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RESEARCH PAPER

Environmental impacts of hydraulic fracturing in shale gas development in the United States

ZHANG Dongxiao[1, 2,*], YANG Tingyun[1, 2]

1. Department of Energy and Resources Engineering, College of Engineering, Peking University, Beijing 100871, China;
2. Shale Oil and Gas Research Institute, Peking University, Beijing 100871, China

Abstract: Through comprehensive investigation of the environmental issues in shale gas development in the US, the environmental impacts of hydraulic fracturing in shale gas development are summarized to provide reference for the shale gas development and management in China. The environmental risks of large-scale commercial shale gas development in the United States include water consumption, water contamination, seismic inducement and air pollution. Compared to conventional oil and gas production and other energy producing industries, shale gas development is not exactly “high-water-consuming” in terms of water consuming intensity. Its water consumption, accounting for a small proportion of the total regional water consumption, will not add much more stress on water supply. In terms of water pollution, hydraulic fracturing is unlikely to cause fractures to directly connect reservoir to the shallow aquifer, the known contamination cases are most likely related to faulty well completion, therefore well integrity is the key to the prevention of contamination; the flow-back fluids in large scale shale gas development have the characteristics of large quantity, many kinds of pollutants and complex composition, thus improper treatment would lead to serious contamination, and continuous monitoring and assessment of the pollutants are necessary. Existing evidence shows that hydraulic fracturing is unlikely to trigger destructive earthquakes. Greenhouse gas emissions in the life cycle of shale gas wells were estimated differently, but no doubt more effective measures should be taken to minimize leakage. The research priorities include contamination monitoring program design, detection indicators, moving pattern of hydraulic fracturing fluid and formation fluid, the effects of shale gas development on high salinity formation water and methane migration, and treatment and re-use of flow-back fluid.

Key words: shale gas; hydraulic fracturing; environmental risks; water consumption; water contamination; earthquake risk; air pollution

Introduction

The horizontal drilling combined with large-scale hydraulic fracturing is the key technique to the successful development of shale gas reservoirs. Hydraulic stimulation is usually necessary to create complex fracture network to increase the flowing ability due to the extremely low permeability, which involves injection of a large amount of water, proppants and chemical additives into the formation[1]. However, as the use of hydraulic fracturing has increased widely, so have the concerns and debates on its potential impacts on environment, including consuming fresh water resources and intensifying water supply stress[2–3], contaminating surface and groundwater[4–7], inducing earthquakes[8–9], and polluting air[10]. Protesters against shale gas development argued that[11], the environmental costs to extract natural gas from shale using hydraulic fracturing are too high, considering the potential risks of methane leakage and water contamination. They also believed that the benefits of CO_2 emission reduction from replacing coal and oil consumption with natural gas are not sufficient enough to offset the risks in shale gas development, and shale gas development should be put off for further research. Whereas the favorers believed that those concerns are beyond the actual risks revealed by the evidence of current research, which can be managed and controlled through technical and regulatory improvements.

By the end of July 2014, more than 400 shale gas wells have been drilled in China. First breakthrough has been made in Sichuan Basin where the shale gas development has entered an early stage of commercial development, while the overall development in China is still in start-up stage[12]. The assessment of environmental impacts and their controlling factors, the establishment of pollutant monitoring system, and the understanding on mechanisms of water contamination and pollutants transport is necessary and important in this period. Researchers in China have summarized the environmental issues in hydraulic fracturing, and the foreign regulatory ex-

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*** Corresponding author.** E-mail: dxz@pku.edu.cn
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perience[13−16], but have not made systematic discussions on this issue yet. In this paper, the research and progress on the environmental impacts of shale gas development in the United States are reviewed, the environmental risks of the use of hydraulic fracturing are analyzed based on case studies and mechanisms research, to provide reference for the shale gas development in China.

1. Water consumption

1.1. Water use and source

Multi-stage fractured horizontal wells are commonly used to extract shale gas, and the water consumption of fracturing stage usually accounts for more than 80% of the total water use of well completion. A shale gas well consumes a lot more water than a conventional vertical gas well[17], which varies from 8 000 to 100 000 m^3 with an average of 15 000 m^3 per shale gas well[18] in the U.S. shale basins. Water use per unit productive interval falls in a narrow range, for example, the water use of horizontal wells in Barnett, Haynesville and Eagle Ford shale play was between 9.5 to 14.0 m^3/m in 2010[19]. Factors affecting water consumption include well depth, length of horizontal section, the number of fractured stages, geological features and fracturing fluids[17].

From a comprehensive perspective, the water consumed per unit energy produced, and whether the water use causes extra water supply stress should be assessed to figure out the impacts of shale gas development on water consumption. In terms of water use intensity per energy produced, shale gas is higher than conventional gas[17], but lower than conventional oil and much lower than enhanced oil recovery (EOR) of conventional oil[20] (Fig. 1). When used for electricity generation, the water use intensity of shale gas is lower than geothermal, nuclear and solar energy[21]. Therefore, compared with conventional oil and gas production and other forms of energy production, shale gas development is not “high-water-consuming”. However, the water demand for a shale gas well concentrates in the early stage of well completion (not considering re-fracturing), and the life-cycle for a shale gas well can be as long as 30 years, therefore the estimates of water use intensity based on the current production data have high uncertainties[17,22]. From the perspective of regional water supply, the proportion of total water use of shale gas development is usually less than 1% of the state total water use in the United States[23], which is far less than other uses such as irrigation and public water use, and will not cause significantly extra stress on water supply[24]. However, as the production activities and water withdrawal usually occur in a small area, the proportion of water use in local level can be high. In addition, since the water for drilling and fracturing needs to be taken within a short period, water scarcity may still be a problem in dry seasons or areas[2,19], leading to an accumulating effects on the watershed. Being in an early development stage, no public data of water use per well or the water source for shale gas is available in China, which needs to be gathered for the purpose of evaluation and monitoring of the impacts of water consumption.

1.2. Research areas to reduce water use in shale gas development

(1) Monitor water use and make comprehensive water withdrawal plan. The impacts of water consumption on the regional environment are related to regional water availability and other competing water demands. In 2014, the World Resources Institute (WRI) released the first assessment report on global shale gas development and water availability distribution[25], which pointed out that more than 60% of shale gas resources distribute in arid areas or areas with high to extremely high baseline water stress conditions in China. In the currently most active shale plays in Sichuan Basin, the uneven distribution of water resources and dense population may constrain shale gas development[25]. To avoid negative effects on local water supply and environment, the water use and

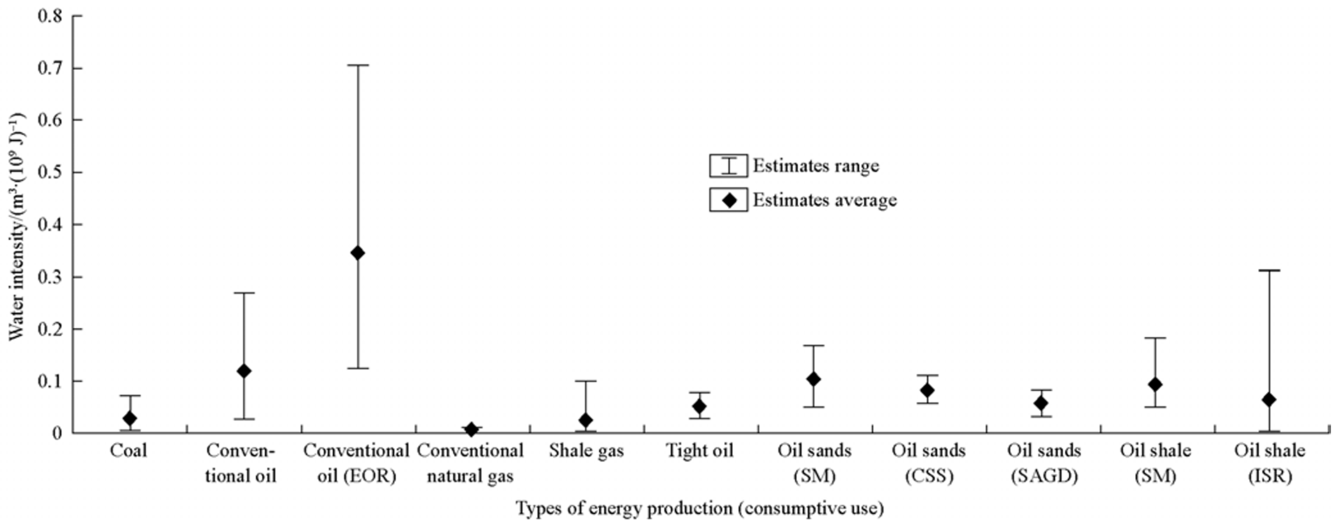

Fig. 1. Water intensity estimates for different energy production types[20] (EOR—enhanced oil recovery, SM—surface mining, CSS—cyclical stream stimulation, SAGD—steam assisted gravity drainage, ISR—in-situ retort).