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Engineering Philosophy-based Reflections on Efficient Development of Shale Gas in China

Abstract The Shale Gas Revolution began to have a significant impact on global supply and demand of natural gas; also the price trend of natural gas has been greatly affected. This phenomenon raised concerns among natural gas producers and consumers. China has abundant shale gas resources, but the development scale is small while facing problems including weak exploration and evaluation basis, overlapping royalties, complex terrestrial environment, lack of technical practices and accumulation, inadequate management and regulatory mechanisms, etc. To overcome these challenges for large-scale shale gas development, we believe that shale gas development is not only a single technical problem, but a systematic engineering demanding multidisciplinary research that will be bound to spread to humans, nature, and society. Therefore, to ensure the healthy development of China's shale gas, it is required to coordinate global and local relationships, engineering and community relations, as well as to break up the conflicts between engineering and nature, engineering and economy, along with engineering and society.

Keywords: shale gas development, engineering, energy revolution, engineering philosophy, reflections

1 Historical background of Shale Gas Revolution

The Shale Gas Revolution, fueled by large scale development of shale gas, is the phased achievement for the United States on the path of seeking energy independence (Li, 2011). Shale gas development will continue to improve the U.S. energy independence and may provide fresh impetus for the development of the U.S. economy (Sun, 2014), thus contributing to the promotion of the U.S. position and power. Meanwhile, this will also make the importance of the traditional energy powers decrease slightly (Li, Hu, & Cheng, 2007). "Shale Gas Revolution" starts to have a significant impact on global supply and demand of natural gas; the price trend of natural gas has been greatly affected. This phenomenon aroused concerns among natural gas producers and consumers. The development and utilization of shale gas become a driving force for the strategic development of low carbon economy, and it has become a catalyst that pushes the structural adjustment of the world's oil and gas geopolitical landscape. China also joins the exploitation of shale gas (Zhao, Wang, Liu, Bai, & Zhang, 2008; Xu, Xu, Duan, Yuan, & Zhang, 2011; Yun, Qin, Xu, Li, Zhong, & Wu, 2012).

2 Development status analysis of the shale gas: China vs the U.S.

According to the data provided by the U.S. Energy Information Administration (EIA), the technically recoverable shale gas resources in the world were $206.7\times10^{12}m^3$, among which, North America had $50.5\times10^{12}m^3$ and Asia had $39.7\times10^{12}m^3$. The United States is the first country in the world to discover research, explore and develop shale gas. The annual output of the U.S. shale gas in 2013 was up to $212\times10^9m^3$, which is expected to reach $(308-339.6)\times10^9m^3$ in 2020. The successful shale gas development practices of the U.S. benefit from the following conditions. The first condition is the policy. Since the early 1990s, Texas has canceled production tax on the development of tight gas and shale gas. In addition, the United States has also established independent and fixed research funds for unconventional oil and gas resources. The second condition is to overcome various technical bottlenecks and successfully put the technologies into production; these include horizontal wells plus multistage fracturing technology, slick water fracturing technology, and factory operation technology. Thirdly, there are favorable geological conditions and surface conditions. Shale gas reservoirs

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in general are in a stable tectonic geological setting, distributed continuously in large areas, with buried depth around 1,000−3,500 m. Currently, the main development formations are the ones shallower than 1,500m. The smooth surface is ideal for the transport of large-scale equipment, the placement of site and drilling, and the fracturing operation. In addition, the U.S. shale has high organic matter content and moderate evolution degree, which is very desirable for shale gas production and the production is relatively stable (Pu, Bao, Wang, & Jiang, 2008; Zhou, Jiang, Zhang, & Fan, 2012; Zhai, 2013; Qin, Zhang, Liu, Feng, Liao, & Chen, 2014).

According to China's "Twelfth Five-Year Plan" for shale gas, in 2015 China's shale gas production will reach $6.5\times10^9 m^3$, and shale gas will become one of the important resources in our country, but domestic shale gas is complex in its geological conditions, deeper in buried depth, and older in formation age. Since the buried depth is generally deeper than that of the United States, we need greater drilling depth. The drilling cost of a single well in the U.S. is less than 20 million CNY, and the estimated exploitation cost of shale gas is 1−1.27 CNY/m^3. However, in Sichuan, Chongqing and other places in China, the buried depths of shale gas are generally between 2,600 meters and 3,000 meters, with only a few meters of reservoir, thus the drilling and fracturing cost of a single well is nearly 100 million CNY, which equals four to five times the exploitation cost in the U.S., i.e., 5−6.3 CNY/m^3. This also means that we need more drilling and fracturing water, but the contradiction between cost and water resource is very serious (Zhai, 2008; Li, Qin, Zeng, He, He, & Chen, 2010; Wu, 2013; Zhu, 2013; Yao & Yang, 2014).

In addition, there are great differences between China and the United States in oil and gas markets. In North American, oil and gas markets are relatively mature and perfect, which mainly reflect in the following four aspects. Firstly, the pricing system is independent: Henry Hub and WTI are the benchmarks of the U.S. natural gas and crude oil price, which makes the United States having independence and initiative in oil and gas deal. Secondly, the supply and marketing chain are complete: there are numerous companies engaged in the development of oil and gas in North America, so oil and gas production supply is adequate; on the other hand, sales distribution channels are numerous. Moreover, there are more than 250 independent natural gas marketers across the United States, and many states have natural gas trading hubs. Thirdly, the United States has a huge consumer market, combined with the LNG export terminal under construction. All combine in a certain extent to solve the worries in sales. The infrastructure is perfect, especially the perfect construction, high coverage, and convenient access to oil and gas pipelines. Fourthly, the investment environment is favorable. The market system, legal system and tax system in North America give full freedom to investors for operation, and attaching great importance to the intellectual property also provides more protection for the resource and technology owners.

3 Opportunities and challenges that China's shale gas development projects face

The Shale Gas Revolution is known as "the most important event in the oil industry for these one hundred years." This revolution has begun to exert an influence on China. China's "gas" revolution seems to be coming. In this "revolution", opportunities and challenges exist side by side.

In 2013, the Society of Petroleum Engineers (SPE) invited over seventy world-class experts in the field of shale gas to a seminar about China's shale gas development. It was agreed in the meeting that China's shale gas development faced many problems and contradictions in engineering, economy, management, standardization, etc. (Wu, 2011). These problems can be summarized as the following four challenges:

First, shale gas resource base faces the challenge. China's shale gas is small in drilling amount, low in the degree of exploration, lacking deep understanding in geological cognition, low in data accuracy, and unclear in block resources situation. Moreover, resource evaluation results at present are largely in the stage of "assumption", which is far from basic and complete "confirmation."

Second, quality of shale gas resource and exploitation efficiency is another challenge. The main difference in shale gas between the United States and China is that the light hydrocarbon content of the U.S. is higher, and the price of light hydrocarbon under high oil price rises. Under the premise of dry gas hedging cost, the light hydrocarbon alone can produce a lot of benefits. China's shale gas, which belongs to dry gas, contains almost no light hydrocarbon. In the case of investing nearly one hundred million CNY in a single well, it is difficult to guarantee the investment recovery due to the high development cost, small and unstable production, fast production decline, and low cumulative yield of a single well.

The third challenge is the environmental risk. In the fracturing engineering of shale gas exploitation, "ten thousand tons of water and one thousand tons of sand" are needed for a single well, which will inevitably bring environmental damage. In the reality where China's population density is much higher than that of the United States, to develop shale gas probably does more harm than good. Environmental risk is inevitable, but we must face the reality (Zhu, Li, Xie, & Yang, 2014).

The fourth challenge is the system and technology. The U.S. "Shale Gas Revolution" is jointly created by thousands of small and medium-sized companies. Although the country has created a relatively loose policy environment for shale gas development, technical problems are the key and where there is no technological breakthrough, there is no benefit, and no people will be willing to invest. The reasons that thousands of companies in the United States invest in shale gas are the technical breakthroughs. Being able to get benefit allows shale gas development to make a breakthrough progress. At present, China's supportive policies for shale gas development are far from enough and investment risk is huge, which restricts the development of shale gas (Li & Liu, 2014).

4 Engineering philosophy-based reflections on the shale gas development

Engineering philosophy is a scientific thinking method, which guides engineers and managers to apply the materialism and dialectics unwittingly to practical activities of oil and gas development. It can let people consciously, systematically and scientifically use correct philosophy in shale gas engineering activities and avoid detours. Engineering philosophy problem in the shale gas development is not to discuss how to specifically develop a gas field and what kind of schemes and measures should be adopted; instead, it is about conducting the research of macro engineering conception.

Facing the great challenge in the effective development of shale gas resources, workers of petroleum science and technology increasingly clearly realize that it is not just a single engineering technical problem; it will also inevitably involve people, nature, and human society, and the interaction among the three factors. It is a complex system engineering that needs multidisciplinary collaboration. We must handle dependence, influences, restrictions and effects between different systems and between internal ingredients of the systems under the guidance of the engineering philosophy. We should grasp the essence of events and contradiction of laws by considering about three aspects, i.e., the harmony between engineering and nature, the harmony between engineering and economy, and the harmony between engineering and social environment. Then we should deal with the relationship between the whole and local, and between engineering and social development, as well as think of and solve the shale gas development in a higher level.

4.1 Ecological outlook of the shale gas development engineering

Shale gas development activity, as a social practice, is inevitably restricted by the law of social development. "Shale Gas Revolution" cannot take root in China only with the advanced shale gas development technology and the domestic abundant shale gas resources. China also needs to solve the local problems that the U.S. shale gas companies have never met, such as obtaining and application of the water resources in the mining area. In the United States where the per capita water resources are very rich, the water problem in the shale gas mining area may not be outstanding; however, as China's main shale gas mining areas are generally distributed in relatively densely populated areas, shale gas exploitation will bring a series of problems to the mining areas, such as grabbing the agricultural water and living water, as well as threatening the fragile ecological environment. According to data from the Food and Agriculture Organization (FAO) of the United Nations, China's renewable water resources per capita were 2,060m^3, only 1/10 of that of the United States. As most areas of China are affected by the monsoon climate, its annual precipitation is uneven. For example, in Chongqing, Sichuan, etc. where the average annual precipitation is relatively abundant, long droughts can also occur. In addition, water consumption of China's shale gas development per single well is greater than that of the U.S. In China, whose water resources are short and unevenly distributed, if the problem of water resources management in shale gas development can not be effectively solved, the massive shale gas development will be likely a beautiful but evanescent dream. Therefore, China must establish strong ecological outlook on the shale gas development engineering.

The shale gas development process in the United States strictly adopts the state and federal two-level management system. The federal government regulations cover the whole production process, which have clear rules on the quality of air and water, the management of dangerous articles, the public's right to know, and the management of pollutants. State governments, according to the local situations, put forward more specific requirements on shale gas production, such as well depth, fracturing fluid composition, water storage, waste water and waste management as well as earthquake monitoring, etc. Such a two-level management system forces the U.S. companies to use 7% of their cost of production to control the pollution risk. The U.S. authorities, through the evaluation of the shale gas production process, think that as long as operation is carried out in accordance with the standards, also the use and recovery of fracturing fluid are properly managed; water pollution risk is completely controllable. Compared with the U.S. with perfect regulatory systems, China is still in the state in which there is no specific regulations to abide by. As China that has put shale gas development on the agenda, it is imperative to fully absorb the U.S. management experience in the development of shale gas and to develop targeted laws and industrial standards.

Under these circumstances, we should actively explore regional and comprehensive process environmental monitoring system for the development and utilization of shale gas. On the basis of the strict implementation of the current environmental management laws and regulations, we should research and determine the related environmental access regulations and environmental regulatory standard system according to the characteristics of the shale gas development, and persist in the synchronization between development and protection. According to environment characteristics and sensitivity of different regions, combined with the relevant requirements of principal function division, and in view of the prominent environmental problems, we should promote environmental management in the development of shale gas by regions. At the same time, we should establish and perfect the whole process supervision system from the planning environmental impact assessment of shale gas development to the "three simultaneities."

4.2 Shale gas development engineering value

In the engineering management of our country's oil and gas industry, maximum efficiency and benefit are the core idea of traditional engineering management and the main control objectives are quality, cost, construction period and safety. Since the reservoirs of our country's shale gas are deep with numerous faults, and the resources are mainly located at mountainous areas with poor environment, inconvenient traffic, complicated terrain and high population intensity, and water resources required by well drilling and fracturing are not optimal, the traditional engineering management idea could no longer meet the requirement of the strategy of sustainable development of shale gas. It is required to establish an evaluation system of shale gas development engineering management value and conduct comprehensive researches on aspects of the operation of engineering technology implementation. Also the integrity of process management and the science of top design need to break through traditional management modes and promote rapid development of shale gas.

First is the operation of engineering technology. In the coming decade, the scale performance investment of China's shale gas will exceed 600 billion CNY. Though shale gas development has attracted attention, the maturity of engineering technology is relatively low. Shale gas development requires highly integrated technology. To purchase the technology of one American company can only obtain one or two parts but not the whole set of integrated technology, and it will not play its due role if the technology bought cannot be digested. So far, China's analysis experiment technology against the exploration and development of shale gas is not complete yet; the knowledge on the accumulation mechanism and enrichment characteristic of shale gas is not clear; the reservoir engineering technologies and shale gas development geological theories, such as selection and evaluation of shale gas producing favorable zones, shale gas reservoir description, productivity prediction, well location deployment and well pattern optimization, are not mature yet. The existing horizontal well drill completion technology cannot totally meet the requirements of shale gas horizontal drill completion yet; segmented multistage fracturing process and kits of horizontal well still need to be introduced, researched, developed, tested and evaluated; shale gas fracture extension law, fracturing scale optimization and productivity prediction still need to be improved; and monitoring the detection equipment, construction technology and evaluation method by microseism is still at the starting stage in China (Zang, Bai, Li, Niu, & Zhang, 2014).

We must face the reality. In the initial stage, we can adopt the strategy of introduction, digestion and re-innovation to give full play to the comprehensive R&D power of state-owned oil companies. To avoid duplicated research and the scattering of R&D funds, we should make overall planning to tackle key problems by different levels. Currently, problems such as multipoint input of shale gas equipment, R&D and low-level duplicated research must be given great attention. Government responsible organs should regularly organize relevant seminars and technological exchange meetings, and state-owned oil companies should also play a technological leading and demonstrating role. Since there are fewer enterprises with innovation ability in China compared with the U.S., it is especially important for private enterprises to enter shale gas development field by directional guidance and favorable information spreading. As the current shale gas engineering technology is at the R&D stage, it is required to add elements to minimize environmental pollution. Harmless treatment to the mud in drilling, the recycling of fracturing fluid and anhydrous fracturing technology should all be further researched and implemented. The breakthrough of Sinopec in the Fuling test site, which has produced commercial-scale shale gas, gives hope to China's shale gas revolution. With the increasing skill level of China National Petroleum Corporation (CNPC) and Sinopec in the formation conditions, reservoir positions, drilling technology and fracturing technology of domestic shale gas demonstration plots and the practical application of cluster well, the exploitation cost of shale gas also shows a year-by-year falling tendency, among which drilling service will be the part with relatively big cost elasticity, and the cost of single well is predicted to reduce from around 100 million CNY to below 50 million CNY. Timely summarizing these experience and formulating state-level technological and industrial standards and specifications can reduce the risks for enterprises to enter this field, absorb concerns from investors and reduce the threshold of entrance, thus helping to form the advantages of funds and large scale (Zhang, et al., 2008; Lin, 2014). "Continuous, integrated and innovative" technological management mode of the effective development of shale gas should be gradually formed: i.e., based on the existing technology and driven by the constantly updating and changing geological contradictions, break through the engineering barrier, organically integrate the innovative elements in the complete system of shale gas exploration and development such as talent, technology, capital and information to form a set of overall optimized resource allocation. In this relatively multidimensional technological management space forms an open and interactive innovation system, and the continuous force for synergetic and orderly development is condensed.

Second is the integrity of process management. Shale gas exploration and development and natural gas utilization need systematic engineering, especially the areas where our country's shale gas sites are mostly the areas with frequent geological disasters and weak ecological systems. It is quite necessary to analyze and judge the mutual impact between engineering and environment from different angles, and integrated precision analysis based on full life circle is needed. Though shale gas development can help to increase energy security, tackle climate changes and solve haze caused by excessive dependence on coal, if there is no environmental protection and supervision measures advanced technological support for full life circle before large scale mining, the development of shale gas industry will not be sustainable. Seeing from Shale Gas Development Planning (2011−2015), due to the urgency of task, CNPC, Sinopec and local governments have gone all out and gone fast. Though the Ministry of Land and Resources has formulated the resource evaluation standard of shale gas and formulated 22 items of technical specifications on 7 aspects including drilling, fracturing and well test in order to complete the technical specifications of shale gas exploration and development, many industrial standards aiming at environmental protection laws and shale gas production are still under exploration and formation. If we advance rashly and blindly, the required supporting facilities of the whole industry will fall behind and inadequate consideration for factors such as environmental protection, ecological impact and population health will also bring a series of problems.

4.3 Social environment view on shale gas development engineering

With the Shale Gas Revolution, the pattern of oil and gas development and equilibrium area output has changed. Public acceptance level has become a great challenge for shale gas development engineering. The prosperity of unconventional resources has brought unprecedented frequent drilling and production operation and larger population to some areas compared with traditional oil development areas. Stakeholders are playing important roles in the future development of shale gas and various public suspect has drawn continuous attention, including environmental problems of water resources utilization, known hazards to underground aquifer, waste treatment, truck passage, dust, noise and emission.

While the output from shale and other dense formations has successfully drawn nationwide and worldwide attention, its future depends much on the value degree, and acceptance level of the output place. Due to the rapid rise of drilling exploration of shale gas, the public will pay much more attention to the social impact of natural gas exploration than any time before. Some judicial districts in the U.S. have suspended or prohibited the use of hydrofracturing, which is an important part to successfully develop shale. Similar measures and other limitations can be extended to other districts. In our country, shale gas development requires large scale of hydro-fracturing, which need large water resources, not abundant in our country, especially in the western areas with serious water shortages. Therefore there are bound to be contradictions between water resources used for shale gas development and for agriculture, drinking water and other industrial water usage. Risks for social cognition degree and acceptability of shale gas development actually exist. It has been realized by industry insiders that it is necessary to go deep into communities and share information. This involves various groups, such as the public, community groups, industrial organizations and supervisors. It is required to contact and listen to the views of stakeholders. Only if stakeholders can continuously benefit from the energy development, which is safe, responsible and meets the requirements of environmentally-friendly production, can the large-scale production of shale gas be implemented. It requires joint and continuous efforts of various stakeholders in order to reach this standard.

5 Understanding and conclusions

China is rich in shale gas reserves, but cannot simply copy the U.S. Shale Gas Revolution, and shale gas development should not be blindly optimistic. We should stand from the present and look forward to the future, then deal with the relationship between continuity and stages, and deal well with the relationship between whole and part and between engineering and social development from three aspects of coordination: engineering and natural environment, engineering and economy, and engineering and social environment. In this way, we can accelerate technology R&D and supporting policies, promote our country's shale gas development progresses and satisfy national energy demands.

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