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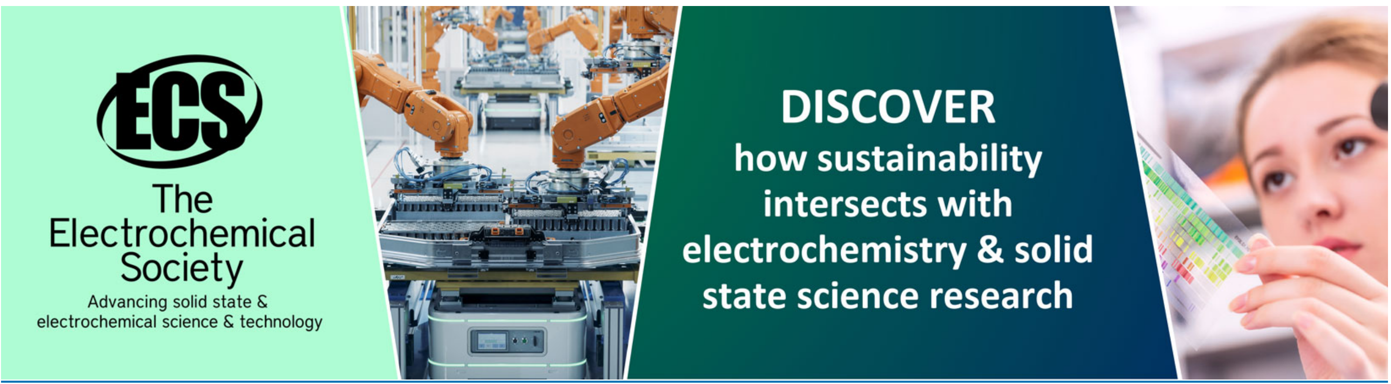

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# Current State and Prospects of Shale Gas Production

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**Abstract**. The article compares the technologically recoverable reserves of shale gas as an unconventional resource of hydrocarbon raw materials in various countries of the world. An assessment is made of the use of horizontal well drilling in combination with hydraulic fracturing of the formation during shale gas production, characterized by the level of technology that allows the most efficient extraction of this resource in the US, Canada, China and Argentina. The article outlines perspectives for the development of shale gas in the near and distant future and shows the obstacles to the development of the oil shale industry in some countries. The basic geo-ecological problems in the development of shale gas: the contamination of surface water and soil, groundwater pollution, gas emissions, seismic risks. The ways of solving these problems are primarily through the use of new field development technologies, the implementation of integrated monitoring safety equipment, taking into account local and regional conditions and the condition of the geological environment.

## 1. Introduction

Using modern methods of drilling wells and developing deposits of shale gas allowed the US to achieve a sharp increase in gas production in 2009. Due to this, the US has turned from a country that imported a significant amount of hydrocarbons into a country exporting liquefied gas. Shale gas is one of the sources of unconventional hydrocarbon resources. Recently, intensive extraction of shale gas has been carried out in the USA, Canada, China and Argentina. The use of horizontal drilling combined with hydraulic fracturing has significantly increased the ability of producers to profitably produce natural gas from geological formations with low permeability, especially shale formations.

## 2. Relevance

Natural gas is currently the third largest fossil fuel, which plays an important role in creating a sustainable energy future. Success in the technology of shale gas production in the United States has changed the geography of supplies and created new prospects for the development of the industry of this unconventional energy source. The volumes of shale gas production are increasing and, obviously, will have a significant impact on the dynamics of prices in the natural gas markets. The consequences of the rapid growth of non-traditional gas supplies on world markets show that non-traditional gas is becoming a global phenomenon and will have an impact on the development of the global gas industry. One of the advantages of shale gas production, unlike the largest traditional deposits, is proximity to consumption centers. However, the extraction of shale gas leads to serious environmental problems due to the coverage of large areas, as well as a significant and intensive violation of the integrity of the subsoil. Among the major geo-ecological problems arising during the development of shale gas deposits are the pollution of surface water and soil, groundwater pollution, gas emissions that contribute to the greenhouse effect and seismic risks. All these factors aggravate anthropogenic climate change and therefore have an adverse effect on human health.

## 3. Shale gas reserves

According to the assessment of the US Department of Energy, the amount of "technically recoverable" world shale gas reserves in 41 countries of the world adds up to more than 200 trillion m3. Reserves of shale rocks are relatively evenly distributed throughout the planet as they are both on land and on the seabed. The only difference is the depth of the occurrence of the gas-bearing strata, which varies from 200 m to 7 km. The table below shows the level of shale gas reserves in 12 countries of the world. The leading place for recoverable shale gas reserves is occupied by China, Argentina, Algeria, the United States and Canada. Russia is in the 9th place in terms of shale gas reserves [9,12].

**Table 1.** International shale gas reserves [13].

| No. | Country | Trillion Cubic Feet (tcf) | Trillion Cubic Metre (tcm) |
|---|---|---|---|
| 1 | China | 1115 | 31.6 |
| 2 | Argentina | 802 | 22.7 |
| 3 | Algeria | 707 | 20.0 |
| 4 | US | 623 | 17.6 |
| 5 | Canada | 573 | 16.2 |
| 6 | Mexico | 545 | 15.4 |
| 7 | Australia | 429 | 12.2 |
| 8 | South Africa | 390 | 11.0 |
| 9 | Russia | 285 | 8.1 |
| 10 | Brazil | 245 | 6.9 |
| 11 | United Arab Emirates | 205 | 5.8 |
| 12 | Venezuela | 167 | 4.7 |
| | World | 7577 | 214.5 |

In the US, the domestic excess supply led to investments that turned import terminals into export terminals, power plants began to use gas instead of coal. All these led to a significant activity in the sphere of exploration and production of shale gas. In 2014, gas production from the seven major shale basins in the United States accounted for 47% of total natural gas production in the US and more than 10% of the world's natural gas production. Since 2016, shale gas has been supplied to the European and Asian markets in the form of LNG. According to the forecast of The World Energy Council's Resources, by 2030 the share of natural gas can reach 25% of the world's energy balance. The US shale revolution serves as a unique example demonstrating how suppliers can use technological innovations to provide more affordable and safe supplies of natural gas [13].

## 4. Shale gas production technologies

For the extraction of shale gas, horizontal drilling of wells and hydraulic fracturing of a productive formation are usually used. The most effective selection of shale gas is achieved when drilling wells with a horizontal trunk passing through the production interval. Horizontal wells that form a fork, fan or spine shape in plan, are drilled in the same interval and are intended to maximize production from shallow deposits. The stages of prospecting, exploration and production of shale gas include drilling vertical wells to detect gas deposits, investigating the physical and chemical properties of gas, and evaluating the profitability of its production. The number of wells drilled during the exploration phase can vary from 2 to 15 wells in the leased area. It is necessary to drill up to 30 wells in order to obtain more data on the reservoir pressure and the reserves themselves. These data are used to model and forecast the volume of gas resources, production capacity and development economy to determine the long-term viability of the production. Shales with commercial gas reserves usually have a thickness of more than 100 meters and the area of their spread can reach hundreds of square kilometers. Once the vertical well reaches the productive drilling bed, the direction of the drill bit changes for horizontal drilling in order to maximize the impact of the wells on the reservoir. To produce a potential gas-bearing shale, it is necessary to contain some silt so that the rock is fragile enough to be hydraulically fractured. The number of wells drilled for prospecting depends on the lateral extent of the deposit, as well as on reservoir pressure. Sometimes a sufficient distance between the wells is required to reduce the pressure in the reservoir to allow the desorption and the release of a significant amount of adsorbed gas. The extraction of gas from a separate well can be from 28 to 40 percent of the total gas present (compared to conventional wells that discharge gas to a large area and restore up to 60-80 percent). Historically, the average well spacing for vertical wells is 400 meters, and the distance between horizontal wells depends on the shape of induced fractures, but is often not less than 800 meters. Operators seek to increase the intervals between wells to reduce costs and environmental impacts. Hydraulic fracture for shale gas is mainly produced in horizontal wells using water with reagents and sand. A mixture of chemical components mixed with water and sand are pumped into the well at a pressure that must be higher than the bursting pressure of the reservoir. The sand keeps the fracture open so that gas can be extracted. The amount of proppant for water and sand required for each fracture stage is very large: up to 1 million liters per operation. The availability of water and transportation of materials over long distances, for example in Australia or Saudi Arabia, is completely different logistically and economically compared to North America. In this regard, it is necessary to rationally use water, cleaning and reusing it. When extraction from the well is no longer economic, the wellbore is filled with cement. It is done to prevent the gas from flowing to the surface or in any zones containing water, aquifers [1,16].

China, which ranks first in the world for shale gas reserves, is successfully carrying out exploration and production of this unconventional energy source. Thanks to the introduction of the results of new technical studies, China has mastered the technology of drilling, hydraulic fracturing of the formation. Chinese producers have the opportunity to drill and carry out milling at a depth of 3,500 meters (in some areas the depth of the resource is 4000 meters) and begin to create their own technological system suitable for the geological conditions of individual regions of the country. In 2017, China made a significant breakthrough in the technology of shale gas production: specialists began to use carbon dioxide to successfully develop continental deposits of shale resources. Carbon dioxide is injected under high pressure into the reservoir, and shale gas begins to flow back into the reservoir. At the same time, harm to the environment is minimized. This technology is particularly important for the regions of China where there is a water shortage problem. Interest in this technology is increasing, so it is likely that in the future it will be possible to avoid using water resources. In fact, more than 60% of China's shale oil and gas resources are located in areas where there is a shortage of water [15].

In the United States of America, a new method for the extraction of shale gas has been developed. It is so-called anhydrous rupture method. In contrast to the method of hydraulic fracturing, where a mixture of sand, water and chemical reagents is used, gel and liquefied gas are used. The revolutionary concept of the production of hydrocarbons from oil shale is without doubt a significant achievement in the field of geological sciences as well as oil and gas engineering over the past few decades [16]. The advantage of producing shale gas, unlike the largest traditional deposits, is the proximity to consumption centers. However, the extraction of shale gas leads to serious environmental problems due to the coverage of large areas, as well as a significant and intensive violation of the integrity of the subsoil. Among the main geo-ecological problems arising during the development of shale gas deposits, it is necessary to distinguish the following: pollution of surface water and soil, groundwater pollution, gas emissions, seismic risks [6].

One of the most serious obstacles to the widespread production of shale gas is the high risk of damage to the environment. The technology used for production of hydraulic fracturing requires the use of a large number of toxic chemicals (from 80 to 300 tons per break). Despite the fact that hydraulic fractures are much lower than the level of groundwater, the soil layer, groundwater and air are still infected with toxic substances due to their infiltration into the surface layers of the soil through cracks formed in the thickness of sedimentary rocks. In addition, frequent hydraulic fractures lead to an increase in the permeability of the shale formation. This is the cause of methane leakage into the upper layers of the soil and its entry into the air and leads to an increase in the greenhouse effect on the planet. The total volume of methane losses in gas production, according to the estimates of the US Environmental Protection Agency, is 3.6-7.9% [4].

It should be noted that a number of large shale deposits, confined to Paleozoic and Mesozoic deposits, have a high level of gamma radiation. As a result of hydraulic fracturing, radiation inevitably enters the upper layer of sedimentary rocks. For this reason, an increase in the radiation background is observed in shale gas production areas. The production of shale gas requires significant water reserves in the vicinity of the fields, since only 7,500 tons of a mixture of water, sand and chemicals are used for one hydraulic fracturing. As a result, a significant amount of contaminated waste water is often accumulated near the fields, which is not utilized by extractive companies in compliance with environmental standards [12]. The estimates show that one hydraulic fracturing of six wells requires 54 - 174 thousand $m^3$ of fresh water and from thousands to 3.5 thousand $m^3$ of special chemicals, or about 10-30 thousand $m^3$ of fresh water - 160 to 60 $m^3$ of chemicals per well. Since in practice, depending on the field, up to 12 hydraulic fractures can be carried out at each well to increase gas recovery, the total amount of fresh water consumed can reach 0.4-0.5 million $m^3$. The list of chemical additives contains several hundred names, many of which have not only acute toxic effects, but are also mutagens and carcinogens [10]. American scientists analyzed 141 wells with drinking water in northeastern Pennsylvania. The concentration of natural gases was studied in close proximity to wells with shale gas. In 82% of samples from wells with drinking water, methane was found with average concentrations 6 times higher than the normative indices, and the ethane content was 23 times higher than the norm. Propane was detected in 10 water wells. The investigated water wells were located at a distance of less than 1 km from wells with shale gas [8]. The obtained data show that in the vicinity of gas wells in the areas where shale gas is actively extracted, methane concentration in subsoil waters is significantly higher than in the areas where there is no activity related to well drilling and fracturing. In the samples of subsoil waters taken over the Marcellus and Utica deposits, methane concentration varied from 10 to 64 mg / l. On average, the methane concentration in the core was 19.2 mg / l, and was 17 times higher than in the inactive zone (1.1 mg / l). At the same time, the methane content in some cases was much higher than the safe level, which was fraught with explosions in a mixture with oxygen in the air. In addition to methane other hydrocarbons were also found as well as ethane, propane and in subsoil waters [11]. One of the environmental problems associated with the extraction of shale gas is the occurrence of earthquakes with a small magnitude in connection with the hydraulic fracturing. In particular, in the city of Cleburne, Texas, several earthquakes with the magnitude of up to 3.3 on the Richter scale occurred. In the process of extraction of shale gas there are significant losses of methane, which contributes to the enhancement of the greenhouse effect. In Brussels, a report was published on the results of the research of the US Environmental Protection Agency. The report provides facts that confirm that greenhouse gas emissions from shale gas production are greater than coal, oil and conventional gas. It should be noted the feature of "shale mining": a rapid decline in daily production of shale wells. In the first year of the operation, the drop was 70%, in the third year it already reached 85%. It means that in order to maintain production levels it is necessary to continuously drill a large number of wells [2]. In addition to the United States of America, shale gas is also produced in Canada, in British Columbia and Alberta. In China, the work on the development of shale gas deposits began in 2005. However, in 2014, the volume of shale gas production already amounted to 1.3 billion $m^3$, and in 2017 exceeded 10 billion $m^3$. China has ambitious plans to develop its shale gas resources. It is assumed that by 2030 the country will be able to produce no less than 30 billion $m^3$ of shale gas. Active development of the unconventional hydrocarbon deposits of Waka Muert Started in Argentina. The reserves of this field are estimated at 16 billion barrels of oil shale and 8.7 trillion $m^3$ of shale gas. The deposit Vaca Muerta located in the Neuquén basin resembles the Eagle Ford shale gas pool in the US. It makes the development process more simple and will allow American operators Chevron and Exxon Mobil to use the experience gained in the US. Vaca Muerta is also a well-proven oil and gas producing complex in Argentina with good road infrastructure, a developed service sector and a significant network of pipelines. Significant progress has been made in Australia. The reserves of the Australian shale deposit are estimated at 12.2 trillion cubic meters. The development of shale gas locations holds an important place in the oil and gas projects in Australia. In Queensland, eastern Australia, shale gas is used as a raw material for the production of liquefied natural gas. In the field of natural gas, Australia positions itself as a major supplier of liquefied natural gas to Asia. Saudi Arabia has also made remarkable progress and is likely to become a commercial oil shale by 2020. The Government of Mexico is currently considering two energy strategies until 2026. Both of them envisage the development of their own gas and oil shale deposits. In Europe, the ability to mine SG is still much lower due to the high population density and strict environmental legislation, but the SG reserves there are very large. The International Energy Agency suggested that by 2040, non-traditional gas will have accounted for up to 30% of total natural gas consumption [14, 18]. Among the factors that positively influence the prospect of extraction of shale gas are the proximity of deposits to possible markets for sales, significant reserves as well as the interest of a number of states in reducing imports of fuel and energy resources. This unconventional resource also has a number of shortcomings such as a high production cost compared to traditional gas; unsuitability for transportation over long distances; rapid depletion of deposits; insignificant share of proved reserves. As for the production of shale gas in Russia, Gazprom is not yet going to deal with this problem, focusing on the production of shale oil. Russia has huge reserves of traditional gas, the cost of production of which is quite low. In connection with this, it is economically unprofitable to develop shale gas deposits.

## 5. Conclusions

The world's shale gas reserves and the rate of development of deposits in the US, Canada, China, Argentina and other countries testify to the significant opportunities for using this unconventional source. In the process of development of shale gas deposits, various environmental problems arise, many of which can be solved in the process of improving gas production technology, as well as through more precise control of drilling and gas production processes. Prospects for the extraction of shale gas are very significant, especially in poorly populated areas and those countries that agree to a decrease in environmental safety. Practically in all countries where there is an opportunity to start industrial production of shale gas, environmental commissions have been set up to address environmental problems associated with the extraction of shale gas. To solve environmental problems, it is necessary to use the most advanced technologies for developing shale gas deposits. It is necessary to carry out complex and strict control over the safety of equipment and processes of possible risks to the environment and human health, to take into account local and regional conditions of the geological and environmental conditions, to make information on the ecological state of the territories within which the mineral is extracted is transparent and accessible to the public and local residents shale gas.

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