Shale Gas Production and Environmental Concerns

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Abstract The shale gas production in the USA has stirred environmental concerns in the face of the impacts arising in the course of the shale play development. Such enhanced interest of the public to this issue is connected with the opinions voiced by ecologists about the negative impacts of the shale gas production on the natural environment and human health. And the key negative factor is considered to be the hydraulic fracturing (fracking) technologies. It is thought that the hydraulic fracturing affects the geological structures, underground and surface waters, atmospheric air, soil, and land condition. Moreover, the preparatory works for construction of the required infrastructure and also the very process of shale gas production – drilling of horizontal and vertical wells, use of water resources, and

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storage of toxic wastes are also detrimental in this respect. All these factors have led to wider public movement against the shale gas production.

Keywords Climate, Ecology, Environment, Law, Production, Shale gas

Contents

1 Introduction

Many countries have already amassed some experience of shale gas extraction. But the leading positions in shale play development are still with the USA that has demonstrated quick rise of this gas production and is currently preparing plans to export this hydrocarbon resource to other world regions.

Three environmental issues should be addressed in shale development: to find considerable volumes of water, to ensure the acceptable level of technogenic impact on environment during pumping of working solution, and to utilize safely the generated slime [1].

While developing new technologies that permitted to boost quickly the gas extraction, the oil and gas companies also faced negative impacts. They are primarily connected with the specific features of shale gas production, i.e., application of hydraulic fracturing technology (fracking) being the only technique to frac the rocks and to bring the shale gas to the surface. In order to increase gas output, the multiple fracking should be applied which enhances the negative impact on the environment and man.

The growing attention to environmental issues in other countries and, first of all, in Europe may be attributed to tougher requirements of local legislations to comply with the norms contained therein. Moreover, the population protests against the shale gas production due to high population density in these countries. Unlike the USA where the shale gas is extracted in sparsely populated areas, the European countries are densely populated, hence, such great anxiety concerning this hydrocarbon production.

2 Environmental Issues of the Shale Gas Production

Assessing the environmental impacts of shale projects, the following kinds of pollution and disturbances become most important (Fig. 1). First, geomechanical disturbances, i.e., deformation of the rock massif and landscape revealing itself in compaction, loosening, appearance of caves, dumps, and quarries. Second, hydrodynamic disturbances connected with flooding of relief with wastewaters or runoff depletion, groundwater rise, changes of water salinity, turbidity, and temperature. Third, biomorphological disturbances connected with destruction, alteration of the species composition of phyto- and zoocenosis, decreased productivity, and reduced area of flora and fauna distribution. And, finally, lithosphere pollution caused by construction of quarries and wells (Fig. 2), surface and subsurface wastes burial, oil spills, movement of drilling mud into a formation, fluid injection for fracking, and change of the hydrogeological regime in soil [2].

The fracking technology of shale gas extraction is designed to unite small individual gas "pockets" to make a total volume. This process envisages constant horizontal drilling, i.e., the territories and permanent fracking are required and, consequently, great volumes of water. Here water tightness of all formations encountered on the way of well boring acquires special importance. And the more so as a great risk of pollution may appear at breakdown of adjacent

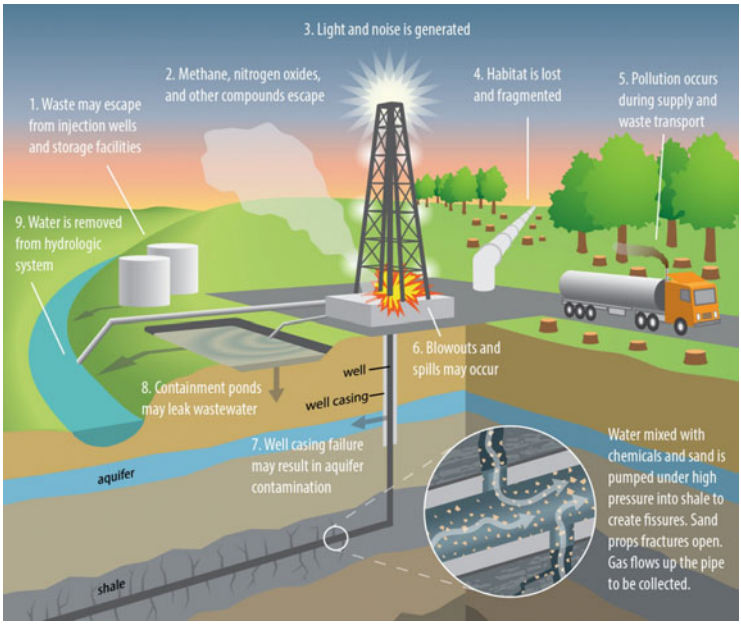

Fig. 1 Environmental problems related to shale gas production (*Source*: http://wws.princeton.edu/sites/default/files/content/images/news/Figure2_Souther.jpeg)

Fig. 2 The ecological impact from shale gas extraction operations on the landscape (Wyoming's Jonah Field, USA) (*Source*: https://blogs.princeton.edu/research/files/2014/07/2014_08_01_Souther_TingleyFREEPressRelease_Photo-500x361.jpeg)

non-shale formations. Penetration into such formations of fluids containing chemical agents will increase the polluted area.

The fracking envisages injection of water containing sand and proppants under a pressure of 500–1,500 atm into gas bearing formations, as a result, cracks are created through which gas flows into the well. The fluid injected into the well contains coarse sand to prevent closing of cracks after pressure drop.

In coal mining, the risks affect primarily those who directly participate in this process, i.e., coal miners, while the potential risks associated with fracking involve environment contamination and negative impacts on human health far from the place of works. Therefore, the implications of the accident during fracking may be comparable to those occurred as a result of accident at the nuclear facility [3].

The main reasoning of ecologists is that after stopping the extraction the hazardous chemical agents that even include radioactive isotopes may get with fluid into subsurface formations. This is fraught with contamination of reservoirs used for drinking water supply of the densely populated northeast of the USA.

3 Impact of Shale Gas Production on Water Resources

The fracking technology requires much water in the vicinity of the developed play as well as significant amounts of sand and proppants added into it. The problem of obtaining water resources is quite acute. In many countries, the water resources are

limited and there is water deficit. The European countries do not have free great volumes of water required for fracking and they have no service companies. As a result, the well drilling and play infrastructure development are fourfold costly than in the USA. Moreover, the fracking technology requires availability of ample water resources nearby the plays as one fracking operation uses 1,000–7,500 tons of water of which 30–50% remain underground, while the remaining amount is pumped by submerged pumps. Consequently, considerable volumes of water are accumulated for which storage extensive land areas are required [4].

Different chemicals are added into fluid to reduce its viscosity and corroding action and to prevent deposition of mineral salts on tube walls. The reagents permanently added into water may get into groundwaters and cause serious hazards. The shale gas production generates toxic water.

The fluid used for fracking in shale gas plays is the water with the minimal required additives accounting for 0.5% and sometimes to 2% [5].

One fracking operation in horizontal wells requires around 4,000 tons of water and 200 tons of sand. On the average, three fracking operations are conducted on each well during 1 year. Thus, the total water requirement reaches 12,000 tons.

Shale gas production causes contamination of subsurface waters as fluids through cracks created by fracking may get into the nearby water aquifers and from there into the formation. At deep occurrence of shales, the probability that the remaining fracking fluids may reach the ground surface is very low; however, at not deep occurrence of formations such probability becomes greater [6].

Shale gas extracted in several states in the USA made drinking water there toxic (Fig. 3). Similar instances of water contamination were witnessed in Colorado, Texas, and West Virginia. The issue of the shale gas impacts was discussed in the US Congress. The authorities of the New York state were the first to impose moratorium on shale gas production. This happened in 2010 after warnings of experts on hazardousness of the hydrolytic extraction technology assuming injection into the shale rocks of great amounts of water with special chemicals added into it.

Based on the Clean Water Act of 2005, the ecologists succeeded adoption of the ordinance obliging shale gas companies to make public the formulation of chemical additives and to reduce the chemical load on the region's environment.

Fig. 3 Burning of drinking water as a result of shale gas seeping into aquifers (*Source*: https://i.ytimg.com/vi/4LBjSXWQRV8/maxresdefault.jpg)

The Quebec's environmental bureau report (Canada) contains recommendation to stop completely the shale gas projects until the additional investigations are conducted. The scientists assert that the shale gas extraction is fraught with the risk of contamination of drinking water sources.

4 Impact of Chemical Agents on Natural Environment

The commercial production of any natural deposits invariably produces the increased technogenic impact on the natural environment. The chemical solutions used in fracking are highly toxic. Much anxiety is stirred by the state of local drinking water wells and underground water aquifers. Ecologists assert that during shale gas extraction such chemical substances as toluene, benzene, dimethylbenzene, ethylbenzene, arsenic, and others find their way into groundwaters. Some companies use hydrochloric acid solutions thickened with polymers. One fracking operation requires 80–300 tons of chemicals. This gives rise to serious environmental concerns. In particular, there are no adequate capacities to treat the whole volume of wastewaters. But even treated mud solution is capable to contaminate significantly the groundwaters and the more so as only a part of wastewaters is lifted from wells. Benzene, arsenic, and radioactive materials will be pumped to the surface from shale formations. The most successful shale plays occur in the Paleozoic and Mesozoic rocks and feature the high gamma-radiation level which correlates with the thermal maturity of the shale deposits. Consequently, fracking radiation penetrates into the top layer of sedimentary rocks; hence, the high radiation background is witnessed in the shale gas production areas.

Chemical agents used in fracking to ensure the required viscosity of injected fluid are carcinogenic and their getting into the artesian aquifers used for drinking water supply will be disastrous (Table 1).

The cracks formed during fracking (their length reaches 150 m) may spread to the overlying formations. More than that, these operations are practically always accompanied by inflow of waters from the upper horizons. This leads either to contamination of groundwaters with injected fluids or penetration of shale gas found in artesian wells into them. It was found about 500 different chemical compounds which toxicity and stability in deep-lying horizons have not been adequately studied so far.

Fracking is conducted much lower than the groundwater level. However, the soil, groundwaters, and air become contaminated with toxic substances. This occurs by seeping of chemical substances through cracks formed in the sedimentary rocks into the topsoil layers. In addition, this technology involves the discharge to the surface of great volumes of contaminated water that should be pumped out so that it does not penetrate into the local drinking water sources. The main environmental concern is the possibility of contamination of water bearing formations with methane and applied solutions.

Table 1 Standard additives in the fracking fluid (for Cotton Valley and Travis Peak plays in Eastern Texas) [7]

Additive name	Additive type	Concentration
10% FE acid	Acid/solvent	1,000–3,000 gal prior to fracking
BA-40L™	Buffer solution	0.5–2.5 gal/1,000 gal
BE-9	Biocidal agent	0.25–0.5 gal/1,000 gal
CL-23	Crosslinked linear polymer	0.2–1 gal/1,000 gal
Common White Sand 100 mesh	Proppant	0.1–1 lbs/gal
FR-66	Friction reducing agent	0.2–1 gal/1,000 gal
Gas Perm 1100	Surface active substance	0.5–10 gal/1,000 gal
HAI-404M™	Anticorrosion agent	5–25 gal/1,000 gal
LGS-36UC	Gel liquid concentrate	2.5–6 gal/1,000 gal
PRC Premium Sand 40/70 mesh	Proppant	2–3 lbs/gal
Premium White Sand 40/70 mesh	Proppant	0.5–2 lbs/gal
ViCon NF	Fracking gel thinner	1–10 gal/1,000 gal

Shale gas that was not trapped by wells rises to the surface with the injected chemicals seeping through the soil, thus, polluting groundwaters and the fertile soil layer.

Such risk appears at any breaches of the well construction technology. To avoid this, the company uses at minimum 2–3 casings with subsequent grouting. For gas recovery, it is necessary to pump out fracking fluid from the production well. Water, even technical, is a mineral deposit that should be paid for. Therefore, to cut the costs the pumped out fluid is collected in special pits from where it is recycled to hydraulic fracturing. It is at this stage that the threat of environment pollution appears, and not of groundwaters, but of soil layer or surface water streams [5].

Fracking fluids contain many hazardous substances. There is about a hundred of the applied chemical additives, including, among others, volatile organic compounds (toluene, cumene, etc.), carcinogenic agents (benzene, ethylene oxide, and formaldehyde), mutagens, and other substances affecting the human endocrine system, as well as stable and biologically accumulated pollutants. In the course of shale gas extraction, water is contaminated with methane and radioactive substances that are washed out from rocks covering plays.

Technological risks are connected with reliability of water tightness of all horizons penetrated during drilling. This is most essential for underground (artesian) aquifers passed through during well construction. Apart from this, there is also a danger of pressure rising to the level of destructing not only shale rocks, but also nearby formations [8]. This requires development of the environmentally friendly chemicals and reagents.

5 Legal Support of Shale Gas Production

Different countries have their own legislations regulating shale gas production. The greatest experience in this field is amassed by the USA that has developed legal acts on the federal level and on the level of individual states regulating the issues of shale gas prospecting, extraction, preparation of infrastructure, ecology, and relations with the population living in the vicinity of drilling sites. Thus, the USA has the National Environmental Policy Act containing requirements to exploration and production of mineral deposits. The US Department of Interior Bureau of Land Management issues permits to fracking application. The USA has also the Clean Water Act regulating the wastewater disposal. Apart from the above, there are also documents imposing restrictions on atmosphere pollution, getting of hazardous chemical substances into water resources and soils.

In individual states, the exploration, production, and environment protection are regulated both by federal laws and by specific legislation. At the same time, all US states should have legislations issuing separate permits to drilling and other operations connected with works on drilling sites. Moreover, some states passed laws obliging companies to disclose the information about chemical reagents.

Regardless of availability of numerous laws, both on the federal level and on the level of individual states, the USA failed to resolve all problems related to nature conservation. And the main reason for this is the influence of political and energy factors connected with endeavors of the US authorities to reduce dependence on oil and gas supply from other regions.

Europe started addressing the issues of environmental legislation related to development of shale plays only in the early second decade of this century. Most active in this respect is Poland that was one of the first European countries to start practical implementation of shale projects. In Poland, these issues are in the competence of the Ministry of Environment that together with the Department of Geology and Geological Concessions issues permits to shale play development. However, the country has no specific legislation. Thus, the shale gas issues are regulated by the geological and mining law passed in February 1994 [9].

In Poland, the lands around wells are privately owned by small landlords who potentially restrict production. In addition, the shale development in the European countries is restricted by environmental considerations and the cost of shale gas production is twice higher than in the USA.

The European legislation has its specific features preventing shale gas production in the same manner as in the USA. In the USA, the landholder also owns the land interior and receives income from the resources contained therein, while in many European countries the land interior is in the ownership of the state and any charges should be paid to the state. There is no reliable and detailed geological investigation of production areas in Europe which makes difficult the assessments of unconventional gas resources. The European environmental legislation does not permit development and production of these resources for considerations of hazards to the natural environment [10]. Besides, the first attempts to drill for shale gas in

European countries increase the public pressure on the governments of these countries to stop shale play development.

In densely populated Europe, this may become a serious obstacle for implementation of shale projects due to the EU stringent environmental regulations. For launching drilling works, it is necessary to have the norms ensuring safety of works and protection of groundwaters. Some components added to attain the required viscosity of fracturing fluid are carcinogenic, therefore, their getting into groundwaters is dangerous. Besides, fracking cracks may develop upwards contaminating groundwaters with injected fluids or facilitating the ingress into them of methane.

France was the first European country that adopted the law banning the shale gas production. On June 30, 2011, the French Parliament voted for the ban of hydraulic fracturing due to likely threat to the environment. The works were stopped upon insistence of ecologists. This was a decisive step of the Parliament members who after studying the US experience in shale gas production expressed their doubts whether the fracking technologies were environmentally friendly. The main hazard was considered to be the horizontal drilling that envisages injection of water into cavities containing gas, thus, forcing it out to other wells. Here the walls between separate cavities in shales are broken down by hydraulic fracturing which, under unfavorable circumstances, may cause large downfalls or flooding of territories. In the USA, shale gas is extracted in sparsely populated areas, but in Ukraine and Poland the situation is quite different. Even without shale projects, Ukraine abounds in territories with enormous underground cavities formed as a result of coal and iron ore mining.

The French association of oilmen declared that it disapproved the decision taken by senators. However, considering the negative attitude of the public to shale projects that was shaped mostly with regard to the ecologists' opinions and also the high cost of such projects it can be said that in the near future the commercial development of shale gas resources in this country is quite unlikely.

Moratorium on shale gas extraction was also imposed in Germany and in Lower Saxony and North Rhine – Westphalian. However, in 2014 Germany declined the complete ban of the fracking technology.

Britain generally supports the shale projects, but does not go beyond political declarations. The reason for such cautious attitude to shale issues of the British government is that the main shale plays in this country are found in the shelf area and their development is still economically unsound.

In April 2012, the EU Parliament conducted hearings at which it was stressed that the shale gas production technologies meet the current environmental regulations. Accordingly, regardless of any negative factors, primarily, related to environment, many countries are not going to abandon the shale projects. For example, Poland advocates the adoption by the EU of the legal acts supporting the shale play development.

In September 2012, the Committee on the Environment, Public Health and Food Safety of the European Parliament passed the resolution stating that the shale oil and gas production in the EU territory should strictly comply with the environmental standards. In November 2012, the EU Parliament authorized shale gas extraction

in the EU countries and did not support the proposal to impose moratorium on the application of fracking technologies.

6 Effect of Hydraulic Fracturing on Subsoil

In the shale gas projects, the application of fracking technologies may enhance the seismic risks and lead to earthquakes. It is thought that fracking technologies caused two small tremors near Blackpool, the seaside resort in Lancashire, Britain. The first tremor was registered on April 1, 2011 with the magnitude of 2.3 by the Richter scale, and the second with the magnitude of 1.5 occurred in May 2011. A similar incident was earlier recorded in the Ohio state in America.

The US Seismological Service did not record in this country any large earthquake that could be connected with gas extraction from shales. It is thought that only in rare cases the fracking can directly cause earthquake with the magnitude not more than three points. But this issue requires further investigation [11].

It can be said with high enough probability that fracking operations could cause small tremors due to an unusual combination of geology factors at the well site coupled with the pressure exerted by water injection as part of operations. Such combination is extremely rare. And although currently the relationship between fracking and underground tremors has not been investigated properly, in the production areas we can still witness land subsidence. Regardless of these facts, Britain is not going to abandon completely the shale projects.

In the USA, there were already scandals connected with breaching the rules of hydraulic fracturing by major service companies. In March 2011, the US President ordered to create the Shale Gas Subcommittee within the frame of the Advisory Council at the Department of Energy. The report prepared by this subcommittee contained nine recommendations on the issues arousing major concerns. First of all, it related to the likely water and air contamination and degradation of living conditions in the territories located nearby the shale gas production sites. Special attention was also focused on the negative implications for settlements and ecosystems in the shale project areas [12].

The moratorium on hydraulic fracturing has been imposed and still operates in Pennsylvania and New Jersey in America. The shale gas production was suspended in Quebec and Alberta provinces in Canada. Quite recently, the legislators approved restrictions on shale drilling in Maryland, Pittsburg, and Buffalo. The moratorium should remain in force till the scientists confirm that there is no negative impact of hydrolysis on the natural environment and drinking water sources. Similar decisions are being prepared in Ohio and West Virginia.

In some drilling sites in Pennsylvania, some alien substances were found in soil, rivers, and groundwaters. Controlling bodies have fixed more than 250 facts of breaching the local norms concerning operation of treatment facilities and safe storage of waste additives. Based on judicial and administrative rulings, the activities of many shale gas companies in Pennsylvania were stopped. Experts also stress

the problem of greenhouse effect caused by methane leaks during shale gas extraction [13]. The greenhouse gas emissions into the atmosphere of shale gas projects are much greater than at traditional extraction [14].

The US scientists declared about the negative impacts of chemical agents used in hydraulic fracturing on human health, but when great profits are at stake they try to neglect such factors. Thus, the issue of the "shale miracle" is used for brain drain of not only ordinary public in America, but in other countries, too. The USA makes attempts to export the respective technologies to Europe. In that they pursue not only economic benefits, but also their political targets – to reduce energy dependence of European countries on traditional gas suppliers, primarily, Russia.

Human right activists call to ban the shale gas production in the USA and Britain as this may lead to disastrous consequences in these regions and will leave the greater part of the population without pure drinking water. Taking into consideration that the shale gas extraction requires more than 100 times greater number of wells than for extraction of traditional gas, the US public expresses great concerns about the likelihood of wide-scale contamination of groundwaters.

7 Seeking New Technologies

The leading petroleum and gas companies have conducted researches to alleviate the negative impacts of shale gas production suggesting alternatives that will substitute water required by fracking technologies. Thus, the Japanese research group of the Kyoto University suggested using carbon dioxide instead of water. The Canadian Company GasFrac has developed a new technique of shale fracturing with injection of propane-based gel instead of water.

Company Halliburton took a different way suggesting new method of water treatment. The CleanWave technique supposes treatment of fracking water with the help of positive ions. At the same time, the company proposed one more option – application of membrane distillation when the wastewater is recycled without mixing with freshwaters. Company Novas Energy USA suggested the plasma pulse technology (PPT) when the horizontal wells are "blown through" not with water, but with electrically generated plasma impulses [15].

The search of new technologies capable to substitute water resources or mitigate the fracking consequences goes on. However, while the world still has considerable resources of traditional gas, the shale gas most likely remains the strategic reserve that may produce its global effect in the far perspective.

8 Conclusions

In May 2011, Britain published the report of the House of Commons of the British Parliament and the Energy and Climate Change Committee saying that the shale gas resources available in Britain will quite unlikely influence cardinally its power

supply. Senior analyst of European gas and LNH markets at Société Générale T. Bros, the author of the book "After the U.S. Shale Gas Revolution," in his interview said that Britain had already come to an understanding that shale gas could bring profit through rivalry and revenues. He also added that it was already quite clear that no shale revolution would occur in Europe. In Britain, the shale gas production may become more real by 2020 when some positive results were attained. At the same time, this document stressed that the government of the country should track closely the changes in the shale gas development in Poland as this information was very important in terms of future plans and adjustments to be made in the national and European legislations with further progress of the situation in this area. But the key issue of this report is that its authors did not support moratorium on the fracking technology application while developing hydrocarbon resources in Britain, believing that the shale gas extraction had no negative environmental impacts.

The public concerns in some European countries in respect of environmental risks urged the EU to have a closer look at this issue. In the early 2014, the European Commission approved the recommendations on environment and climate protection while applying hydraulic fracturing in shale gas extraction. These recommendations were called to assist the EU states intending to apply fracking technologies in shale play development with management of environmental risks [16].

It follows from the above that the shale gas cannot not be considered the alternative of the natural gas, because its extraction fails to meet the modern stringent environment safety requirements to the commercial scale development of plays in many world countries. The prospects of shale gas production are available only in the sparsely populated areas and in the countries that are ready to sacrifice environmental safety for extraction of this hydrocarbon. In addition, the limiting factor of commercial shale gas production is also the high cost of its extraction.

The technology of shale gas production and environmental implications of its application have already roused protests in many countries. Ecologists stress that in endeavoring to increase the scales of shale gas production many global issues faced by whole regions are neglected. One of such issues is the shortage of water resources required for fracking. By different forecasts, by 2025 the planet will face the water crisis and in this context the shale gas production seems a suicidal idea.

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