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Research Article

IMPACT OF HYDRAULIC FRACTURING ON THE QUALITY OF NATURAL WATERS

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ABSTRACT
Poland, due to the estimated shale gas deposits amounting to 346–768 billion m^3 has become one of the most attractive regions for shale gas exploration in Europe. Throughout the period 2010–2015, 72 exploratory drillings were made (as of 4.01.2016), while hydraulic fracturing was carried out 25 times. Employing new drilling and shale gas prospecting technologies raises a question pertaining to their impact on the environment. The number of chemical compounds used (approximately 2000) for the production of new technological fluids may potentially pollute the environment. The fact that the composition of these fluids remains undisclosed hinders the assessment of their impact on the environment and devising optimal methods for managing this type of waste. The presented work indicates the chemical compounds which may infiltrate to groundwater, identified on the basis of technological fluids characteristics, as well as the review of studies pertaining to their impact on potable water carried out in the United States. The study focused on marking heavy metals, calcium, sodium, magnesium, potassium, chlorides and sulphates in the surface waters collected in proximity of Lewino well.

Keywords: shale gas, hydraulic fracturing.

INTRODUCTION

Rapid increase in shale gas extraction observed in the United States may indicate that with adequate economic conditions a similar process will take place in Poland. In 2005, there were 18 485 active wells in the United States, whereas in 2007, there were already 25 145 wells [U.S. EIA 2014]. Shale gas extraction increased from 0.15 quintillion m$_3$ in 2010 to 0.25 quintillion in 2015. In Poland, 72 exploratory wells were drilled in the years 2010–2015 (as of 4.01.2016) [www.pgi.gov.pl], while the hydraulic fracturing process was carried out 25 times.

Due to the low throughput of shale rock formations – where shale gas is trapped – it is necessary to drill horizontal and vertical wells, and employ the hydraulic fracturing process in order to release it. This process involves pumping a drilling fluid into a drilled well under high pressure (approximately 1000 bar) to crack rocks. At the end of the process, the pressure in the well drops and the pumped fluid flows back. However, the chemical composition of flowback fluid is modified, mainly through leaching of dissolved salts and clay from the fractured deposits. A detailed composition of the utilized fluids is confidential; however, on the basis of available publications it is possible to characterize the chemical composition of drilling fluids in a general way.

The hydraulic fracturing, as well as the produced waste, including spent technological fluids, raise concerns related to their potential impact on the natural environment, especially potable water and human health hazard. Growing extraction of shale gas in the United States and research on its impact on the environment are relevant to the overall assessment of environmental threat of shale gas drillings and hydraulic fracturing. The review of literature enables to select the chemical compounds which are necessary for monitoring water and soil in the proximity of wells.

Over 2000 different compounds and chemical substances are used for the production of fluids employed in exploration [Starzycka 2012]. The technological fluids used for shale gas extraction are characterized below.

Hydraulic fracturing involves the use of fracturing fluids, composed mainly of water (approximately 98–99%), proppants (1–1.9%) and chemical additives (less than 1%), which are pumped under high pressure. Proppants denote small grains of sand or ceramic grains which prevent the fractures from closing after the pressure decrease and removal of fracturing fluid. This enables greater flux of gas from its source to the well. There are numerous chemical additives which are components of fracturing fluids. Their selection depends on the depth and characteristics of a given deposit [http://www.shale-gas-information-platform.org/pl].

Although it is obligatory to disclose the composition of drilling fluid, the existence of other components cannot be ruled out. An exemplary fluid employed in the fracturing of Marcellus Shale in the USA comprises: acid (0.1186%), stabilizers (0.0844%), residue inhibitor (0.0822%), gelling agents (0.0575%), iron control agents (0.0540%), polymer breaker (0.0237%), corrosion inhibitor (0.0105%), surface-active agents (0.0016%), biocides (0.0065%), lubricants (0.0395%), pH regulators (0.0093%), webbing agents (0.0008%).

The composition of fracturing fluid employed in the considered object in Lewinowo, Poland, was as follows: 94.5% water, 2.78% kaolinite. The remaining 2.72% constitute additions utilized in order to improve the fracturing efficiency, for instance by reducing friction between the fluid and pipe walls. The composition of fracturing fluid additives was presented in Table 1.

Following the fracturing process, the pressure in the well drops, enabling the pumped fracturing fluid mixed with water from the deposit to flow back. This waste is known as the flowback water. At the initial phase, it flows out with high intensity reaching approximately 1300 m^3/d for up to three weeks. Afterwards, it stabilizes at the level of 0.8–1.6 m^3/d and is known as produced water.

The volume of flowback water ranges from 10% to 80% of the volume of the pumped fracturing fluid. For Marcellus shale in the USA, this amount equals 15–20%, whereas in the case of Barnett Shale – 75% [Hoffman et al. 2014, Pawłowski et al. 2015].

In contrast to the fracturing fluid, the flowback water – apart from the originally used components – can be modified with additional substances such as: total dissolved solids (TDS), including chlorides from the contact of fracturing fluid with water in the deposit organic compounds (aliphatic and aromatic hydrocarbons), heavy metals and radioactive elements. The amount and chemical composition of total dissolved solids largely depends on the local geological conditions. Apart from chlorides, TDS may also include sulphates, bromides, and the following ions: sodium, potassium, calcium, magnesium, etc. [Steliga and Uliasz 2012]. In Poland, neither the composition of typical flowback nor produced water has been

Table 1. Composition of chemical compounds added to fracturing fluid used in Lewino well.

Chemical compounds	Maximum concentration in fracturing fluid [%]	Chemical compounds	Maximum concentration in fracturing fluid [%]
Water	94.5	2-butyloxyethanol	0.0018%
Kaolinite	2.78	Isopropyl alcohol	0.0018
Silicon compounds	2.6	Sodium bisulphate	0.0018
Choline chloride	0.005	Ammonium thiosulphate	0.0025
Hydrochloric acid	0.030	C12-C15 alcohols	0.0015
Kerosene	0.0038	Ethylene glycol	0.0014
EPI-DMA Polymer	0.004	Propylene glycol	0.0006
2-(2-butoxyetoxy)ethanol	0.0416%	EDTA	0.0005
Potassium hydroxide	0.000051	Methanol	0.00002
Aliphatic alcohol	0.0011	Aliphatic acids	0.0011
Guar gum	0.0032		

[http://www.opppw.pl/projekt/Lewino_1G2_Component_disclosure_card_OPPPW.pdf]
[http://www.sanleonenergy.com/media-centre/news-releases/2014/january/23/lewino-1g2-successful-vertical-frac-leads-to-horizontal-well.aspx]

disclosed thus far. Table 2 presents a typical composition of flowback water from wells in the USA [Shramko 2009].

On the other hand, produced water comes mainly from dewatering of a deposit in shale formations. Its composition is variable and depends on the geological structure of a deposit. This water is characterized by a high level of total dissolved solids and leaches metals from shales, including barium, calcium, iron, and magnesium. It also contains dissolved hydrocarbons, such as methane, ethane, propane, along with the naturally occurring radioactive compounds like radium isotopes. Usually, salinity of produced waters is lower than in the case of flowback water. Table 3 presents the composition of typical produced waters from wells drilled in the USA [Clark 2009].

In Poland, technological fluids are not considered waste, but they are not legally accepted in wastewater treatment plants. Technological fluids are most often stored in open containers that enable evaporation of water into the atmosphere. Compounds, such as: carbon dioxide, volatile organic compounds, polycyclic aromatic hydrocarbons, barium and sodium compounds, soluble heavy metal salts, glycols, and nitrogen oxides may infiltrate into soil and groundwater in the form of precipitation or fog.

Table 2. Content of typical chemical compounds in flowback water from wells drilled in the USA [Shramko 2009]

Chemical compound	Concentration [ppm]	Chemical compound	Concentration [ppm]
Alkalinity	100–600	Iron	50–300
Calcium	500–12000	Silicon	50–300
Magnesium	50–2000	Sulphates	10–400
Barium	50–9000	Chlorides	5000–80000
Strontium	50–6000	TDS	1000–150000
Sodium	4000–40000	Ammonia ion	0.58–441
		TOC	1.8–2.2

Table 3. Content of typical chemical compounds in produced water from wells drilled in the USA [Clark 2009]

Chemical compounds	Concentration [ppm]	Chemical compounds	Concentration [ppm]
TDS	1000–150000	Iron	0–228
Magnesium	0–90	Sulphates	0–2300
Barium	50–9000	Chlorides	0–2350
Strontium	50–6000		

Simultaneously, municipal and communal wastewater treatment plants are not prepared to treat such amounts of technological fluids with high content of toxic substances [Babko 2016]. Lack of commonly available information on the shale gas extraction technology raises great concern within the society. Unknown composition of technological fluids, their diversity, as well as the amount of chemical compounds used for their preparation may undoubtedly impact the environment.

Apart from being stored in tanks, these fluids – with prior treatment at the drilling site – may be dumped into rivers. The contract of pumped fluids with ground water may also occur as a result of design errors of a drilled well, especially pertaining to cementing of the vertical part of the well.

Because wells in Poland are drilled mainly in rural areas with blooming agrotourism, shale gas extraction raises even greater concerns of the society related to the pollution of water and infiltration of the pollutants to the produced food. Additionally, media and press present multiple and contradictory information pertaining to the impact of shale gas on the environment in the United States. The USA is a country with richest shale gas deposits and greatest experience in shale gas extraction. By drawing on their experience, it is possible to avoid making mistakes and avert ecological disasters.

The review of literature related to the studies on water from domestic water wells in proximity to drillings performed in the United States confirm that the exploratory and prospecting operations do not impact the quality of potable water in a negative way.

Studies concerning 236 water wells in Pavillion, Wyoming in the USA indicated elevated pH in two wells, high content of potassium and chlorides; however, no raised barium on chromium content was observed in any of the considered wells [Di Giulio 2011]. On the other hand, the studies on groundwater in north-east Pennsylvania indicated elevated content of chlorides, calcium, sodium, and strontium, which is not necessarily connected with the shale gas extraction, but mainly stems from the composition of brine in shale formations [Warner 2012].

The characteristics of technological fluids and the studies conducted in the United States enabled to identify the compounds which may infiltrate to groundwaters. Our studies focused on marking: heavy metals, calcium, sodium, magnesium, potassium, chlorides, and sulphates in waters taken in the vicinity of Lewino well.

MATERIALS AND METHODS

The field studies were carried out in 2015 in Lewino country, located in Pomeranian Voivodeship, Wejherowo County, in Linia Commune in the northern tip of Kashubian Lake District. A shale gas well was drilled there, followed by hydraulic fracturing process. The testing phase of this well concluded in January 2014 and thus far it still remains unexploited.

The study also included part of Bolszewki river, which flows in direct proximity to the drilled well and the shortest distance from the area explored for shale gas amounts to 150m. Moreover, three ponds, located in depressions and filled with stagnant water, were sampled. The distance of these ponds from the well amounted to 350 m (body I), 550 m (body II), 810 m (body III).

The area in the vicinity of the analyzed object comprises agricultural fields, meadows, and local bushes. It is mostly undeveloped and unfenced, which enables a gravitational run-off of water. The river drop is low towards north-east. The altitude of the considered area ranges from 165 to 185 m.

Water samples were collected according to the standard. Following parameters were marked:

- content of chlorides, with argentometric Mohr method,
- concentration of sulphate ions, by means of PBL/CH/28/06 issue 02 out of 07.11.2011, based on HACH 8051,
- content of metals: Ba, Ca, Cd, Cr, Cu, K, Na, Ni, Pb with inductively coupled plasma mass spectrometry ICP-OES JY 238 Ultrace (Jobin Yvon-Horriba France) with prior mineralization of samples in aqua region, in line with PN-ISO 11047 (2001) and PN-ISO 11466 (2002).

RESULTS

Tables 4 and 5 present the concentration of metals, chlorides, and sulphates in water collected from the ponds in Lewino.

No heavy metals were detected in the examined water samples, despite high content of barium in drilling and technological fluids.

The concentrations of barium, chromium, copper, iron, cadmium, lead, nickel, and cobalt in the examined samples from water wells in Lewino are within the standards described in the Resolution of the Minister of Health on the quality of water intended for human consumption [Journal of Laws 2015, item 1989] and meet its requirements.

The content of calcium, magnesium, sodium, potassium, as well as chlorides and sulphates was low in the considered samples of water, despite their high concentration in technological fluids. The examined water is suitable for consumption and does not exceed the values given in the Resolution of the Minister of Health on the quality of water intended for human consumption [Journal of Laws 2015, item 1989]

The concentrations of all the examined parameters in individual study areas are similar. The obtained results confirm that the carried out hy-

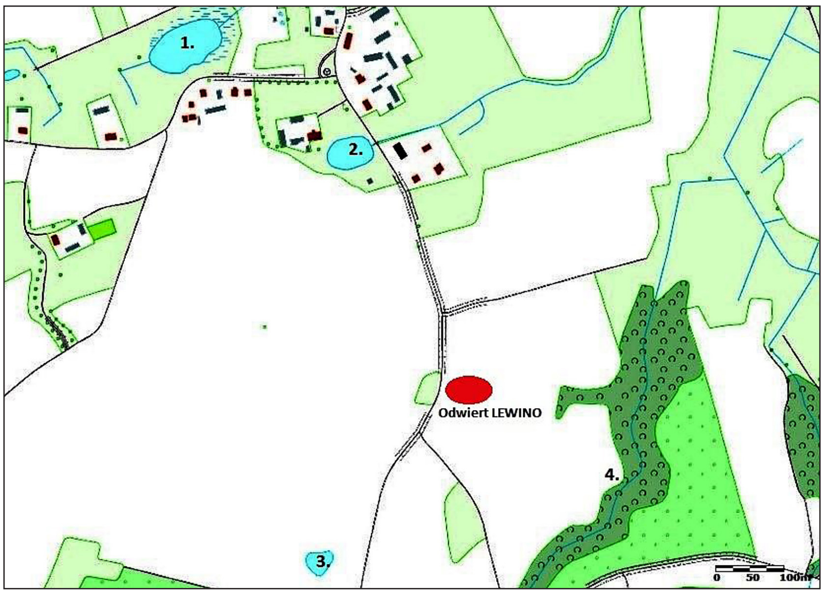

Figure 1. Location of sampling points. Source: http://mapy.geoportal.gov.pl

Table 4. Heavy metal content in the examined water samples from Lewino

Sample	Ba ppm	Cd ppb	Co ppb	Cr ppb	Cu ppm	Fe ppm	Pb ppb	Ni ppb
River	0.03	1.01	1.11	1.952	0.65	155	2.0	2.56
Pond I	0.05	1.07	1.22	1.23	0.54	156	1.01	3.05
Pond II	0.04	1.01	1.45	1.33	0.59	167	1.76	2.99
Pond III	0.03	1.12	1.31	1.11	0.49	164	1.65	3.12

Table 5. Content of alkali metals, chlorides, and sulphates in the examined samples from Lewino

Sample	Ca	Mg	Na	K	Chlorides	Sulphates
	[ppm]					
River	40.315	3.66	4.76	8.55	6.29	79
Pond I	111.89	4.54	9.79	11.95	6.4	85
Pond II	115.6	3.91	8.98	12.0	6.76	81
Pond III	127.1	4.00	9.01	11.65	5.99	83

draulic fracturing process and the utilized technological fluids did not increase the concentration of the considered compounds. Our previous studies on the quality of water from wells in the village of Syczyn also did not show elevated content of these compounds in water samples [Cel 2015].

CONCLUSION

Extraction of hydrocarbons from shale rock formations in Poland is a factor which could improve the power independence of the country. Exploration, extraction, and exploitation of shale gas raise concerns due to the employed technologies and technological fluids, related to the impact on the natural environment, especially aquatic ecosystems.

Carrying out and continuing mining works requires social trust and acceptance, which can be built by improving extraction technologies, mitigate the impact on the environment. However, first and foremost, it requires efficient monitoring methods of the state of the environment.

The current regulations which are in force in many areas may be used efficiently for the assessment of the shale gas extraction impact, but the novelty of hydraulic fracturing process requires devising dedicated procedures for actual evaluation and environmental protection, including natural waters. Monitoring the environment, especially water resources, may be based on the American model, involving constant examinations of water samples in regard to the presence of characteristic substances, called markers.

The water quality studies conducted in vicinity of Lewino well and the presented results of the analyses do not indicate any negative impact of the drilling and hydraulic fracturing process on changes in the quality of nearby waters.

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