловини припадає значна кількість викидів парникових газів. Розглянуто організовані джерела викиду парникових газів на етапах буріння та ліквідації свердловин. Розраховано валові викиди парникових газів у повітря у процесі буріння та ліквідації трьох свердловин, які відрізняються глибиною та тривалістю циклу буріння. Встановлено, що викиди парникових газів підприємством не несуть загрози здоров'ю персоналу. *Ключові слова:* життєвий цикл свердловини, парникові гази, довкілля, джерела викиду, продукти згорання, процес буріння.

Introduction. Formulation of the problem. The sectors of the national economy have felt the devastating impact of Russian aggression in Ukraine. The oil and gas industry is no exception, as the uninterrupted functioning of all economic sectors depends on its stable operation. The military aggression of the Russian Federation against Ukraine has caused critical damage to the country's energy infrastructure. However, adaptability to challenges under the conditions of full-scale war has enabled oil and gas enterprises to maintain a positive dynamic.

Despite the state of war, oil and gas companies remain committed to ensuring that Ukraine fulfills its international and European integration obligations in the field of climate change mitigation [1]. Over the next two decades, natural gas will play a key role in the country's energy security and will serve as a transitional fuel in the processes of economic decarbonization. The construction of new oil and gas wells will enhance the state's energy potential. However, oil and gas wells pose a threat to the environment both during technological processes and in the event of emergencies.

The relevance of the research and the connection of the author's work with important scientific and practical tasks. The problem remains relevant despite efforts to optimize the structure of the national energy sector by increasing the use of low-carbon energy sources and reducing greenhouse gas emissions. To address it effectively, a detailed analysis of the factors contributing to environmental pollution is necessary. This will make it possible to implement appropriate measures to minimize greenhouse gas emissions. This constitutes the practical significance of the author's work.

Analysis of recent research and publications. The issues of greenhouse gas emissions and the environmental assessment of atmospheric air quality are addressed in scientific works [2, 3, 4]. The improvement of production processes aimed at reducing the environmental impact of industrial enterprises is discussed in works [5, 6, 7]. The analysis of technogenic pressure on the atmospheric environment is presented in studies [8, 9]. Environmental impacts during well drilling may occur not only as a result of emergency situations but also under normal operating conditions. This is primarily due to significant emissions of greenhouse gases and other pollutants into the atmosphere [10, 11]. The release of hydrocarbons and other hazardous substances from wells and their resulting environmental consequences are described in [12].

Highlighting previously unresolved parts of the general problem, to which the specified article is devoted. To date, the issue of reducing greenhouse gas emissions into the atmosphere remains unresolved. Therefore, a comprehensive analysis of greenhouse gas emissions is necessary to identify effective mitigation strategies.

The purpose and objectives of the study. The purpose of this study is to analyze greenhouse gas emissions into the atmosphere at various stages of the well life cycle. To achieve this goal, the following research objectives were formulated: to analyze greenhouse gas emissions during the drilling and abandonment stages of wells; to identify measures aimed at minimizing these emissions. The object of the study is oil and gas wells located at an industrial site. The subject of the study is greenhouse gas emissions.

Novelty and general scientific significance. The novelty of the research lies in the comprehensive investigation of greenhouse gas emissions at different stages of the well life cycle. The results of this scientific work, in combination with other studies, will enable the implementation of appropriate measures to minimize greenhouse gas emissions.

Materials and Methods. The analysis of greenhouse gas emissions into the atmosphere was conducted using the example of three oil and gas wells located within the administrative boundaries of a united territorial community in the Poltava region. The drilling depths of the wells to the top of the productive horizon are 2400 m, 2500 m, and 2750 m, respectively. The drilling method is rotary, combined (rotary and screw downhole motor). The duration of the drilling cycle for each well is 40, 76, and 99 days, respectively [13].

Oil and gas industry enterprises are associated with emissions of greenhouse gases into the atmosphere, including carbon dioxide, methane, and nitrous oxide, as well as other air pollutants. A diagram illustrating greenhouse gas emissions into the atmosphere by oil and gas sector enterprises in 2021 has been constructed (Fig. 1) [14].

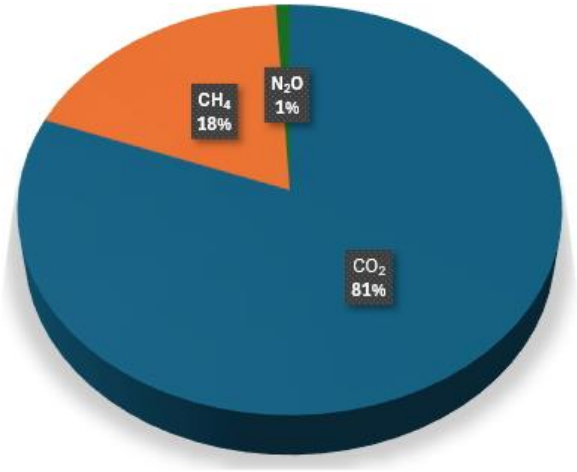

Fig. 1. Structure of Greenhouse Gas Emissions into the Atmosphere by Oil and Gas Sector Enterprise

According to the emission structure shown in Fig. 1, carbon dioxide (CO_2) emissions account for 81% of total atmospheric emissions. Since they represent the majority of emissions, it is reasonable to analyze their specific impact on the environment.

The gross emission of the *j*-th pollutant M_j released into the atmosphere is determined by the following equation:

$$M_j = \sum_i M_{ji} = 10^{-6} \sum_i k_{ji} B_i (Q_i^r)_i , \qquad (1)$$

where M_{ji} – gross emission of the *j*-th pollutant during the combustion of the *i*-th type of fuel over the time period *t*, in tonnes; k_{ji} – emission factor of the *j*-th pollutant for the *i*-th fuel, g/GJ; B_i – consumption of the *i*-th fuel over the time period *t*, in tonnes; $(Q_i^r)_i$ – lower heating value of the *i*-th fuel, MJ/kg.

The emission factor carbon dioxide CO_2 during the combustion of organic fuels, in g/GJ, is determined by the formula:

$$k_{co_2} = \frac{44}{12} \cdot \frac{C^1}{100} \cdot \frac{10^6}{Q_i^r} \varepsilon_c = 3.67 k_c \varepsilon_c \qquad (2)$$

where C^l – carbon content in the fuel based on working mass, %; Q_i^r – lower heating value of the fuel, MJ/kg; ε_c – oxidation factor of carbon in the fuel (CO_2); k_c – carbon emission factor of the fuel, g/GJ.

Numerical values of the emission factors for methane and nitrogen oxide (NO) are provided in [15].

Presentation of the main material. The life cycle of oil and gas wells, during which greenhouse gas and pollutant emissions are observed, consists of the following stages: site preparation for drilling operations, well drilling, well connection, operation, and well abandonment. Each stage is characterized by a specific percentage of greenhouse gas emissions into the atmosphere as a result of industrial activities.

The structure of greenhouse gas emissions at different stages of the well life cycle is shown in Fig. 2 [13].

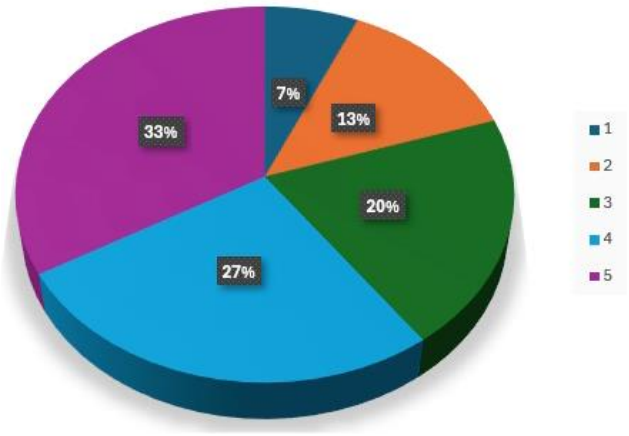

Fig. 2. Structure of Greenhouse Gas Emissions at Different Stages of the Well Life Cycle

1 – site preparation; 2 – drilling; 3 – well connection; 4 – well operation; 5 – abandonment

According to Fig. 2, at the well abandonment stage, greenhouse gas emissions account for 33% of the total emissions over the entire life cycle; during well operation – 27%; well connection – 20%; drilling – 13%; and site preparation for drilling operations – 7%.

Since the duration of each stage of the oil and gas well life cycle varies, it is recommended to consider the emission intensity of greenhouse gases to assess the degree of environmental pollution.

The drilling stage demonstrates the highest emission intensity. However, its duration is only about 2% of the total well life cycle. The well abandonment stage is characterized by a high emission intensity of greenhouse gases. The operational stage lasts approximately up to 85% of the total well life cycle and is characterized by medium levels of emission intensity.

The greenhouse gas emission intensities at different stages of the well life cycle are presented below. During the site preparation stage, the emission intensity of greenhouse gases is 0.1221675 g/s; during drilling – 121.1757 g/s; during well connection – 0.0486675 g/s; during operation – 0.155325 g/s; and during abandonment – 40.4237 g/s [13].

At the drilling stage, greenhouse gas emissions account for only 13% of the total emissions throughout the well's life cycle, while at the abandonment stage – 33%. However, since the emission intensity at the drilling stage constitutes 74.9% of the total emission intensity, and at the abandonment stage – 24.9%, these two stages will be further considered for a detailed analysis of greenhouse gas emissions.

Greenhouse gas emissions from organized sources during well drilling and abandonment have been determined. We will analyze the emissions of greenhouse gases – CO_2, CH_4, and N_2O – into the atmospheric air through the exhaust pipes of diesel engines during the drilling of wells No. 1, No. 2, and No. 3, as well as during their abandonment.

The results of the calculated greenhouse gas emissions from diesel engine exhaust pipes during drilling and abandonment are presented in Figures 3, 4, and 5.

From the analysis of Fig. 3 it follows that during the drilling of wells No. 1, No. 2, No. 3, carbon dioxide

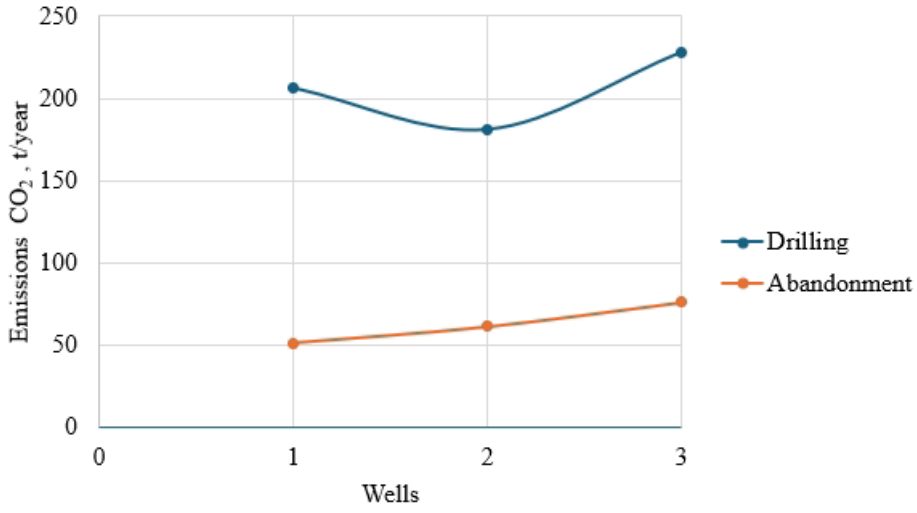

Fig. 3. Carbon dioxide emissions from diesel engine exhaust pipe

emissions of 206.0 t/year, 180.8 t/year and 228.2 t/year are observed through the exhaust pipes of diesel engines, respectively.

A 12% reduction in CO_2 emissions from well No. 2 compared to No. 1 can be explained by an increase in the average drilling rate achieved through the use of upgraded rigs. The 26% increase in greenhouse gas emissions from well No. 3 compared to No. 2 is due to the greater drilling depth of well No. 3 – its vertical depth to the roof of the productive horizon is 250 m deeper than that of well No. 2 – as well as the longer drilling cycle, which is extended by 23 days.

Well abandonment is a set of measures aimed at restoring the natural state of rock formations disrupted by the well, in order to protect subsoil resources. During the abandonment of wells No. 1, No. 2, and No. 3, carbon dioxide emissions amount to 51.5 t/year, 60.3 t/year, and 76.1 t/year, respectively.

Carbon dioxide (CO_2) emissions from organized sources during drilling and abandonment of wells are shown in Figure 4. The first and second sources of greenhouse gas emissions are the exhaust systems of two diesel engines used to drive the rotary table and the drawworks. The third and fourth sources are the exhaust systems of two diesel engines powering the drilling mud pumps. The fifth and sixth sources correspond to the exhaust systems of two diesel engines operating the electric generators.

Analysis of the data indicates that the highest greenhouse gas emissions occur during the drilling stage from the diesel engines powering the mud pumps, reaching 61.52 tonnes per year. During the well abandonment stage, emissions from these sources decrease to 20.53 tonnes per year. The deviation in emissions from the identified organized sources does not exceed 3.4%. Thus, during drilling operations, the sources are used alternately: either the first or second emission source, the third or fourth, and the fifth or sixth, respectively. To reduce emissions of greenhouse gases and air pollutants, the operation of equipment involved in continuous technological processes is temporally distributed.

Analysis of Fig. 5 indicates that during the drilling of wells, methane (CH_4) emissions through the exhaust pipes of diesel engines range from 0.00769 t/year to 0.00958 t/year, while nitrous oxide (N_2O) emissions range from 0.00615 t/year to 0.00938 t/year.

During well abandonment, CH_4 emissions range from 0.002116 t/year to 0.00313 t/year, and N_2O emissions range from 0.015375 t/year to 0.0175 t/year.

To reduce greenhouse gas emissions into the atmosphere, the following mitigation measures are recommended: improving resource efficiency; reducing methane emissions and leaks; avoiding flaring and well blowouts during technological processes; transitioning to renewable energy sources to meet internal energy demands; prohibiting engine operation in overload mode; and distributing the operation of equipment involved in continuous technological processes over time.

The implementation of these and other measures will contribute to the reduction of emissions at the drilling site.

Since carbon dioxide (CO_2) emissions account for 81%, we will assess its impact on atmospheric air. The assessment of the impact of greenhouse gas emissions on the state of atmospheric air is carried out based on the results of calculations of greenhouse gas content in emissions from organized sources.

The change in ground-level concentration relative to the background concentration (C_f) is determined as follows:

$$\Delta C = \frac{C + C_f}{C_f}, \qquad (3)$$

where C is the ground-level concentration of CO_2 emissions, g/m^3, and C_f is the background concentration of CO_2 in atmospheric air, g/m^3.

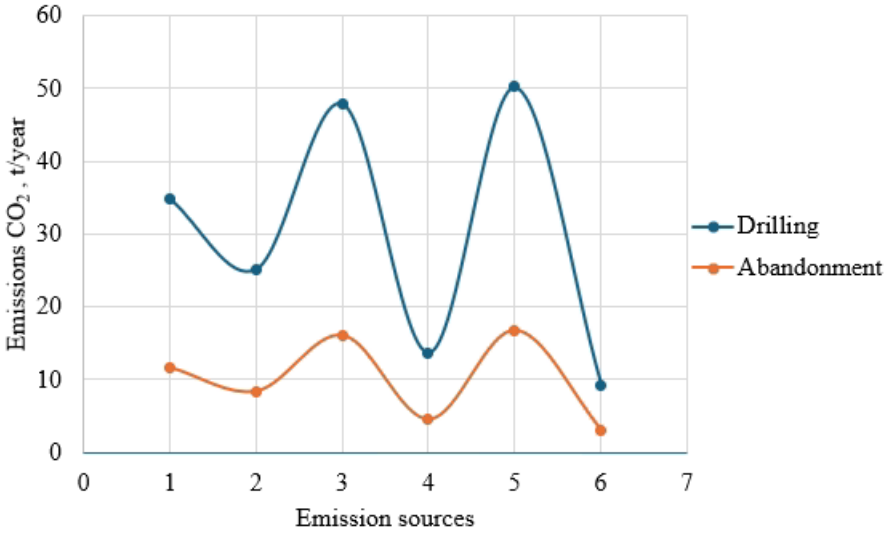

Fig. 4. Carbon dioxide emissions from organized sources

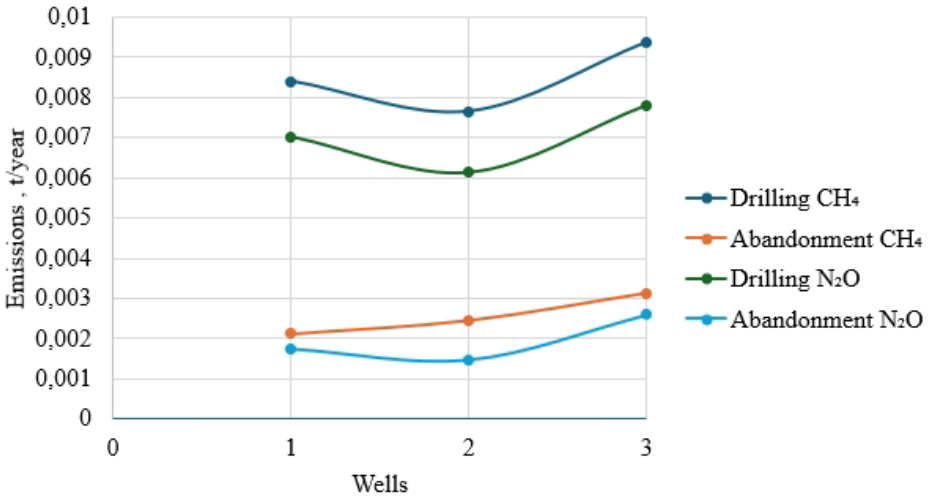

Fig. 5. Emissions of greenhouse gases CH_4 and N_2O

Under normal conditions, approximately 350 cm³ of CO_2 is contained in 1 m³ of atmospheric air, which corresponds to 350 ppm – the optimal concentration of carbon dioxide in the air in terms of its impact on human health. Based on the gas density under standard conditions, the background concentration was calculated to be 0.687 g/m³. According to the results of greenhouse gas emission calculations from six organized sources during the drilling and abandonment of wells, the ground-level concentration of CO_2 was determined using the methodology presented in [16], amounting to 3.326 g/m³ at an emission rate of 119.32 g/s.

Under normal background levels of CO_2, the company's emissions do not pose a threat to personnel health, even at a concentration increase of 4.841 times, which corresponds to 1694 ppm in open space. It should be noted that emissions during drilling operations are temporary in nature. For example, if the life cycle of a well is 10 years, and the average duration of the drilling phase is approximately 70 days, then the drilling stage accounts for only about 2% of the total well life cycle [13].

Conclusions. An analysis of total greenhouse gas emissions at various life cycle stages of three wells was carried out. Differences in emissions are attributed to the increased average drilling speed achieved by modernized rigs and the varying duration of the drilling cycles. The company's emissions do not pose a threat to personnel health, even with a concentration increase of up to 4.841 times, which corresponds to 1694 ppm in open air. The emissions produced during drilling are short-term and limited to the duration of the drilling phase.

Prospects for the use of research results. The findings of the scientific research presented in this article may be applied to address issues related to greenhouse gas emissions during the drilling and abandonment of oil and gas wells. Future studies will focus on a comprehensive assessment of pollutant emissions at oil and gas industry facilities.

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