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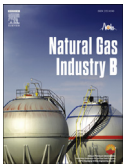

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Research article

A comprehensive environmental impact assessment method for shale gas development

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Abstract

The great success of US commercial shale gas exploitation stimulates the shale gas development in China, subsequently, the corresponding supporting policies were issued in the 12th Five-Year Plan. But from the experience in the US shale gas development, we know that the resulted environmental threats are always an unavoidable issue, but no uniform and standard evaluation system has yet been set up in China. The comprehensive environment refers to the combination of natural ecological environment and external macro-environment. In view of this, we conducted a series of studies on how to set up a comprehensive environmental impact assessment system as well as the related evaluation methodology and models. First, we made an in-depth investigation into shale gas development procedures and any possible environmental impacts, and then compared, screened and modified environmental impact assessment methods for shale gas development. Also, we established an evaluating system and assessment models according to different status of the above two types of environment: the correlation matrix method was employed to assess the impacts on natural ecological environment and the optimization distance method was modified to evaluate the impacts on external macro-environment. Finally, we substitute the two subindexes into the comprehensive environmental impact assessment model and achieved the final numerical result of environmental impact assessment. This model can be used to evaluate if a shale gas project has any impact on environment, compare the impacts before and after a shale gas development project, or the impacts of different projects.

Keywords: Shale gas; Development process; Environmental impact; Correlation matrix method; Modified optimization distance method; Comprehensive evaluation; Assessment model

Complex technologies such as multi-stage large-scale hydraulic fracturing, horizontal well drilling not commonly used in the development of conventional gas are generally necessary in shale gas development [1]. The application of such high-end sophisticated technologies is associated with higher resource investment and energy cost, and thus more serious impacts on the environment.

According to the shale gas development impact on environment, environmental regulators should develop a more appropriate method of environmental impact assessment, to provide a guiding method for the feasibility study and environment supervision of shale gas development.

1. Analysis of the environmental impact of shale gas development

In environmental protection, we can learn and draw lessons and get inspiration from the experience of shale gas development in the United States, which will provide reference for the upcoming large-scale shale gas development.

1.1. Shale gas development process and its impact on natural environment

1.1.1. Shale gas development process

Shale gas development process can be divided into starting and drilling stage, hydraulic fracturing stage, production and processing stage, and well plugging and abandonment stage. Starting and drilling stage involves the wellsite construction

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and drilling; the key of hydraulic fracturing is fluid (high pressure air or fresh mud) and proppant pumping, during which high pressure produced by ground equipment breaks down the shale and makes the crack propagate to allow hydrocarbon drainage; after drilling and hydraulic fracturing, the wellhead will be installed, and gas will be collected and delivered by flowlines to processing facility for processing, but in some cases, the production and drilling may be carried out at the same time; when a gas well reaches the end of its service life or fails in development, it will be plugged and abandoned.

1.1.2. The impact on natural environment

1.1.2.1. The impact on water

1) Impacts on underground water. The groundwater contacted with shale gas wells may be polluted in the following ways: ① Fracturing fluid and flowback fluid could access and pollute groundwater source by leaking through wellbore outer layer, or in the creating or propagating of hydraulic fractures. Hydraulic fracturing is aimed at creating fractures in the target formations, but once the fractures extend beyond the target formation and reach other formations, pollutants would be carried to other formations and pollute groundwater [2]. ② Groundwater contamination is caused by operational errors or catastrophic failure of development. Generally, a shale gas well goes through several layers of aquifer, so a wellbore must be constructed to support and isolate formations. Casing is installed in a wellbore to isolate the well and surrounding formations and other formations such as freshwater aquifers, saline aquifers, etc. The damage of gas well casing or the lack of integrity of initial casing configuration is likely to cause pollution of formations including aquifers. In the case of a wellbore failure, fracturing fluid and flowback fluid may cause pollution through the casing.
2) Impacts on surface water. Generally, surface water is the general name of creeks, rivers, streams, lakes and ponds on the ground. The main hazards of well site operating independently to surface water include: leak or spill of waste liquid or gas because of limited storage capacity, operating error, rain or flood, or poor quality of the project; Leakage of fracturing fluid in the transportation or mixing operation due to pipeline failure or operation errors, etc; flowback fluid spill in transmission or delivery to the storage space due to pipeline troubles, failed reservoir fracturing, insufficient storage space, or operating errors etc; lost control of flowback fluid because of storage tank break, limited storage capacity, heavy rain or flood etc; spill of flowback fluid during transportation or in waste water processing plant.

1.1.2.2. Land occupation and ecological impact

If cluster well technology, the most popular development mode in the U.S. at present, is applied, only one wellpad is needed for 6–8 horizontal wells[2]. When several multi-lateral horizontal wells are drilled from one wellsite, the land area of the well site may be 2000 m^2 bigger than a single vertical wellsite. Therefore, at the beginning of drilling and fracturing, an average wellsite occupies an area of 15,000–20,000 m^2.

In 2008, a survey on the Fayetteville shale play in Arkansas by DOI showed that every vertical shallow well has a wellsite of about 8000 m^2, construction passageway of about 160 m, and equipment channel of about 880 m, so each well would cause surface disturbance of 20,000 m^2. The survey also showed that a horizontal wellsite, and associated construction passageway and equipment channel in Arkansas state take up 14,000 m^2, and make ground disturbance of 28,000 m^2. If the horizontal well pattern is adopted for a wellsite with four branch horizontal wells, although the wellsite is 2000 m^2 larger than a single vertical wellsite, a ground disturbance of 30,000 m^2 will be resulted in. Comparatively, the ground disturbance caused by a single multi-lateral horizontal well is much less than a vertical well, which is one of the advantages of multi-lateral horizontal wells.

1.1.2.3. Impact on atmosphere

1) Air pollution. Shale gas exploration and production process may become an air pollution source, but in different construction stages air pollution sources are different: in the early stage of construction, atmospheric emissions may come from the rig of fossil fuels or diesel pump from fracturing process; in the process of completion, atmospheric emissions may come from shale gas burning and blowoff and the transportation vehicle tail gas emission. The components of air emissions in the process of shale gas exploration and development are: nitrogen oxides generated by fossil fuel combustion for providing machine power; volatilization of organic compounds (VOCs) during the dehydration process when shale gas is out of the ground; benzene, toluene, ethylbenzene and other substances in the natural gas although very low in content, are environmental pollutant sources of shale gas.
2) Emission of greenhouse gases. In order to compare conveniently, the greenhouse gases emitted during shale gas development are converted into CO_2 equivalents. According to statistics, the greenhouse effect value of NO_2 (100y) is 310, and that of CH_4 GWP (100y) is 25. According to the references in this paper [3–5], in accordance with the development process, the shale gas development is divided into wellsite preparation, drilling, hydraulic fracturing, completion, wastewater treatment, production and processing, well plugging and abandonment stages, and the greenhouse gas emission in each stage was estimated, the results are shown in Table 1.