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Review the impact of shale gas extraction on water resources

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Abstract
Shale gas is an emerging energy resource, but also a clean, high quality and efficient energy, the development of shale gas is also a hot topic of worldwide concern, but in the process of shale gas development on water resources brought impact cannot be ignored. Shale gas mining technology in the U.S. has been very mature, China in recent years have begun to prepare to develop shale gas. In this paper, draw the U.S. shale gas exploitation when water management experience and technology, combined with the water resources situation facing China shale gas exploitation are analyzed , and finally water issues of concern for the future of shale gas exploitation in China some suggestions.

Keywords: shale gas; water resource management; environmental issues; review

1. Introduction

Shale gas refers to the unconventional gas [1], which gathers in the dark clay shale or the high-carbon clay shale, has the main composition of pyrolysis gas or biological methane gas, and stays in the pores and fractures in the form of free gas, or stays in the clays in the state of adsorbed gas and free gas. As a sort of important unconventional gas, shale gas needs to make great exploitation and development. The research demonstrates that by 2020 China's natural gas consumption is anticipated to exceed 200 billion m3, and natural gas supply quantity is anticipated to reach 120 billion m3, hence the difference between consumption and supply being nearly 80 billion m3 [2]. However, America has mature shale gas industry, and its exploitation quantity is far ahead; in 2009, American shale gas production reached 120 billion m3, and its annual production accounted for 13%-15% of the national whole natural gas production, but China had a total of natural gas production of 94 billion m3 in 2009. This means only shale gas production in America had exceeded China total natural gas production in 2009 [3].

In recent years, China domestic scholars have made numerous researches mainly on shale gas accumulation mechanism [4], shale gas resources exploitation potential [5], shale gas resources evaluation method and technology [6], and shale gas exploitation and theoretical method [7]. Since 2008, America has exploited Marcellus Shale Gas Field, as well as consumed a great deal of water resources and caused potential environmental hazards, therefore, a great national discussion [8] about the influence of American shale gas exploitation on the environment is performed. Fewer China domestic scholars begin to pay attention to the influence of shale gas exploitation on the environment [9], and the consumption of large quantity of water resources and the other ecological environment issues [10]. Although the impact of shale gas exploitation on the environment is still controversial, shale gas as the alternative for conventional energy motives the shale gas exploitation in many countries, including China [11]. As such, this review will mainly make a deep introduction of American experience on water resources management for shale gas exploitation, so as to provide the reference and feasible suggestions for China's shale gas exploitation and development.

2. American water resources experience on shale gas

2.1 Demand for water resources

Currently, Drilling Horizontally technology and Hydraulic Fracturing technology are mainly used as the core technologies for shale gas extraction, and Hydraulic Fracturing is the most successful technology for shale gas development [12]. As one of the core technologies for shale gas development, Hydraulic Fracturing technology is widely used at home and abroad, and based on the research, shale gas exploitation and development via Hydraulic Fracturing in China present stage shall start with two aspects, 1) repeated fracturing in old wells, and 2) performed hydraulic fracturing in new wells [13]. American experience shows Hydraulic Fracturing technology is performed with large water consumption. Hydraulic fracturing for horizontal shale gas well is participated to need 7500-15000 m3 water for experiment, and in general needs 11500 m3 [14]. Table 1 describes the water consumption per well (approximation, changes in different wells) of four shale gas wells developed before. As shown in Table 1, water consumption per well via Drilling Horizontally technology is less than that of Hydraulic Fracturing technology, therefore, we may make improvement on technology and method to reduce water consumption.

Drilling horizontally method and Hydraulic Fracturing method is often performed by using the water from the surface water body, such as rivers and lakes, as well as from groundwater, private water sources, municipal water and repeated production water. America, having the most mature shale gas industry, at present makes shale gas exploitation in the areas common with medium high annual precipitation [15]. However, even in the areas with high precipitation, due to increase of population, water demand of other industries, and seasonal variation of precipitation, there remain difficulties in meeting the water demand for shale gas development and local residents living. The research demonstrates that water consumption will increase from less than 0.1% to 0.8% of the total water consumption [16]. This increase is likely to be very small compared with the estimated total water consumption in an area, but it becomes very hard to meet the water demand for shale gas exploitation, as well as local residents living at the same time. All in all, shale gas is in great demand for water, and it seems to be quite significant on how to make scientific management of water resources and satisfaction of water demand for shale gas production and residents living.

Table 1. Estimated water consumption per well via Drilling Horizontally technology and Hydraulic Fracturing technology [14]

Shale gas	Water consumption per well via Drilling Horizontally (m^3)	Water consumption per well via Hydraulic Fracturing (m^3)	Total water consumption (m^3)
Barnett Shale	5，700	8，700	14，400
Fayetteville Shale	230	11,000	11,230
Haynes Shale	3,800	10,000	13,800
Marcellus Shale	300	14,000	14,300

2.2 Management of water resources

With a shortage of water resources, China has the other issues on water resources, including uneven spatial distribution of water resources, serious imbalance between supply and demand of water resources, inefficient utilization of water resources, and so on [17]. In addition, there is a large difference on water use efficiency between China and America [18]. As such, we urgently need to learn American advanced management experience in water consumption for shale gas production.

Shale gas exploitation requires a great deal of water, and a significant proportion of the water comes from the surface runoff. River runoff changes with the seasons and in the period of small river runoff, the water subtle changes may affect the survival of fish and other aquatic organisms, as well as the fishing and other activities, like urban water supply, power plants and the other industrial water consumption [19]. The government and shale gas manufacturers consider how to make full use of river runoff changes with the seasons to collect water in the period of fast surface water flow. Performing different water storage plans based on different seasonal runoff can effectively avoid the potential impact on urban water supply or aquatic organisms and riverside communities. Taking Fayetteville Shale in Arkansas for instance, a manufacturer is planning to build a reservoir to store the water retuned from the Red River. Hereto the water returned refers to the water produced by the floods in rainy season or released by the hydroelectric power. Besides, in order to minimize the impact of water consumption of shale gas production on local water supply, this manufacturer builds additional pipelines and fire hydrants to provide water for fire protection in some remote areas, and monitors the river water quality and survival condition of fish in the river, as well as designs a water regeneration system similar to municipal water supply facility. In a word, this manufacturer takes a series of measures to ensure production water and reduce the impact on local water supply. The whole project is performed under the active cooperation of a local environmental group, and represents an innovative solution for environmental problems [20].

How to meet the water demand when drilling technology and fracturing technology is performed is one of key factors of successful development of shale gas. But shale gas development is still in its infancy in some areas, so water demand of shale gas exploitation probably produces challenges to local water supply and related infrastructure. Communication between shale gas exploitation enterprise and local water resources planning authority enables the enterprise to live with local community in peace and effectively manage local water resources; therefore, shale gas developer shall master some rules and regulations related with local water resources [21]. For example, Clean Water Act has provisions on the water discharged from shale gas drilling and production to the earth surface, and the rainwater spilled out from shale gas production base; Safe Drinking Water Act sets provisions on injection of liquid into underground in shale gas production. As noted above, there is particularly critical to attend to these challenges and take measures to handle the shale gas production wastewater.

2.3 Disposal of wastewater

Using Hydraulic Fracturing, pump pressure is eliminated, hydraulic fractures treated, and then water-based fracturing fluid mixed with natural groundwater, and backflow performed via well casing. Such produced water contains some dissolved components, and that may generate compounds, and vary from one shale area to the next shale area, for instance, the initial oil producing wastewater varies from freshwater (Total Dissolved Solids (TDS) less than 5000%) to physiological saline in various degrees (TDS more than 5000% but less than 10000% or higher). Most of the fracturing fluid will be recovered from few hours to few weeks, but sometimes few months or even longer [22].

Each of all institutions related with shale gas production, like government, enterprise, and more, is seeking a method of management of oil producing wastewater, enabling them to protect the surface water and groundwater resources, and reduce the need for fresh water in the future. At the present stage the method of "Reduce, reuse, and recycle water" is used to prevent continued pollution and control oil producing wastewater of shale gas. Table 2 demonstrates the main treatment methods of wastewater from oil extraction of current shale gas basins, underground injection, emission disposal, recovery utilization, and more [23] is included.

Table 2. Treatment methods of wastewater from oil extraction of current shale gas basins [23]

Shale gas basins	Water treatment technology	Utilization	Remark
Barnett Shale	Class II water injection well	Commercial and non-commercial	
	Recovery utilization	Treatment practice in situ and recovery utilization	Reuse at re-fracturing
Fayetteville Shale	Class II water injection well	Non-commercial	Water is sent to the water injection wells of two independent production companies
	Recovery utilization	Recovery utilization in situ	Reuse at re-fracturing
Haynes Shale	Class II water injection well	Commercial and non-commercial	
Marcellus Shale	Class II water injection well	Commercial and non-commercial	restricted for use in Class II water injection well
	Treatment and discharge	Similar to municipal government water treatment facility	Mainly in Pennsylvania
	Recovery utilization	Recovery utilization in situ	Reuse at re-fracturing
Woodford Shale	Class II water injection well	Commercial	Processed into multi-layer formations
	Land utilization		
	Recovery utilization	Non-commercial	Recover the water and store in the device
Antrim Shale	Class II water injection well	Commercial and non-commercial	
New Albany Shale	Class II water injection well	Commercial and non-commercial	

Underground injection is considered as the traditional treatment method for wastewater from oil extraction and natural gas. Among the most treatment methods, this method is likely to the top choice of treatment of oil production wastewater of shale gas. Underground injection, also called environmental injection in China, refers to an injection method, which aims for environmental protection by injecting the oil producing wastewater to high-permeability security formation, rather than discharging the oilfield sewage to the natural environment [24]. This method is performed via salt water disposal well to store the wastewater in the multi-layer impermeable rock formations of underground thousands of meters. Underground injection for treatment of oil producing wastewater is not feasible in all areas due to lack of appropriate injection area, but penetrable underground formation can be found nearby to achieve injected fluid. Therefore, if there is lack of possibilities to find such formation in shale gas production area, the oil producing wastewater can be transported to the farther injection area. For this, pipeline transportation is used as an easy and safe method for wastewater transportation. Shale gas area near the developed city, such as Barnett Shale near Fort Worth, has used pipelines to send the oil producing wastewater to the injection well disposal area [14]. Well Injection Disposal method is jointly authorized by American Safe Drinking Water Act (SDWA) and Underground Injection Control (UIC).

The assessment of fracturing fluid reuse is being performed by research institutes and shale gas operators, for the purpose of discovering the degree of treatment for all reuse water in different uses. Specifically, the treatment facilities and treatment methods in situ are used according to these factors: 1) flow rate and total flow of fracturing liquid, 2) composition and concentration needed to remove, and 3) requirements of reuse or discharge of treatment goal and water. In most cases, the water via treatment can be used for re-fracturing or the other industrial uses, rather than discharged to the surface water bodies or even used as drinking water. As such, according to the different requirements of degrees of treatment, there is necessary to make plans on establishment of commercial wastewater treatment facilities and on treatment of wastewater produced by shale gas. Undoubtedly, completion and success of such treatment facilities is an important part of success of shale gas production [15]. An experiment of the use of new water treatment processing technology, together with existing emerging processing application device, is performed in some areas to deal with the wastewater. The water via treatment can be reused for fracturing production and irrigation, and even as drinking water [25].

3. Water resources shortage in China shale gas exploitation

As shown in 12·5 energy development plan, China clearly demonstrates that great efforts shall be made to break though the bottleneck of coalbed methane, shale gas and the other unconventional oil and gas resources, strengthen the supervision and management of exploration and development of shale gas, and so on [26]. In addition, the Oil and Gas Resources Strategic Research Center of Ministry of Land and Resources of PRC summarizes American successful experience on shale gas industry, including strong support of national policy, breakthrough and promotion of key technology, good market conditions and infrastructure, etc., and also puts forward a series of corresponding measures [27]. However, all parties fail to highlight China’s restricted geographical environment for shale gas resource development, especially the shortage of China’s water resources.

In fact, shortage of water resources is a big problem. As noted in 2011’s China water resources bulletin as issued recently by the Ministry of Water Resources of the PRC, it demonstrates that China had so serious climate disasters in 2011 that drought and flood interweaved, numerous disasters continuously happened, and winter wheat area in the north, lower reaches of the Yangtze River and southwest areas suffered consecutive three wide-range serious droughts. Throughout the year 2011, the average annual rainfall reached 582.3mm, equivalent with total rainfall of 5513.29 billion m3, a decrease of 9.4% compared with perennial values and 16.3% decrease compared with that of 2010, 2011 rainfall was deemed as the lowest since 1956 [28].

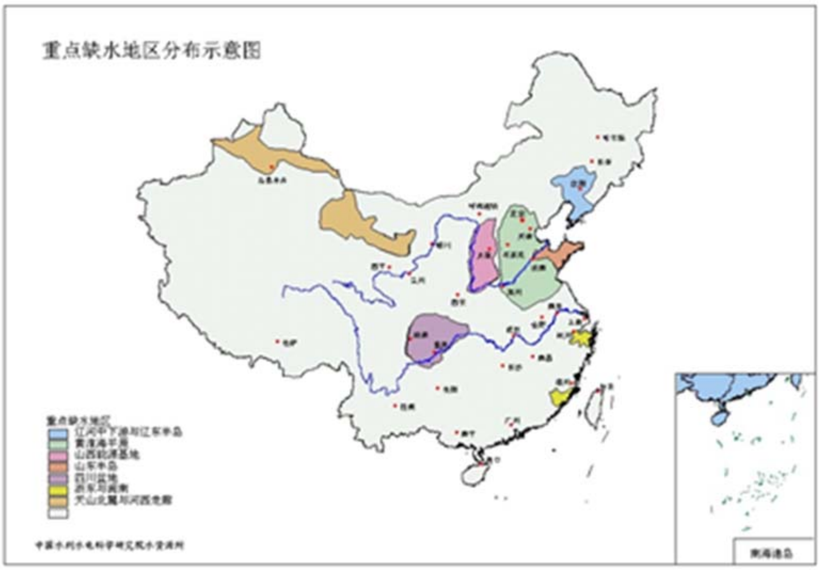

Fig 1. Distribution chart of China's key water-deficient regions [29]

Uneven distribution of water resources is considered as one prominent problem of China's water resources. As shown in the above figure issued by China Institute of Water Resources and Hydropower Research, Sichuan Basin, North China Plain, Hexi Corridor, Shanxi region and so on are the key regions with deficient water resources. But 12·5 energy development plan points out that Sichuan, Chongqing, Yunnan, Guizhou, Hubei, Shaanxi, Shanxi and the other provinces are the main regions to accelerate the shale gas exploitation and development [26], Chongqing and Shanxi are included in the key water-deficient regions. Hence, an apparent contradiction is formed between the great demand of water of shale gas development and the serious shortage of local water. As shown in the table below, total water supply of Shanxi and Chongqing separately posed the last but six and seven in China provincial administrative regions, with the separate water supply amount of 7.42 billion m3 and 8.68 billion m^3.

Table 3. 2011's Water supply and water consumption of each provincial administrative region [29]

Provincial administrative region	Water supply (a hundred million m^3)				Water consumption (a hundred million m^3)					
	Surface water	Underground water	Others	Total	Living	Industrial	Others	Agricultural	Eco-environment	Total
Whole nation	4953.3	1109.1	44.8	6107.2	789.9	1461.8	437.5	3743.6	111.9	6107.2
Beijing	8.1	20.9	7.0	36.0	16.3	5.0	0.4	10.2	4.5	36.0
Tianjin	16.8	5.8	0.5	23.1	5.4	5.0		11.6	1.1	23.1
Hebei	38.5	154.9	2.6	196.0	26.1	25.7	0.7	140.5	3.6	196.0
Shanxi	32.7	38.6	2.9	74.2	13.1	14.3		43.4	3.4	74.2
Inner Mongalia	91.1	92.5	1.1	184.7	15.1	23.6		135.9	10.0	184.7
Liaoning	76.7	64.3	3.6	144.5	25.9	24.0		89.7	4.9	144.5
Jilin	87.4	43.7	0.2	131.2	15.1	26.6	6.9	81.6	7.9	131.2
Heilongjiang	201.4	149.9	1.1	352.4	21.2	53.2	10.3	272.3	5.6	352.4
Shanghai	124.4	0.1	0.0	124.5	24.9	82.6	71.4	16.5	0.5	124.5

Jiangsu	546.1	10.1	0.0	556.2	52.4	192.9	134.2	307.6	3.3	556.2
Zhejiang	193.7	4.2	0.7	198.5	40.0	61.8	1.3	92.1	4.6	198.5
Anhui	259.9	33.4	1.3	294.6	31.7	90.6	35.4	168.4	4.0	294.6
Fujian	203.5	5.0	0.3	208.8	25.2	83.5	19.2	98.6	1.5	208.8
Jiangxi	252.7	10.2	0.0	262.9	28.4	60.6	20.4	171.7	2.1	262.9
Shandong	127.4	89.3	7.4	224.1	38.2	29.8	0.2	148.9	7.2	224.1
Henan	96.9	131.3	0.9	229.1	37.4	56.8	2.0	124.6	10.3	229.1
Hubei	286.2	9.7	0.8	296.7	33.8	120.4	34.9	142.3	0.3	296.7
Hunan	308.9	17.4	0.1	326.5	45.2	95.6	27.4	183.1	2.6	326.5
Guangdong	443.4	19.4	1.5	464.2	97.3	133.6	38.9	224.2	9.1	464.2
Guangxi	286.9	10.8	4.1	301.8	45.7	57.3	17.1	193.2	5.6	301.8
Hainan	41.1	3.3	0.1	44.5	6.7	3.9		33.8	0.1	44.5
Chongqing	84.9	1.8	0.1	86.8	19.1	43.3	14.7	23.6	0.7	86.8
Sichuan	212.1	18.1	3.2	233.5	38.3	64.6		128.4	2.2	233.5
Guizhou	93.2	1.1	1.7	95.9	14.9	30.7		49.7	0.6	95.9
Yunnan	141.1	4.8	0.9	146.8	24.4	25.2	0.8	96.1	1.0	146.8
Tibet	28.1	2.8	0.0	31.0	1.9	1.7		27.4	0.0	31.0
Shaanxi	54.5	32.7	0.5	87.8	16.2	13.2		56.2	2.1	87.8
Gansu	97.0	24.4	1.4	122.9	10.6	15.4	1.1	93.8	3.0	122.9
Qinghai	25.8	5.3	0.1	31.1	3.7	3.5		23.5	0.5	31.1
Ningxia	68.0	5.6	0.0	73.6	1.9	4.6		66.1	1.0	73.6
Xinjiang	425.0	97.8	0.8	523.5	13.8	12.6	0.3	488.4	8.7	523.5

As noted in the studies, overall average gas production in single well in the Unites States reaches about 1000 m3, and water demand of each horizontal well, in the amount of 114 m3 each day, is five times more than that of each vertical well [8]. Imagination that there are 1000 wells at work in the same time in Chongqing or Shanxi, and water consumption for that is 41 million m3 for one year, shale gas production is 360 million m3. Based on the data shown in Table 3, it accounts for 0.47% of 2011's Chongqing total water consumption and 2.1% of Chongqing living water, and besides, accounts for 0.55% of 2011's Shanxi total water consumption and 3.1% of Shanxi living water. Also, taking into consideration the regional and seasonal shortage of water in such regions, the sustainable utilization of water resources probably creates the limitation of local shale gas production. To sum up, water conservancy infrastructure for shale gas exploitation needs to be established to make management of the water resources and treatment of the wastewater, but due to large investment of water conservancy project and low return rate of investment, it is quite difficult to attract sufficient construction funds in Chongqing, Shanxi and the other Midwest areas, resulting in engineering water shortage [30]. In short, large-scale shale gas exploitation in China's serious water-deficient regions is likely to bring severe challenges to local ecological environment and local residence lives, especially when large amounts of water resources need to use for shale gas exploitation.

4. Conclusions and suggestions

American experience and situation of shale gas development shows that shale gas will hold or is holding a quite important position in American energy strategy, whereas all parties in China are paying attention to the technologies and policies of shale gas exploration and exploitation. In this situation, this article draws on American experience on the method of dealing with water resources challenges caused by shale gas exploitation, and proposes the following three suggestions for China's shale gas development:

(1) Large amounts of water resources need to make shale gas exploitation, but relatively, some regions in China have deficient water resources, as such, except introducing American shale gas exploitation technology, China should pay more attention to American mature management experience of water resources and environmental technology, avoiding waste and pollution of water resources and ensuring living water od local residences;

(2) China should accurately deal with backflow water produced by shale gas exploitation, and actively learn American wastewater treatment experience, as well as introduce their underground injection technology to solve backflow water. Do not directly discharge the untreated backflow water to the rivers, lakes and any other surface runoffs;

(3) China is getting ready for shale gas development and utilization, but constraint conditions of local water resources need to be fully considered for making development plans related with shale gas. Shale gas exploitation should be performed based on the water resources and abilities in Chongqing, Shanxi, and any other key water-deficient regions, and detailed researches should be made before the development of shale gas. No matter for economic development or national energy security, it prohibits making shale gas exploitation at the cost of polluting environment and water resources people live on.

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