

Groundwater environmental impact and supervise recommendation in process of shale gas development in China

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Abstract. There are rich shale gas resources in China at present, which are going to be exploited and utilized in a large scale. However, of a series of environmental issues caused by the development and utilization of the resources, the influence on the groundwater environment is the most important. Shale gas development in China is in an initial stage. The new guidelines for environmental impact assessment on shale gas development are still not issued while traditional environmental impact assessment on oil and gas field development could not meet the need of environmental management for shale gas development and construction projects. In this paper, based on the current situation of shale gas development in China region, the influences of shale gas development in different stages on the groundwater environment are analyzed. The ideas and key points in assessing the influences of shale gas development on the groundwater's environmental quality in different stages are proposed when the technical guidelines for the environmental impact assessment on shale gas development are not available. The result of the paper will provide a new idea for the Groundwater environmental impact and Supervise Recommendation in shale gas development in China.

1. Introduction

There are rich shale gas resources in China at present, which are 2.4 times reserves of conventional natural gas. Potential recoverable resources in a certain area account for one fourth of the total national resources. Exploration and development of shale gas will inevitably cause a series of environmental issues, such as destruction of ecological environment, challenge of water resources, pollution of surface water and groundwater, and emission of warm gas etc. [1-4]. The influence of exploration and development of shale gas on the quality of groundwater is one of important environmental issues.

As an unconventional natural gas, shale gas attracts a wide attention in the world. In China, the exploration and development of shale gas is still in an initial stage [5]. At present, related laws and criterions in the environmental impact assessment on shale gas development is lacked and no technical guidelines for the assessment are issued, especially for ground water environment. Exploration and development of shale gas could have an influence on both shallow groundwater and deep groundwater. Traditional environmental impact assessment on oil and gas field development could not meet the need of environmental management for shale gas development and construction projects. In this paper, based on the current situation of shale gas development in Southwest China, the influences of shale gas development in different stages on the groundwater environment are analyzed.



In the southwestern China, there are excellent geologic conditions for oil accumulation of industrial shale gas [6,7]. Water resources and capacities are relatively rich as well as reserves. A national shale gas demonstration area in southwest China is a key development zone in China. After it is constructed, the theory, method and technology of the environmental impact assessment on groundwater summarized from this demonstration area will show a good promotion and application prospect.

2. Ideas and methods

2.1. Ideas

Based on a survey on ground water environment quality of development zone, the influence of project on the groundwater environment is predicted and assessed in its construction period, operation period and out of service period, respectively. Combined with the object of ground water protection, groundwater protection measure is proposed to provide a scientific norm for the groundwater environment management in the design, construction and operation period of the project.

2.2. Assessment methods

By an analysis on the waste discharging processes during shale gas development and an identification of groundwater environment impact, it was found that the influences of shale gas development on the shallow groundwater environment are similar to that of conventional natural gas, which is mainly from various water during drilling project, ground project and operation period. The influences of shale gas development on the deep groundwater environment are mainly from filling of flow-back fluid (gas field water) back into the deep layer in operation period. According to the characteristics of shale gas development, groundwater environment assessment could be classified as shallow and deep groundwater assessment. For the shallow groundwater, the assessment could be referred to “Technical guidelines for environmental impact assessment-groundwater environment” (HJ 610-2016) (abbreviated as Groundwater Guidelines) and, for deep groundwater, the assessment could be carried out based on module9 in the TOUGHREACT.

2.2.1. Environmental impact assessment on the shallow groundwater. The influences of shale gas development on the shallow groundwater environment could be carried out according to assessment levels issued in the groundwater guidelines. Firstly, the environmental protection objects in groundwater should be investigated in the development zone and its adjacent regions. Secondly, work levels of groundwater assessment should be determined according to types of projects and sensitivity degrees of groundwater environment; based on project analysis, the possible direct influence of shale gas development on groundwater environment should also be identified; present groundwater environment quality should be investigated, monitored and assessed according to various assessment work levels. On the basis of present investigation of groundwater environment condition, according to the various pollution sources and groundwater types, the possible influence of shale gas development on shallow groundwater quality should also be predicted and assessed. Related measures preventing groundwater from pollution and controlling pollution should be proposed. Monitoring plan and contingency plan for groundwater environment assessment should also be made.

2.2.2. Environmental impact assessment on the deep groundwater. Groundwater Guidelines are suitable for shallow groundwater environment assessment and not for deep groundwater. In the paper, authors insist that, in assessment of deep groundwater environment in shale gas development, the model for multiphases fluid and therm transport in ground rock pore and fracture could be adopted to simulate and predict. The simulation could be carried out by the software TOUGH (Transport of Unsaturated Groundwater and Heat). The software TOUGH is designed by the Earth Science Department in the Lawrence Berkeley National Lab (LBNL) and widely applied in geological disposal of nuclear waste, geological storage of carbon dioxide, study of gas hydrate, reservoir engineering and other fields related to material transportation and energy transferring. TOUGH 2 is an important

edition of software TOUGH, which could solve material-energy conservation equation in multiphase and multicomponent fluids and thermal fluids systems. TOUGHREACT is a mathematics software which introduces chemical reactions equations to simulate the migration of multi-phases fluid in porous media or fractures and geochemical reactions based on original functions of TOUGH 2, and is widely applied in fluid migration and geochemical simulation by the scholars in the world. TOUGHREACT provides equation of state (EOS) related to seven types of fluids, of which, module 9 is designed to simulate the migration and chemical reaction of saturated-undersaturated fluids. In the paper, project is related to filling of discharging liquid (gas field water) back into stratum, and therefore, module 9 could be applied to simulate this process of back filling, fluid migration and aquatic chemistry reaction in high temperatures and high pressures.

3. Groundwater environment impact assessment in shale gas development

3.1. Identification of groundwater environment impact

According to the characteristics of construction projects of shale gas development in southwest region in China, the influences of exploration of shale gas on the shallow groundwater environment could be mainly divided into two stages: construction period and operation period.

- Construction period

In construction period, the influences of construction on the shallow groundwater are mainly the wastewater produced in normal condition in drilling project (including well cementation, well completion, crushing and gas collection), in well flushing, in pipe pressure trial and in life of constructor; in accident condition, leakage of liquid due to accidental leakage wastewater pool, collapse of well wall and crash of well pipe are main influence factors.

- Operation period

In operation period of normal condition, the possible influences on the groundwater environment are mainly the back filling water separated from well field (gas field water), the wastewater produced in cleaning pipe and repairing equipment, and the life wastewater by the duty workers. In accident condition, leakage of liquid due to accidental leakage wastewater pool and pipe are main influence factors.

According to production skill, process producing wastewater and way to influence groundwater environment, combined with methods dealing with wastewater in various processes, wastewater pool in well field, reserves pool of fracturing flow-back fluid, accidental leakage of back filling pipe of fracturing flow-back fluid and fracture of well tube are main risk factors for shallow groundwater. Fracturing flow-back fluid is a main risk factor for deep groundwater.

3.2. The assessment on influence of exploration of shale gas in a certain area in China on the shallow groundwater environment

3.2.1. The hydrogeology condition in the assessment region. The trial area is located in transitional zone between mountains in southern Sichuan basin and Yungui plateau in China. The geologic condition of the area is complicated and carbonate rock is widespread. The karst landform such as karst depression, sinkhole and vertical shaft etc., and few loose rock porewater are distributed in the area. The karst water is classified as exposed type and buried type. The aquifer of exposed type of karst water is exposed outside and a recharge area of vertical groundwater circulation; the aquifer of buried type of karst water is buried under non karst stratum and a horizontal runoff area of groundwater. There is an underground river developing nearby the H₂ drilling plat in the trial areas and adjacent to Shangluo town.

3.2.2. The shallow groundwater environment impact assessment. (1) The various types of wastewater produced in construction and operation period is all dealt with validly and therefore its influence on the shallow groundwater environment is less in normal condition.

(2) In accidental condition, the influence of the break of drilling wastewater pool and well tube, and break of fracturing flow-back fluid storing pool are most significant in construction period and operation period, respectively.

- Model selection

In predicting the groundwater environment impact, groundwater flow field and solute transport could be simulated by finite difference method to generalize underground-river as a main runoff zone. The karst stratum could be generalized by the software Visual MODFLOW and two-dimension rivine stable water quality model could be adopted in simulation and prediction if the pollutants enter into the underground river. Since there is an underground river nearby the H₂ drilling plat, which is adjacent to the Shangluo town, the project zone including H₂ drilling plat and its adjacent area is selected to carry out numerical simulation.

- Prediction and analysis

The result of prediction showed that in construction period if drilling wastewater storing pool is broken and pollutants such as oil is entering into the unground river, the concentration of pollutant will be diluted and transported with the water flow, reaching its background value at the outlet of the river. Therefore, the influence of the pollutant on the drinking water of Shangluo town is less; in operation period under the accident condition, if the fracturing flow-back fluid storing pool is broken and chloride is entering into underground river, the concentration of chloride will also be diluted and transported with the water flow, reaching its background value at the outlet of the river. Therefore, the influence of the chloride on the drinking water of Shangluo town is also less.

3.2.3. The deep groundwater environment impact assessment. The influence of shale gas development in the trial zone on the deep groundwater environment is mainly focus on filling of fracturing flow-back fluid (gas field water) into the deep stratum. In collecting gas period, when the natural gas is dealed with by gas-liquid separation, the separated fracturing flow-back fluid will be reused and discharged into fracturing water pool for the purpose of preparing fracturing fluid. Only when the fracturing is completed in the last plat in the trial area, the fracturing flow-back fluid will be refilled into well 1.

The refilled stratum in the trial area is the Jialingjiang group lime, which is about 1366 m deep. In the refilling area, the total thickness of lime is about 20 m and the injection volume into the deep stratum is 322 m³/d, which will be sustained for 10 years. It is inferred from the prediction by the Module EOS9 in software TOUGHREACT that the influence of injection in the deep stratum on the groundwater are related to the spreading range of pressure and diffusing range of pollutants. The pressure accumulation and diffusion range of refilling well are related to injection volume, pattern, physical parameters and the thickness of injected stratum. When the pressure reaches 21 Mpa at the injection point and spreads over 15 km in 10 years, the range will be 2.5 km beyond the assessment range. Therefore, within the assessment range, the level of groundwater will rise in 10 years. If there is spring exposed in the lime stratum within the range of pressure spreading, the flow volume of the spring will increase but it will decrease to an initial level when water injection is stopped. It is suggested that the injection should be carried out intermittently to reduce the influence of pressure accumulation on the stratum.

3.2.4. The measures adopted in the protecting groundwater environment in shale gas development. According to the characteristics of skills in development of trial area and identified groundwater pollution sources, based on a rule of “source control, prevention in various zones, pollution monitoring and emergency response” in groundwater pollution prevention, the overall control measures from the production, infiltration and diffusion of pollutants to emergency response should be taken in groundwater environment protection.

In the possible polluted areas by the projects, the key and normal pollution prevention zone should be set up respectively. The different infiltration prevention measures should be taken in different infiltration prevention zones. Meanwhile, the long-term groundwater monitoring system covering the

whole area will be established to find and control the groundwater pollution timely.

- Source control measures

The source control measures mainly include clean production and reuse of various wastes and reducing the discharge of pollutants; taking measures in skills, pipes, equipment, wastewater storing and structure disposing to prevent and reduce the leakage of the pollutants and the risk of leakage to a lowest degree.

- Prevention measures in various zones

In various trial areas, the ground possibly contaminated by leakage of the pollutants should be dealt with to prevent infiltration and protect the groundwater from pollution by the infiltration of the pollutants.

- Pollution monitoring and emergency response

To learn the groundwater environment condition in the field and downstream area, groundwater pollution monitoring well in the related areas should be set up to establish groundwater monitoring and warning system based on the groundwater flow direction and distribution of pollutants in the project field.

4. Conclusions

- The technical guidelines for environmental impact assessment on shale gas development are still not issued. In the paper, the environmental impact assessment suitable for the shallow and deep groundwater is proposed respectively.
- In development of shale gas, the various wastewaters produced in operation period and in drilling project and ground project in the construction period have an influence on the shallow groundwater, and therefore, in this case, the technical guides could be applied in the assessment. Since the refilling of fracturing flow-back fluid (gas field water) has a direct influence on deep groundwater, the module EOS 9 in the software TOUGHREACT could be adopted in predicting and assessing.
- In normal condition, the various wastewater produced in exploration of shale gas in the trial area has a little influence on the environment of shallow groundwater. In accidental condition, the break of drilling wastewater pool and well tube in fracturing has an obvious influence in the construction period; the break of storing pool of fracturing flow-back fluid has an obvious influence in the operation period. It has been inferred by simulation and prediction that whether in construction and operation period when pollutants enter into underground river and transport with water flow, the concentrations of these pollutants will reach their background values and therefore have a little influence on the drink water in the Shangluo town.
- The influencing factors of rejection in the deep stratum are related to the spread range of pressures and possible diffusion range of pollutants. The result of simulation and prediction by the EOS 9 showed that when the accumulated pressure maximum at the injection site reaches about 21Mpa, the flow amount of spring in the assessment range will increase possibly. It is suggested that the injection should be carried out intermittently to reduce the influence of pressure accumulation on the stratum.
- Based on a rule of “source control, prevention in various zones, pollution monitoring and emergency response” in groundwater pollution prevention, the overall control measures from the production, infiltration and diffusion of pollutants to emergency response should be taken in groundwater environment protection.

References

- [1] Chen L and Ren Y 2012 Analysis of environmental impact of shale gas exploitation *Environ. Sustain. Develop.* **3** 52-5
- [2] Yue T, Hu S L, Peng J C, *et al* 2013 Environmental and ecological problems in the process of shale gas's exploration and development *Chin. Min. Mag.* **22** 12-5, 28
- [3] Xia Y Q 2010 The challenges of water resources and the environmental impact of marcellus

- shale gas drilling *Sci. Technol.* **28** 103-10
- [4] Robert W, Howarth, Enee S and Antho I 2011 Methane and the greenhouse-gas footprint of natural gas from shaleformation *Climatic Change* **106** 679-90
 - [5] Liang R, Dong T and Xiang Q G 2014 Management of and proposals on environmental impact assessment (EIA) for shale gas development in China *Safety Manage.* **34** 135-40
 - [6] Zhu T, Bao S J and Wang F 2012 Pooling condition of non-marine shale gas in the Sichuan Basin and its exploration and development prospect *Nat. Gas Ind.* **32** 16-21
 - [7] Zhang J C, Nie H K, Xu B, *et al* 2008 Geological condition of shale gas accumulation in Sichuan Basin *Nat. Gas Ind.* **28** 151-6