Exploration and Development Technology of Shale Oil and Gas in the World: Progress, Impact, and Implication

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Abstract. Shale oil and gas resources in the worldwide are mainly distributed in the United States, Canada and other countries. Thanks to the continuous progress of shale oil and gas development technology, the upsurge of shale oil development started after the shale gas revolution in the United States. At the same time, the United States has introduced supporting policies and measures related to shale oil development, which have promoted the economic and efficient development of shale oil and gas. Taken as a whole, the successful commercial development of shale gas and oil in the United States is profoundly changing the world's energy and political landscape, and some of the initiatives of the shale gas revolution have profound implications for China and other countries.

1. Introduction
At present, the shale oil and gas revolution is taking place on a global scale, and the results of this revolution will greatly adjust the global energy landscape to a large extent. The United States is the first country to research and develop shale gas in the world. Since the first shale gas well was drilled in 1821, after the exploration and development of shale gas in the 1970s, and the promotion of policies, prices and technologies in the 1990s, the United States successfully transformed from an oil and gas importing country to an exporting country at the beginning of this century. The successful exploration and development of shale production in the United States has greatly enhanced the commercial value of shale gas. Shale gas has naturally become the focus of global energy field. More than 30 countries, including Germany, France, Poland, Argentina, Mexico, Brazil, Australia, China, India and Indonesia, have actively carried out research, exploration and development of shale gas technology, setting off a worldwide "shale gas revolution". [1]

2. Main technologies of shale oil exploration and development
Throughout the process of shale oil resources exploration and development engineering technology, shale oil development technologies mainly include drilling engineering technology of shale oil resources, fracturing engineering technology of shale oil resources development, fracturing fluid technology and fracturing proppant technology.

The first is about the drilling engineering technology of shale oil resources. Throughout history, the way of discovering shale oil drilling has experienced the development of vertical wells, horizontal wells and cluster well factories. The earliest idea of a well factory development proposed by a Canadian energy company is to use the method of horizontal well drilling, and then complete multiple processes of the drilling, perforation, fracturing, completion and production in one well site at the
same time. This process is to make all wellbores work in batch mode. This construction mode greatly improves the timeliness of drilling operations, which can realize the safe and efficient exploration and development of shale oil and gas reservoirs.

The second is the fracturing engineering technology for the development of shale oil resources. By summarizing the current fracturing technology and process of shale oil, it is found that the shale oil fracturing process is similar to the shale gas fracturing process, which is mainly composed of the following technologies: horizontal well staged fracturing technology, horizontal well synchronous fracturing technology, water-free fracturing technology and high-diversion hydraulic fracturing technology. [2]

The third is the fracturing fluid technology. The development of shale oil resources also requires fracturing fluids, and the commonly used fracturing fluids for shale oil are slippery water and linear glue. If a higher viscosity fracturing fluid is used, a proppant with a larger particle size is also provided. In addition to the higher sand ratio, special attention should be paid to the matching degree of fracturing fluid and fracturing proppant. To some certain extent, these above measures can achieve the formation of main fractures with high-conductivity and reduce the flow resistance of formation shale oil into the bottom of the well, which can greatly increase the production of shale oil wells.

Finally, the fracturing proppant technology for shale oil development. The shale oil and gas resources in North America are largely developed using quartz sand as the primary proppant for fracturing due to shallow reservoir burial and relatively low reservoir closure pressure. In addition, for some reservoirs, the construction workers will use a mixture of quartz sand and ceramsite as proppant to provide the necessary support for the fractures, which will result in a large width of the support fractures, and greatly improve the diversion capacity of the main fractures.

At present, China has initially formed a low-viscosity and high-cut oil-based drilling fluid system with independent intellectual property rights, and has developed core additives such as emulsifiers and fluid loss additives. To some extent, this has significantly reduced the actual production cost of the shale oil resource development. In fact, the actual production cost of oil resource development has been reduced by 30% compared with the same type of products abroad, and the system performance of shale oil resource development can be said to have reached the international advanced level, thus initially solving the stability problem of shale oil resource exploration and development. [3]

3. Current status of shale gas resources development in the world
Shale gas resources are globally abundant. According to the assessment of the US Energy Information Administration (EIA), there are 137 sets of shale formations in 95 basins in 41 countries in the world. The geological resource of shale gas is about 1013 trillion cubic meters, and the technically recoverable resource is 220.7 trillion cubic meters, mainly distributed in North America, East Asia, South America, North Africa, Australia and other regions. In terms of shale oil exploration reserves, Russia, the United States and China rank among the top three with recoverable reserves of 75 billion barrels, 58 billion barrels and 32 billion barrels respectively. China, Argentina and Algeria rank top three with 1,115 and 802 and 707 trillion cubic feet of recoverable reserves respectively. The following table lists the top 10 countries with technically recoverable shale oil and gas resources. [4]
Shale gas was developed early in North America. The United States is the first country to carry out exploration and development of shale gas resources. The annual production of shale gas in the United States has increased rapidly 117 times from 3.661 billion cubic meters in 2007 to 430.787 billion cubic meters in 2015. In 2009, the United States surpassed Russia to become the world's largest natural gas producer with an output of 624 billion cubic meters. Canada is the second country in the world to successfully develop shale gas commercially. In 2005, Canada drilled the first tight gas and shale gas wells in Montney Play, and discovered shale gas with exploration value in British Columbia, Alberta, New Brunswick and Quebec. Latin America has 56 trillion cubic meters of recoverable shale gas resources, mainly concentrated in countries such as Argentina, Mexico and Brazil. The potential resource of shale gas in Europe is about 14.4 trillion cubic meters, and its development level is still in its infancy. European shale gas resources are mainly distributed in countries such as Russia, Poland, Ireland, France and Ukraine, including the Baltic sea region, the Silurian in Poland, the Lower Carboniferous in Ireland, the Rhine region and the Wales region in England, and the Upper Jurassic in the Vienna Basin are all considered areas of great development potential. On the whole, although European countries have also embarked on exploratory shale gas development, they are still far from large-scale commercial development of shale gas due to a series of problems, such as population density, strict environmental protection regulation, high development costs, and divergent domestic opinion. [1]

4. Shale gas development in the United States

With a series of technological innovations and maturity of American horizontal wells sub-fracturing technology, it has laid the foundation for the commercial exploitation of unconventional natural gas such as shale gas. Using this technology, oil and gas resources in shale formations that were previously considered impossible to be exploited can be exploited in large quantities. Domestic shale oil and gas production in the United States has grown rapidly since 2008. From 2008 to 2011, the average annual growth rate of domestic natural gas production in the United States reached 4.49%. In 2011 alone, the year-on-year growth rate reached 7.81%. 44% of natural gas production comes from unconventional natural gas. [5] In 2011, the United States surpassed Russia to become the world's
largest natural gas producer. According to the forecast of the US Energy Information Administration, shale gas production in the United States will increase from 9.7 trillion cubic feet in 2012 to 19.8 trillion cubic feet in 2040. The proportion of shale gas in natural gas in the United States will rise from 40% in 2012 to 2040 53% of the year. [6] At the same time, petroleum production in the United States has also increased. Since 2009, the United States has reversed the decline in petroleum production. In 2012, the United States crude petroleum production reached 6.5 million barrels per day, a year-on-year increase of 13.8%, and the total petroleum production reached 2.38 billion barrels. In the same year, the United States crossed the inflection point where both net oil imports and import dependence rose, and a downward trend began. [7]

The "shale gas revolution" in the United States has achieved a great success, which has helped the country get rid of its current economic difficulties, eased its employment problems, and injected vitality into its economic recovery. In 2012, the production of shale gas and shale oil created 800,000 jobs in the United States. Within five years, the revenue of shale gas and shale oil industry alone could add more than a percentage point to annual GDP growth rate and newly create 3 million jobs. At the same time, the decline in natural gas prices can reduce US per capita spending by nearly $1,000 per year. [8] The "Shale gas revolution" is driving the American industrial recovery. The proportion of natural gas power generation in the United States jumped from 17.1% in 2001 to 24.7% in 2011. Thanks to lower natural gas prices, some high energy-consumption enterprises in the United States are returning to their home countries. American companies plan to add up to $72 billion in investments in industries such as paper-making, chemical, scrap material, steel, aluminum, tires, and plastics. These investments will create 1.18 million jobs in the United States. [9] In addition, the increased production of shale gas and shale oil in the United States will also help to reduce its fiscal deficit and government debt. With the development of domestic oil and gas resources in the United States, especially the large-scale exploration of unconventional oil and gas resources such as shale oil and shale gas, the United States will gradually reduce its dependence on imported energy and may gradually achieve its "energy independence" goal. This means that the United States will save a lot of money, and its deteriorating fiscal deficit and government debt will also be eased. [10]

5. The impact of the US "Shale Gas Revolution" on the international energy structure
The "energy independence" of the United States will not only benefit its economic recovery, but will also have a huge impact on the global energy geopolitical landscape. With the large-scale development of shale gas and shale oil in the United States, new changes have taken place in the global oil and gas industry. The new energy line starts from Alberta in Canada, passes south through North Dakota and southern Texas, and then passes a newly discovered large oil field off the coast of French Guiana, and finally reached the offshore large oil field discovered near Brazil. The center of the world’s oil map shifted from Middle East and Central Asia to the Western Hemisphere. [11] At this point, the world will form an "Eastern and Western Polar Energy Supply Pattern", which is composed of the central plate of conventional oil and gas resources in the eastern hemisphere centered on the Middle East and Central Asia and the central plate of unconventional oil and gas resources in the western hemisphere centered on the Americas. [12]

First, the shale gas revolution has greatly increased energy production in the United States and increased its impact on international energy prices. OPEC has weakened its oil production and pricing power. In the short term, in the international energy system, the international energy supply and demand pattern will be formed with the four major energy supply sectors with the Middle East, Central Asia, Russia, and North America as the main body, and the energy demand sector with the three major regions as Europe, East Asia, and South Asia. International oil and gas prices will fall as competition between the United States, Russia and Middle East countries intensifies in the international energy market. In the long run, since shale oil and shale gas are non-renewable sources of energy, with large-scale exploitation and use, oil and shale gas will always be depleted. Demand for oil and natural gas in the United States, Europe, Japan and India, including China, will not abate until new energy breakthroughs are made. Therefore, it has become an inevitable choice for all countries to
adjust the energy structure, vigorously develop new and renewable energy sources and develop a low-carbon economy.

Second, the large-scale development of shale gas has affected the development of renewable energy. The vigorous exploitation and development of shale gas in the United States has led to a decline in the price of shale gas, which has a substitution effect on the formation of renewable energy and has a huge impact on it. Large new energy enterprises in the United States are facing bankruptcy risk, and the pace of development of renewable energy has also become relatively slow. In order to protect its new energy industry, the United States pursues a trade protectionism policy, carries out double-reverse investigations on Chinese photovoltaic products and wind energy products, and imposes punitive tariffs. As a result, China's solar and wind energy industries are under tremendous pressure. Driven by the United States, countries such as Canada, Mexico, Argentina, Australia, China, India and Indonesia have explored or developed shale gas. From this, it can be predicted that natural gas will exceed coal in the energy structure in the next ten years and become the second largest energy source, and may even go hand in hand with oil. This will also slow down the development of non-fossil renewable energy. [13]

Third, with the development of shale gas, the degree of energy self-sufficiency in the United States continues to increase. The focus of the US foreign strategy has shifted from ensuring the security of energy supply to protecting homeland security and economic security. For example, as the Middle East's position in the US's international energy strategy is declining, the United States has greater flexibility in handling Middle East affairs. At the same time, with the further rise of the Asia-Pacific economy, the global strategic focus of the United States is gradually shifting to the Asia-Pacific.

Fourth, due to the high cost of long-distance natural gas transmission, coupled with the influence of trade methods and political factors, there is currently no global natural gas market. There are only three regional markets in North America, Asia and Europe, and the prices of these three major markets are hardly related. The large-scale development of shale gas will greatly increase the supply of liquefied natural gas, and the flexibility of liquefied natural gas trade will likely change the long-term contract trading method and the relatively independent pattern of the three regional market prices, thereby decoupling natural gas prices from oil prices, and accelerating the integration process of the global natural gas market. [10]

6. Implication of American "energy independence"

The "energy independence" of the United States has made it the fastest-growing natural gas producer in the world, which has brought a series of positive changes to the transformation of the energy situation, economic recovery and diplomatic strategy adjustment of the United States. The "shale gas revolution" first occurred in the United States mainly for the following reasons: First, the in-depth scientific research and technological innovation. The research team's many years of research and practice have combined to make breakthrough progress in drilling technologies such as horizontal fracturing and water well drilling. Second, the support of government policies. Government investment in scientific research funds, subsidy policies for new energy development, and policy guidance on energy conversion, substitution of enterprises and grid integration have all provided a solid foundation for technological development. Third, the rise in energy prices. It provides a profit margin for shale gas development, and promotes the enthusiasm of small and medium-sized private enterprises for investment. [13]

According to the measurement and evaluation by a research team composed of multiple agencies of US government, 29.2% of global shale gas recoverable resources are in North America, 27% are in Asia-Pacific, and 43.8% are in other regions, among which China has the most abundant shale gas resources, accounting for about 20% of the world's total. The potential of onshore shale gas geological resources in China is 134.42 trillion cubic meters, and the recoverable resource potential is 25 trillion cubic meters, which can theoretically meet China's natural gas demand for the next two centuries. [14] For China, how to learn the American experience of "energy independence" has become an
important and urgent task. The energy independence of the United States also offers many lessons for China.

First, strengthen research and development to achieve technological and management innovation. China has worked out the "Shale Gas Development Plan (2001-2015)" and developed 62 shale gas wells in the trial production area. However, the main areas where shale gas is distributed in China are not only the poor surface environment, but also many mountainous areas or desert, and the shale gas reservoirs are deeper than those in the United States, and the cost of exploitation is extremely high. The cost per well is as high as 16 million US dollars (while the United States only needs a few million US dollars). Therefore, the government needs to invest and provide support in the field of research and development. [15] At the same time, it encourages foreign investors to transfer mining technology to China by means of technology share conversion, and attracts foreign investors to invest in China under preferential tax terms. On top of that, technological innovation should be carried out in accordance with China's geological conditions. In the development and construction of shale gas, technological innovation and management innovation should be combined with each other to centrally allocate human resources, material resources, investment, organization and other elements to achieve the development goals. [16]

Secondly, give private enterprises equal mining rights and stimulate their enthusiasm and vitality in the early exploration of shale gas. [10] The development of shale gas in the United States adopts a bottom-up model. In the early stage of shale gas development, many small companies took the lead in exploration and production activities, based on the successful early development of small and medium-sized oil and gas companies, "Shell", "Chevron", "ConocoPhillips" and other oil giants were able to enter field of the shale gas development. For China, due to the existence of exclusive rights to operate oil and gas, some powerful and qualified companies have been blocked from the market, which makes it difficult to promote competition in the energy development market. Therefore, it is necessary to open the market access authority moderately in the early stage of the industry, introduce diversified investment subjects, encourage technological development, and cultivate specialized service system. [16]

Finally, the Chinese government must coordinate and provide services for enterprises in the conversion and replacement of new energy and grid connection. When necessary, administrative measures can be taken in accordance with the "Environmental Protection Law" to require enterprises to carry out energy conversions. Meanwhile, the government should also provide certain financial subsidies for the power grids upgrade project required by the enterprise. [13]

Acknowledgments
This research was financially supported by Shanghai Pujiang Program.

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