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Shale Gas Exploitation and Utilization

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Abstract

Shale gas is one of the most promising unconventional resources both in China and abroad. It is known as a form of self-contained source-reservoir system with large and continuous dimensions. The geological theories for shale gas development have progressed rapidly all over the word. The shale gas storage mechanism has been widely accepted as differing from conventional natural gas in that it is adsorbed on organic matter or a mineral surface or occurs as free gas trapped in pores and fractures of the shale. Significant advances in the techniques of microstructural characterization have provided new insights on how gas molecules are stored in micro-and nano-scale porous shales. Furthermore, newly-developed concepts and practices in the petroleum industry, like hydraulic fracturing, have made the production of this unevenly distributed but promising unconventional natural gas a reality. China has 10-36 trillion m3 of promising shale gas among the world's whole predicted technically recoverable reserves of 206.6 trillion m;. China is on the way to achieving its goal of an annual yield of 30-50 billion m3 by launching more trials within shale gas projects. Additionally, we also introduced the potential dangers of shale gas development and the inconvenience caused to people.

Keywords: Shale gas; Exploitation; Utilization; Challenges; Prospect

1. Introduction

1.1 What is Shale Gas

Former Secretary of the Interior Ken Salazar once said, "shale gas has provided the opportunity to have 100 years of supply that is domestically produced."

Shale gas, also known as parent rock gas or schist gas, is the same as the gas we usually use for heating. Conspicuously, that means the shale gas is a kind of unconventional natural gas. However, it was found in shale formation, actually, trapped in the rocks and schist. Until recently energy companies couldn't figure out how to unlock the gas that was trapped in those tight shale formations. It wasn't until the combination of horizontal drilling and hydraulic fracturing came together that energy companies were able to economically unlock the gas trapped in these rocks. But this method is banned in many countries because it poses risks for the environment. Compared with conventional natural gas development, this may result in greater risk to air, water, and health. Shale gas is now increasingly used in the United States, but is a subject of debate in other countries.

With the advance of extraction technology, shale gas production has led to a new abundance of natural gas supply in the United States over the past decade, and is expected to continue to do so for the foreseeable future. According to the Energy Information Administration (EIA), the unproved technically recoverable U.S. shale gas resource is estimated at 482 trillion cubic.

1.2 Properties

Shale gas is a combustible gas that is a mixture of simple hydrocarbon compounds. It is a fossil fuel that contains primarily methane, along with small amounts of ethane, butane, pentane, and propane. Natural gas does not contain carbon monoxide. The byproducts of burning natural gas are primarily carbon dioxide and water vapor.

Shale gas is a colorless, tasteless, odorless, and non-toxic gas. Because it is odorless, a powerful chemical called mercaptan is added to the gas, in very small amounts, to give the gas a distinctive smell of rotten eggs. This strong smell can be helpful in detecting the source of any gas leak.

Shale gas is about 40% lighter than air, so should it ever leak, it can dissipate into the air. Other positive attributes of shale gas are a high ignition temperature and a narrow flammability range, meaning natural gas will ignite at temperatures above 1,100 degrees and burn at a mix of 4-15% volume in air.

Shale gas is found in rocks beneath the earth’s surface, in sedimentary rock that is porous. Production companies explore, drill, and bring the natural gas to the surface. Transmission companies operate large pipelines that bring the gas from the production sites (wellheads) to “gate stations” where distribution companies, like Enbridge St. Lawrence Gas, bring the natural gas to homes and businesses through a network of underground pipelines.

1.3 Formation Processes

1.3.1 Depositional environment

Shales can be found in both marine and terrestrial environments. For the formation of organic-rich shales, two important criteria should be met [1]: (1) plankton in surface water should be prominent and have high productivity; (2) the conditions are suitable for organic matter storage, accumulation and transformation. An oxygen-deficient environment is suitable for the storage of organic material to accumulate organic-rich sediments. Only under the condition of a low flow velocity can the accumulation of organic material manifest and be accompanied by other-grained sediments. Organicrich shales are mainly formed in a sedimentary environment such as an oxygendeficient occluded bay, lagoon, abyssal resign, under compensation basin or deep shelf. Sedimentary modes to generate organic-rich shale in marine facies mainly include transgression(fig 1.2 and fig 1.3), thresholding, stratification of the water body and marine current upwelling (fig 1.1).For the limited sedimentary water of a lake basin, the circulation capacity of that water of a lake basin, the circulation capacity of that water body is inferior to that of the ocean, and the sedimentary modes of organic-rich shales primarily consist of stratification of the water body and lake transgression mode can consists of three forms, i.e. fresh-water lake basin, saline water basin and brackish water lake basin (fig 1.3). Since brackish water basins frequently connect with a wider external environment, high productivity, lack of clastic dilution and sulfur-free reduction by bacteria will all play a key role in the formation of organic-rich shales.

The deepest part of a freshwater lake with seasonal stratification often develops thick organic-rich shale, because the circulatory convection of the deep water body is blocked and lacks oxygen. However, considering its more stable state for water body stratification, the saline water lake is more suitable for the storage of organic material (fig 1.3).

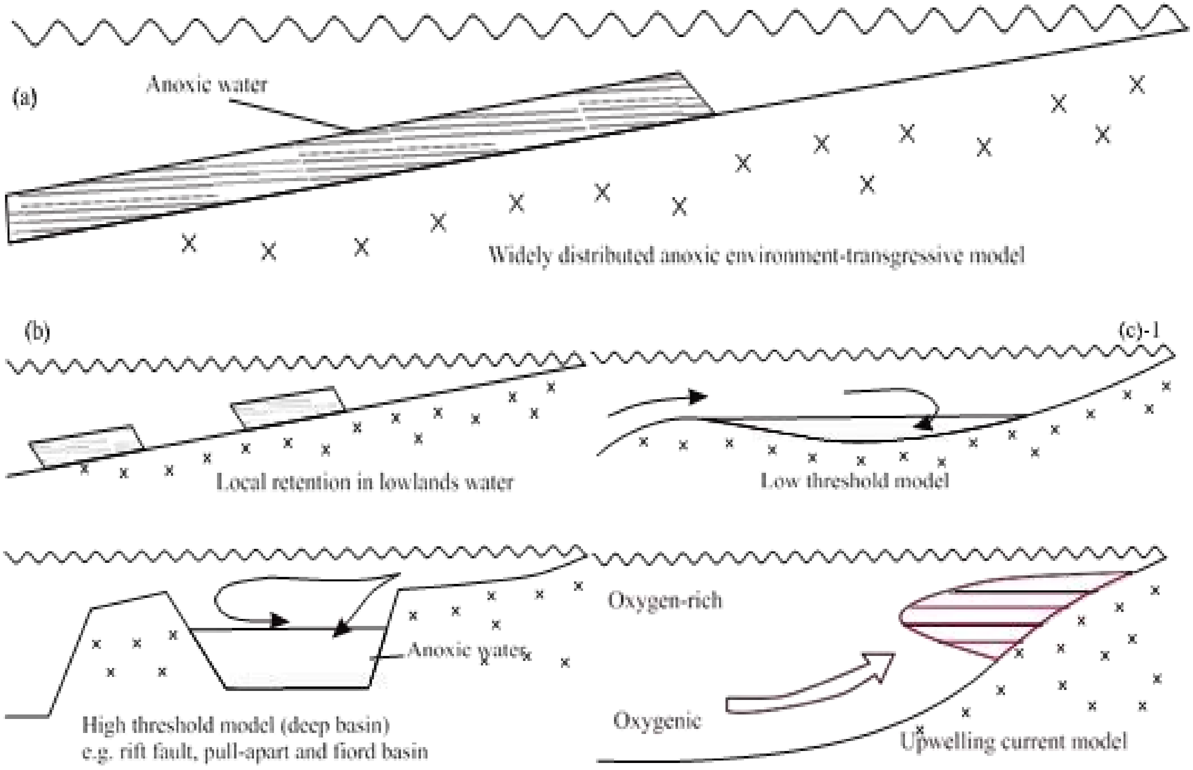

Fig 1.1 Sedimentary model of black shale (a)Sea (lake) transgression; (b)Stratification of water body; (c)1-2 thresholding; (d)Ocean current upwelling

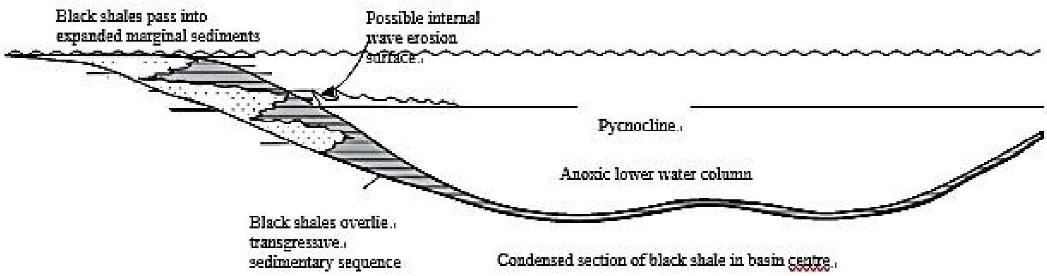

Fig 1.2 Lake transgression sedimentary model of organic-rich shale in a continental lake basin

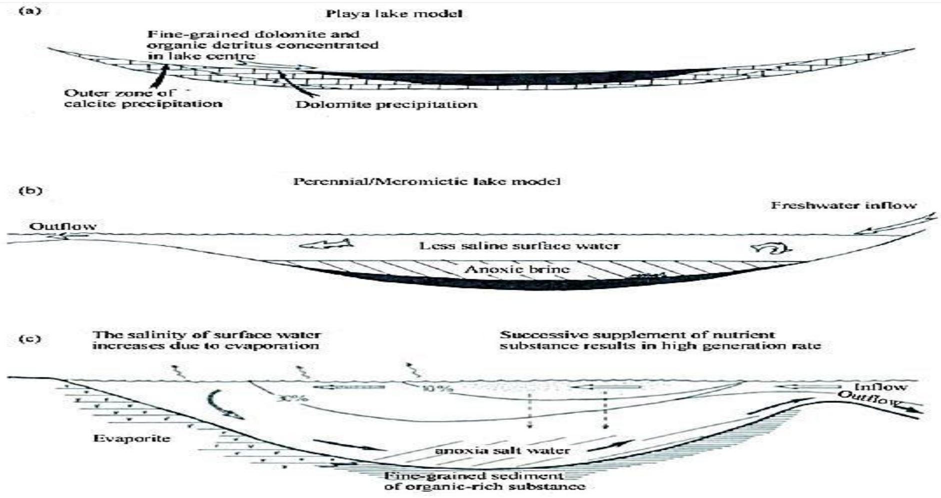

Fig 1.3 Stratification sedimentary model of organic-rich shale in a continental lake basin (a) Saline water lake; (b)Brackish water lake; (c)Fresh water lake.

1.3.2 The geochemistry of organic-rich shales

(1) Organic matter richness. TOC is an important indicator for measuring the organic matter abundance of any given rock. TOC is an prospecting area is generally great than 2.0%, and the shale with a higher TOC usually has relatively higher gas content;

(2) Kerogen types. The amount of oil and gas generated from different types of organic matter in different evolutionary stages varies substantially. The organic matter types formed within a marine or lacustrine environment mainly consist of Type I and Type II1, the organic matter type formed under a transitional and terrigenous environment mainly consists of Type II2 and Type III. At a high degree of thermal evolution, all types of organic matter can generate a lot of gas. And the high the TOC is, the greater the hydrocarbon potential is;

(3) Thermal maturation. The maturity of the organic matter is a key indicator to identify organic matter gas generation or the degree of transformation to hydrocarbons. From the relationship between shale gas content and yield, the lower the shale gas is; the higher the maturity is, the higher the shale gas is; the lower the maturity is.

1.3.3 Forming conditions of shale gas reservoirs

Shale gas is a kind of unconventional natural gas, occurring in dark grey-grey black shale with extremely low permeability and abundant organic matter, or in the natural fractures and porosities of shales with high carbon content. Most of shale gas presents as attached gas or free gas, with a small amount as dissolved gas in bitumen and kerogen. Shale gas reservoirs are a kind of continuous gas accumulation, the shale with abundant organic matter acting as source, reservoir, seal. They are the “selfgeneration and self-bearing” gas reservoir, without migration and accumulation process basically, having the features of “thick, wealthy, muddy, mature, dense and brittle”[2-4].

1.3.4 The general formation process

Shale gas formation mechanism is in situ "stranded reservoir", continuous distribution. Methane is sequentially packed in shale micropores (pore size less than 2 nm), adsorbed in multiple layers in mesoporous (2 to 50 nm in pore size) to capillaries. And in the macropores (pores larger than 50 nm), methane is compressed or dissolved, which forms its state of storage. After accumulation in the adsorption, desorption, proliferation and so on. The organic matter or oil is cracked into gas, and then the natural gas is saturated and adsorbed on the inner surface of the pores of the organic matter first; then desorbed and diffused into the pores of the matrix to adsorb and saturate the free phase in situ; the supersaturated gas is firstly transported to the overlying inorganic shale pores; After the gas is saturated again, the second migration forms a gas reservoir[5].

1.4 The Layout of Shale Gas

1.4.1 The global Shale Gas Resources

Actually, the shale gas resources is abundant in this world. According to the forecast of HIS, the consulting company, the global amount of the total resources of shale gas reaches about 456 trillion. It is equivalent to 1.4 times of conventional natural gas. What’s more, shale gas is mainly distributed in North America, Central Asia and China, the Middle East, North Africa and other regions with worldwide unconventional natural gas resources.

According to the data given [6], China has the largest technically recoverable shale gas resource around the globe, estimated at staggering 31.6 trillion cubic metres. Argentina and Algeria follow China with the world's second and third largest shale gas resource potentials. The United States, world's premier economy and second largest energy consumer has the fourth largest shale gas resource potential in the world, estimated at 18.8 tcm. Canada, Mexico and South Africa follow the United States. Russia, which has vast fossil fuel sources, also has the 9th largest shale gas resource potential around the globe, estimated at 8.1 tcm. Finally, Brazil has 6.9 tcm of shale gas resource potential. In total, the top 10 countries have an estimated 163.1 tcm of shale gas resource potential, whereas the rest of the world has only

43.5 tcm. In other words, the top 10 countries have 79% of the world's shale gas resource potential.

Table 2. Technically recoverable shale gas resources around the globe, 2013 estimation

Country	Natural gas reserves (trillion cubic meter)
China	31.6
Argentina	22,7
Algeria	20.2
U.S.	18.8
Canada	16.2
Mexico	15.4
Australia	12.4
South Africa	11.0
Russia	8.1
Brazil	6.9
Other countries	43.5
World total	206.7

1.4.2 The Shale Gas Resources in China

China has the world's largest shale gas resource potential, the biggest energy market and the government is eager to expand its gas production[7]. The country's shale gas resource is estimated at 31.6 tcm in 2013. This is almost 10 times the proved natural gas reserves of the country. As a result, global energy firms Shell, Exxon Mobil, Chevron, Eni and Total are actively trying to extract most of this valuable resource . Among them Royal Dutch Shell p.l.c is the first to land a production sharing contract, who is working with Chinese oil giant Sinopec Corp for joint evaluation of shale resources in Xiang E Xi (XEX) block, at the junction of central Hunan, Hubei and Jiangxi provinces in east central China; and also in Sichuan conducting evaluation drilling of the Fushun-Yongchuan block in partnership with Chinese primary oil and gas producer PetroChina, and expected to start commercial production after 2014[8]. Sinopec and PetroChina estimated their shale output in 2015 at around 2 billion cubic metres (bcm) each[9].

There are also serious problems in front of shale gas production in China. The shale gas resources are found mostly in the arid west and southwest at deeper locations like Cambrian, Ordovician and Silurian strata of China[10]. And specifically, for shale gas production in Southern China the following problems lay in front of international and local investors: the effects of nanopore formation on shale gas production are unclear; the prediction methods for shale gas production have not yet been established; the horizontal section might collapse in the process of drilling, the drilling cycle is too long, and finally the stimulation effect is not ideal with low single well production. In addition, China does not have the required infrastructure to process the shale gas at larger volumes in a shorter period. In 2013, the U.S. Secretary of Energy, Ernest Moniz, stated that the U.S. have a favourable geology for producing shale gas, have the most mature natural gas infrastructure in terms of pipelines, market structures, trading hubs, futures contracts, regulation of production etc; and if China wants to develop its resources “at a large scale in rapid fashion” they must tackle these issues[11].

In this study, it is estimated that the total natural gas consumption in China between 2010 and 2040 would be 7.9 tcm. This huge consumption is 2.61 times the proved natural gas reserves and 23% of the shale resources plus the proved natural gas reserves of the country. Consequently, if the shale gas resources of China would be proven to be true, world's largest energy importer may not need to import natural gas in the second quarter of the 21st century.

2 Exploitation Processes

2.1 About Fracturing

Geology. Fracturing rocks at great depth frequently becomes suppressed by pressure due to the weight of the overlying rock strata and the cementation of the formation. This suppression process is particularly significant in "tensile" fractures which require the walls of the fracture to move against this pressure. Fracturing occurs when effective stress is overcome by the pressure of fluids within the rock. The minimum principal stress becomes tensile and exceeds the tensile strength of the material.[12-13] Fractures formed in this way are generally oriented in a plane perpendicular to the minimum principal stress, and for this reason, hydraulic fractures in well bores can be used to determine the orientation of stresses. In natural examples, such as dikes or vein-filled fractures, the orientations can be used to infer past states of stress.[14] Also see a general review paper on the mechanics of fracking.

Veins. Most mineral vein systems are a result of repeated natural fracturing during periods of relatively high pore fluid pressure. The impact of high pore fluid pressure on the formation process of mineral vein systems is particularly evident in "crack-seal" veins, where the vein material is part of a series of discrete fracturing events, and extra vein material is deposited on each occasion.[15] One example of long-term repeated natural fracturing is in the effects of seismic activity. Stress levels rise and fall episodically, and earthquakes can cause large volumes of connate water to be expelled from fluid-filled fractures. This process is referred to as "seismic pumping".

Dikes. Minor intrusions in the upper part of the crust, such as dikes, propagate in the form of fluid-filled cracks. In such cases, the fluid is magma. In sedimentary rocks with a significant water content, fluid at fracture tip will be steam.

History. Fracturing as a method to stimulate shallow, hard rock oil wells dates back to the 1860s. Dynamite or nitroglycerin detonations were used to increase oil and natural gas production from petroleum bearing formations. On 25 April 1865, US Civil War veteran Col. Edward A. L. Roberts received a patent for an "exploding torpedo".[24] It was employed in Pennsylvania, New York, Kentucky, and West Virginia using liquid and also, later, solidified nitroglycerin. Later still the same method was applied to water and gas wells. Stimulation of wells with acid, instead of explosive fluids, was introduced in the 1930s. Due to acid etching, fractures would not close completely resulting in further productivity increase.

Oil and gas wells. The relationship between well performance and treatment pressures was studied by Floyd Farris of Stanolind Oil and Gas Corporation. This study was the basis of the first hydraulic fracturing experiment, conducted in 1947 at the Hugoton gas field in Grant County of southwestern Kansas by Stanolind. [16] For the well treatment, 1,000 US gallons of gelled gasoline and sand from the Arkansas River was injected into the gas-producing limestone formation at 2,400 feet. The experiment was not very successful as deliverability of the well did not change appreciably. The process was further described by J.B. Clark of Stanolind in his paper published in 1948. A patent on this process was issued in

1949 and exclusive license was granted to the Halliburton Oil Well Cementing Company. On 17 March 1949, Halliburton performed the first two commercial hydraulic fracturing treatments in Stephens County, Oklahoma, and Archer County, Texas. Since then, hydraulic fracturing has been used to stimulate approximately one million oil and gas wells in various geologic regimes with good success.

In contrast with large-scale hydraulic fracturing used in low-permeability formations, small hydraulic fracturing treatments are commonly used in highpermeability formations to remedy "skin damage", a low-permeability zone that sometimes forms at the rock-borehole interface. In such cases the fracturing may extend only a few feet from the borehole.

In the Soviet Union, the first hydraulic proppant fracturing was carried out in 1952. Other countries in Europe and Northern Africa subsequently employed hydraulic fracturing techniques including Norway, Poland, Czechoslovakia, Yugoslavia, Hungary, Austria, France, Italy, Bulgaria, Romania, Turkey, Tunisia, and Algeria.

Massive hydraulic fracturing (also known as high-volume hydraulic fracturing) is a technique first applied by Pan American Petroleum in Stephens County, Oklahoma, USA in 1968. The definition of massive hydraulic fracturing varies, but generally refers to treatments injecting over 150 short tons, or approximately 300,000 pounds of proppant [17].

American geologists gradually became aware that there were huge volumes of gassaturated sandstones with permeability too low (generally less than 0.1 millidarcy) to recover the gas economically. Starting in 1973, massive hydraulic fracturing was used in thousands of gas wells in the San Juan Basin, Denver Basin the Piceance Basin, and the Green River Basin, and in other hard rock formations of the western US. Other tight sandstone wells in the US made economically viable by massive hydraulic fracturing were in the Clinton-Medina Sandstone (Ohio, Pennsylvania, and New York), and Cotton Valley Sandstone (Texas and Louisiana).

Massive hydraulic fracturing quickly spread in the late 1970s to western Canada, Rotliegend and Carboniferous gas-bearing sandstones in Germany, Netherlands (onshore and offshore gas fields), and the United Kingdom in the North Sea. Horizontal oil or gas wells were unusual until the late 1980s. Then, operators in Texas began completing thousands of oil wells by drilling horizontally in the Austin Chalk, and giving massive slickwater hydraulic fracturing treatments to the wellbores. Horizontal wells proved much more effective than vertical wells in producing oil from tight chalk;[18] sedimentary beds are usually nearly horizontal, so horizontal wells have much larger contact areas with the target formation.[19]

2.2 Hydraulic fracturing used to mine shales

Hydraulic fracturing of shales goes back at least to 1965, when some operators in the Big Sandy gas field of eastern Kentucky and southern West Virginia started hydraulically fracturing the Ohio Shale and Cleveland Shale, using relatively small fracs. The frac jobs generally increased production, especially from lower-yielding wells.[20]

In 1976, the United States government started the Eastern Gas Shales Project, which included numerous public-private hydraulic fracturing demonstration projects.[21] During the same period, the Gas Research Institute, a gas industry research consortium, received approval for research and funding from the Federal Energy Regulatory Commission.[22]

In 1997, Nick Steinsberger, an engineer of Mitchell Energy (now part of Devon Energy), applied the slickwater fracturing technique, using more water and higher pump pressure than previous fracturing techniques, which was used in East Texas by Union Pacific Resources (now part of Anadarko Petroleum Corporation), in the Barnett Shale of north Texas.[23] In 1998, the new technique proved to be successful when the first 90 days gas production from the well called S.H. Griffin No. 3 exceeded production of any of the company's previous wells. This new completion technique made gas extraction widely economical in the Barnett Shale, and was later applied to other shales, including the Eagle Ford and Bakken Shale. George P. Mitchell has been called the "father of fracking" because of his role in applying it in shales. The first horizontal well in the Barnett Shale was drilled in 1991, but was not widely done in the Barnett until it was demonstrated that gas could be economically extracted from vertical wells in the Barnett.[23]

As of 2013, massive hydraulic fracturing is being applied on a commercial scale to shales in the United States, Canada, and China. Several additional countries are planning to use hydraulic fracturing.

Process. According to the United States Environmental Protection Agency (EPA), hydraulic fracturing is a process to stimulate a natural gas, oil, or geothermal well to maximize extraction. The EPA defines the broader process to include acquisition of source water, well construction, well stimulation, and waste disposal.[24]

Method. A hydraulic fracture is formed by pumping fracturing fluid into a wellbore at a rate sufficient to increase pressure at the target depth (determined by the location of the well casing perforations), to exceed that of the fracture gradient (pressure gradient) of the rock.[25] The fracture gradient is defined as pressure increase per unit of depth relative to density, and is usually measured in pounds per square inch, per square foot, or bars. The rock cracks, and the fracture fluid permeates the rock extending the crack further, and further, and so on. Fractures are localized as pressure drops off with the rate of frictional loss, which is relative to the distance from the well. Operators typically try to maintain "fracture width", or slow its decline following treatment, by introducing a proppant into the injected fluid-a material such as grains of sand, ceramic, or other particulate, thus preventing the fractures from closing when injection is stopped and pressure removed. Consideration of proppant strength and prevention of proppant failure becomes more important at greater depths where pressure and stresses on fractures are higher. The propped fracture is permeable enough to allow the flow of gas, oil, salt water and hydraulic fracturing fluids to the well [48].

During the process, fracturing fluid leakoff (loss of fracturing fluid from the fracture channel into the surrounding permeable rock) occurs. If not controlled, it can exceed 70% of the injected volume. This may result in formation matrix damage, adverse formation fluid interaction, and altered fracture geometry, thereby decreasing efficiency.

The location of one or more fractures along the length of the borehole is strictly controlled by various methods that create or seal holes in the side of the wellbore. Hydraulic fracturing is performed in cased wellbores, and the zones to be fractured are accessed by perforating the casing at those locations [26].

Hydraulic-fracturing equipment used in oil and natural gas fields usually consists of a slurry blender, one or more high-pressure, high-volume fracturing pumps (typically powerful triplex or quintuplex pumps) and a monitoring unit. Associated equipment includes fracturing tanks, one or more units for storage and handling of proppant, high-pressure treating iron[clarification needed], a chemical additive unit (used to accurately monitor chemical addition), low-pressure flexible hoses, and many gauges and meters for flow rate, fluid density, and treating pressure.[27] Chemical additives are typically 0.5% percent of the total fluid volume. Fracturing equipment operates over a range of pressures and injection rates, and can reach up to 100 megapascals (15,000 psi) and 265 litres per second (9.4 cu ft/s) (100 barrels per minute) [28].

Well types. A distinction can be made between conventional, low-volume hydraulic fracturing, used to stimulate high-permeability reservoirs for a single well, and unconventional, high-volume hydraulic fracturing, used in the completion of tight gas and shale gas wells. High-volume hydraulic fracturing usually requires higher pressures than low-volume fracturing; the higher pressures are needed to push out larger volumes of fluid and proppant that extend farther from the borehole [29].

Horizontal drilling involves wellbores with a terminal drillhole completed as a "lateral" that extends parallel with the rock layer containing the substance to be extracted. For example, laterals extend 1,500 to 5,000 feet (460 to 1,520 m) in the Barnett Shale basin in Texas, and up to 10,000 feet (3,000 m) in the Bakken formation in North Dakota. In contrast, a vertical well only accesses the thickness of the rock layer, typically 50-300 feet (15-91 m). Horizontal drilling reduces surface disruptions as fewer wells are required to access the same volume of rock.

Drilling often plugs up the pore spaces at the wellbore wall, reducing permeability at and near the wellbore. This reduces flow into the borehole from the surrounding rock formation, and partially seals off the borehole from the surrounding rock. Low-volume hydraulic fracturing can be used to restore permeability [30].

The main purposes of fracturing fluid are to extend fractures, add lubrication, change gel strength, and to carry proppant into the formation. There are two methods of transporting proppant in the fluid-high-rate and high-viscosity. High-viscosity fracturing tends to cause large dominant fractures, while high-rate (slickwater) fracturing causes small spread-out micro-fractures.

Fluid is typically slurry of water, proppant, and chemical additives.[31] Typically, 90% of the fluid is water and 9.5% is sand with chemical additives accounting to about 0.5%. However, fracturing fluids have been developed using liquefied petroleum gas (LPG) and propane in which water is unnecessary [31].

The proppant is a granular material that prevents the created fractures from closing after the fracturing treatment. Types of proppant include silica sand, resin-coated sand, bauxite, and man-made ceramics. The choice of proppant depends on the type of permeability or grain strength needed. In some formations, where the pressure is great enough to crush grains of natural silica sand, higher-strength proppants such as bauxite or ceramics may be used. The most commonly used proppant is silica sand, though proppants of uniform size and shape, such as a ceramic proppant, are believed to be more effective.

3. Utilization of Shale Gas

Shale gas after refining is known as Natural gas and it is a versatile, clean-burning, and efficient fuel that is used in a wide variety of applications.

In 2011, for example, the US consumed nearly 24 trillion cubic feet of natural gas, 30 percent of US energy consumption and the energy equivalent of almost 190 billion gallons of gasoline.

In 2012, the United States consumed nearly 26 trillion cubic feet of natural gas, primarily in the electric power and industrial sectors. Although domestic natural gas production has grown substantially in the last decade, consumption still exceeded production in 2012. Pipeline imports from Canada supply most of the balance. A smaller amount is imported as liquefied natural gas via supertankers. The US Energy Information Administration projects a 50 percent rise in global natural gas consumption between 2010 and 2035, with growth in Brazil and China driving increased demand.

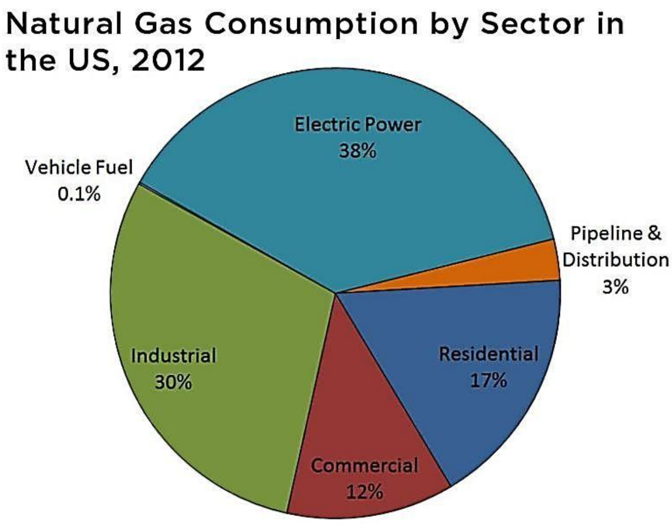

Fig 3.1 Natural gas consumption by sector in the US,2012

3.1 Electric power

The fastest growing use of natural gas today is for the generation of electric power. Natural gas power plants usually generate electricity in gas turbines (which are derived from jet engines), directly using the hot exhaust gases of fuel combustion.

Single-cycle gas turbines generally convert the heat energy from combustion into electricity at efficiencies of 35 to 40 percent. Higher efficiencies of 50 percent or more are possible in natural gas “combined-cycle” (NGCC) plants. NGCC plants first use the combustion gases to drive a gas turbine, after which the hot exhaust from the gas turbine is used to boil water into steam and drive a steam turbine.

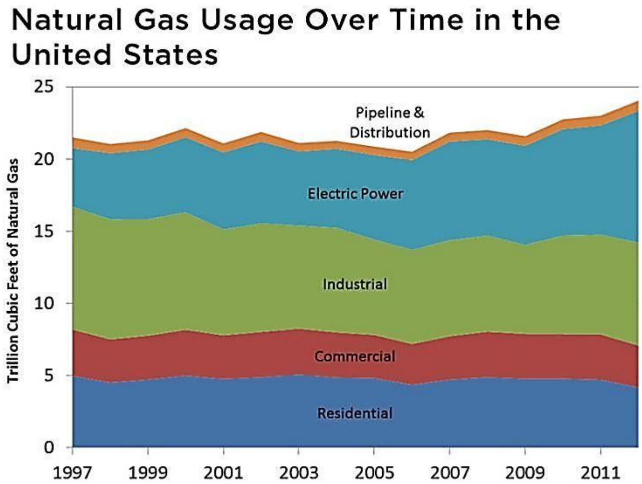

Fig 3.2 Nature gas usage over time in the US

Low natural gas prices in the 1990s and early 2000s stimulated the rapid construction of gas-fired power plants. In 2003, natural gas passed coal as the energy source with the largest installed electricity generation capacity in the United States. Natural gas-fired plants are currently among the cheapest power plants to construct. Historically, their operating costs were generally higher than those of coal-fired power plants because the fuel was more expensive.

Natural gas-fired plants have greater operational flexibility than coal plants because they can be fired up and turned down rapidly. Because of this, many natural gas plants were originally used to provide peaking capacity at times when electricity demand was especially high, such as the summer months when air conditioning is widely used. During much of the year, these natural gas “peaker” plants were idle, while coal-fired power plants typically provided base load power. However, since 2008, natural gas prices in the US have fallen significantly, and natural gas is now increasingly used as a base and intermediate load power source in many places.

A 2011 MIT study calculated that increased utilization of existing natural gas power plants to displace coal-fired power could reduce the electric sector's carbon emissions by 22 percent in the near term Natural gas' contribution to electricity generation is growing rapidly: from only 17 percent in 2001 to 30 percent in 2012.

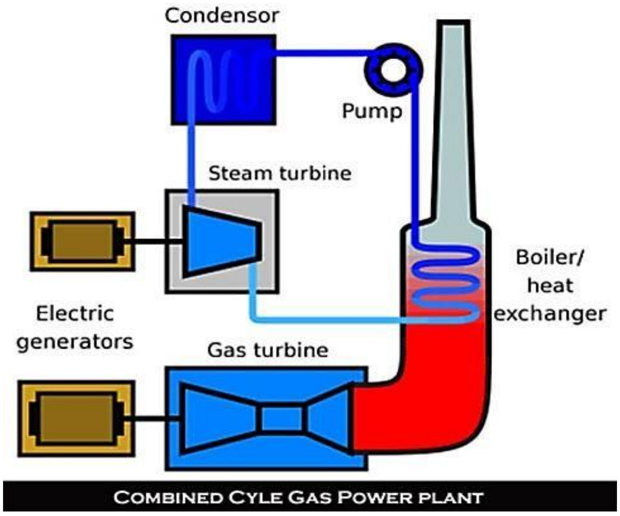

Fig 3.3 Shale gas used to generate power

3.2 Heating and cogeneration

Residential and commercial uses account for over a third of US natural gas consumption, as gas is used in buildings for space and water heating and for cooking. About half of all US homes used natural gas for heating in 2013[32] and 70 percent of all new homes are built with gas heating systems. Home furnaces can reach efficiencies of over 90 percent.

Measures to increase building efficiency are widely considered the most costeffective way to reduce the amount of natural gas we use. One study estimated that an ambitious program to improve building performance through means such as highefficiency insulation, windows, furnaces, water heaters, and other appliances could save 234 trillion cubic feet of natural gas over the next 50 years.

Natural gas can also be used to produce both heat and electricity simultaneously, a technology called "cogeneration" or "combined heat and power" (CHP).

Cogeneration systems are highly efficient, able to put 75 to 80 percent of the energy in gas to use. "Trigeneration" systems, which provide electricity, heating, and cooling, can reach even higher efficiencies. A 2009 UCS report indicates that CHP use could more than triple by 2030 if policies are enacted to make steep cuts in carbon emissions.

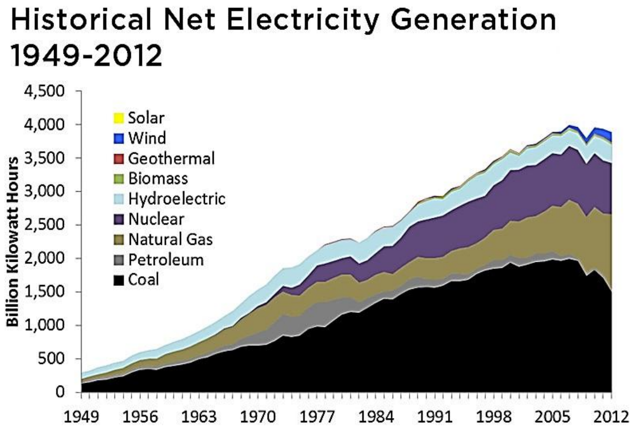

Fig 3.4 Historical net electricity generation

3.3 Industrial and other uses

Natural gas sees a broad range of other uses in industry, as a source of both heat and power and as an input for producing plastics and chemicals. Most hydrogen gas (H2) production, for example, comes from reacting high temperature water vapor (steam) with methane. Today, the resulting hydrogen is mostly used to produce ammonia for fertilizer, one of the most important industrial products derived from natural gas. Hydrogen produced from natural gas can itself be used as a fuel. The most efficient way to convert hydrogen into electricity is by using a fuel cell, which combines hydrogen with oxygen to produce electricity, water, and heat. Although the process of reforming natural gas to hydrogen still has associated carbon dioxide emissions, the amount released for each unit of electricity generated is much lower than for a combustion turbine. Compressed natural gas (CNG) has been used as a transportation fuel, mostly in public transit. CNG, which is compressed at over 3,000 psi to one percent of the volume the gas would occupy at normal atmospheric pressure, can be burned in an internal combustion engine that has been appropriately modified. About 0.1 percent of the natural gas consumed in the United States in 2012 powered vehicles represented the energy content of more than 5 million barrels of oil.

Compared to gasoline, CNG vehicles emit far less carbon monoxide, nitrogen oxides (NOx), and particulates. The main disadvantage of CNG is its low energy density compared with liquid fuels. A gallon of CNG has only a quarter of the energy in a gallon of gasoline [33]. CNG vehicles therefore require big, bulky fuel tanks, making CNG practical mainly for large vehicles such as buses and trucks.

In most cases, a better use for natural gas in the transportation sector would be as a resource to generate electricity for plug-in vehicles or hydrogen for fuel cell vehicles, which can provide global warming emissions savings on the order of 40 or more percent.

4. Development Challenges of Shale Gas for environment

Although the shale gas has brought huge economic effects to the governments, its potential environmental impact is worried by experts and local people around the oil and gas field. The exploitation of Shale gas has brought a series of negative environmental problems, and even hinder the exploitation in some places. Taking American Marcellus Oil and Gas Field as an example, this part introduces the negative environmental impacts of shale gas exploitation.

4.1 Consumption and pollution of water

Shale gas production requires a lot of water, especially hydraulic fracturing process water consumption is huge. According to the statistics of the US Department of Energy [1], the average water consumption of a well in the Marcellus shale gas field is about 1.5×104 m3, of which hydraulic fracturing water accounts for 98%. Vast water consumption may affect urban life and other industries, damaging rivers and lakes. The report emphasizes that a crucial factor for the successful development of shale gas is whether local water supplies can meet the needs of shale gas wells without disturbing industry and agriculture.

Fracturing fluids are mixed with auxiliary chemicals, some of which are harmful to human health and ecosystems. If leaked or spilled, it can contaminate surface water, groundwater and soil. 30%-70% of fracturing fluids could flow back, carrying hydrocarbons, heavy metals and high dissolved solids (TDS). [34] If the flow back water is not treated in time or leaked, the impact on water quality and ecological environment should not be underestimated. In fact, 23.3km2 of the Cabot area has been polluted, leaving the locals without access to potable water.

4.2 Earthquake

Hydraulic fracturing and the injection of sewage into deep wells can induce earthquakes[35]. A magnitude-3.8 earthquake struck the Horne Basin in Canada in 2011, and the investigation of the incident concluded that the earthquake was caused by a liquid injection operation during hydraulic fracturing. At a well site in Ohio, the number of earthquakes around the well site decreased significantly in a month after the injection to deep wells was banned.

Although the magnitude of earthquakes induced by hydraulic fracturing operations is relatively low based on the available data, and no obvious hazard has been caused, but the possibility of causing serious accidents cannot be ruled out. In order to better manage the seismic risk associated with shale gas production and deep well injection, the government should set thresholds for seismic activity aimed at reducing injection rates or pressures and even prohibiting deep injection operations that could trigger severe earthquakes.

4.3 Surface and vegetation damage

The excavation of Shale gas wells and hydraulic fracturing fluid storage, together with the layout of fracturing equipment, make the field is much larger than the conventional well area. In the original ecological areas, it causes wild vegetation damage, and even lead to hazards of local soil erosion and debris flow.

4.4 Emission of greenhouse gases

The main component of shale gas is alkane, of which CH4 accounts for the vast majority. The effect of methane on the greenhouse effect is 25 times that of CO2 in 100 years and 72 times that of CO2 in 20 years [36].The greenhouse effect of methane is several times that of carbon dioxide. Statistics for the development of shale gas in the United States show that methane emission at drilling and fracturing are at least 30% more than conventional gas development.

CH4 emission from the well completion process is the largest source of CH4 emissions during the development process. A large amount of CH4 gas is returned to the ground with the return fluid. The total CH4 emissions from shale gas wells estimated from the production and storage processes account for 3.6%-7.9% [37].CH4 emissions directly increased from shale gas development and storage are small relative to the national total of greenhouse gas emissions and will not result in a significant increase in total emissions as well as the replacement of coal with shale gas offset some of the greenhouse gas emissions.

4.5 Other aspects

4.5.1 Noise

Noise pollution exists in horizontal well drilling, hydraulic fracturing, wellsite construction, and compressor operation for natural gas export.

4.5.2 Traffic pressure

The fracturing fluid used in shale gas fracturing is often tens of thousands of cubic meters and requires a large number of tankers to be transported back and forth. This not only causes pressure to traffic in the vicinity, but also generates large amounts of dust, especially in the non-hardened sections [38].

4.5.3 Radiation

In some cases, traces of natural radioactive materials such as uranium, thorium and their decay products, such as radium elements, are encountered during drilling and fracturing [39]. Significant amounts of radiation have ended up in wastewater, much of it sent to Public Treatment Plants, posing a health risk to field operators.

5. Prospect of shale gas

5.1 Economy and prospect of global shale gas development

Low oil and gas prices compel all enterprises engaging in shale gas business to intensify their cost control, with updating and upgrading of key technologies to improve development effect and “multi-well pad” to greatly operation efficiency and achieve self “cost revolution” in development of shale oil and gas. Henry Hub Data Center in the US shows that since natural gas price was down to RMB 0.46/m3 [42], it should be on the low side, and now, the natural gas price is RMB 0.8/m3 (June, 2017).

Marcellus Shale Gas Field is taken as an example, there were there were 141 drilling machines in operation in peak period in Jan. 2012, and then, with the increase of gas price, the number of drilling machines was down to 24 in June, 2016, and then the number of which bounced back to 45[43]. Although the number of drilling machines was on the decrease to a great extent, due to improvement in the construction level and operation efficiency. The gas field output was increased from 17764×104 m3/d in Jan. 2012 from 50873×104 m3/d to 50873×104 m3/d in July, 2016. The output was increased to 54701×104m3/d in June 2017. At present, the breakeven point for shale gas fields in the US is from USD[44] 0.58 to 0.91/m3, therefore, there is economic benefit in development of shale gas although the natural gas price is low. Marcellus Shale Gas Field is taken as an example, in case that the single well is USD 4 million in investment cost and (EUR) 1.06×108 m3 in ultimate recoverable reserves, it is estimated that its internal rate of return is 9.1% [45]. The natural gas price in China has been on the decrease since 2012 under the influence of international natural gas market, with further improvement in engineering technology, market mechanism, management mode, policy supports, China shall gradually highlight economic and social benefits in development of shale gas industry.

5.2Great demands for natural gas in China's market

China's social economy continues to develop steadily and the demands for energy will continue to maintain at a high level. China became an oil net importer in 1993 and a natural gas importer in 2006. Currently, China is the world's largest energy consumer and producer and net importer. China's external oil dependency surged up to 59% in 2014 from 1.2% in 1993 and from 0.8% in 2006 to 32% in 2014 in natural gas external dependency, by which China became the most important importer in the global energy market. In natural gas demand, in recent years (2006-2014), although the annual average production growth was more than 12%, one of the fastest growing countries around the world, China still has a small volume of the total gas production [46], with the volume of 1345×108 m3 in 2014. Annual gas consumption in the same period rose by more than 16%, with the volume of 1855×108 m3 in 2014. According to the forecast (Development Research Center of State Council, 2014), by 2020, China's annual natural gas consumption will continue to increase at a compound growth rate of 19%, and the proportion of gas in the energy structure will rise to 10%-15% from 5.6% in 2014, with the total volume up to 3500×108 m3; however, the conventional gas production will be only about 2000×108 m3 then, and the rest demands have to rely on the shale gas and other unconventional gas production and import.

5.3 Prospect of shale gas development in China

Since the starting of shale gas exploration and development in 2005, China primarily achieved the first leaping-forward in the understanding of shale gas resources from 2006 to 2012, and made the preliminary forecast of the shale gas resources in the key areas and especially selected the most favorable areas for marine shale gas resources. Between 2010 and 2015, China realized shale gas discovery, production and proven reserves submission; large marine shale gas area was discovered in WufengLongmaxi Fms of Sichuan Basin, Upper Yangtze region and Middle Yangtze region; the key gas-bearing areas in southern Sichuan, eastern Sichuan and NE Sichuan were made clear; a few shale gas fields of billions of cubic meters such as Fuling, Changning and Weiyuan were determined, with the proven reserves more than 5000×108 m3. From 2013 to 2015, China realized a leaping-forward in the shale gas production; since the first 1 m3 shale gas production in 2010, China's shale gas production exceeded 1.0×108 m3 in 2012 and 10×108 m3 (up to 12.47×108 m3) in 2014, and will be more than 40.0×108 m3 in 2015.

On this basis, the author predicted that, during the "13th Five-Year Plan", in addition to the Sichuan Basin, Wufeng-Longmaxi Fms, there will be new breakthrough in the aspects of areas, series of strata and types of shale gas and new leaping-forward progress will be made in shale gas reserves and production; around 2020, China's shale gas production will be expected to grow to 300×108 m3, laying the groundwork for the rapid development from 2020 to 2030.

6. Conclusion

Shale gas, methane in essence, is one of the most important unconventional natural gas resources. Prospects for shale gas resources have aroused great concern in all levels all over the world. In recent years, China's shale gas program has undergone a rapid expansion, establishing several large shale gas fields.

Theoretical and technological advances have marked shale gas development as one of the most significant events in the history of the petroleum industry. We have introduced several important mining methods, like "hydraulic fracturing technology".

North American shale gas development shows excellent prospect for Chinese shale gas, and accelerates Chinese shale gas development, we should use advanced experience and technique of U.S. shale gas exploration and development as reference, select strong foreign companies in developing shale gas cooperation and development, and formulate standards and criteria of shale gas industry as soon as possible, thereby guiding industry sustainable, effective, and healthy development. Gas will account for a large proportion of the energy used in the next few decades. And Shale gas's exploitation will be likely to drive the economic transformation and development of the entire Yangtze river valley and even the whole China.

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