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Hydraulic Fracturing – Postscriptum. A geologist's attempt to summarize what we know and where we go

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Key words: hydraulic fracturing, natural gas, unconventional gas, global energy, global climate, methane, CO_2, coal, greenhouse gas

1 Introduction

During my professional life as a geologist there has never been a geoscience topic so hotly and emotionally debated as is the case with the concept and application of hydraulic fracturing, the only likely exception being the geological concepts surrounding nuclear waste disposal. There has also rarely been a topic in geology and subsurface-engineering that has led to such violent opposition and attacks. Many geoscientists – grown up in the belief that science was largely a matter of logical debate where rational arguments, empirical facts and observations prevailed – were caught off-guard by this wave of rejection and had difficulties adapting to a new world in which the knowledge of scientific facts and arguments was not good enough anymore. Scientists discovered that there was a need to explain their lines of thought to a large, often sceptical – if not hostile – public. They also discovered that the trust of the public in scientific judgment and wisdom had been seriously impaired; a loss of credibility caused to a large extent by the scientific community itself which did not deem necessary to «sell» its arguments outside its own circles. The scientific community has now become aware that talking to the media, the politicians and the greater public has become a must in order to be heard beyond the «ivory tower». This applies not only to hydraulic fracturing but also equally to other geoscientific activities that are in the public focus (e.g. waste disposal, mining, large engineering works, exploration for fossil fuels). In Europe the time of innocence of the geoscience community appears to be definitely gone and it will take a long, tedious effort at all levels to re-establish a new base of confidence.

A second aspect of the discussion on hydraulic fracturing is the speed with which opposition to the technology has spread. During over 60 years hydraulic fracturing was practiced in Europe with many thousand frac jobs carried out in Germany, NL, UK, Denmark and Norway. This occurred without any known accidents or any impairment to the environment and was accepted by the authorities as a routine process, necessary for increasing flow rates from poor reservoirs, be it oil, gas or water. As recently as five years ago, hydraulic fracturing was a process unknown to anybody outside the technical world and the mining authorities. This changed after 2010 when the film «Gasland» stirred up opposition against hydraulic fracturing and unconventional gas

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in some parts of the US. The pictures in the feature play in an emotionally very suggestive way to the fears of the broad public. Unease exists in the greater public with anything that impacts the ground under our feet or the quality of our drinking water as the lifeline of humans. The approach of the film is best characterized by the cover picture, showing the author playing banjo in front of a drilling rig with a gas mask on his face. Although in the meantime most of the accusations of the film have proven to be wrong – not by industry but by the environmental authorities in the US – the pictures of burning water taps, gas seeps in scenic streams and murky water samples have long started to lead their own life. Within a year the pictures had spread to Europe and – true to the rule: only bad news is good news – there is today no television debate without a diligent replay of the alleged horror pictures. Many unfounded ideas prevail even though in the meantime a second film by an Irish Journalist («Fracknation») has tried to confront «Gasland» with the real facts. It is possible that without the film «Gasland», hydraulic fracturing would still be a technical term, known to few technical insiders only and we could devote ourselves to the more urgent environmental problems of this planet.

Having said this, it is fully understandable that the public is concerned by the many accusations and doubts raised about the technology. The scientific community has, therefore, the duty to provide insight and contribute as much as possible to factual arguments. Getting back to a rational discussion is also essential since a potential ban on hydraulic fracturing would also severely endanger deep geothermal projects that have to rely on creating artificial heat exchangers, requiring extensive fracturing of the reservoir rock.

2 Hydraulic Fracturing: Criticism vs. Facts

The process of hydraulic fracturing is confronted with the following main points of criticism:

- Artificially created fractures can reach the surface or intersect aquifers of drinking water, thus creating pathways for possible pollutants.
- Additives to fracturing or drilling fluids are toxic and a hazard to drinking water as well as to the water in the fractured reservoirs.
- Hydraulic Fracturing uses large quantities of freshwater.
- Hydraulic Fracturing causes earthquakes.
- Unconventional gas production leads to excessive land use.
- In the course of the hydraulic fracturing and the later gas production large quantities of methane leak into groundwater, the soil and into the atmosphere.
- Hydraulic fracturing leads to heavy traffic during the operations.
- Wells stimulated by hydraulic fracturing have high decline rates, dropping to negligible levels within months. Shale gas production requires continuous high levels of drilling and unconventional gas is, therefore, not sustainable and largely uneconomic.

Some of the above issues have indeed been areas of concern during the earlier «gold rush» boom time of unconventional gas exploration in the US. Most of the problems have in the meantime been resolved (partly due to more severe regulations, partly through self-control of industry in an effort to keeping the licence to operate). It has to be noted that the majority of the critical points have never been issues in Europe, given the fact that European legislations have already introduced a much stricter control and regulation of deep-well-drilling, well integrity and hydraulic stimulations.

At the risk of duplicating the statements in some of the other papers in this special volume of the Bulletin, I like to sum up briefly the present state of knowledge, relating to the above criticism. The factual arguments for the statements below can be found in the following publications: Emmermann (editor) 2014, EASAC 2014, Reinicke 2014, Reichetseder 2014, Burri & Leu 2012, Burri & Häring 2014 and Burri 2014.

Hydraulic fractures reach the surface and create pollution pathways to the drinking water aquifers

- Microseismic measurements allow a very precise mapping of the extension of artificial hydraulic fractures.
- Fracture volume cannot exceed the volume of fluid injected. With the limited injected volumes and pressures, a creation of vertical fractures over 1.000 and more metres is physically not possible.
- In the very rare cases where leaks into aquifers have been observed, they have been caused by poor well integrity, defect casings or poor cement jobs.

Conclusion: There is no proven case where hydraulic fracturing has created a vertical fissure as a pathway extending from depths of > 1.000 m to surface.

Toxic additives in fracking and drilling fluids

- Potentially harmful substances have indeed been used in some of the US operations. Recent developments in Europe have, however, led to a reduction to only two additives, both non-toxic and biodegradable (recent publication Exxon Germany).
- Additives used in Germany in the past are classified by the authorities at the lowest water-hazard level (in concentrated form); liquid agricultural manure belongs to the same category. In contrast to manure (spread at a few 10 m above groundwater) the frac additives are, however, diluted by a factor of about 1:100 and are injected in reservoirs at a depth of several 1.000 m.
- Disclosure of additives is today common practice in Europe and many parts of the US and should become compulsory standard practice worldwide.

Conclusion: Hydraulic fracturing can today be carried out without any harmful additives.

Large water use

- Hydraulic fracturing requires indeed large quantities of water: several 100 m^3 per frac in gas wells, 10.000–20.000 m^3 in geothermal wells (smaller volumes in future multifracs).
- A large part of these fluids is recovered in backflow and production.
- Burning of gas produces CO_2 and water. The gas from an average Marcellus shale well produces over its lifetime some 15 times the water needed originally for drilling and the frac job (AAPG convention 2014, panel on shale gas).
- Companies in the US with best practice operations recycle up to 100% of the backflow.
- Hydraulic fracturing does not need freshwater. It can equally use saltwater, brackish water or even wastewater.

Conclusions: Hydraulic fracturing still uses relatively large quantities of water but does not require freshwater. Water use is being significantly reduced through recycling. Water availability is a potential problem only in very arid climate with no access to brackish water.

Induced seismicity, earthquakes

- Any artificial fracturing of rock causes microseismicity. Seismic magnitudes correlate directly with injected volumes and fracture size.
- In shale gas and other sedimentary fracs the induced seismicity lies generally below M 1 (Magnitude), i.e. far below the threshold noticed by human beings. The highest magnitude known and related to shale gas fracturing has reached M 2.5 (Quadrilla UK). In geothermal wells, injecting into basement or close to basement, seismicity

of up to M 3.5 has been observed, largely caused by shear movements, releasing tensions in pre-existing tectonic stress fields.
- Induced seismicity has in several areas been observed in wells where large fluid volumes were being injected.

Conclusions: In spite of some 3 Million frac jobs that have been carried out globally for oil and gas production from sedimentary rocks, there has been no recorded case of a damage quake. Seismicity in injection wells can be eliminated by avoiding disposal of fluids through recycling. In deep geothermal stimulation the risk of higher magnitude seismicity can be mitigated by replacing very large volume single fracs by much smaller volume multifrac jobs.

Land use

- Land used has been intensive in the early stages of shale gas developments when exclusively vertical wells were drilled.
- The use of horizontal drilling and the development of cluster drilling with up to 30 wells from one drilling location have led to a drastic reduction in land use. Up to 10 km^2 or more of reservoirs in the subsurface can be drained from one location. Drilling sites can now be spaced at several km intervals.

Conclusions: Land use is no longer an issue in modern cluster shale gas development. Geothermal projects have the lowest footprint of any renewable energy.

Methane leaks (see also «Methane as a climate gas» below)

- In large gas generating basins mature source rocks and mature coal seams produce trillions of m^3 of methane of which a significant part migrates to surface and leaks out into the atmosphere. In prolific basins, e.g. in the Marcellus Shale of Pennsylvania thousands of natural gas seeps occur and studies by environmental authorities reveal that, depending on the area, between 24% and 36% of all drinking water wells contained significant amounts of methane.
- Except for very few and yet unproven cases with damaged wells, where gas could leak into neighbouring sediments, there is no leakage from shale gas wells into groundwater and the sediments. All alleged methane contaminations in the film «Gasland» have been proven to be of natural origin.

Conclusion: Where high drilling standards and good maintenance of the surface equipment are observed there is no risk of contamination of groundwater or sediments with methane. High standards of regulations for well design and operations in Europe have led to a situation where methane leaks are not an issue.

Heavy traffic during hydraulic fracturing operations

- This has been a serious issue in areas of intense drilling and stimulation efforts that often have led to thousands of truckloads within a few months of operations.
- Trucking can be reduced significantly where recycling of backflow (with recovery of water and chemicals) is applied. Several US companies have a 100% recycling target. Also the reduction of additives leads to a lower transport intensity.
- Using local groundwater of non-drinking quality can further reduce traffic.
- Temporary water pipelines are increasingly used to replace trucking.

Conclusion: Trucking remains an issue with local communities during the drilling and fracturing phase. It is not an issue during production. Traffic intensity needs close attention and further improvement. Recycling and temporary pipelines go a long way to mitigate the impact.

High decline rates of fractured wells requires continuous drilling

- In most hydro-fractured wells production is highest in the weeks after the stimulation and shows then a steep decline within the first year.
- After the initial decline phase the wells enter a phase with very slow further

decline and most wells continue production over many years. Production lifetimes of 10 years and more are known even in old, not optimally treated wells.

- Focus on geological sweet spots and better completion has led to lower decline rates, considerably longer production life and an up to tenfold increase of ultimate recovery per well. Drilling time per unit gas produced has decreased by a factor 10 between 2008 and 2014 (US EIA Drilling Productivity Report, March 2014). Over the same period the number of rigs drilling for gas has fallen by 80% while total unconventional gas production kept growing.
- 25% of all the Marcellus shale gas reserves can be produced at gas prices below 5 USD/1.000 cubic feet. For the more valuable wet gas the percentage is much higher.

Conclusion: Fractured wells do show high initial decline rates but stabilize later for many years at still commercial levels. Recent technological progress has multiplied ultimate recovery per well. Drilling time per unit gas produced has in the Marcellus operations been reduced to as little as 10% of the time required 6 years ago. Unconventional gas production has therefore become increasingly sustainable and commercially robust.

3 Methane as a climate gas

Methane is a potent greenhouse gas (over a time frame of 100 years it is 28 × more effective than CO_2) and should therefore not enter the atmosphere. There is no doubt that in the past methane leaks from the oil and gas industry have significantly contributed to the amount of greenhouse gases. Source of the emissions are mostly leaks during testing and from poorly maintained production installations as well as pipeline systems and venting. Again, these emissions are still a concern in parts of the US and in some other oil and gas producing countries but methane leaks are today insignificant in Europe, where tight regulations for production operations and maintenance prevent gas to escape into the atmosphere. In Germany 53% of the total methane originates from agriculture, 3% from the energy industry and only 0.1% from gas production. Since 1990 the methane emissions in Germany have been decreasing by 55%, mainly through closing coal mines (Umweltbundesamt 2014).

It is scientifically incorrect to use individual US worst case examples and extrapolate them to a global scale. Such an extrapolation has recently been presented by Howarth 2014. His assumptions for methane emissions from unconventional gas production range from 3.6% to 7% of total gas production. Emissions at such high levels would imply leakage of millions of m^3 of gas from one location. Leaks at such levels would cause a very high level of explosion risk that would be incompatible with even low safety standards. Gas concentrations at production locations are routinely monitored and emissions in the several % range would automatically lead to a shut down of the plant.

What is certainly not tolerable in today's world is the widespread flaring and partly venting of associated gas in oil fields and particularly in unconventional oil production where the initial lack of infrastructure makes a gathering of the associated gas economically not attractive. US flaring and venting has reached the highest level since the early 70's with almost 7.5 Billion m^3/y (over 2 × annual gas consumption of Switzerland). Flaring and venting is banned in Europe except for production tests. Such wastage of gas needs to be eliminated through stringent regulations. Flaring, as occurring in some parts of the US is, however, not a valid argument to ban gas production – we do not ban cars because they cause accidents, we regulate the traffic and carry out technical inspections.

The level of methane emissions in European gas fields lies well below 1% and is thus an order of magnitude below the Howard estimates. The European experience demonstrates that methane emissions can be successfully eliminated. In well run and well maintained gas fields the risk of methane leakage is minimal.

4 Gas production and CO_2 emissions

Doubts are regularly surfacing on whether the new availability of much larger gas resources can have an impact on climate change at all. Proof of this is relatively simple: from 2008 to 2013 the US were able to reduce CO_2 emissions by 600–700 million t, i.e. by over 12% or 15 × the annual CO_2 emissions of Switzerland. The lion share of this reduction was achieved through replacement of coal by gas in power plants. With this, the US have achieved the largest CO_2 reduction of any industrial country and have almost reached the 1990 emission levels, target of the Kyoto Protocol (not signed by the US). During the same time CO_2 emissions in Germany have been rising against a backdrop of a politically strangled gas production and its replacement by coal.

5 Gas, fossil fuels and the world energy supply

The likely link between manmade greenhouse gases and the burning of fossil fuels suggests that it is wise to reduce our dependence on non-renewable energy, no matter where we stand in the discussion on global warming. Requests for reduction range from «no investment into fossil energy after 2017» to a reduction of CO_2 by 40–70% until 2050 and zero fossil fuels by 2100 (Press release IPPC, 2 November 2014). Reaching these targets will require transformations at an extremely high speed that is not in line with the statistical experience of the last decade. In spite of a very impressive growth of over 300% in the last 10 years, renewables w. o. hydro provide today only 2.4% of the global energy supply while the share of fossil fuels has decreased since 2004 only very marginally from 87% to 86% (Reinicke 2014). Only 7% of the energy growth in the same 10 years period could be covered by the large rise in the new energies. This implies that, while we make most impressive progress in developing renewables, we are still decades away from even covering the growth in energy, let alone replace fossil fuels. In addition the supply may have to cover an approximate doubling of world energy demand within 50 years (assuming the present growth can be halved).

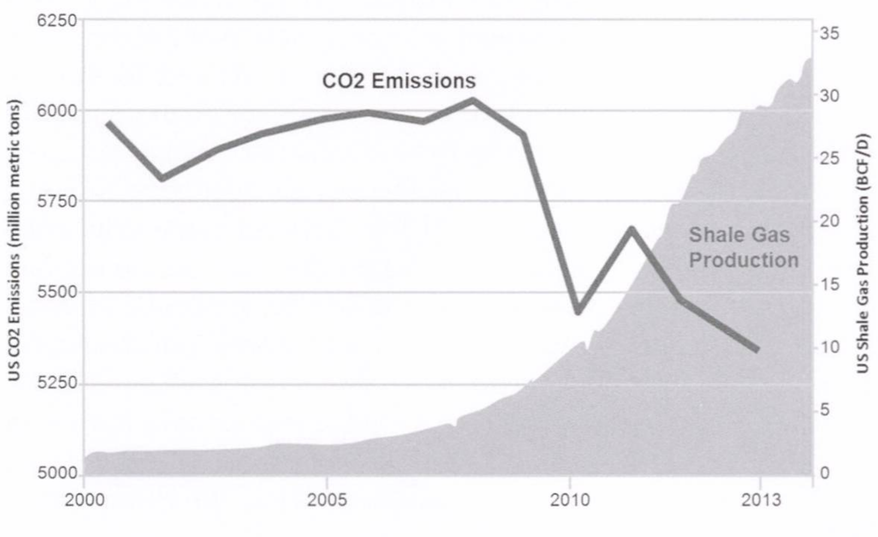

Fig. 1: US CO_2 emissions and shale gas production. The availability of shale gas allows emission reductions that are not achieved in any other industrialized country. The 1990 CO_2 emissions of the US were 5.100 million t (Kyoto Protokoll target). Source US DOE.

It will be important to structure the transition to a renewable energy world in a way that protects economic development and does not put the burden on a few countries alone. We should not forget that only prosperous countries can afford a high level of environmental protection. Where countries and people are in survival mode there is little concern about the state of the world that we may leave to future generations.
In the absence of a major technological breakthrough that would revolutionize the global energy supply (like nuclear fusion) the world has two options:

The «pure renewables scenario»: political barriers will be used to block the development of unconventional gas in many parts of the world. Growth of renewable energies will cover an increasingly larger share of the market but – given the likelihood of rising NIMBY public opposition to windfarms, hydro dams, geothermal powerplants and solar farms – renewables may take well into the next century to cover the global needs. The remaining energy will predominantly be supplied by coal, the cheapest and most abundant fossil energy. Oil will gradually make place to renewables, especially in transport and heating. The consequence will be a very slow improvement of the global CO_2 balance (see developments in present day Germany) and a severe deterioration of air quality in most of the Asian, African and Latin American megacities with millions of fatalities caused by respiratory diseases.

The «mixed gas – renewables scenario»: The present abundance of gas resources (reach 250-300 years at present day demand) is being deliberately used for a rapid replacement of coal power stations and of diesel-driven heavy vehicles by gas. This could within two decades lead to a very drastic reduction in global CO_2 emissions (several 10%) and would improve the air quality in most megacities of the developing countries. Political steering of the energy use would be required, probably in the form of a CO_2 tax, which ideally should be complemented with an additional pollution tax for coal.

6 Scientific advice and decision makers

A proper assessment of chances and risks of new technological applications requires in-depth knowledge and profound experience in the sciences involved. In the case of hydraulic fracturing and unconventional gas production this calls for geologists and geophysicists with expert knowhow of the processes in deep sedimentary basins and for engineers, specialized in drilling and in the very sophisticated subsurface engineering technologies. Unfortunately decision makers have often ignored the need for competent specialists, with very unfortunate results: most of the bans declared on the technology have not been introduced on the grounds of technical expertise but were largely emotionally and politically motivated.

Today we have a very peculiar situation where there is not a single scientific organization or institution worldwide (with competence in these technologies), that advocates a ban on hydraulic fracturing, neither in gas nor in geothermal applications. All these institutions, private as well as state controlled, recommend that the technology be properly regulated and that adequate standards and controls be introduced. In Europe they also stress the need for pilot projects without which there will be no learning and no scientific progress.

The worrying aspect is that the advice of all these highly competent scientific bodies has, so far, been almost totally ignored by decision makers. France has banned the technology at the very moment when the Academie des Sciences de France and the Bureau des Recherches Geologiques et

Minières advised to the contrary; Germany and several other countries show similar behaviour patterns. It is time that geoscientists regain their voice and make themselves heard. Important decisions, like the future of our energy supply and the quality of our environment, should not be left to politicians, pressure groups and sensation-hungry media alone.

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