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Chemicals usage in stimulation processes for shale gas and deep geothermal systems: A comprehensive review and comparison

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ABSTRACT

With the economic establishment of the shale gas exploitation, horizontal drilling and hydraulic fracturing have become nowadays common procedures, but not without any controversy. In parallel, the emergent case of deep geothermal energy systems is claimed to not have much to do with the fracking process. Through an intensive review of the available literature and data, we aim to lift the veil on the differences and similarities between shale gas and deep geothermal energy regarding the chemical substances used during the stimulation phase, as far as possible. Such a comparison appears finally not so obvious. In a general way, the effective used quantity of each chemical should not be neglected, even if advertised as being an extremely small percentage of the total stimulation fluids composition. Although some of these substances are considered purely environment/human health friendly, the diversity of potential risks associated with the hazardous chemicals can lead to severe consequences. However, the multitude of possible pathways for these risks tends to show that the main hazards are not especially or exclusively linked to the fluids injection process itself.

1. Introduction

Over the last decades, the attempt to satisfy the perpetual increasing needs in traditional fossil energy and the question of a possible or unavoidable drying up of such a resource, led to an intensive race to new potential energy sources, renewable or not.

With the recent and fast development of the exploitation of unconventional reservoirs of oil and natural gas, the practices to create efficient productive systems have been subject to diverse improvements as well as to numerous controversies. On the other hand, the current aim to build sustainable solutions for energy production and consumption is associated with a growing focus on the development of deep geothermal energy [1–3]. For both technologies, the extraction of underground resources implies to use techniques, named stimulation, enabling the creation and maintenance of an efficient productive system, enough to be economically viable [4].

Among the existing stimulation processes, the hydraulic fracturing is frequently highlighted and subject to intense discussions due to its wide usage in the oil/gas industry and is especially linked to shale gas exploitation. Another frequent practice is known as the chemical stimulation, implying the injection of chemical solutions, mostly acids, which have been recently showed as commonly used in numerous deep geothermal systems as well [5–8].

Although these types of practices are known and have been used since the 1950's [9], some parts of the processes connected to the usage of chemical substances are still poorly documented.

Unfortunately, no energy system is completely free of risk, and the probability of a potential incident is never zero. In general, chemicals are extensively used for a technological purpose and potential impacts of chemical substances on the environment and the human health are a worldwide concern. Various pathways of contamination exist for human health as well as for environmental effects, and in case of hazardous substances the consequences of direct or indirect exposures to the chemicals might be not negligible.

Furthermore, a lack of information can strongly restrict or avoid the assessment of risks associated to each energy technology in a quantitative way. Although some reviews for both shale gas and deep geothermal energy systems exist, they are mainly related to Life Cycle Analysis rather than to the specific chemical risks [10–13]. As the public perception of the different risks can be influenced by the information propagated through the Media [14–16], it appears crucial to provide a neutral and fact-based overview of existing practices in the use of chemicals for shale gas and deep geothermal systems.

Therefore, this paper aims to review both the differences and similarities between the use of chemicals in the exploitation of shale gas and deep geothermal energy, as well as the gaps that must be filled to reach a complete transparency of the prevailing practices.

In the remainder, this review first characterizes the technologies of

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interest (Section 2), followed by a description of the mechanisms of stimulation and the current use of chemicals (Section 3). Afterwards, the potential accident risks associated with the use of hazardous substances in the stimulation phase in both shale gas and deep geothermal energy systems are discussed (Section 4). Finally, the common, divergent, or even missing points between the stimulation practices in both technologies are summarized.

2. Overview of shale gas and deep geothermal energy systems

In this section, the description of the technology behind the shale gas extraction and the deep geothermal energy systems is presented. In addition, the main common characteristics of both systems are discussed.

2.1. Shale gas systems

When the highly exploited traditional, conventional, hydrocarbons resources have shown the first signs of a potential incapacity to supply the constant increasing demand on fossil energies, new sources of oil and gas should have been found. Although potential fields of unconventional hydrocarbons are established or estimated around the world, the United States have particularly shown a notable development of unconventional productions during the last decade. In general, the aim to increase energy independence combined with the higher price for oil and natural gas, led to a strong growth of research and investment into unconventional fossil fuels resources over the last two decades. Trapped in hard dense sedimentary rocks buried in the deep underground, the extraction of unconventional fossil energy resources has appeared with new challenges as well as technological innovations. Within the unconventional hydrocarbon category, the shale gases are probably the most “famous” all over the world due to the diverse controversies associated with their development. Little consideration has been shown in the past for these formations representing potential source rocks, before to receive a recent active interest in the view of their nature as potential reservoir [17].

Originally related to the common use of the term *shale* describing the very fine-grained sedimentary rocks formed from the compaction of silt and clay-sized particles [17,18], the particularity of these specific formations is their capacities to retain the hydrocarbons generated from their organic content through different maturation stages. As a consequence, the shales are not only the source rock, but also the reservoir, and the seal [19]. Because of their property of impermeability, or at least less permeable than other conventional resources [20], the shale gas cannot normally escape from these tight rocks of low permeability, and thus fracturing stimulation technologies and preferably horizontal drillings are required [19].

The phase of exploration of more and more dense formations started in the 1970's in the USA, but the development of the Barnett field in Texas (USA) around 2005 marked a turning point in the fast industrial-scale access to the shale gas plays [20,21], and nowadays it is well established, especially in North America. With such an impressive development, the environmental potential impacts of the shale gas extraction became a main pubic and politic concern especially about water contaminations [20]. Consequently, several studies have been carried out to assess the risk of water pollution, as well as the potential risk to human health, associated with shale gas extraction and more particularly with the hydraulic fracturing process in use (e.g. [22–26]).

Later than in the USA, an interest in the shale gas exploration has been shown also in Europe, and since 2009 shale gas activities have increased in European countries like for example in Germany and in Poland. However, recently the influence of the information coming from the USA raised a large public disagreement with these projects leading, for example, in France to a ban of the hydraulic fracturing process in the context of hydrocarbons exploitation [20].

2.2. Enhanced Geothermal Systems (EGS)

While the question of the exhaustion of fossil resources is always facing a more and more intensive exploration and exploitation, the deep geothermal energy (> 400 m depth [2]) appears currently as a main interest for a more sustainable energy production in several countries. Frequently used, the acronym EGS hides a concept apparently clear, but which is unfortunately still presented through a variety of definitions. Commonly, EGS stands for “Enhanced Geothermal Systems”, but is also referred to as “Engineered Geothermal Systems”. Even if these two expressions look quite similar and are equally used as synonyms, the second tends to accentuate the involvement of the engineering of the heat exchanger in the geothermal power plant, whereas the first is more easily linked to the improvement of the geothermal system by applying stimulation processes.

The EGS technology has evolved from the previous concept of Hot Dry Rock (HDR) designed in the 1970s [5,27]. Considering the crystalline basement as an impermeable and dry block, the HDR concept showed the necessity to create artificial fractures requiring the help of hydraulic fracturing processes. When not completely dry, showing the presence of some fluids, the concept was named Hot Wet Rock (HWR).

Over 40 years of research in this domain, the fact that crystalline basement rocks are found to be almost impermeable but never dry, and that they present numerous natural fractures also deeply extended, has led to the development of the EGS concept considering the basement as a natural network of fractures [27]. Within this technology, the fluid is still injected under high pressure, but aims to open pre-existing fractures rather than to create new ones [28]. These kinds of systems are also frequently called petrothermal systems, contrasting with the other main and more traditional category of deep geothermal systems that are the hydrothermal systems. While the hydrothermal systems benefit from the presence of deep hot ground water or steam with temperatures in the range of 100–150 °C, in petrothermal systems the thermal energy is naturally stored in the rock where the water flow is initially not present or negligible, but temperatures are higher, e.g., > 150 °C [29]. To create or improve the hot reservoir some hydraulic and chemical stimulation processes are needed. Therefore, the term EGS is often exclusively associated with petrothermal systems. However, even if the link between petrothermal and EGS systems is easy to establish, a unique definition of the Enhanced Geothermal Systems is still missing. This lack was recently highlighted by [5] presenting some examples of the currently used definitions varying in the type of rocks as well as in the type of stimulation technique. A common issue between these definitions is the non-restriction of the acronym EGS to the petrothermal systems only, as it is usually perceived in the public. Furthermore, hydrothermal systems may also need to be stimulated with the aim to improve the well's connection to the naturally fractured or faulted reservoirs containing enough hot fluid and flow [30].

As a consequence, we consider in this study that a petrothermal system is an EGS, but an EGS is not necessarily a petrothermal system. Therefore, we took into consideration all types of deep stimulated geothermal systems, including hydrothermal systems as well as HDR or HWR systems if subject to chemical usage during stimulation phases.

2.3. Characteristics of the systems

For both shale gas and deep geothermal domains some fundamental terms, despite of their wide usage, still need a universal definition to enable a clearer understanding of these practices. However, in both cases, typical characteristics can be detailed to establish the basics constituting each of these two technologies. A summary of these characteristics is shown in Table 1.

Among the characteristics listed in Table 1, the flows constrains, that are the porosity and permeability, represent crucial parameters for