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Environmental consequences of gas fields development in the Transcarpathia on the example of Solotvyno Field

Lina Uhraк*
Assistant
Ivano-Frankivsk National Technical University of Oil and Gas
76019, 15 Karpatska Str., Ivano-Frankivsk, Ukraine
https://orcid.org/0000-0002-2040-3937

Natalia Goptarova
PhD in Geological Sciences, Associate Professor
Ivano-Frankivsk National Technical University of Oil and Gas
76019, 15 Karpatska Str., Ivano-Frankivsk, Ukraine
https://orcid.org/0000-0001-5584-4006

Oleksandra Paliichuk
PhD in Technical Sciences, Associate Professor
Ivano-Frankivsk National Technical University of Oil and Gas
76019, 15 Karpatska Str., Ivano-Frankivsk, Ukraine
https://orcid.org/0000-0002-0493-7816

Khrystyna Halipchak
Assistant
Ivano-Frankivsk National Technical University of Oil and Gas
76019, 15 Karpatska Str., Ivano-Frankivsk, Ukraine
https://orcid.org/0000-0002-9463-1043

Taras Uhrak
Postgraduate Student
Ivano-Frankivsk National Technical University of Oil and Gas
76019, 15 Karpatska Str., Ivano-Frankivsk, Ukraine
https://orcid.org/0009-0000-5222-694X

Abstract. The Transcarpathian Trough has a sufficient number of recorded oil and gas manifestations that make it one of the most promising oil and gas bearing areas. The field development is carried out with a large number of wells and is certainly accompanied by a negative impact on the environment. The purpose of the study was to analyse the impact of the Solotvyno Field development on the environment and natural resources of the region, taking into account the geological conditions of the territory and to identify the environmental consequences of the field development. In a narrower sense, this includes the lithological characteristics of all gas-bearing horizons, physical and chemical characteristics of free gas determined by laboratory and field methods, and hydrogeological characteristics. Analytical methods (analysis of literature sources and archive materials) and experimental methods were used in the study. The article deals with the problems of environmental impact of the Solotvyno Gas Field development process. Although the operation of wells is a short-term process and the area of influence is the territory of the drilling site (except for intensive gas flow with open gushing, which is excluded under the accepted drilling technology), the impact of the projected activity on the

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*Corresponding author

environment is significant. The paper identified the main components of the environment that are most affected by the projected activities. Sources and types of pollutants for each environmental component are identified. Environmental protection measures were proposed and conclusions were drawn regarding the actual impact on the environment of direct production activities. A risk assessment was carried out. The results of the research can be used in practice by oil and gas industry employees, since the impact of the projected activity on the environment is expected

Keywords: oil and gas manifestations; well; environment; risk level; pollutants; laboratory methods; field methods

Introduction

Long-term oil and gas production results in contamination of almost all environmental components by reservoir fluids – oil, gas, and highly mineralised reservoir water. The main possible negative impacts are emissions of pollutants into the air, contamination of groundwater by uncontrolled gas and liquid flows caused by their emissions or spills, leakage of drilling fluids and uncontrolled discharge of waste water. Analysing global trends in science, researchers can focus on the prevalence of studies of environmental impacts of shale gas extraction, as the prospects of shale gas extraction have already been proven by the development of oil shale deposits in Brazil, China and Estonia. As shale gas is a promising resource, the US, China and a number of other countries continue to develop the shale gas industry despite the negative environmental impacts. The COVID-19 pandemic and the current geopolitical situation have forced scientists to suspend most of the research on the environmental assessment of conventional gas fields.

Unlike conventional gas, shale gas is extracted using horizontal drilling and hydraulic fracturing technology. Among the environmentally negative consequences of this method of extraction, N. Zhuravska *et al*. (2023) highlighted the use of a large amount of water resources, which may result in a shortage of drinking water over a period of time. Scientists also pointed out an even greater threat to the environment and public health, namely the exacerbation of chronic diseases and an increase in the number of cancers due to the frequent use of chemical mixtures in hydraulic fracturing. L.I. Pymonenko *et al*. (2023), in their study of the geological factors of shale formations in Ukraine, also noted the increased polluting impact on the environment and the harmful effects on the human body of gas emissions and wastewater from shale processing facilities. However, according to the Energy Security Strategy of Ukraine (Resolution of the Cabinet of Ministers of Ukraine No. 907-r, 2021), the oil and gas sector has seen a significant decline in natural gas production. According to this strategy, one of the goals is to increase natural gas and oil production in an economically justified manner, as well as to reduce Ukraine's dependence on external suppliers. Therefore, Ukraine needs to increase domestic gas production more than ever.

The Transcarpathian Trough has a sufficient number of recorded oil and gas manifestations that make it one of the most promising oil and gas bearing areas. Therefore, one of these fields was chosen to assess the environmental impact of gas field development. In this case, it is a field discovered in 1982. Five wells have been drilled within the field (1-Slt (Slt – Solotvyno), 2-Slt, 6-Slt, 11-Slt and 68-3-Slt). The field was put into pilot development in 1988. As of the reporting date, two wells are in production (2-Slt, 11-Slt). As of 1 January 2021, gas production totalled 24 million m^3. The State Balance Sheet showed initial gas reserves of 371 million m^3 (State Balance of Mineral Reserves, 2021). Scientists are actively researching the topic of assessing the environmental impact of the salt mining industry in Solotvyno. For example, S.B. Shekhunova *et al*. (2019) and S.M. Stadnichenko *et al*. (2023) conducted a comprehensive environmental monitoring in the Solotvyno area. Scientists note the difficult geological and environmental situation in Solotvyno and identify a number of potentially dangerous natural and anthropogenic processes such as karst, sufosis, floods, flooding, erosion and landslides. It is worth noting that many of these authors' works are devoted to Solotvyno Salt Dome structures. It is impossible to study the environmental impacts of the Solotvyno Gas Field in isolation from the geo-environmental situation during the development of the Solotvyno Salt Dome.

The environment of the designated site (field) is a part of the natural and industrial complex formed under the influence of agricultural production and industrial facilities of Solotvyno. Therefore, there is a need to assess the environmental impact of the projected activity. Accordingly, the purpose of the study was to assess the environmental impact of the field operation and forecast the development of adverse effects. The main tasks to be solved to achieve the goal were to study the geological structure of the study area, investigate the lithological characteristics of gas-bearing layers and the physical and chemical properties of gas.

Materials and Methods

The Solotvyno Gas Field is administratively located in Tiachiv District of Transcarpathian Region, on the north-eastern outskirts of the Solotvyno Village (Fig. 1). Literary sources and archive materials were analysed, in particular, the Solotvyno Gas Field development project by Lviv Integrated Research Department of UkrNDIGas, which was aimed at designing a rational development based on the refined geological model of the field based on the results of the Novoselytska formation development and drilling of the 11-Slt production well (FAME, 2002). Recommendations for further development, control and monitoring of development, subsoil and environmental protection are provided. Lithological characteristics of all gas-bearing horizons and physical and chemical characteristics of free gas were determined by laboratory and field methods and hydrogeological characteristics. The field survey methods were carried out as a reconnaissance survey of the territory and comprised an inspection of the projected wells site, including a description of outcrops, watercourses and groundwater outlets, signs of engineering and geological processes, and a visual inspection of the existing buildings. Reconnaissance surveys are carried out along pre-planned routes (the survey may be combined with route observations). These surveys were carried out to: assess the quality, clarify and supplement the collected materials on the construction area (site); comparative assessment of engineering and geological conditions at certain options of the construction site and communication routes; preliminary assessment of physical and geological processes and phenomena, as well as possible changes in the geological environment under the influence of construction and operation of the projected facilities; assessment of the complexity of geological conditions, terrain passability and other factors affecting further research, as well as collecting the data required to draw up the work programme.

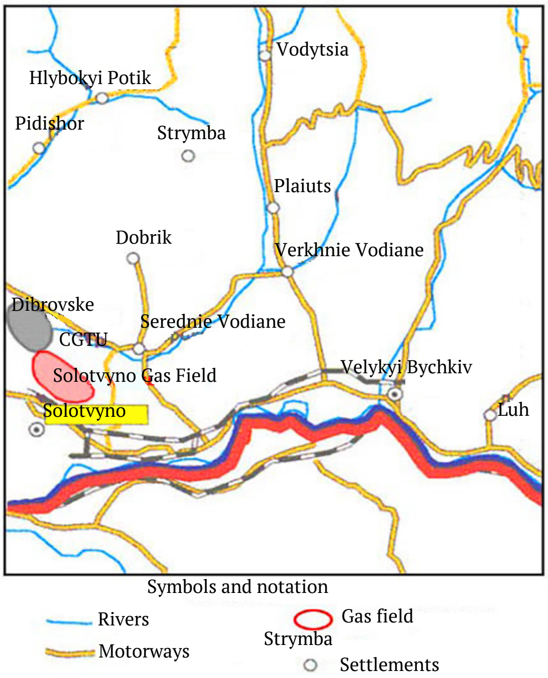

Figure 1. Overview map of the study area

Note: CGTU – complex gas treatment unit
Source: created by the authors

Laboratory research methods were carried out in accordance with GOST 17.1.3.10-83 (1983), GOST 17.1.3.12-86 (1986), DSTU B V.2.1-8-2001 (2001), DBN A.2.2-1-2003 (2003), DSTU ISO 5667-2:2003 (2003), DSTU GOST 27384:2005 (2005), DSTU ISO 15175:2005 (2005), DSTU ISO 10381-5:2009 (2009), DBN V.2.4-3:2010 (2010) and DSTU GOST 17.4.4.02:2019 (2019). They were carried out to determine the classification, physical, strength, deformation and other indicators of soil properties, as well as the chemical properties of groundwater, which are necessary for making design decisions and performing technical calculations. The composition and scope of laboratory work was determined based on both the intended purpose of the survey and the presence of soils with special properties. It was necessary to ensure that at least 10 separate values of physical characteristics and at least six values of strength and deformation characteristics of soil properties are obtained for each selected engineering and geological element. The physical and lithological features of the rocks were determined to determine the lithological and petrographic composition and physical properties. A total of 3 gas samples were taken from gas facilities in the field in wells 1-Slt, 2-Slt. Gas samples were taken from the gas reservoirs at the wellhead and with downhole samplers during the exploration of gas-bearing and water-bearing horizons. The water samples were studied in the sediments of the Hrushevska Suite of the Paleogene, Tereshulska Suite of the Carpathian and Novoselytska Suite of the Badenian in wells 1-Slt, 2-Slt, 6-Slt, 7-Slt, 10-Slt. A total of 28 water samples were analysed for the following parameters: density, mineralisation, sodium, potassium, calcium, magnesium, ammonium, chlorine, sulphate, bicarbonate, carbonates, bromine, iodine, boron, nitrogen oxide, boron oxide, silicon dioxide.

Results and Discussion

According to the goal, it is first necessary to study the geological structure of the study area, investigate the lithological characteristics of gas-bearing layers and the physical and chemical properties of gas. Geomorphologically, the field is located in the southeastern part of the Solotvyno Depression, in the upper reaches of the Tysa River. The depression is bounded to the north by the Carpathian and to the southwest by the Vygorlat-Gutyn Ranges. The terrain is hilly with a large number of rivers and streams. Cuestas are developed in the area, the formation of which is due to monoclinic layers of conglomerates and sandstones, which are not subject to denudation processes. Absolute elevations range from 250-370 m, with the eastern part of the area being the most elevated (Kravchuk, 2021). The main waterways in the area are the Tysa River and its right tributary, the Apshytsia River. In addition to the Apshytsia River, which flows in the northern part of the area, many small streams flow into the Tysa River, which mostly dry up in summer. The surface waters are suitable for water supply, fishing, hydropower, and timber processing. The local population uses well and artesian water for food needs. The seismicity of the area is up to 6 points. The construction and climatic zone are normal according to the state construction standards (DBN A.2.2-1-2003, 2003). The geological structure of the field consists of Cretaceous and Paleogene-Neogene deposits (Fig. 2).

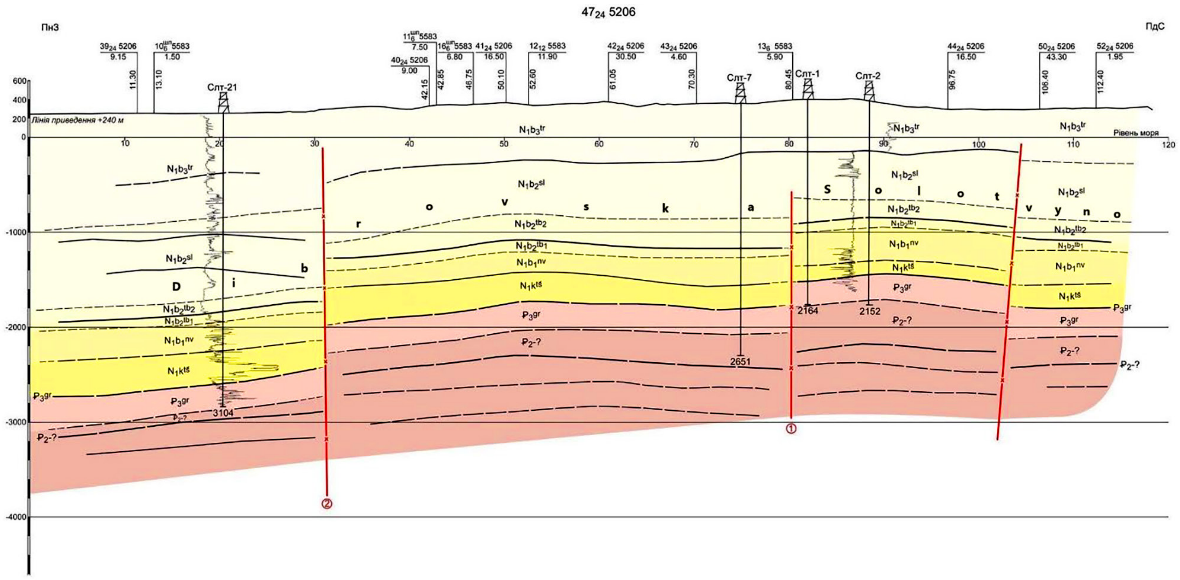

Figure 2. Seismic and geological profile

Source: created by the authors

The Cretaceous deposits within the field and the Solotvyno area as a whole have not been uncovered by drilled wells. They have been studied in neighbouring areas: Tiachevo, Tereblia, Sokirnytsia and others. They are represented by the Krychivska Suite of the Upper Cretaceous, which is composed of interbedded mudstones, sandstones, siltstones, marls and, rarely, limestones. The deposits of the Paleogene system were tapped by wells 1-Slt, 2-Slt, 3-Slt, 4-Slt, 5-Slt, 7-Slt, 8-Slt, 10-Slt. These sediments are dislocated (dip angles reach 50-90°) and are represented by a dark grey thickness consisting mainly of siltstones with marls, sandstones and mudstones interbedded. According to P. Lozyniak & M. Petrashkevich (2007) and P. Lozynjak (2013), this formation was identified in 1989 as the Hrushevska Suite. Numerous remains of fish scales, fins, and skeletons, single fishes (*Cardium ex. gr. praechinaum hieb*), and pyritised *Spiratella* are found in the sediments of the Hrushevska Suite. Based on these findings, researchers from the Ukrainian State Geological Research Institute (UkrSGRI) dated the formation to the Oligocene – Lower Miocene.

The siltstones and sandstones are grey and dark grey, dense, carbonate, mica, fine- and medium-grained. The effective thickness of sandstones in well 1-Slt varies from 3 to 8 m according to geological surveys of the wells. Marls are dark grey, black, dense, strong, slightly mica-bearing, calcareous, obliquely and parallel layered with charred organic remains. The mudstones are dark grey, mica, calcareous, silty. The exposed thickness of the Hrushevska Formation sediments within the Solotvyno area varies from 65-1,453 m, and within the field from 266-342 m. Two gas deposits of uncertain commercial significance are associated with the Hrushevska Formation. The Neogene stratigraphic section is presented according to the scheme proposed by UkrSGRI in 1968 (Kruglov & Smirnov, 1968) and revised in 1986 (Burov *et al.*, 1986).

The Neogene system is represented by three layers: the Egenburgian, Carpathian and Badenian. The Egenburgian layer is represented by the Burkalian Suite, which includes sandstones and grey, multi-grained, massive, sandy, clay, siltstones. In the sections of Solotvyno wells, the Burkalian Suite is not faunally distinguished, and it is probably absent in the area. Due to stratigraphic unconformity, the Egenburg overlies the Carpathian layer, which is represented by the Tereshulian Suite at the Solotvyno Field. In the lower part of the formation, colourful conglomerates are developed, composed of poorly sorted pebbles and boulders – grey and white Jurassic and Cretaceous limestones, sandstones and siltstones. Upwards in the section, conglomerates are replaced by grey and greenish-grey sandstones with interbedded quartz siltstones and small amounts of mudstones. The thickness of the formation ranges from 168-322 m. The Carpathian is stratigraphically unconformably overlain by the Badenian layer, which is represented at the field by the Novoselytska, Tereblyanska, Solotvynska and Teresvynska Suites.

The Novoselytska Suite has been penetrated by all wells. The lower part is composed of volcanic formations – light greenish-grey tuffs, psamite, siltstone and pelitomorphic, massive, windblown and ash; dark greenish-grey tuffs are aleupeuropeanite to psamite, layered, 50% composed of terrigenous pyroclastic fragments. The capacitive characteristic of the volcanic sediments is good, with porosity reaching 11%. The upper part is represented by terrigenous formations – mudstones, siltstones, sandstones, marls with tuff and tuffite interlayers. The thickness of the formation within the Solotvyno area is 79-384 m, and within the field 79-310 m. Together with tuffs and tuffites, sandy aleurite deposits create good conditions for hydrocarbon accumulation.

The Tereblyanska Suite is believed to be based on the Novoselytsia sediments. According to lithological features, the Tereblya Suite is divided into two sub-suites. The Lower Tereblyanska subsuite is represented by a terrigenous stratum of mica, siltstone, sandstone, calcareous sandstone with interlayers of light grey gypsum and anhydrite, tuff-altered siltstone, tuff, and tuff-sandstone. The thickness is 30-151 m. The Upper Tereblyanska subsuite is a rock salt with thin layers and separate clay, siltstone, and sandstone beds ranging in thickness from several cm to several m. The thickness of the subsurface within the deposit varies from 55-295 m. The presence of rock salt in the subsurface makes it a reliable cover (Morozov & Barylo, 2023).

Without any visible stratigraphic discrepancy, the Tereblyanska Suite passes into the Solotvyno Suite, which has been penetrated by all wells at the field. The Solotvyno Suite is composed of grey and dark grey mudstone-like siltstone and siltstone clays interbedded with sandstones and siltstones. There are two tuffs, 20-80 m thick, which are exposed in the western direction. The nature of the terrigenous sediments changes in the same direction and becomes more clayey. The thickness of the formation at the field is 574-950 m. The Teresvynska Suite was discovered in wells 1-6-Slt, 7-Slt, 8-Slt, 10-Slt, 11-Slt, 21-23-Slt. Sediments are represented by alternating mudstones, sandstones and siltstones. The thickness of the formation within the Solotvyno area is 40-752 m, and within the field 254-752 m. Quaternary sediments are widespread at the Solotvyno Field. These are clays, loams, and shale. The thickness is 0-30 m.

The Solotvyno Field consists of a single deposit associated with the Novoselytska Suite of the Carpathian, discovered by wells at depths of 1,340-1,530 m. The field is classified as a gas field with produced water. A total of 5 wells have been drilled within the field. Two wells (2-Slt, 11-Slt) are in operation. During the study of the Solotvyno Field wells, gas samples were taken to obtain data on their physical and chemical composition. The chemical composition and physical properties of gas are shown in Table 1 and Table 2.

Three samples were taken in the Novoselytska Suite sediments. The gas is hydrocarbon, marginal, with the sum of heavy hydrocarbons equal to 0.08-0.20%. The methane content is 53.86-68.46%, ethane 1.21-2.65%. The gas contains a fairly significant content of nitrogen (14.15-23.06%) and carbon dioxide (4.02-24.68%), which is in line with the findings of A.A. Loktev (2019). Two samples (1-Slt, 2-Slt) contained insignificant levels of helium. The absolute density of the gas is 0.8495-0.8801 kg/m^3, and the relative density ranges from 0.7049-0.7303. The lower calorific value of the gas is on average 6,362 kcal/m^3 or 26,638 kJ. During the operation, 9 samples were taken from the Novoselytska Suite sediments in the wells. The results of determining the physical and chemical composition of gas are shown in Table 2. A rather sharp change in the composition of the gas sampled during operation in 1-Slt can be explained by both the accuracy of the analyses and the possible inflow of gas portions from previously idle intervals. Helium was not determined in the samples.

Gas from Paleogene sediments was collected and studied in a single sample in 1-Slt (interval 1,842-1,910 m). The gas is dry, methane (91.08%). The ethane content is quite significant (4.52%). Heavy hydrocarbons (pentane + higher) are absent. The content of nitrogen and carbon dioxide is insignificant. It is 1.09% and 0.75%, respectively. Helium was not determined. The lowest calorific value is 8,202 kcal/m^3 or 34,342 kJ. The absolute density of the gas is 0.7018 kg/m^3, and the relative density is 0.5824. Solotvyno gas is suitable as a raw material for the petrochemical industry and is high in calories.

The water-bearing objects were studied in the sediments of the Hrushevska Suite of the Paleogene, Tereshulska Suite of the Carpathian and Novoselytska Suite of the Badenian in wells 1-Slt, 2-Slt, 6-Slt, 7-Slt, 10-Slt. A total of 28 water samples were examined. When testing the deposits of the Hrushevska Suite of the Paleogene in wells 7-Slt, 10-Slt, water inflows of 5.52-415.2 m^3/day were obtained at a dynamic level of 1,879 m. The reservoir water is predominantly of chlorine-calcium, and sometimes chlorine-magnesium and sodium sulphate type with a density of 1,024-1,103 kg/m^3 and salinity of 33.21-120.73 g/l, metamorphosed (rNa/rCl) – 0.93-5.6, chlorine-bromine ratio – 3,179-3,812, calcium prevails over magnesium (rCa/rMg) – 0.96-39.6, sulphation ratio (rSO4 × 100/rCl) is 1.54-7.15. The content of microelements is as follows: iodine – 1.7-3.22 mg/l, bromine – 3.22-13.3 mg/l. The values of the metamorphisation coefficient indicate hydrogeological closure of the subsoil. The waters of the Paleogene sediments belong to the zone of difficult exchange.

Sediments of the Tereshulian Suite, which are represented by tuffs and conglomerates, were studied in wells 2-Slt, 7-Slt, and 10-Slt. During their testing, water inflows of 0.6-12.09 m^3/day were obtained at dynamic levels of 1,420 and 752.5 m, respectively. Formation waters are mainly of chlorine-calcium, sometimes sodium sulphate type with salinity of 10-174 g/l, metamorphosed (rNa/rCl) – 0.74-1.02, calcium prevails over magnesium (rCa/rMg) – 1.7-30.6, sulphation coefficient (rSO4 × 100/rCl) is 0.23-11.7. Micro components include bromine and iodine. Their content is respectively: bromine – 4.4-25.4 mg/l; iodine 0.4-6.4 mg/l.

Table 1. Characteristics of free gas

Reservoir deposit	Well No.	Test interval, m / absolute mark	Reservoir pressure / critical pressure MPa	Reservoir temperature / critical temperature K	The reduced pressure	The coefficient of supercompressibility fraction of a unit	Corrections, fraction of a unit		Density kg/m^3 absolute / relative	Mole content, g/cm^3											
							for deviations from the Boyle-Mariotte law	for temperature		methane	ethane	propane	iso-butane	H-butane	pentane + higher	helium	argon	carbon dioxide	nitrogen	paraffin wax	other related useful components
N_1nv	1-Slt	1,530-1,440 / -1,134.1-1,044.2	14.45 / 4.81	340 / 202	3.0	0.877	1.14	0.86	0.8801 / 0.7303	53.86	2.65	1.34	0.32	0.41	0.20	0.01	–	18.14	23.06	–	–
N_1nv	2-Slt	1,530-1,454 / -1,117.4-1,042.4	14.69 / 5.0	343 / 207.6	2.94	0.880	1.14	0.85	0.8495 / 0.7049	61.51	1.21	0.62	0.25	0.23	0.08	0.001	–	22.04	14.15	–	–
		1,530-1,302 / -1,117.4-891.3	14.32 / 5.07	341 / 212	2.82	0.845	1.18	0.86	0.8593 / 0.7137	57.04	1.91	0.83	0.23	0.26	0.19	–	–	24.68	14.88	–	–
average for the deposit			14.49 / 4.81	341 / 200	3.01	0.876	1.14	0.86		57.47	1.93	0.93	0.27	0.30	0.16			17.36	21.62		
₽	1-Slt	1,910-1,842 / -1,514-1,446.1	14.62 / 14.62	350 / 201	3.2	0.861	1.16	0.84	0.7018 / 0.5824	91.08	4.52	1.87	0.22	0.47	–	–	–	0.75	1.09	–	–

Note: N_1nv – Novoselytska Suite of Miocene; ₽ – Palaeogene; 2-Slt – no helium content at depth interval 1,530-1,302
Source: created by the authors

Table 2. Characteristics of free gas in the development process

Reservoir deposit	Well No.	Test interval, m absolute mark	Density kg/m^3 absolute relative	Mole content, g/cm^3											
				methane	ethane	propane	butane	pentane + higher	hydrogen sulphide	helium	argon	carbon dioxide	nitrogen	paraffin wax	other related useful components
N_1nv	1-Slt	1,530-1,440 -1,134.1-1,044.2	0.9917 0.8230	65.48	1.20	0.44	0.23	0.13	–	was not determined	–	21.0	11.52	–	–
		–"–	0.9952 0.8252	62.21	1.19	0.45	0.53	0.10	–	–"–	–	21.4	11.42	–	–
		–"–	0.8673 0.7198	79.04	1.49	0.50	0.22	0.04	–	–"–	–	13.44	4.37	–	–
		–"–	0.7747 0.6429	85.95	1.56	0.54	0.29	0.13	–	–"–	–	3.56	7.97	–	–
		–"–	0.9125 0.7438	73.65	1.92	0.56	1.43	0.13	–	–"–	–	12.82	15.27	–	–
		–"–	0.9505 0.7808	73.33	1.512	0.457	0.129	0.393	–	–"–	–	15.27	9.07	–	–
N_1nv	2- Slt	1,467-1,445 -1,055.2-1,033.4	–. 0.721	77.866	1.976	0.427	0.267	–	–	–	–	7.896	11.896		
		–"–	–. 0.711	77.866	1.976	0.427	0.267	–	–	–	–	7.896	11.896		
		–"–	0.917 0.761	73.977	1.433	0.465	0.214	0.217	–	–"–	–	15.863	7.850	–	–
		–"–	0.876 0.726	76.567	1.382	0.371	0.149	0.146	–	–"–	–	11.967	9.418	–	–
		–"–	0.974 0.809	67.224	1.435	0.469	0.235	0.220	–	–"–	–	19.250	11.617	–	–
		–"–	–. 0.786	73.587	1.555	0.474	0.236	–	–	–	–	12.153	11.747		
N_1nv	11-Slt	1,467-1,366 -1,075.2-974.2	–. 0.711	68.735	1.578	0.479	0.107	0.370	–	–	–	18.018	10.685		
N_1nv	68-3-Slt		–. 0.711	68.46	1.47	0.33	0.09	–	–	–	–	4.02	25.63		

Note: N_1nv – Novoselytska Suite of Miocene
Source: created by the authors

The reservoir waters of the Novoselytske deposits have been studied the most. During their testing in wells 1-Slt, 2-Slt, 6-Slt, 7-Slt, 10-Slt, water inflows of 7.2-72 m^3/day were obtained at dynamic levels of 165-860.5 m. Formation waters are mainly of chlorine-calcium type, and sometimes of sodium bicarbonate, sodium sulfate and chlorine-magnesium type with mineralisation of 18.6-180.3 g/l and density of 1,010-1,122 kg/m^3, the metamorphosis ratio (rNa/rCl) is 0.6-1.13, calcium prevails over magnesium (rCa/rMg) – 0.47-54.99, chlorine-bromine ratio ranges from 648.8 to 62,941.5, sulphation ratio (rSO4 × 100/rCl) – 0.04-7.79. Content of micro components: Br – 3.3-120 mg/l; iodine – 0.4-5.08 mg/l. The high metamorphisation and mineralisation of the Novoselytska Suite waters indicate that the field is located in a zone of difficult exchange.

The water enrichment of the host sediments depends mainly on their reservoir properties. Water salinity increases with depth. No other patterns of change can be found in the section or in the blocks. The reservoirs in the Novoselytsia Formation are tuffs, tuffites and sandstones. Clays and salts of the Tereblyanska Suite are the regional reservoir cover for the Novoselytsia Suite. In the saline Upper Tereblyanska Subsuite and Teresvynska Suite, according to geological wells, the horizons are associated with sandstone and siltstone layers. These deposits have not been tested at the field. The field itself is divided into separate blocks by a system of transverse and longitudinal faults, and the reservoir waters of these blocks differ in chemical composition, although it is not possible to identify the patterns of this difference.

Technogenic load on the landscape is created by: residential development of Solotvyno settlement; road network; power and communication lines; gas transmission network; two production wells with a depth of 1,580-1,252 m. The Solotvyno Field, as an object of technogenic environmental impact, consists of: two production wells (2-Slt, 11-Slt) with a depth of 1,580-2,152 m designed to extract gas from the subsoil; plumes with a diameter of 114×10 mm and 114×6 mm and a length of 680 m and 250 m. At the Solotvyno Field, gas is collected, treated and supplied according to the following scheme (Fig. 3).

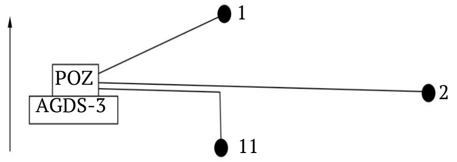

Figure 3. Solotvyno Field gas collection scheme

Note: AGDS – automatic gas distribution station

Source: created by the authors based on FAME (2002)

Gas from production wells 2-Slt and 11-Slt is supplied to the Solotvyno Gas Pre-Treatment Unit via individual pipelines with diameters of 114×10 and 114×6 mm and lengths of 680 and 250 m, respectively (Fig. 4).

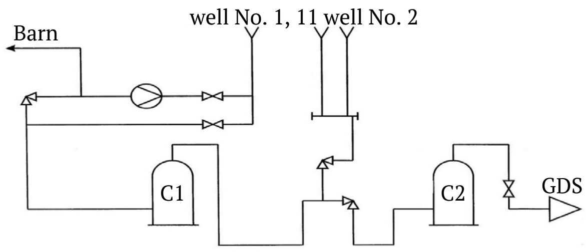

Figure 4. Solotvyno Gas Pre-Treatment Unit

Source: created by the authors based on FAME (2002)

As a processing company, the production complex consumes the following natural resources: natural gas (dry or water-gas mixture) from deep deposits; electricity for lighting and electrical equipment at the GTU; water, which is consumed only to fill heating radiators at the GTU and maintain a constant fire-fighting reserve of 150 m^3. Water is supplied by tanker trucks. The gas field products are gas purified in accordance with the requirements of the state standard, and the wastes are associated formation water (AFW), regeneration gas and minor emissions of gas and combustion products. In this regard, gas production at Solotvyno Field worsens the environment due to the following.

Gas production: each production well is a technological source of permanent damage to the subsoil with irreversible consequences – depleted natural gas deposits cannot be restored. Gas emissions from venting through the spark plugs of the GTU gearboxes and through the flare nozzles of wells during their repair: the locations of these emissions are technological sources of intermittent gas pollution with eliminable impacts – the air is self-purified between individual emissions. Emissions of gas combustion products through the chimneys of the boiler room, the gas metering station boiler, the fire pump boiler, the gas heater and the emergency motor generator are permanent sources of continuous air pollution (Kryvenko, 2020). Emergency gas emissions: temporary sources of pollution or, in the case of spontaneous combustion, environmental damage. After the accident is eliminated, the air is self-purified and the damaged areas are reclaimed.

The negative impact of Solotvyno gas production complex on the environment during operation is limited to the subsoil and atmosphere. There are no sources of direct impact on the hydrosphere and biosphere in the production process. The impact on the social sphere is positive (SOU 73.1-41-11.00.01:2005, 2005). The impact of gas extraction on the geological environment in the subsoil extends beyond the well casing only to the deposits. Due to gas extraction, the reservoir pressure in the deposits will decrease from the initial 4.8 MPa to the residual 0.3-0.1 MPa. The volume of the environment with a damaged gas-dynamic regime is currently ~20 million m^3. The atmosphere is polluted by permanent (chimneys of the operator's room boiler room, gas metering boiler, fire pump boiler, gas heater), emergency (motor generator chimney), and periodic ("spark plugs" at the GTU outlets) sources located on the GTU territory. Characteristics of the main harmful substances emitted into the atmosphere by gas and industrial facilities are shown in Table 3. The values of the estimated emissions of harmful substances from the field development facilities can be considered as maximum permissible concentrations (MPC).

Table 3. Characteristics of the main harmful substances emitted into the atmosphere

Name of the harmful substance	Maximum single MPC, mg/m^3		Hazard class	Aggregate state
	MPC of harmful substances in the air of settlements	MPC of harmful substances in the air of work areas		
Nitrogen oxide Nitrogen dioxide Carbon monoxide	0.4 0.085 5.0	5.0 5.0 20	3 3 3	gas gas gas
Saturated hydrocarbons C_1-C_3 (methane, ethane, propane)	50 (approximate safe exposure level for methane)	300	4	gas
Saturated hydrocarbons C_4-C_6 (butane, pentane, hexane)	200 100 60	300 300 300	4 4 4	gas vapours vapours
Soot	0.15	4.0	3	suspended solids

Source: created by the authors

When performing air pollution calculations for the most typical air pollutant gradients, the limit of surface concentrations from industrial emissions of 0.4 MPC is assumed. The results of air pollution calculations for some fields operating in the operational mode, performed by UkrNDGI Open Joint Stock Company, show that the concentration of harmful substances at the border of the sanitary protection zone of the facilities does not exceed 0.26 MPC. Based on practical measurements at Ukrnafta's wells, the maximum amount of emissions per well during the test is as follows: carbon monoxide – 4 kg; hydrocarbons – 5 kg; nitrogen dioxide – 1 kg; soot – 2 kg; sulphur dioxide – 1 kg. Based on the above data and actual measurements at Ukrnafta's drilling sites and group collection points, the following conclusions can be drawn: no local air pollution occurs; dispersion of harmful substances occurs entirely in the residential area. The hazard category of the enterprise according to the environmental protection classification (OND-84) is not lower than 2.

As noted by the scientists of the Ivano-Frankivsk National Technical University of Oil and Gas L. Poberezhna *et al*. (2022), a key group of indicators affecting the environmental safety of man-made facilities, including oil and gas wells, is the quality of technical means. The construction of oil and gas wells and their subsequent operation are accompanied by a variety of equipment that is essential for trouble-free operation. Additional risks associated with the failure of oil and gas equipment are caused by its long service life. Product quality is characterised by both quantitative and qualitative indicators that affect the environmental impact of oil and gas well construction and include design characteristics, reliability, efficiency of use of raw materials, fuel and energy, manufacturability, transportation, environmental aspects, and safety. These indicators can directly or indirectly affect the risks of hazardous situations, highlighting the importance of their monitoring and management to ensure environmental safety in the oil and gas industry. Effective management of technical equipment quality indicators is critical to reducing the risks associated with the environmental safety of oil and gas wells, which in turn contributes to environmental protection and accident prevention.

Scientists O. Mishchenko & A. Pelts (2019) analysed the prospects for the further functioning of the Lokachi Gas Field. The article noted that despite the negative impact on the environment, it is advisable to further develop this field. The proposed measures for the further functioning of the gas production system of the Lokachi District reduce the harmful impact on the environment. Given the similarity of the high level of complexity of the environmental situation at the Lokachi Gas Field and the Solotvyno Gas Field, the authors can adopt the experience of their colleagues and supplement it with proposals based on the results obtained.

Analytical studies of oil and gas well construction processes, including their environmental aspects, were conducted by A. Pavlychenko *et al.* (2023) according to a clearly defined methodology. This methodology includes the formulation of the problem, development of mathematical and physical models, selection of a solution method, computational experiment, laboratory research, and analysis of the results. It is important to note that land plots for drilling are provided for temporary use and must be returned in a condition suitable for agriculture. From an environmental point of view, drilling affects the geological environment, disrupting its normal state. To avoid negative consequences, it is recommended to use rational well designs that ensure consistent overlap of drilled intervals.

M.A. Caretta *et al*. (2024) mediated the risks with a number of benefits that further extraction is expected to bring. In addition to the general negative impact on the environment, this article examined in detail how energy infrastructure projects aimed at extracting minerals negatively affect local residents, their identity and sense of belonging to a particular area. In particular, the article focused on the protest of the indigenous population of Virginia against the extraction of minerals on their territory, which threatens their sense of place and identity. T. Yatsyshyn (2021) proposed the development of a system that would help reduce the development of environmentally hazardous processes at different stages of the life cycle of oil and gas production facilities. However, this development, in the opinion of the authors of the current study, is more appropriate to apply at the stage of well drilling. At this stage of the study, the goal is to address the issue of reducing the negative environmental impact of the operation of existing wells.

One of the methods of environmental monitoring proposed by V.Ye. Filipovych *et al*. (2020) is remote sensing of the Earth in the area of hydrocarbon production. The scientists have proven the effectiveness of this method on the example of Boryslav and proposed a scheme for remote environmental monitoring at oil and gas facilities with the study of hydrocarbon pollution of the geological environment. They noted that the results of this method should be used to study subsidence, flooding of groundwater and the production area, migration of pollutants along tectonically weakened zones and zones of increased rock fracturing. Since the list of these hazardous processes is also relevant for the area studied in this paper, the remote monitoring method can be recommended for use in the Solotvyno Gas Field.

The article by G. Gorvanko *et al*. (2021) argued that due to the increasing anthropogenic load and negative impact on natural processes in the Transcarpathian Region, there is an urgent need to develop comprehensive environmental protection measures to preserve the river system of the region. The natural potential of water resources and the economic potential of the Transcarpathian Region allow to identify key areas for their use and protection. Rivers, temporary watercourses and reservoirs for water purification and water supply and irrigation should be included. Particular attention should be paid to protecting the river system from deluges and floods that occur periodically in the region. Based on the analysis and after reviewing the research results of the above scientists and comparing them with current results, the prospects of production at Solotvyno Gas Field should be discussed and further possible options for reducing the negative impact on the environment can be suggested. The Solotvyno Field is located in the valley of the Tysa River and its tributaries. Therefore, surface waters require protection from the products of gas production processes. In addition, surface waters are connected to the waters of the upper part of the geological section, which are used as drinking water. Potential sources of surface and drinking water contamination include: working fluids used in underground and workover operations and methods of stimulating gas flow to wells; chemicals and reagents used in well workovers and methods of stimulating gas flow to wells; contaminated rainwaters.

To prevent contamination of surface, ground and drinking water, it is necessary to use a closed system of working fluid circulation during well workovers with the collection of sludge and well flushing products and their removal for neutralisation and destruction; use a closed system of bottomhole treatment with the collection of treatment products and their removal for neutralisation and purification; store chemicals for treating well bottomhole zones and combating complications during their operation in sealed containers; maintain cleanliness in the areas near the wellhead and at gas treatment facilities, and timely clean up and decontaminate contaminated areas. A special factor of possible environmental impact is the mixture of condensate moisture and AFW that is carried out of the well. According to the experience of development of Baden gas deposits in the Outer Zone (Hrynivske, Kadobnianske, Bohorodchanske), the amount of AFW is not significant and can be up to 5-10 m^3 per year. It is recommended to dispose of the Solotvyno Field's AFW in the contour part of the Vygodske Deposit of the Bytkiv-Babchenske Gas Condensate Field (absorption wells 24-Bt (Bt – Bytkivska), 478-Bt). Delivery of AFW for injection into the absorption wells (24-Bt, 278-Bt) is planned by road.

Accidents in the gas industry are associated with depressurisation of the technological scheme, and therefore cannot influence the intensity and degree of impact of all the identified sources. In the event of an accident, a new source of gas pollution arises – the place of depressurisation. The emergency gas release lasts from the moment the accident occurs until the gas flow is shut off. After the accident is eliminated, the air above the accident site is self-purified. The Solotvyno Field is planned to be developed for pilot and commercial production of natural gas. There is 1 horizon under development, which is operated by two wells. To prevent soil contamination, the following measures are envisaged: selection of sites and routes for structures and communications only on alienated lands; rational placement of equipment on the territory; covering the equipment sites with resistant materials; equipment of special places for dosing reagents, where these reagents do not enter the soil; hydraulic pressure testing of pipelines before their commissioning; corrosion protection of pipelines; use of a sealed system for collection, preparation, accounting and treatment of waste water. To protect groundwater, the following measures are proposed to prevent groundwater contamination: sealing of equipment; insulation of underground pipelines with bitumen-rubber insulation; installation of curbs and improvement of pavement at sites; collection of surface wastewater from sites bounded by curbs (methanol tanks, gas dehydration units); designation and observance of sanitary protection zones; control of groundwater quality near underground tanks.

The comprehensive environmental impact assessment of the proposed activity and the assessment of the impact on each environmental component showed the following. Taking into account that well operation is a short-term process, the area of influence of which is the territory of the drilling site (except for intensive gas flow with open fountain, which is excluded under the adopted drilling technology), the impact of the planned activity on the environment will be minimal. The parameters of harmful impact of the planned activity on the environment will not exceed the regulatory indicators, provided that the proposed measures aimed at minimising the environmental impact and preventing the exceeding of the established standards are followed. Compliance with these requirements, as well as continuous supervision and control over the technological process and timely implementation of environmental protection measures, will help to minimise the environmental impact.

Conclusions

Due to the sufficient number of wells for the Solotvyno Field development, it was necessary to analyse the impact of the field development on the environment and natural resources, study the geological conditions of the territory and identify the environmental impact of the field development. The study of the geological structure of the Solotvyno Field revealed the gas content of the Novoselytska Suite of the Carpathian Formation, which was tapped by wells at depths of 1,340-1,530 m. Technogenic load on the landscape is created by: residential development of Solotvyno Village; road network; power and communication lines; gas transmission network; two production wells with a depth of 1,580-1,252 m. The environmental impact assessment of the planned activities, as well as the impact on certain elements of nature, was analysed in accordance with the state construction standards.

Taking into account that well operation is a temporary process limited to the drilling site (except for cases of intensive gas production with open-flow, which is excluded if the accepted drilling technology is used), the environmental impact of the planned activities is expected to be minimal. The indicators of negative impact of the planned activities on the environment will not exceed the regulatory values if the proposed measures aimed at reducing the environmental impact and preventing the exceeding of the established standards are followed. Fulfilment of these requirements, as well as constant supervision and control of the technological process and timely implementation of environmental protection measures, will reduce the environmental impact to a minimum level. In the future, further research is planned to expand the study area and assess the negative environmental impact of other gas fields in the western region. The aim will be to provide a comprehensive and accurate study of environmental impacts, recommend new ways to reduce the negative environmental impact of gas production and ensure maximum benefit at minimum cost.

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None.

Conflict of Interest

None.

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Екологічні наслідки експлуатації газових родовищ Закарпаття на прикладі Солотвинського родовища

Ліна Уграк

Асистент
Івано-Франківський національний технічний університет нафти і газу
76019, вул. Карпатська, 15, м. Івано-Франківськ, Україна
https://orcid.org/0000-0002-2040-3937

Наталія Гоптарьова

Кандидат геологічних наук, доцент
Івано-Франківський національний технічний університет нафти і газу
76019, вул. Карпатська, 15, м. Івано-Франківськ, Україна
https://orcid.org/0000-0001-5584-4006

Олександра Палійчук

Кандидат технічних наук, доцент
Івано-Франківський національний технічний університет нафти і газу
76019, вул. Карпатська, 15, м. Івано-Франківськ, Україна
https://orcid.org/0000-0002-0493-7816

Христина Галіпчак

Асистент
Івано-Франківський національний технічний університет нафти і газу
76019, вул. Карпатська, 15, м. Івано-Франківськ, Україна
https://orcid.org/0000-0002-9463-1043

Тарас Уграк

Аспірант
Івано-Франківський національний технічний університет нафти і газу
76019, вул. Карпатська, 15, м. Івано-Франківськ, Україна
https://orcid.org/0009-0000-5222-694X

Анотація. У Закарпатському прогині налічується достатня кількість зафіксованих нафтогазопроявів, які дають змогу ставити його в ряд перспективних нафтогазоносних областей. Розробка родовища проводиться великою кількістю свердловин та безумовно супроводжується негативним впливом на навколишнє середовище. Метою дослідження було проаналізувати вплив експлуатації Солотвинського родовища на стан навколишнього середовища й природних ресурсів регіону зважаючи на геологічні умови території та виявлення екологічних наслідків експлуатації родовища. У більш вузькому значенні – це літологічна характеристика всіх газоносних горизонтів, визначена лабораторними та польовими методами фізико-хімічна характеристика вільного газу, гідрогеологічна характеристика. У роботі використовувались аналітичні методи (аналіз літературних джерел та фондових матеріалів) та експериментальні. У статті розглянуто проблеми впливу на навколишнє середовище процесу експлуатації Солотвинського газового родовища. Хоч експлуатація свердловин є процес не довготривалий і зоною впливу є територія бурового майданчика (за винятком інтенсивного газопроявлення із відкритим фонтануванням, яке при дотриманні прийнятої технології буріння виключається), вплив проектованої діяльності на навколишнє середовище значний. У роботі виділено головні складові навколишнього середовища, на які створюється найбільший вплив прогнозованої діяльності. Виділено джерела та типи забруднювачів відносно кожної складової природи. Запропоновано природоохоронні заходи й зроблено висновки відносно реального впливу на середовище прямої виробничої діяльності. Оцінено ступінь ризику. Результати дослідження можуть бути використані на практиці працівниками нафтогазової промисловості, оскільки вплив проектованої діяльності на навколишнє середовище очікуваний

Ключові слова: нафтогазопрояви; свердловина; навколишнє середовище; ступінь ризику; забруднювачі; лабораторні методи; польові методи