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AN ANALYSIS OF FLUIDS AFTER HYDRAULIC FRACTURING IN THE ASPECT OF THEIR FURTHER USE OR NEUTRALIZATION**

1. INTRODUCTION

Hydraulic fracturing connected with the development of drilling technologies, especially horizontal drilling technology, enabled economically justifiable production of natural gas from unconventional sources. It should be also stressed that hydraulic procedures are a standard part of drilling for hydrocarbons from unconventional sources. In fact natural gas extraction from conventional or unconventional sources does not differ much. The most important and environmentally controversial difference is the quantity of used water and fracturing procedures as well as the amount of flowback water from hydraulic fracturing. In conventional reservoirs the amount of water needed for fracturing is about 200 m^3, whereas in the case of shale deposits the required quantity oscillated between about 1,500 m^3 and 2,000 m^3, and even dozen thousand cubic meters of water.

2. WATER DEMAND AND WATER SUPPLY

The report *An analysis of environmental aspects of hydraulic fracturing jobs in Łebień LE-2H well* [1] published in November 2011 reveals that the biggest problems related to hydraulic fracturing is the logistics of fresh water deliveries (artificial water reservoirs have to be made within the mine area), and the processing of fluid after fracturing jobs. In the case of Łebień LE-2H well, surface water reservoirs (6,000 m^3 and 12,000 m^3) had to be constructed. They were filled with water from mine's wells of productivity 10 m^3/h. Water was taken from a production well and an emergency well producing water from Quaternary horizons. The basins were filled from spring to August 2011.

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The basic source of drinking and all-purpose water in the area within which Coal Mine Łebień is located is the Quaternary horizon which is the main useful aquifer (MUA). The depth of groundwater level measured in a well localized within the mine's premises in July 2011 was 14.4 m b.s.; the useful aquifer level within the job area ranged between 10–20 m b.s.

Hydraulic fracturing in a horizontal section of Łebień well was conducted in 13 depth intervals, for which perforation, fracturing and tests were planned. About 1,181.73 m^3 to 1,744.47 m^3 of fracturing fluid with chemical additives, and on average about 100 Mg of proppant were used in particular intervals. On the whole, 17,322.6 m^3 of water were used in 13 intervals of Łebień well to which about 462.09 m^3 of various chemical substances were added. This constituted about 2.5 vol.% of fracturing fluid with 1,271.88 Mg of proppant added.

The water balance of performed hydraulic fracturing job on the example of Łebień LE-2H well is presented in Table 1.

Table 1

Water balance in hydraulic fracturing process performed in LE-2H well [1]

Job	Technological water injected to well [m^3]	Volume of technological backwater in the process duration [m^3]	Volume of backwater from hydraulic fracturing [m^3]
Preparation of well to hydraulic fracturing	324.0	324.0	–
Fracturing	17,784.69	–	–
Drilling plugs	3,131.5	3,131.5	805.5
Gas tests	–	–	1,975.2
Total	21,240.19	3,455.5	2,780.7

Similar volumes of fracturing fluid per one rock interval were used in Warblin LE-1H well (fracturing was performed in a horizontal borehole in seven intervals [15]), in Markowola well (1,423.6 m^3, two fracturing jobs in a vertical well: in interval 3.467–3.462 m b.s. and in interval 3.491 to 3.486 m b.s. [13]), Lubocino LE1-2H well (1 fracturing job in a vertical well in interval 2.894–2.907 m b.s., a total of 1,600 m^3 of fluids were injected [5]).

The average water use per well in unconventional shale gas deposits in the United States is presented in Table 2.

Table 2

Estimated water needs for drilling and fracturing wells in selected shale gas plays in U.S.A. [12]

Shale gas play	Volume of drilling water per well [m^3]	Volume of fracturing water per well [m^3]	Total volumes of water per well [m^3]
Barnet Shale	1,500	8,700	10,200
Fayetteville Shale	600	11,000	11,600
Haynesville Shale	3,800	12,000	14,000
Marcellus Shale	300	14,400	14,700

The comparison of data listed in Tables 1 and 2 about water use per well for unconventional gas deposits in the U.S.A. reveals that the consumption of water used for hydraulic fracturing jobs in the Łebień well was higher than in the case of shale gas wells in the U.S.A. This can be explained by geological setting (permeability, depth of deposition of perspective deposits, etc.) in Poland.

In Poland the effect of drilling works on geological conditions should be viewed through frac procedures and water consumption from the same main useful aquifers (MUA). This stems from the fact that many perspective gas fields are covered by the same MUA, e.g. Łebień LE-2H, Warblino LE-1H and Lubocino LE1-2H wells; only Łebień field consumed water for five months at a rate of 10 m^3/h (see the map in Figure 1).

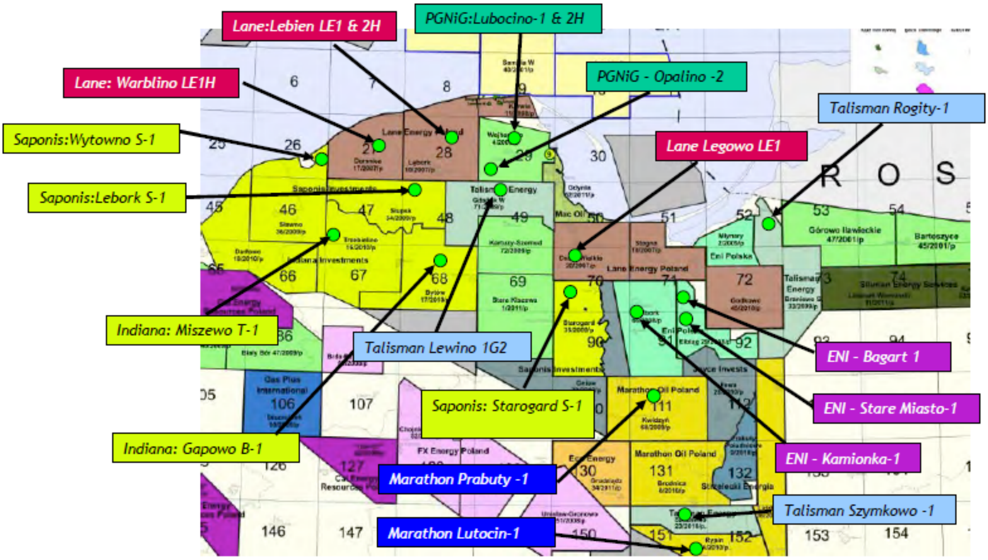

Fig. 1. Shale gas prospecting in the Baltic Basin area [15]

Additionally, the monitoring of groundwater level in wells localized close to the coal mine seems to be necessary. It is also worth noting that numerous main useful aquifers can be found in the shale rock areas in Poland which are qualified as the highest protection areas and high protection areas [11].

In the U.S.A. water needed for shale gas recovery is supplied to the rig area by pipelines or cisterns, mainly from surface waters (rivers, lakes), groundwater, private or municipal waters and recirculated waters from technological processes [3]. A slightly different situation is observed in Poland. Frac water is taken from special wells in the mine's area. This stems from the fact that waterworks in Poland have only small reserves, and surface water coming from rivers is mostly of low quality, requiring prior treatment. Presently in Poland groundwater is mainly used for consumption and is a source of drinking water for about 70% of Poles [7]. Surface water supplies remain the major sources of water utilized by agriculture and industry.

Poland belongs to a group of countries with the lowest reserves of regular waters in the Old Continent, therefore is frequently called the “Egipt of Europe”. Total recoverable water resources (yearly mean of a multiannual period) were determined as of 63 km^3, which in comparison to other European countries, e.g. Norway (391 km^3) or Turkey (234 km^3) is indicative of a considerable shortage of water available for the national economy and household purposes. According to statistics, in 2008 Poland had 1,426.5 m^3 of surface water and 444.3 m^3 of groundwater per inhabitant. Huge oscillations of annual water flowback and the uneven distribution of production and consumption of groundwater and surface water in Poland creates another problem [19].

Accordingly, it seems important to monitor water production from the same main useful aquifer for hydraulic fracturing purposes as excessive exploitation may result in lowering of water resources and reducing the amount of water for hydraulic fracturing. Besides optimal cleaning methods for treating post-fracturing water should be also worked out.

It is also worth noting that the amount of water to be used in the hydraulic frac procedures will mainly depend on the type of fractures formation (shales, coal beds) and the type of job (length of borehole, type of fracturing fluid, plan of frac job) [14].

3. SELECTED LEGAL REGULATIONS AND RESULTANT OBLIGATIONS ON PRODUCTION WASTE

Works connected with natural gas prospecting and extraction from unconventional deposits generate the following types of production waste [4]:

- solid waste, e.g: cuttings, clay, barite, salt, cement, etc.;
- waste in the form of technological fluids, e.g.: drilling mud; sealing slurries, process and post-process (fluids acid solutions, emulsions, gels, microgels, surfactant solutions and other chemicals) and overpacker fluids (e.g. brines);
- waste in the form of reservoir fluids: formation water-brine, oil-water emulsions and other oil-based products, acid gases (hydrogen sulfide and carbon dioxide);
- technological waste coming from oil and natural gas treatment for transport purposes (glycol, methanol, etc.).

The basic Polish document regulating the production waste issue is the law about production waste (Official Journal 131 item 865 with amendments) of 10 July 2008 being a transposition of EU Directive 2006/21/UE about production waste management. According to the regulation the Investor or Contractor is obliged to have a decision on the production waste management program [20].

According to art. 4 pt. 1 of the law about production waste a unit producing waste has the following obligations:

- Look for such methods of prospecting, recognition, extraction, processing and storing which would protect against production waste production or maintain it on the lowest possible level and also limit negative environmental impact or threat to the human health and live, accounting for the best available techniques spoken of in art. 3 pt. 10 of law of 27 April 2001 – *Environmental Protection Law*.
- Introduce limitations resulting from the negative impact of production waste on the environment, human life and health, accounting for the best available techniques.

- Recover production waste firstly, if not possible for technological reasons or unjustified economically, neutralize the waste in line with environmental requirements or production waste management program, accounting for the best available techniques.
- Transfer production waste, which cannot be recovered for technological or economic reasons, to places where it can be neutralized with the best available techniques mentioned in art. 3 pt. 10 of law of 27 April 2001 – *Environmental Protection Law*, especially to objects specializing in production waste neutralization.

4. PROBLEMS RELATED TO FRACTURING FLUIDS UTILIZATION

While conducting natural gas prospecting and production from unconventional deposits attention should be paid to the correct management of waste brought about in the course of drilling and hydraulic fracturing jobs.

According to the law about production waste, the most advantageous and permanent solution of the production waste issue would be limiting its generation, and if it is not possible, to manage it, use several times, treat and reuse and recover the minerals.

If the type of waste, its chemical composition and ways of it managing in Poland are well known, the question of backfluid generated in the process of hydraulic fracturing is a novelty arising controversy among society. Another potential problem may be related to the lack of expertise in hydraulic frac jobs. North America countries have spent many years working out an advantageous and environmentally acceptable technology of backfluid neutralization. Besides, the countries also differ in their law. In the U.S.A. post-frac fluid is not considered to be a waste – it is treated as sewage. According to this classification the investor or his contractor may decide about further activities on post-facturing fluids. In Poland post-frac fluid is classified as production waste on the basis of a law about waste and a law about production waste.

Flowback fluid was not given a separate code in the catalog of wastes; it has been labeled as [20]:

- 01 01 02 – waste from the extraction of raw minerals other than metal ores,
- 01 05 06* – drilling muds and drilling waste containing hazardous substances,
- 01 05 08 – drilling muds containing chlorides and other waste than listed in 01 05 05 and 01 05 06,
- 01 05 99 – other, not mentioned waste.

The quality and quantity of the flowback is a function of a number of key factors:

- quality of the initial source water used to make the frac fluid,
- frac fluid chemical program,
- formation geology,
- contact of the frac fluid with formation waters,
- time the fluid spends both underground and on the surface after the frac.

The main component of fracturing fluid is water therefore its quality will affect the quality of the fracturing fluid. Another factor influencing the post-frac fluid quality is the type and amount of chemicals added to the fracturing fluid. It should be emphasized that fluids used for fracturing are multicomponent mixtures of materials and chemical agents, the presence and mutual interactions of which decide about their technological usability. The potentially hazardous environmental influence of frac fluid depends on the type and concentration of its components. The type of chemical agents added to the fracturing fluid depends on the geology of drilled rocks; also geological formation has an influence on the quality of post-frac fluid. During the fracturing job the fluid creates an interface between the geological formation; the dissolved salts and minerals making up the geological formation returns to the surface with the flowback water. The amount of dissolved materials in fluid depends on geological formation and the duration of fluid-rock contact. The longer the fluid remained in contact with the reservoir rock, the more total dissolved solids (TDS) were present in it [8].

The American experience reveals that most of the flowback was observed during the first hours (to a few days). There are however known cases when it lasted a few months. The dynamics of this outflow decreases with time, which mainly results from a drop in pressure in the well followed by decreasing saturation of rock with fluid and drop of permeability for the liquid phase. The drop in phase permeability with respect to fluid finally leads to the vanishing of the flow and capturing of its part in pores and micropores of the reservoir rock. Additionally, the drop of pressure results in the closing of fractures, which have not been backfilled and the trapping of part of the fluid inside. As a consequence, the backfill covers only part of the injected fluid, i.e. about 20–70%. About 2–30%, max. 50% of flowback is related with horizontal wells, and about 50–70% with vertical wells [6, 12, 21].

As a result of contact with reservoir fluid the fracturing fluid interacts with the rock mass. As shales are natural sorbents, the desorption effect takes place to a bigger or smaller degree, depending on the type of shale. Desorption, i.e. washing out of elements sorbed by source rock, depends on the duration time of the frac fluid / rock contact. It should be also observed that fracturing fluid mixes with reservoir water filling part of the rock pores. As a consequence, the chemical composition of flowbacking water is different from that of the injected fluid; this change is even more distinct when the fracturing fluid remains in contact with the rock for a longer time. The chemical composition of the backfluid and its relation against the time of the backfluid / rock contact is presented in Figure 2 [16].

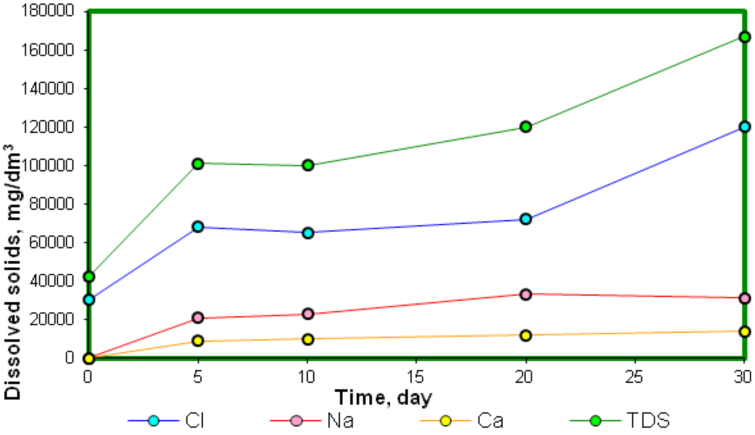

Fig. 2. Chemical composition of backwater after hydraulic fracturing vs. time of flowbacking to surface [16]

The chemical composition of flowback in a function of quantity of fluid returning to the surface exemplified by Marcellus Play is presented in Figure 3 and the volume of post-frac fluid returning to the surface within 1, 5, 14 and 90 days in Figure 4. The data come from a few wells in Marcellus Play.

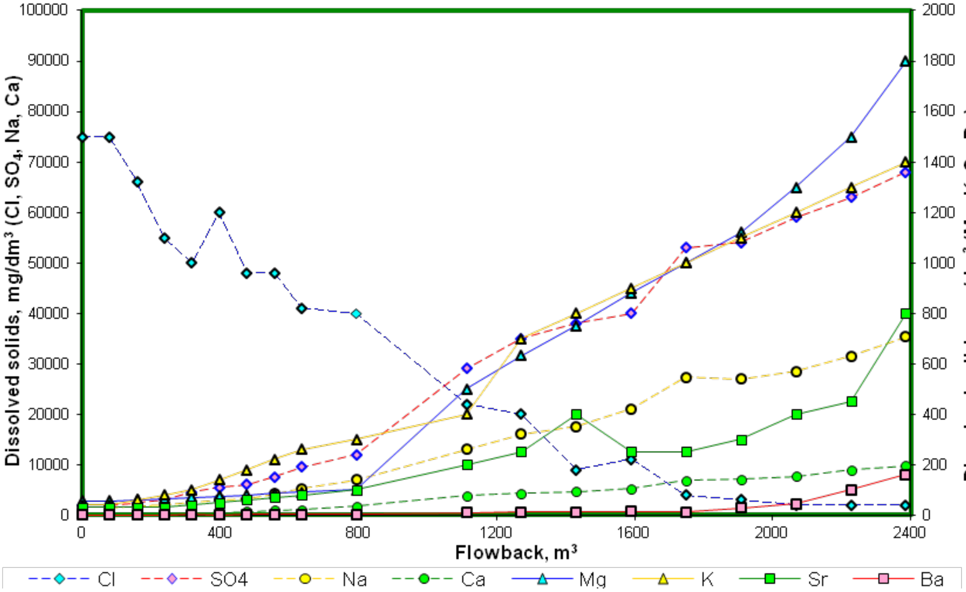

Fig. 3. Marcellus Shale Well A flowback analysis – major cation and anion trend vs. volume of flowback water [2]

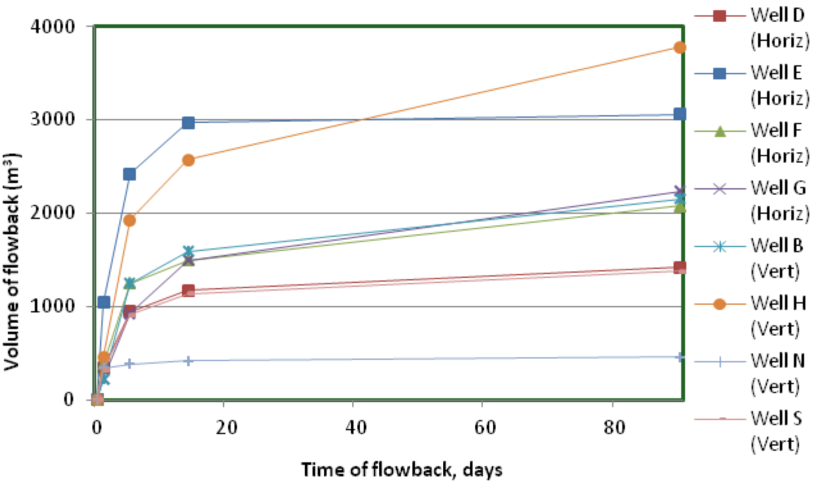

Fig. 4. Volume of flowback water vs. time of flowback from Marcellus wells [9]

The chemical composition of post-frac job is modified. At earlier stages following up the fracturing job, most of the flowbacking fluid consists of injected water, however with time the amount of returning fluid decreases whereas their mineralization and total dissolved solids (TDS) increases. Simultaneously, apart from dissolved solids, e.g. chlorides, the fracturing fluid may be also composed of sulfides, bromides as well as ions of sodium, potassium, calcium, magnesium, strontium, barium, heavy metals, etc. Their quantity and chemical composition vary and depend on local geological conditions. A comparative flowback analysis of various U.S.A. shale plays is presented in Table 3.

Table 3

Flowback analysis from various U.S.A. shale plays [8, 17]

Component	Shale play					
	Fayetteville	Marcellus	Barnett	Eagleford	Bakken	Haynesville
Cation						
Na^+ [mg Na^+/l]	13,804.00	24,445.00	10,741.00	10,900.00	45,100.00	34,879.00
K^+ [mg K^+/l]	256.00	190.00	484.00	192.00	3,550.00	735.00
Mg^{2+} [mg Mg^{2+}/l]	293.00	263.10	316.00	111.00	720.00	828.00
Ca^{2+} [mg Ca^{2+}/l]	1,046.00	2,921.00	2,916.00	1,270.00	9,020.00	7,052.00
Sr^{2+} [mg Sr^{2+}/l]	267.00	347.00	505.00	203.00	–	1,354.00
Ba^{2+} [mg Ba^{2+}/l]	18.00	679.00	15.00	10.00	13.00	1,121.00
Mn^{2+} [mg Mn^{2+}/l]	0.50	3.90	44.00	–	–	–
Fe^{2+} [mg Fe^{2+}/l]	0.00	25.50	28.00	112.00	77.00	147.00
Anion						
SO_4^{2-} [mg SO_4^{2-}/l]	13.00	4.00	309.00	163.00	440.00	–
HCO_3^- [mg HCO_3^-/l]	6,161.00	261.40	405.00	736.00	126.00	382.00
Cl^- [mg Cl^-/l]	23,856.00	43,578.40	23,797.50	19,318.00	91,300.00	71,143.00
Other						
Total Dissolved Solids TDS	45,725.00	72,714.00	39,516.00	33,015.00	150,346.00	117,641.00
Total Suspended Solids TSS	700.00	–	1,272.00	840.00	–	868.00

Another comparison was made in Table 4 where the laboratory analyses of technological fluids used for hydraulic fracturing in Łebień LE-2H well were presented.

Table 4

Laboratory analyses of technological fluids used for hydraulic fracturing in Łebień LE-2H well [2]

Component	Sample			
	flowback fluid treated after drilling the third plug	flowback fluid after drilling the sixth plug	filtered flowback fluid (treated), the second day after drilling all plugs	technological water from open basin no. 1, one day after drilling all plugs
pH	6.35	5.80	6.72	5.73
SPCA (surfactants) [mg/l]	<0.5	8.0	31.0	6.0
Cations				
Na^+ [mg Na^+/l]	2,118.00	2,164.00	22,596.00	2,423.00
K^+ [mg K^+/l]	82.00	123.00	536.00	130.00
Mg^{2+} [mg Mg^{2+}/l]	31.00	51.00	759.00	62.00
Ca^{2+} [mg Ca^{2+}/l]	318.00	531.00	7,568.00	620.00
Sr^{2+} [mg Sr^{2+}/l]	25.80	46.70	856.90	61.00
Ba^{2+} [mg Ba^{2+}/l]	2.50	3.80	40.10	4.00
Mn^2 [mg Mn^{2+}/l]	1.44	1.24	11.32	1.78
Fe^2 [mg Fe^{2+}/l]	23.40	17.40	22.20	17.60
Anions	82.00	123.00	536.00	130.00
SO_4^{2-} [mg SO_4^{2-}/l]	52.00	<5.00	<150.00	<5.00
HCO_3^- [mg HCO_3^-/l]	211.00	243.00	509.00	270.00
Cl^- [mg Cl^-/l]	4,100.00	4,500.00	48,000.00	5,200.00

In color: highlights exceeding highest admissible contaminants in industrial waste: in compliance with App. no. 3 to the Regulation of the Minister of Environment of 24 July 2006 about conditions to be met when introducing sewage to water or to the ground, and about very hazardous substances for water environment.

The analysis of data listed in Tables 3 and 4 reveals that the composition of fracturing fluids varies and depends on:

- particular stages of jobs performed in wells,
- the duration of the fracturing fluid/reservoir rock contact,
- the type of fracturing fluid,
- the local geological conditions.

At the same time, the data in tables 3 and 4 show that the properties of the frac backfluid also change, though generally have large loads of chemical substances and are highly toxic. Among the most troublesome contaminants both in flowback water from various U.S.A. Shale Plays and in flowback water from Łebień well creating considerable hazard for ground and water environment are soluble salts of alkaline metals in the form of excessive chlorides, sulfides, carbonates hydrogen carbonates, as well as limited quantities of Total Suspended solid (TSS) and Total Dissolved Solids (TDS) components, i.e. liquid hydrocarbons and surfactants.

The quantity of surfactants, TDS, toxic heavy metals and moderately toxic metals, e.g. manganese or iron is taken into consideration when determining the toxicity level of drilling fluids and their environmental impact. Data presented in Table 4 are indicative of the fact that most of the toxic substances listed there exceed admissible standards. Accordingly, no such substance can be introduced to the water-ground environment without prior treatment. The main objective of the correct backfluid management should be obeying the respective legal regulations and tending to the minimization of the amount of this type of waste through cleaning and directing it to reuse.

5. METHODS OF FRACTURING FLUIDS UTILIZATION

For establishing potential management of flowback fluid and determining the types of processes to which post-frac backfluid should be subjected to properly adjust it to reuse or cleaning – the chemical composition of such fluid must be known. Therefore, complete chemical composition analyses of post-frac fluids should be made and so that on the basis of the obtained results a proper management method or further utilization or reuse can be selected.

The quality of water used to develop the frac fluid and see how this impacts upon well production is a critical factor in developing a water management strategy. Multivalent ions (Fe, Ca, Mg, Ba, Sr) and chlorides in the water can limit friction reducer effectiveness and drive up horsepower costs for the producer's frac pumping job. The type and dose of friction reducer can be adjusted to accommodate for higher TDS water but at an added costs. Bacteria in the frac fluids can cause formation biofouling, reducing permeability and gas production. The presence of sulphate reducing bacteria (SBR) can hydrogen sulphide (H_2S), making the well sour, creating making the well sour, creating safety issues and increasing overall costs. Metal in the water, specifically iron, can oxidize and form deposits, reducing permeability and gas production. Suspended solids in the frac fluid such as sand, silt, clays and, scale particles can lead to a reduction in permeability and gas production [8].

A few years ago the main limitation in the recycled water use was the high salt ions content (it should not exceed 30,000 mg/l.) Over time new fracturing chemicals have been developed specifically to address the chemistry of recycled fluids, but there are still limitations on the constituents that may be present in mixing a high quality hydraulic fracturing fluid with recycled water. The most current list of limitations was taken from the New York SGEIS, shown in Table 5 [10].

Table 5

The maximum levels of constituents that may be present to reuse waste fluids for hydraulic fracturing mixtures in 2011 [10]

Component	Level
Chlorides	3,000–90,000 mg/l
Calcium	350–1,000 mg/l
Barium	low levels
Entrained oil and soluble organics	<25 mg/l
Total Suspended Solids (TSS)	<50 mg/l
Bacteria	<100 cells/100 ml

The analysis of data presented in table 5 reveals that new-generation substances added to frac fluids tolerate salinity even at a level of 90,000 mg/l; if this level is exceeded the fluid is diluted with fresh water. It should be also stressed that when water is planned to be reused for fracturing purposes, bacteriological control is very important. Another challenge related to the post-frac fluid use is the total dissolved solids (TDS) content and total suspended solids (TSS) content.

Several reuse parameters, most notably TDS, have increased dramatically since reuse for hydraulic fracturing was initially considered. However, based on the range of contaminants shown in fracking and brine wastewater (see Table 3) much of the waste must be treated in some way prior to reuse. The levels to which the flowback fluid should be treated to enable its reuse or recycling are presented in Table 6.

The analysis of data listed in Table 6 shows that cleaning processes have to be applied if we want to obtain such parameters of post-frac fluids which would allow for their further reuse as basic fluids or an additive to a new fracturing fluid.

Among them are:

- removal of sediments and suspensions: filtration and coagulation; presently the conventional water pretreatment tends to be substituted with microfiltration or ultraflotation;
- removal of hydrocarbon contaminants: flotation, sorption, hydrocyclones, biodegrading of contaminated oil-products with the use of biopreparers based on microorganisms responsible for the oil-products decomposition, ceramic membranes [18].

If the admissible salinity level of the received fluid is exceeded, salt should be removed and fluid utilized.

There are a variety of different treatment technologies that are used by advanced Centralized Waste Treatment (CWT) facilities, and of these have different energy, quality, and cost requirements. The most commonly discussed advanced treatment options are reverse osmosis, thermal distillation, electro-dialysis, and ion exchange. Various advanced treatment options which are able to manage relatively low levels of TDS in the influent are presented in Table 7.

Table 6

Possible levels post-frac fluid treatment [8]

Re-use treatment	Level 0 – no treatment, direct blending of flowback with make-up water	TSS – no change TDS – no change 100% available for re-use
	Level I – basic TSS removal	TSS <25 mg/l TDS – no change 100% available for re-use
	Level II – Low Polish, basic TSS removal followed by membrane filtration	TSS – filtered to 5 µm TDS – no change 100% available for re-use
	Level III – High Polish, basic TSS removal followed by membrane filtration	TSS – filtered to <1 µm TDS – no change 100% available for re-use
	Level IV – selective ion removal, basic TSS removal followed by membrane filtration and ion exchange or nanofiltration	TSS – filtered to <1 µm TDS – divalent ions removed as required 100% available for re-use
Recycle treatment	Level V – distillation, basic TSS removal followed by MVR evaporator (TDS removal)	TSS <10 mg/l TDS <100 mg/l 60–90% available for re-use
	Level VI – crystallization, basic TSS removal followed by MVR evaporator and crystallizer (TDS removal) or direct fired evaporator	TSS <10 mg/l TDS <100 mg/l 100% available for re-use

Table 7

Factors for various advanced treatment options to remove TDS [10]

Treatment	Energy cost	Energy input relative to TDS	Applicable to	Pretreatment requirement	Final water TDS [mg/l]	Use
Ion exchange	low	low increase	all waste	filtration	200–500	yes, Montana and Wyoming
Reverse osmosis	moderate	increase	moderate TDS	extensive	200–500	yes, Texas and proposed Pennsylvania
Electro-dialysis reversal	high	high increase	high TDS	filtration	200–1000	–
Thermal distillation	high	independent	high TDS	minimal	<10	yes, Texas and Pennsylvania
Ozone/ Ultrasonic/ Ultraviolet	low	increase	all water	filtration	variable	yes, Texas

The current produced water management of post-frac fluid by shale gas basin in U.S.A. is presented in Table 8.

Table 8

Current produced water management by shale gas basin in U.S.A. [12]

Shale gas basin	Water management technology	Availability	Comments
Barnett Shale	class II injection wells	commercial and non-commercial	disposal into the Barnett and underlying Ellenberger Group
	recycling	on-site treatment and recycling	for reuse in subsequent fracturing jobs
Fayetteville Shale	class II injection wells	non-commercial	water is transported to two injection wells owned and operated by a single producing company
	recycling	on-site recycling	for reuse in subsequent fracturing jobs
Marcellus Shale	class II injection wells	commercial and non-commercial	limited use of class ii injection wells
	recycling	on-site recycling	for reuse in subsequent fracturing jobs
	treatment and discharge	municipal waste water treatment facilities, commercial facilities reportedly contemplated	primarily in Pennsylvania
Woodford Shale	class II injection wells	commercial	disposal into multiple confining formations
	land application	–	permit required through the Oklahoma Corporation Commission
	recycling	non-commercial	water recycling and storage facilities at a central location
Haynesville Shale	class II injection wells	commercial and non-commercial	–
Antrim Shale	class II injection wells	commercial and non-commercial	–
New Albany Shale	class II injection wells	commercial and non-commercial	–

The data presented in Tables 7 and 8 show that deep injection to the rock mass is one of the most popular and economically feasible methods of post-frac flowback fluid utilization both in the U.S.A. and Canada. The remaining methods lie in cleaning and reuse in fracturing procedures, and in extreme cases, directing to sewage treatment plants followed by utilization for agricultural purposes.

In Poland the flowback water management cannot rely mainly on flowback fluid injection to the rock mass because of the present regulations, and also hydrogeological and hydrological conditions (water supplies may turn out insufficient), character and environmental aspects which have to be accounted for, more advantageous also because of the public opinion if the backfluid is reused-recycled. At the same time one should expect that the continuous development of industry and new technologies will result in more innovative solutions providing more complex economic processing of backfluid. It should be also mentioned that petroleum concerns, services and academic circles focus their research on limiting the negative impact of fracturing fluids on natural environment.

6. RESUME

1. Presently, the hydraulic fracturing of shales is the key process employed for natural gas production, but unluckily these processes require large amounts of water for preparing fracturing fluids. Now in Poland, such water is of groundwater origin, which does not seem rational because these are the main sources of drinking water. Accordingly, attempts should be made to recover water mostly from the surface and make the amounts minimal.
2. For minimizing the amount of water used for fracturing, flowback water should be subjected to cleaning so that it can be reused for hydraulic fracturing again. This procedure is congruent with the relevant legal regulations; according to the waste management principles referred to in art. 7 par. 2 and 3 of the law on waste the owner of waste is obliged to primarily recycle the waste, otherwise, when it turns out to be technologically or environmentally or economically impossible the waste should be neutralized in line with environmental regulations. Accordingly, an efficient method of managing post-frac fluids should be worked out bearing in mind that the deposition of waste can be applied only to waste which cannot be recovered or neutralized otherwise. Deposition should be the last element in the waste management chain.
3. The technology of cleaning flowback water should enable longest possible use of backfluid in the successive technological processes. The technology of cleaning flowback fluids is determined with a number of factors, e.g. price, transport, availability of water and removability of waste, especially waste containing radionuclides. It should be also mentioned that the profitability of a given method has environmental and technical issues as well as legal aspects. However, the superordinate principle governing shale gas prospecting and extraction is the principle of rational use of water, safeguarding the needs of future generations and environmental protection.
4. The organization of reception and proceeding with post-frac fluid requires decisions about the way in which it is going to be managed. Various solutions are possible, e.g. storing, recycling *in situ*, recycling beyond the mining area, etc. The composition of the fluid will have a great impact on the undertaken measures. Re-use of recycled water is limited because of the applied additives. The complexity of this issue stems from, e.g. salinity, TDS, TSS, pH, presence of hydrogen sulfide and surfactants. In this situation the changing parameters should be monitored.

5. According to the Polish Law, post-frac backfluid cannot be injected to rock mass without prior treatment, as this is the case in the North American countries nowadays. Therefore, working out an efficient technology of cleaning post-frac fluids is a must now.
6. Concluding, challenges still are being undertaken and progress is being made. New technologies and new variations of old technologies are being introduced on a regular basis, and some industry researchers are pursuing ways to reduce the amount of treatment needed.

REFERENCES

[1] *Badania aspektów środowiskowych procesu szczelinowania hydraulicznego wykonanego w otworze Łebień LE-2H. Raport końcowy*. Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy, Warszawa, listopad 2011.

[2] Blauch M., Myers R.R., Moore T., Lipinski B.A., Houston N.A.: *Marcellus Shale Post-Frac flowback Waters – Where is All the Salt Coming from and What are the implications?* SPE Eastern Regional Meeting, 23–25 September 2009, Charleston, West Virginia, USA, pp. 1–20.

[3] Bujakowski W., Tomaszewska B.: *Zarys problematyki wodno-środowiskowej w aspekcie technologii eksploatacji gazu łupkowego*. Bezpieczeństwo Pracy i Ochrona Środowiska w Górnictwie, nr 6, 2011, pp. 21–26.

[4] Dubiel S., Jamrozik A., Matyasik A., Ziaja J.: *Problems related to oil and gas mining waste deposition in view of legal regulations*. AGH Drilling, Oil, Gas, vol. 29, no. 3, 2012, pp. 403–410.

[5] *Gaz z łupków*. Polskie Górnictwo Naftowe i Gazownictwo SA, Department of Prospecting, [on-line:] http://www.pgnig.pl/pgnig/gaz-z-lupkow [access: September 2013].

[6] Grzybek I.: *Techniczne i środowiskowe aspekty pozyskania gazu łupkowego*. Bezpieczeństwo Pracy i Ochrona Środowiska w Górnictwie, nr 6, 2011, pp. 12–20.

[7] Herbich P.: *Bilans wodnogospodarczy wód podziemnych z uwzględnieniem oddziaływań z wodami powierzchniowymi w dorzeczu Wisły: informator Państwowej Służby Hydrogeologicznej*. Państwowy Insytut Geologiczny – Państwowy Instytut Badawczy, Warszawa 2012.

[8] Horner P., Halldorson B., Slutz J.: *Shale Gas Water Treatment Value Chain – A Review of Technologies, including Case Studies*. SPE Annual Technical Conference and Exhibition, 30 October – 2 November 2011, Denver, Colorado, USA, pp. 1–10.

[9] Kirby C.S.: *Inorganic Geochemistry of Pennsylvania Marcellus Flowback Waters*. US EPA Hydraulic Fracturing Workshops, Arlington VA, February 24, 2011, pp. 1–48.

[10] Lewis A.: *Wastewater Generation and Disposal from Natural Gas Wells in Pennsylvania*. Nicholas School of the Environment, Duke University, May 2012.

[11] Macuda J., Hadro J., Łukańko Ł.: *Środowiskowe implikacje gazu łupkowego*. Bezpieczeństwo Pracy i Ochrona Środowiska w Górnictwie, nr 6(202), 2011, pp. 3–11.

[12] *Modern Shale Gas Development in the United States: A primer prepared for U.S. Department of Energy*. Office of Fossil Energy and National Energy Technology Laboratory, Ground Water Protection Council and All Consulting, April 2009.

[13] *Otwór badawczy Markowola-1 jako przykład działań prowadzonych z troską o środowiska*. Polskie Górnictwo Naftowe i Gazownictwo SA, Rzeszów 2011, [on-line:] http://www.wios.rzeszow.pl/cms/upload/edit/file/Konferencja%2010_2011/Otwor_badawczy_Markowola.pdf [access: September 2013].

[14] *Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*. EPA Hydraulic Fracturing Study Plan, EPA/600/R-11/122, Office of Research and Development US Environmental Protection Agency, Washington 2011.

[15] *Shale gas in Poland. An introduction to 3Legs Resources*. 3Legs, February 2012, [on-line:] http://www.3legsresources.com/wp-content/uploads/2013/06/Brussels-presentation-Feb-20121.pdf [access: September 2013].

[16] Skousen J., Ziemkiewicz P.: *Reclamation of Marcellus Shale Drilling Sites in West Virginia*. West Virginia University, 2009.

[17] Slutz J., Anderson J., Broderick R., Horner P.: *Key Shale Gas Water Management Strategies: An Economic Assessment Tool*. SPE/APPEA International Conference on Health, Safety, and Environment in Oil and Gas Exploration and Production, Perth, Australia, 11–13 September 2012, pp. 1–15.

[18] Steliga T., Uliasz M.: *Wybrane zagadnienia środowiskowe podczas poszukiwania, udostępniania i eksploatacji gazu ziemnego z formacji łupkowych*. Nafta – Gaz, R. 68, nr 5, 2012, pp. 273–283.

[19] Syposz-Łuczak B.: *Gospodarowanie wodami powierzchniowymi i podziemnymi w Polsce*. Technika Poszukiwań Geologicznych, R. 49, nr 1–2, 2010, pp. 151–160.

[20] *Ustawa z dnia 10 lipca 2008 r. o odpadach wydobywczych*. Dz. U. 2008 nr 138, poz. 865 [*Law of 10 July 2008 about production waste*. Official Journal 2008 no. 138, item 865 with amendments].

[21] Willberg D.M., Steinsberger N., Hoover R., Card R.J., Queen J.: *Optimization of fracture cleanup using flowback analysis*. SPE 39920, SPE Rocky Mountain Regional / Low-permeability Reservoirs Symposium and Exhibition, Denver, 5–8 April 1998, pp. 1–13.