Environmental Impact Associated with Shale Gas Extraction

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Abstract. Countries around the world are now stepping up efforts to develop the extraction of shale gas resource. Shale gas, as an unconventional energy with huge reserves and broad development prospects, has an increasing impact on the global energy market. However, the environmental impact brought by shale gas extraction has also attracted wide attention from the society. For example, ground water and air pollution and the negative influence on local ecological system caused by hydraulic fracturing have become the focus of attention from the society and public opinion. In this paper, the environmental impact caused by hydraulic fracturing on local water resource, surface water and ground water contamination, air pollution, and induced earthquakes are summarized and discussed. In the future, this analysis will have guiding significance for environmental protection in the process of shale gas extraction.

1. Introduction

Shale gas refers to the unconventional natural gas that is trapped within the reservoir rock series dominated by rich shale. It is a continuous generation of biochemical gas, thermal genetic gas or the mixture of the two, which can exist in natural fractures and pores with very low permeability. Since shale gas is a clean and high efficient energy resource, it is becoming a hotspot in new energy research area. Shale gas is also regarded as a vital strategic resource, and in recent years, lots of countries have increased the development strength on shale gas extraction. US energy information administration (EIA) estimates the technically recoverable shale gas is 1.87×10^{14} m^3 in the US, constituting 26 % of the domestic natural gas resources [1]. China has 1.35×10^{14} m^3 shale gas reserves, mostly in Sichuan and Tarim basin, and the technically recoverable shale gas is 2.5×10^{13} m^3 [2].

2. Environmental issues on shale gas extraction

The main environmental risks related to shale gas extraction include water, air quality and habitat classification. So far, the impact of water and air quality is the most heated debated. The potential negative environmental impacts are a major obstacle to shale gas development in many parts of the world [3].

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2.1. Hydraulic fracturing process

The process of extracting nature gas from shale gas formation is called hydraulic fracturing. The hydraulic fracturing process utilizes fluid and proppants to generate small fractures in the tight shale formation, creating pathways for the gases and oils to go from the reservoir to the wellbore. The fracturing fluid is usually consists of water, proppants, and chemical additives. Specifically, the fracturing fluid is pumped under very high pressure through the perforations on the horizontal well [4]. The fracturing fluid and mainly the high pressure help to open up the existing fractures or crack the shale and create new fractures that extend out into the surrounding rock. Once been cracked up, these fractures can continue to propagate for hundreds of feet and then be prop up by the proppants. Thus, the natural gas and the oil that exist in the shale are able to come out to the wellbore. However, in many cases, the horizontal well is too long to maintain sufficient pressure to fracture the shale across its entire length. To solve this problem, the well is then divided into several stages separated by plugs [5].

The hydraulic fracturing starts from the farthest stage to the nearest stage from the wellhead. The high pressure first comes to the farthest stage of the horizontal well and starts fracturing, after this stage is finished, this area is locked up with a plug. Then the high pressure comes to the previous stage, which is nearer to the start of the wellhead and repeats the same technological process. The plugs of each stage are later drilled through and the well is depressurized. After the pressure is released, the shale gas and shale oil go into the well driven by the pressure gradient, as well as the fracturing fluid and formation water [6].

2.2. Water lifecycle for hydraulic fracturing process

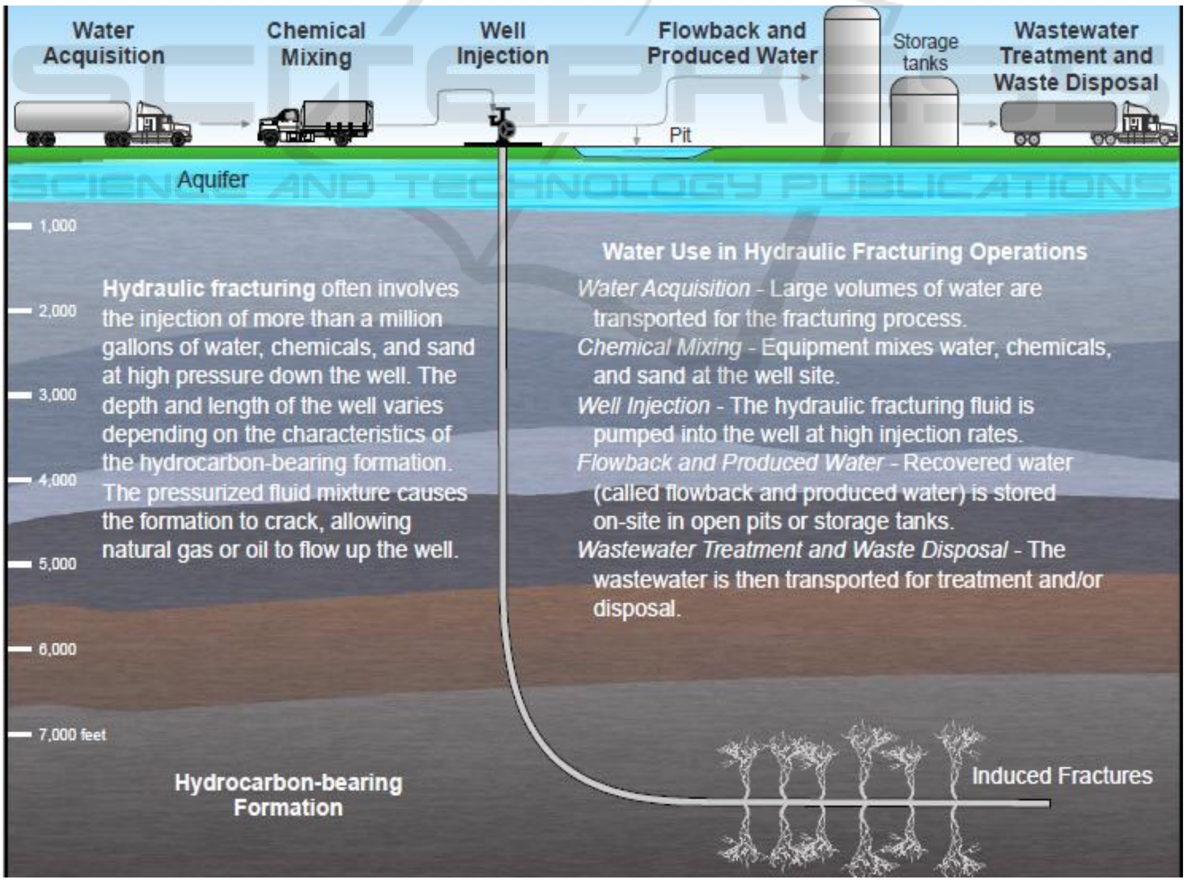

Figure 1. Water lifecycle in hydraulic fracturing process [8].

Shale gas production needs lots of water. Water management is one of the major challenges faced by the unconventional oil and gas operators. The total cost of water management can be as high as 12 % of the operation cost of a shale gas extraction well [7].

The specific water lifecycle in hydraulic fracturing process is showed in Figure 1, which includes water acquisition, chemical mixing, well injection, flowback and produced water storage, and wastewater treatment and waste disposal. Potential environmental issues caused by each process is discussed as follow.

2.3. Environmental impact on water resource

Water makes up more than 87 wt% of the hydraulic fracturing fluid. The hydraulic fracturing process requires large amount of water being injected into the formation in a short period of time. The water mainly comes from surface water and ground water resource, and sometimes the water comes from municipal water and reused water. At shale gas extraction places, the large amount of water needed for hydraulic fracturing process will compete with other water uses and endanger aquatic habitats.

2.4. Surface water and groundwater contamination

During chemical mixing process, a variety of chemicals are used in hydraulic fracturing fluid to complete the fracturing job. These chemicals are mixed with water and proppants before injection, and some of them have negative effects on human health as well as the ecosystem [9]. In accidental events, it is possible for the chemicals to be released into the environment through leaks and spills, contaminating the surface water, groundwater and soil.

During the well injection process, the main environmental concern is to protect the groundwater aquifer, which is a major source for drinking water supply. Different problems will be faced depending on the well completion practices. Well completion needs to be carried out in either typical deep shale gas formations or shallower shale gas formations. During the well construction, several layers of casing and cement are supposed to isolate the fluids and gases inside the well from outside geological formation. Specifically, the surface casing is designed to extend below the base of the deepest groundwater aquifer and be cemented all the way to the ground surface, which is expected to effectively isolate groundwater aquifer from the drilling environment [10]. However, failures in casing and cementing of the well might cause the leak of fracturing fluids or shale gas/oil from the well into the groundwater aquifer. Drilling through ground water aquifer also might disturb and alter ground water redox conditions and pressure gradients. At the end of the production life of the well, the well needs to be properly plugged to prevent fracturing fluid and flowback water migration that could contaminate soils and ground water [11].

The hydraulic fracturing process also generates a large amount of flowback water. The flowback water contain various naturally occurring substances in the formation, such as gases, oil and grease, total suspend solids (TSS), total dissolved solids (TDS), NORM (naturally occurring radioactive substances) [12]. Additionally, residual of chemical additives used in the fracturing fluid can be found in the flowback water. The flowback water is usually treated on-site or transported to other facilities to be treated or disposed of. Inadequate treatment before discharge or disposal or accidental spill during transportation could lead to contamination of surface and groundwater resource. Once it is not handled properly, these actions will cause serious environmental contamination, since ground water aquifer is difficult to recover.

2.5. Cause of air pollution

Most of the shale gas sites are located in arid regions, where water is quite cherished. Thus, reliable access to water supply is quite difficult to achieve in these areas, especially during drought seasons. To solve this problem, fresh water is transported to the site by heavy-duty trucks. The diesel powered heavy-duty trucks cause emissions of pollutants that affect the local air quality [13]. The immediate pollutants are VOCs, NOx, and PM2.5 and PM10. Moreover, the presence of high level of VOCs andPM 2.5 and PM 10 is known to harm the human respiratory system [14]. Also, many types of equipment used for hydraulic fracturing such as compressors and pumps require fuel combustion. These activities increase atmospheric emission of air pollutants, which affects the local air quality.

During shale gas extraction process, another potential air pollutant is the crystalline silica dust originated from the silica proppant. It is generated during the transportation and mixing of sand into the fracturing fluid. The acute toxicity of silica is low to moderate. However, crystalline silica has chronic effects to cause silicosis, which is a progressive lung disease which may result in lung cancer in humans. In the United State, the National Institute for Occupational Safety and Health (NIOSH) conducted a field study of silica exposure in 11 hydraulic fracturing sites in five different states [15]. Among the 116 samples collected, 79% samples have levels of crystalline silica that exceeded NIOSH recommended exposure limits (REL, 0.05 mg/m^3). 31% samples showed silica exposures > 10 times higher than REL and one sample is more than 100 times higher. The shocking results highlighted the high occupational health risk associated with handling silica proppant.

After the hydraulic fracturing process, the fluid that returns to the surface before the well is put in production is referred to as flowback water. The produced water is the fluid that returns to the surface after the well is put to production. The flowback water and produced water are usually stored in on-site tanks or pits before being treated, or transported for treatment and disposal. The storage tanks and pits need to be properly managed to avoid potential leaks and storm water overflow. In addition to surface and groundwater contamination, fugitive VOC emission from the flowback and produced water might also be a concern for air pollution.

2.6. Induced earthquakes

It is well known that earthquakes can be induced by surface and underground mining, impoundment of reservoirs, and injection or withdrawal of fluids and gases into or from the subsurface formation. Both hydraulic fracturing and deep well injection of wastewater could result in induced seismicity [16, 17].

The hydraulic fracturing process may induce a large number of micro-earthquakes which usually lower than 1.0 magnitude. There are a few incidences when earthquakes large enough to be felt were attributed to hydraulic fracturing activities; the biggest one happened at the Horn River Basin in Canada in 2013 with a magnitude of 3.8, which did not pose significant risk. The investigation carried out by British Columbia Oil and Gas Commission concluded that the event was caused by fluid injection during hydraulic fracturing in proximity of pre-existing faults [18]. In 2014, a hydraulic fracturing job was suspended in north England due to a potential link between its activity and two seismicity reports of 2.3 and 1.5 in magnitude near the well [19].

Deep well injection of shale gas produced water has also been related to earthquakes. In Youngstown, Ohio, 10 small earthquakes (all < 3.9 in magnitude) were recorded from April to November, 2016. These earthquakes were linked to the operation of a Class II deep injection well used to dispose of produced water as the fluid increased pore pressure along a pre-existing subsurface faults located close to the wellbore [20]. Disposal wells are also linked to the increase in the seismic activities in Oklahoma, including a 4.0 magnitude earthquake that occurred on October 15, 2013 [21].

3. Discussion and conclusions

Overall, the environmental impact associated with shale gas extraction mainly include habitat division, fracturing fluid spills and leaks, local air quality, water resource, ground water aquifer, and seismicity. Among them, the pollution on ground water aquifer and local air quality are the biggest environmental issue caused by shale gas extraction. These problems should attract the government's attention, since these environmental damage could harm the health of local residents, and these environmental damage is difficult to recover. Thus, the government should strengthen supervision and make relevant laws to prevent the environmental pollution caused by shale gas extraction.

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