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Research Article

Shale Gas Technical Development and Innovation

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Abstract:

The classical theory of geology believe that shale reservoir physical property is poor, the oil and gas could not be saved, or only as source rock cover, almost have no exploitation value. Later people found that shale belongs to in-situ large area continuous reservoirs, and put forward a series of shale gas development technology. In this paper, we base on time sequence and shale gas production, study the transition of the shale gas geology theory and shale gas development technology advances, analyzing the important role of technological innovation, in order to give some enlightenment to the development of shale gas development technology.

1.Introduction

In 1821, the first bite of shale gas is used in street lamp lighting in the United States, which is the beginnings of the U.S. natural gas development[1,2]. Then shale gas is known by people gradually. Through untiring efforts, the development and production of shale gas has finally entered the stage of rapid development. 2005 ~ 2008, the United States of shale gas production increased at an annual rate of 10 billion, 2008 ~ 2011 years increased at an annual rate of 40 billion. By 2012, the U.S. shale gas production reaches 2653 x $10^8 m^3$, 853 x $10^8 m^3$ more than in 2011 (Fig. 1). From the perspective of the development of shale gas development technology, the transition of the shale geological theory and exploratory development technology progress is the key to the success of the shale gas.

1.1 The transition of the shale geological theory

The classical theory of geology believes that the valuable oil and gas reservoir must have three general conditions[1-4], which are source, reservoir and cap. Due to shale matrix porosity is less than 10%, permeability is less than 1 mD, namely poor reservoir physical property .Therefore, although a lot of oil and gas Wells in the drilling process encountered the dark shale section, organic matter is thought to be only produce air source of oil and gas layer, rather than a reservoir. For a long time, dark organic matter has been as hydrocarbon source rocks or shale cap-rock, only a few have crack shale as reservoir development. And the success of the North American commercial shale gas development, breaking the traditional geological theory. People found a lot of gas resources from shale, gradually realized the dark mud shale is not only a gas source rock, but also a reservoir and capping layer, is the typical of gas accumulation. The success of the shale gas development also makes people widened to find oil and gas fields. Traditional geological theory, the porosity and permeability of rock strata below a certain threshold value, it almost has no economic value. And the success of the shale gas mining, make a lot of gas density layers, which are previously discarded by conventional oil also has

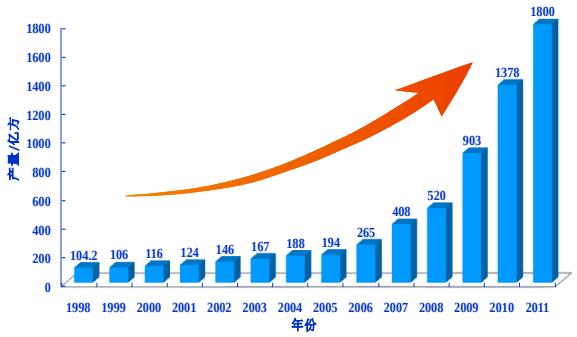

Fig. 1 *The calendar year American shale gas production*

the development value. Data show that new proved reserves in the proportion of low permeability reserves increased from about 30% to nearly 70%[5]. Horizontal Wells of low permeability reservoir and fracturing technology can get considerable exploration effect greatly.

In the past, people focused on gathered hydrocarbons, which is composed by large area dispersed gas through migration .And the good physical properties in trap formation is the key area of oil and gas development. Because the shale system's matrix porosity and permeability are both low, and it's nearly impossible to migrate the oil and gas. So people think that the amount of oil and gas in shale system should be very little. Later people found that there are a large number of nano-scale holes and gaps in shale, and clay minerals of plant-based ultrafine particles, which have large surface area and strong adsorption ability. Gas is adsorbed on clay surface and free in the micro pore. That is to say, the whole shale formations are reservoir. The discovery once again changed the traditional geological cognition, because the aim of the traditional prospecting theory is to find oil and gas gathering the limitation of the trap, and shale gas is a large area of continuous accumulation. In layman's terms, conventional natural gas storage in "point", and shale gas is stored in the "face"(Fig.2).

2 Innovation of shale gas exploration and development technology

On the basis of new geological theory knowledge, People emancipate the mind, change ideas, explore new technology to increase production of shale gas continuously.

2.1 Water fracturing

Before 1997, most people used gel fracturing technology at home and abroad, but he construction effect was bad. Because of high liquid rubber plug concentration, the damage to the reservoir, long operation period and high cost. Traditional fracturing theory considered that the cracks will be closed after fracturing, so people must use a lot of proppant for supporting, in order to prevent the crack closure. but due to the incomplete drainage and stratigraphic residues within a large amount of residue can affected the fracture diverting capacity, furthermore residue can damage formation, and reduce the development effect.

Later people found that[6]for high brittleness index, natural fracture development and scratchy crack shale gas reservoirs, water fracturing shearing force in the process of fracturing can make natural micro cracks in the shale gas reservoir slip, and cracks couldn't return to its original state after being stopped pump. Therefore, the cracks can keep a high permeability (Fig.2), at the same time ,also greatly reduce the amount of proppant and residual damage to the reservoir. In 1997, Mitchell energy company tried to use water in the Barnett shale instead of scraping gum fracturing, the result was very satisfactory. Water fracturing has increased Barnett shale ultimate recovery more than 20%, but also reduced the cost more than 60% of the work, the construction effect is significantly more than scraping gum fracturing technology.

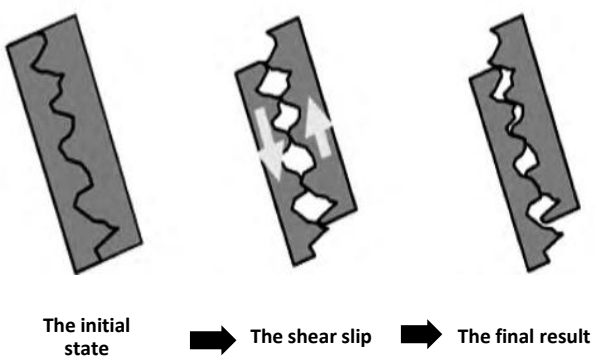

Fig. 2 *Shear slip mechanism*

Water Fracturing is a technology[7], which is adding surfactant and drag reduction agent in clean water as the working fluid fracturing operation. With only a small amount of proppant in work fluid, sometimes, sand amount according to the situation. Compared with the scraping gum fracturing, water fracturing has the following several advantages: ①Due to water fracturing does not require the preparation of gel cross linking agent and gelling agent, etc., thus it eliminats the gel hurt, doesn't contain residues, won't block formation and can accelerate the flow back process; ②Easy to form a certain diversion ability long cracks; ③Easy to extend the natural cracks or cracks formed interconnected network;④Reduces the transport and dosage of proppant, greatly reduces the operating costs, than with the size of

the gel fracturing operation cost reduced by 40% ~ 60%.

2.2 Bold attempt of horizontal well

Before the 21st century, the development of shale gas mining almost all adopted the way of a vertical Wells, but because of thin shale gas reservoir, reservoir physical property was poor, vertical Wells development had not been able to obtain high yield. In 1992, Mitchell Energy Company completed the first horizontal well in the Barnett shale, since then the application in the development of shale gas horizontal well was began. In 2002, Devon Energy Company in Barentt shale drilled a number of horizontal well; then the horizontal well technology scale expanded unceasingly. 2003 ~ 2007, the number of horizontal wells in Barnett is more than 4960, which is more than 50% of the total number of Barnett shale gas production Wells, in 2007 ,there was 2219 horizontal Wells, accounted for 94% of the year number of shale gas well completed. At present, horizontal Well has become the main development of shale gas, which greatly accelerated the development process of shale gas[8]. Fig. 3 is based on the well type Barnett shale gas production every year.

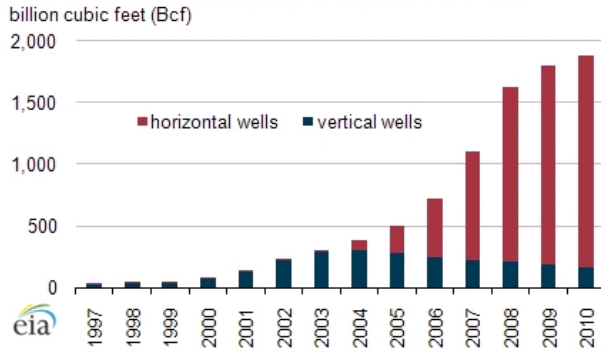

Fig. 3 *Horizontal Wells and vertical Wells shale gas output (from EIA)*

Compared with vertical Wells, the advantages of the horizontal Wells are as follows: ① horizontal well can cross the longer the length of the reservoir, and has bigger chance to fellowship with more cracks, furthermore, the single well production is 3 ~ 5 times of vertical Wells, the cost is 1 ~ 1.5 times of vertical Wells[9];②mining areas is bigger, can avoid the interference of ground disadvantage;③ vertical Wells can't get industrial hydrocarbon flow region, horizontal well development effect is very good;④the development cycle is longer.

2.3 The combination of the horizontal well staged fracturing

In the 1980 s[10], people began to use horizontal well fracturing technology for oil and gas, the first is the general fracturing, but the fracturing effect is not obvious ,which is because of the long horizontal section , multi-layers and lower surface pump pressure.

Later, people put forward a way, which is dividing the horizontal well into several segments by packer, and then fracturing step by step. In 2005[11], Newfield company of the United States adopted 5 ~ 7 sections of staged fracturing in parts of the Woodford shale, the shale gas single-well maximum initial yield reached 28.32 x 10^4 m^3 / d, the maximum yield of 16.99 x 10^4 m^3 / d. At present, 85% of the shale gas production Wells in the United States is using horizontal well and multi-stage fracturing technology combination of drilling, increases the yield significantly.

Horizontal well staged fracturing is that packer or bridge plug is used to change the horizontal section is divided into several small pieces, then step by step fracturing. Multistage fracturing can undertake targeted construction according to the characteristics of the reservoir, the target accurately. And the fracturing effect is remarkable. The emphasis and difficulty in multi-stage fracturing is the down hole completion tools of research and development. Both at home and abroad have been staged fracturing down hole tool of independent research and development and technical innovation. At present, the mainstream of the down hole tool has two types: one is the pitch sliding sleeve, the other is the rapid drillable bridge plug.

2.3.1 Pitching sliding sleeve

Baker hughes, in 2005,successfully developed pitch sliding sleeve multi-stage segmental fracturing technology[12], has successfully finished 40 segments. Pitching sliding sleeve multi-stage segmental fracturing technology use expandable casing packer and sliding, by closing one and multiple layers in a wellbore selectively into a number of different reservoirs, instead of using articulated tubing or coiled tubing to separate interval. In the fracturing fluid input, in turn, bigger diameter packer ball, can be the interval after fracturing packer, then go to the next layer fracturing, the continuous operation process, need not stop pumping fracturing fluid. The process pipe strings generally adopt the fixed string structure,

fracturing string and production string are together, and construction efficiency is higher.

Open hole packer and the sliding sleeve technology can give full play to the advantages of open hole[13], which expose more drainage period, short operation time, simple technology, which is a multistage horizontal well fracturing in the forefront of well completion technology, it can be in a vertical or horizontal well fracturing multiple interval and at the same time do not need to use the bridge plug space.

2.3.2 Drilling bridge plug

At present, many domestic and foreign companies adopt pumping bridge plug and staged fracturing perforating technology in this kind of well completion. Through the bridge plug the packer, the technology is presented. The perforating and fracturing, pressure with coiled tubing belt grinding shoes after a drilling bridge plug fluid side by side. Fast drilling bridge plug fracturing technology with unlimited block series, bridge plug pressure as high as 70 MPa, heat-resistant up to 150 ℃, the effective rate was 100%. The technology is suitable for large liquid volume, large displacement characteristics of shale gas fracturing, wellbore isolation high reliability, and quick construction. In addition, the pumping bridge plug and perforation pattern perforating the process using cluster, so more conducive to form a joint network.

Due to the bridge plug perforating technology [14], can in a short time after fracturing drill out all bridge plug, greatly save the construction time and cost, and also reduce the retention time of fracturing fluid in formation, reduce the liquid damage to reservoir. By means of this kind of perforating, each fracturing period of 4 ~ 6 cracks can be formed, stress interference between the cracks will be more apparent, fracturing after the completion of the formation of the joint network will be more complex. Transform the horizontal section is divided into multiple segments, after the completion ,they can form 8 to 15 paragraph of fracture clusters, transforming volume is bigger, the effect after fracturing operations is also more satisfied.

2.4 The application of factory fracturing

Traditional fracturing is decorated well and then fracturing, wells are often scattered. Shale gas fracturing need to use a lot of big crews take, and related supporting facilities, such as personnel, materials and pools, etc., at the same time many shale gas reservoir are extremely flat terrain. Traditional way of fracturing is fast for a certain area of a few Wells after completion of construction, then turn to the next block of several Wells to construction, the "hit a shot, in one place", which can lead to a long construction period, operation cost increases.

In 2005, Halliburton proposes the concept of "fracturing factory"[15,16], that is in a central region for hundreds of meters to thousands meters apart of fracturing Wells. All fracturing equipment layout in central region, do not need to move equipment, personnel and materials to multiple fracturing Wells. Later, this concept gradually expanded into a "factory" Well (Well Plant), namely the multi-port Well from drilling, perforation, fracturing and completion and production, the entire process is completed by a "central". Through "Well factory", completion cycle from 60 days to complete 1 Wells down to the present 20 days to complete 5 Wells, the completion cost was reduced by 60%.This construction method can generate more complex cracks, the average output by 21% ~ 25% higher than single fracturing, cost down more than 50%.

Factory fracturing technology is characterized by: ① high land utilization: deploy multiple location in a region, in every multi-port horizontal well site deployment. Each drill Wells usually 4 ~ 10 Wells, sometimes 12 ~ 16, up to more than 50; ② quick: drilling, cementing, perforating and fracturing operation which are mass, streamline, standardization, and achieve seamless connection between each working procedure;③ low cost: fluid recycling, relocation costs less; ④ form complex fracture fracturing, easy volume reconstruction;⑤ the ground utilization high infrastructure construction (public pools); ⑥ mass operation, reduce moving time, high work efficiency, the construction efficiency can be improved more than 1 times; ⑦ All landowners liquid concentration, facilitate processing and recycling, every 3 Wells can save water of the well.

2.5 Innovation of Synchronous/Zipper fracturing

Fracturing cracks of press out as much as possible, is the purpose of improving fracture diverting capacity, so as to reduce the resistance of hydrocarbon migration. In order to be able to press out more cracks, people developed synchronous/zipper fracturing technology. In 2006[17], synchronous fracturing technique for the first time in the Barnett shale, operators within the range of 152 ~ 305 m apart on two parallel

horizontal well fracturing at the same time. After operation, 2 Wells are all manufactured with fairly high speed, with nissan 25.5 x 1 well among them a rate of 10^4 m^3 continual production for 30 days, and the other without fracturing Wells nissan speed between 5.66 x 10^4 ~ 14.16 x 10^4 m^3.At present, the commonly used in synchronous fracturing has become in the Barnett shale development of hydraulic fracturing technology.

Synchronous Fracturing refers to two or more adjacent parallel Wells Fracturing at the same time[13]. In the process of fracturing, the fracturing fluid and proppant at high pressure from a well to the other well migration distance is the shortest way, to increase the fracture surface area of the grid and density, advantage between Wells and well connected to increase the degree and intensity of the workspace cracks, thus the rapid increase of shale gas well production. If the limited space can't for multi-port well Fracturing at the same time, people put forward the "Zipper Fracturing".

Synchronous fracturing and Zipper Fracturing comparing with ordinal fracturing[11,17,18], maximize the fracture fracturing Wells have been achieved, the yield increased by 20% ~ 55%, and small environmental impacts of the workspace, low cost and fast completion, and started to return time is short. Originally two close to each other and depth of roughly the same between the horizontal well fracturing at the same time, now the technology has developed into three or even four Wells fracturing at the same time.

2.6 The concept of "volume fracturing" is put forward

Due to the reservoir conditions, injection-production well spacing, fracturing process and so on, a single increase length to increase production of ultra-low permeability reservoir and the effect is not obvious, the conventional fracturing modification is difficult to achive commercial exploitation of the oil and gas reservoirs, so we must explore new fracturing technology.

In 2006, M.J.Mayerhofer et al. first mentioned the "Stimulated Reservoir Volume" the SRV) concept [19]. The principle of Volume fracturing is that in the process of hydraulic fracturing, the natural crack expanding and brittle rock shear sliding, the mutual interactions form the natural and artificial cracks fracture network, thus increasing volume, improve the initial production and ultimate recovery. Operators fractured 19 Wells in Barnett, fracturing volume is 5.3 x 10^6 ~ 52.7 x 10^6 m^3, and the production is bigger and bigger as the volume increasing[20].

The concept of "volume fracturing" overturn the classic theory of fracturing, volume reconstruction of form is no longer wings symmetry, but a complex network fracture system, crack fracture with the extension not only is the destruction of tensile fracture, but also is a cut, sliding, such as fault section of complex mechanical behavior. Volume fracturing technology is the most representative in the Barnett shale gas development in the United States.

3 Summary

The effective development of America's shale gas changed the pattern of world energy. The success of the shale gas exploration and development is the transformation of shale geological theory and engineering technology innovation results. According to the development of shale gas mining technology, people should realize the importance of theoretical innovation and technological innovation.

(1) Through geological theory innovation, people find the commercial value of natural gas, from the poor physical properties of shale, and expanded the oil and gas fields.

(2) In view of the high brittleness index, natural fracture development and scratchy crack shale gas reservoir, people developed water fracturing technology, and replaced the crosslinked gel fracturing technology, reducing reservoir damage, and increases the fracture diverting capacity.

(3) Because of the shale reservoir physical property is poor, a vertical Wells are unable to get high yield, people successfully used horizontal well to drill the reservoir.

(4) Because of the horizontal well length is longer, the fracturing effect is poorer, people developed staged fracturing technology, and developed a pitching sliding sleeve and fast drilling down hole completion tools ,such as bridge plug, to improve the shale gas production, simplifies the construction.

(5) Aiming at the problem of limited space, the cost is too high, people worked out the "factory" well fracturing technology, greatly reduce the cost, operation time, and increase the production.

(6) In order to fracturing more cracks, worked out the synchronous fracturing and zipper

fracturing technology, cause the fracturing well fracture to maximize, improved fracture diverting capacity.

(7) For wings symmetric seam output effect is not obvious, people put forward the concept of "volume fracturing", make the yield increase after modification, and subvert the traditional theory of fracturing.

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