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Research Progress of Anhydrous Fracturing

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Abstract: Oil and gas reserves in our country are large and widely distributed, and usually fracturing techniques are needed to extract oil and gas. Currently, the more mature hydraulic fracturing technology is difficult to extract coal bed methane. Combined with the research progress of fracturing at home and abroad, this paper summarizes the development of relevant anhydrous fracturing technology, fracturing fluid, fracturing process and other aspects, compares and analyzes the advantages and disadvantages of fracturing technology, and provides some ideas for the development of anhydrous fracturing technology in the future. In order to reduce the cost of anhydrous fracturing, meet the requirements of field application, and accelerate the research progress of anhydrous fracturing, the commonly used fracturing technologies are combined to study new fracturing fluids and carry out composite anhydrous fracturing.

Keywords: No water fracturing, Fracturing fluid, Fracturing process.

1. Introduction

Coal bed gas is widely distributed and abundant in reserves. According to the International Energy Agency (IEA), the world's CBM reserves could reach 260 trillion cubic meters, 90% of which are distributed in 12 coal-rich countries such as Russia, Canada and China. China is rich in coal bed gas reserves, with 36.8 trillion cubic meters of coal bed gas resources, ranking third in the world[1][2]. Although China has the third largest reserves of coal-bed methane in the world, it is difficult to extract coal-bed methane due to the complex geological environment in China, so it must be extracted in some special ways to achieve commercial purposes.

Most coal bed methane is extracted by fracturing[3], and hydraulic fracturing is the most commonly used fracturing technique. After many years of research, hydraulic fracturing technology in China is also becoming more and more mature[4][5]. However, in view of coal-bed methane exploitation, combined with the current trend of environmental protection, hydraulic fracturing technology has some problems, such as excessive use of water resources, damage to strata, and failure of hydraulic fracturing in water-sensitive environment. In view of these problems, more and more researchers begin to engage in the research of anhydrous fracturing technology. Therefore, based on the research and practice of anhydrous fracturing technology at home and abroad in recent years, this paper summarizes the relatively mature anhydrous fracturing technology, summarizes the fracturing fluid and fracturing process, and compares it with the traditional fracturing method, so as to provide some guidance for the efficient exploitation of coal-bed methane in China.

2. Foam Fracturing Technology

Foam fracturing technology was developed and applied in the 1970. Since then, the technology has been rapidly developed and put into field use in countries such as the United States and Canada. Foam Fracking technology has been introduced in China in recent years. However, the development of foam fracking technology in our country has been restricted because of the effects of foam fracking equipment, foam fracking technology and input costs.

Foam fracturing fluid is a dispersive system in which a small amount of liquid is uniformly dispersed and a large amount of gas is dispersed[6]. It consists of gas, liquid, surfactant and other chemical additives. From the composition of foam fracturing fluid, foam fracturing fluid has been developed for three generations. Initially, PLUMMER[7] found a gas-encased-foam fracturing fluid that was 50 to 90 percent foam by mass, using nitrogen gas. This fluid prevents fluid loss from fracturing fluid and improves fluid penetration. Nitrogen is an inert gas that dissolves slightly into the formation without causing damage to the formation. However, after a lot of field practice, it is found that the sand carrying capacity of nitrogen foam fracturing fluid is weak, which cannot meet the demand of sand carrying capacity during fracturing. After that, composite gas fracturing fluids were developed. In the late 20th century,ELSBERND[8] developed a combination of nitrogen and liquid carbon dioxide to improve the stability of the foam fracturing fluid through a fluorinated surfactant, and to improve the viscosity and sand carrying capacity of the foam fracturing fluid.

There are three main modes of foam fracturing: constant internal phase; Constant foam volume; Constant total bottom-hole displacement. Constant internal phase means that the amount of proppant added is equal to the foam reduction; Constant foam volume means to increase the supporting dose and keep the foam volume constant; Constant bottom-hole total displacement means that other things are constant, the support dose increases, and the foam mass increases after sand addition. The core idea is to control the total displacement and foam volume according to the actual situation in the field to achieve the optimal field effect[9].

Ratio of foam fracturing fluid to conventional water-based fracturing liquid[10][11][12]:

1) Foam fracturing construction equipment is different from traditional fracturing equipment. There are two sets of fracturing equipment for foam fracturing, one is booster pump truck, fracturing truck and supporting equipment, and the other is the recovery and treatment equipment for foam fracturing back-discharge fluid.

2) Only a small amount of fluid in the foam fracturing fluid

enters the formation and forms a barrier layer in the formation, which greatly reduces the rate of fluid loss, reduces the filtration loss, and reduces the damage to the reservoir from the root;

3) The density of the foam fracturing fluid is lower than that of the traditional water-based fracturing fluid, which can reduce the energy required to lift the fluid during back-discharge and achieve better back-discharge effect.

3. Supercritical CO_2 Fracturing Technology

As early as 1981, researchers in the United States proposed using carbon dioxide, which is widely distributed in the atmosphere, as a fracturing fluid. The liquefied carbon dioxide is mixed with prop-pant in a special sand mixing facility, pressurized by a high-pressure pump and pumped into the well-bore into the reservoir, where the reservoir is fractured and forced out of the fracture. In the early 21st century, our country began to introduce liquid carbon dioxide fracturing technology, which was successively applied in many fields such as oil and natural gas and gained great breakthroughs in technology.

Liquid carbon dioxide fracturing technology can alleviate the pressure of water resources supply to a certain extent and solve the problem of reservoir water sensitivity in hydraulic fracturing[13]. However, after years of field practice, the liquid carbon dioxide fracturing technology has some problems, such as low liquid carbon dioxide sand carrying capacity, high filtration loss, and large construction cost. In this context, supercritical carbon dioxide fracturing technology was developed.

Supercritical carbon dioxide means that carbon dioxide is kept in a supercritical environment. When the temperature and fracturing of the environment where carbon dioxide is located exceed the critical value, carbon dioxide will enter the supercritical state. The carbon dioxide in this state is between the gas and liquid, and has the characteristics of both gas and liquid[14][15][16].

The main difference between supercritical carbon dioxide fracturing and carbon dioxide foam fracturing is the need to keep the carbon dioxide at the bottom of the well in a supercritical state. In 2013, Li Gensheng[17][18]. proposed the supercritical carbon dioxide injection fracturing technology and proposed that the supercritical carbon dioxide injection fracturing mainly includes two parts: sandblasting perforated and fractured formations. The supercritical carbon dioxide injection fracturing system is composed of carbon dioxide storage device, wellhead control system, fracturing pump system, sand mixing system, injection transmission system, etc. Experiments show that supercritical carbon dioxide jet has higher rock-breaking pressure and faster rock-breaking speed than water jet[19].

Compared with other fracturing technologies, supercritical carbon dioxide fracturing technology has the following advantages[20][21]:

1) Compared with traditional hydraulic fracturing, supercritical carbon dioxide fracturing almost does not cause damage to the reservoir, and all fracturing fractures are basically effective fractures;

2) For coal-bed methane, a large amount of coal-bed methane in coal seam is adsorbed to coal rock, and supercritical carbon dioxide can replace methane gas adsorbed to coal rock, directly improve the production of coal-bed methane and realize partial carbon dioxide storage;

3) Compared with other anhydrous fracturing technologies, supercritical carbon dioxide fracturing solves the problem that nitrogen fracturing cannot carry sand; Compared with LPG fracturing technology, supercritical carbon dioxide fracturing technology has low cost and high safety.

It has been proved in practice that supercritical carbon dioxide fracturing technology is more suitable for coal-bed methane fracturing.

4. LPG (Liquefied Petroleum Gas) Fracturing Technology

In the late 1950s, the United States carried out fracturing work in Hugoton gas field in Kansas[23][24]. Halliburton, an engineer, injected the thickened gasoline into deep limestone geology for fracturing. According to the production calculation, the fracturing did not achieve the expected effect. But the use of gel-gasoline fracturing fluids is actually a precursor to LPG fracturing fluids.

Currently, the most common LPG fracturing fluids are liquid propane mixtures. It has the characteristics of low viscosity, low density, high flow-back rate and large sand carrying capacity. After a series of developments, the combination of n-hexane or n-pentane as base fluid and the development of new cross-linking agents have been developed to improve the application of fracturing fluid systems[25].

Liu Peng[26]. used a two-step method to synthesize phospholipid cross-linking agent, and combined with compound cross-linking agent, verified the influence of n-hexane and n-pentyl liquid on low-molecular-weight alkanes after cross-linking. The internal structure of n-hexane gel is more stable and the resistance is stronger. Zhang Ling[27]. used 2.5% low carbon chain alkyl cross-linking agent PA-2 and 4%FC-1 (30% sodium citrate, 10% ethylene glycol, 30%$Fe_2(SO_4)_3$ and 30% deionized water mixture) to obtain n-hexyl anhydrous gel, in which the complex formed by positive ferric ion and organic sodium citrate has a synergistic effect. Greatly improve the performance of the system; In 2017, Wang Manxue[29][28]. developed a new type of pentyl FRAC-H fracturing fluid, which could withstand temperature of 130℃. Due to the characteristics of low boiling point of short chain pentane, colloid can be automatically broken, to achieve no pollution, zero residue effect.

The LPG fracturing system is mainly composed of gas gel system, nitrogen sealing system, gel and prop-pant system, fracturing injection system, remote monitoring system (risk control), gas recovery and other systems. As the main components of LPG fracturing fluid are flammable and explosive alkanes, extra attention should be paid to the tightness of the device during LPG fracturing[29]. Before LPG fracturing, a pressure test is performed, prop-pant is added to a sealed vessel, and the system is checked for tightness by circulating nitrogen through the system. During fracturing, LPG gas is added and the LPG mixture is thickened using nitrogen to adjust pressure and temperature. The reservoir is fractured by applying pressure through a pressurized pump.

Compared to conventional hydraulic fracturing fluids:

1) LPG fracturing fluid[30] has the characteristics of low surface tension, complete compatibility with reservoir fluids, and reuse.

2) The viscosity of the LPG fracturing fluid allows the

prop-pant to be completely suspended, avoiding the prop-pant deposition caused by the low viscosity of the normal fracturing fluid;

5. High Energy Gas Fracturing Technology

More than 100 years ago, the United States conducted successful experiments on well-bore explosions. In the mid-late 1970s, the United States, the Soviet Union and other countries carried out further research on explosive fracturing, and it was not until the end of the 1980s that the technology became mature and the high-energy gas fracturing system was formed.

5.1. Pulse Fracturing

High-energy gas fracturing[31][32] is referred to as HEGF, also known as pulse fracturing, which uses gunpowder or rocket propellant to rapidly react in the well-bore to produce a large amount of high temperature and high pressure gas to fracture the formation, improve permeability in the near-well zone, and thus increase oil and gas production. It is a special stimulation measure.

There are two kinds of high energy gas fracturing technology: shell fracturing bomb and shell-less fracturing bomb. The gas generator in the shell fracturing bomb is equipped with a metal shell, and the fracturing charge is filled inside the metal pipeline. After ignition, the fracturing charge is deflated radial or axially through the metal tube. The advantages of shell shell are that the fracturing charge burns more fully and the pressure starts faster. The shell-less frac bomb generator is characterized by the ability to fire at the center, simultaneously fire, and simultaneously burn. Compared with shell shells, shell-free fracturing shells have large loading capacity, simple structure and convenient construction[34].

At present, high energy gas fracturing is widely used in coal-bed methane exploitation. High-energy gas fracturing can create complex fracture networks at lower pressures, increasing the volume of effective fractures and extending the connectivity to natural fractures. Compared with water-based fracturing, high-energy gas fracturing has less pollution. As the fracturing fluid is mainly liquid medicine, gunpowder is fully burned during fracturing, and the combustion products are mainly CO, CO2, H2O, etc., resulting in no pollution to the reservoir[33]. Most fracturing methods require proppant to support the fracture. The fracture with high energy gas fracturing pressure does not require prop-pant support, but also has a certain conductivity. The residual stress can keep the fracture open and closed to a certain extent.

Both shell-free and shell-free fracturing shell technology can only form a single pulse, which has the problems of less crack opening and short fracture extension length[35]. To solve these problems, multistage pulse fracturing technology was developed based on the existing high energy gas fracturing technology.

5.2. Multistage Pulse Fracturing

Fracturing technology of multistage pulse fracturing technology is a kind of combination, the basic principle is the powder of different burning rate are combined, the reasonable control of the combustion rate of fracturing medicine[36][37], let primary gunpowder first deflagration, instantly at multiple directions perforation cracking pressure, secondary and tertiary gunpowder explosion in a row, on the formation period of continuous loading pulse pressure, To maintain the energy required for fracture extension after first-stage deflagration, so as to achieve the purpose of continuous fracturing and fracture extension. At present, the fracturing fluid involved in multistage pulse fracturing is mainly gunpowder, which has certain risks. In order to ensure the safety of multi-direction fracturing and fracturing initiation, the charge rate of multistage pulse fracturing is usually in the following order: first-stage burning rate-high-medium rate gunpowder[38][39].

The multistage pulse fracturing technology device is mainly composed of control ignition device, detonation device, multistage compound structure, delay ignition device and other systems. Control the combustion of multistage gunpowder step by step to achieve the purpose of orderly and continuous release of energy.

Compared with traditional fracturing methods, high-energy gas fracturing has the following characteristics:

1) Compared with hydraulic fracturing fluid, gunpowder used in high-energy gas fracturing is fully burned in the process of fracturing, with almost no pollution residue;

2) After the high energy gas fracturing powder is fully burned, there is no problem that fracturing fluid penetrates into the formation and pollutes the formation;

3) The construction process of high-energy gas fracturing is simple and the cost is low.

6. Conclusion and Prospect

At present, the research of anhydrous fracturing technology has made some achievements, and it is widely used in the exploitation of coal-bed methane. After long-term practice, some disadvantages of anhydrous fracturing have gradually emerged. Such as:

1) Safety is a major challenge when performing LPG fracturing because of the stringent requirements on vessel tightness;

2) High-energy gas fracturing is widely used in CBM development without prop-pant injection. Although stress can maintain fracture opening, long-term exploitation and slow fracture closure will affect the fracturing effect and CBM production.

Therefore, in view of these existing problems, on the one hand, it is necessary to optimize the process flow through individual technology research; On the other hand, current waterless fracturing technologies need to be integrated to complement each other's strengths. At present, anhydrous fracturing technology based on high-energy gas fracturing is studying the acidification ratio of fracturing fluid, optimizing the fracturing drug characteristics, so that the fracturing drug can have acidification characteristics after combustion, simulate the acidification effect in hydraulic fracturing, and transform the formation more effectively.

As a new fracturing technology, anhydrous fracturing was developed to balance the disadvantages of traditional fracturing technology. At present, the application of anhydrous fracturing technology in coal-bed methane development is not comprehensive. It is necessary to carry out the composite application of anhydrous fracturing technology according to the actual situation to solve the problems of safety, equipment and cost, so as to meet the needs of on-site application of coal-bed methane development.

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