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A Review on In-situ Extraction Technology of Oil Shale

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Abstract

China is one of the countries with the most abundant oil shale reserves, and as an important alternative energy material, oil shale has important practical significance for its development and utilization, so the in-situ exploitation of oil shale is an inevitable response of The Times. This paper mainly analyzes the oil shale mining technology and development trend, and puts forward corresponding measures for the problems in the initial stage of in-situ oil shale mining in China.

Keywords

In-situ Oil Shale Exploitation; Groundwater Environment.

1. Introduction

As a high-quality energy material, oil shale is an important strategic material for national livelihood and one of the basic industries for national economic development, and its development and utilization has irreplaceable practical significance. Many large energy companies and research institutions have carried out research on in-situ oil shale mining technology.

At present, there are dozens of in-situ oil shale production technologies, such as Shell ICP technology, ExxonMobil Electrofrac TM technology, Chevron and Los Alamos National Laboratory CRUSH technology, Raytheon RF/CF technology, Taiyuan University of Technology convection heating technology, etc. The principles of different in-situ oil shale in-situ mining technologies are basically similar, and their general mining steps are as follows: (1) Fracturing of oil shale formations by hydraulic or high-temperature gas, etc., which both increases the contact area between heat source and oil shale and increases the porosity and permeability of oil shale formations to facilitate oil and gas recovery. (2) Passing high-temperature fluids or conductive materials into oil shale formations and pyrolyzing them to produce shale oil. (3) The generated pyrolytic oil and gas are recovered through the production well to separate water, oil and gas [1-3]. Each technology is to improve the permeability of oil shale as much as possible to improve the oil recovery rate, but the high temperature heating causes complex physical and chemical reactions and mineral transformation of organic matter in oil shale, resulting in a large number of pores and fissures in oil shale, which increases the porosity and permeability of oil shale layer. In-situ pyrolysis allows oil shale formations to evolve from the usual water barrier or weakly permeable formations to gradually become permeable. Under natural conditions, the amount of organic contaminants in groundwater is low, but when the oil-bearing strata are hydraulically connected to the aquifer, the contaminants in groundwater change accordingly.

2. Analysis and development trend of oil shale in-situ mining process

Oil shale is a dense, flaky, very fine-grained sedimentary rock containing large amounts of immature organic matter or case roots, which can be converted to liquid hydrocarbons by pyrolysis of immature case roots through high temperature heating (>300°C, typically 300-

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500°C) [1]. Oil shale in-situ exploitation technology is a more economical and environmentally friendly oil and gas resource exploitation technology that the world's famous oil companies have begun to explore since the 1980s. The principle of this technology is to directly heat the underground oil shale layer, crack it into oil and gas underground, and finally extract the oil and gas through production Wells.

2.1. Process Introduction

In-situ oil shale extraction is a technology that heats and dry distillation and oil shale oil and gas extraction directly underground through fracturing and heat injection. There are three types of shale heating methods: electric heating, fluid heating, and radiation heating, and the relatively mature ones are Shell ICP technology, ExxonMobil ElectrofracTM technology, and EGL in-situ extraction technology.

2.1.1. Chevron CRUSH Technology

CRUSH technology (Figure 1) uses Rubbization to fracture shale formations into discontinuous bodies of rock, thereby increasing the specific surface area of the fractures, and injects hot steam (or carbon dioxide) into the fractures via a surface compressor to heat the formation, which is transformed into oil and gas by convective heating in contact with the hot fluid and then extracted by conventional methods. Chevron proposes two possible methods of petrochemical fragmentation: the first is the freezing method, where the rock contracts in a cooled state and extreme cooling can stretch the rock, changing its thermal expansion correlation coefficient, which can lead to changes in shrinkage and shear stress; the second is the explosive method, in which the physical form of the rock is changed by blasting to form fissures of a specific shape [1]. This process requires a large amount of water and on-site production, which is more damaging to the environment [2].

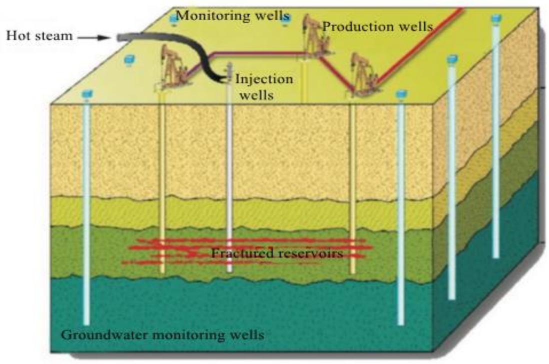

Fig. 1 Schematic diagram of Chevron's CRUSH technology [3]

2.1.2. Shell ICP technology (In-Site Conversion Process technology)

ICP technology (Figure. 2) uses small-spacing downhole electric heating method to heat underground oil shale to accelerate the maturation process of kerogen, so that kerogen is pyrolyzed into oil and gas resources, and injected into H2 to obtain ultra-clean light oil and natural gas, which is processed by conventional oil and gas extraction technology. ICP technology often uses freeze wall technology to introduce the interaction between electric heating and water bodies, and the freeze wall forms a closed piping system to isolate the surrounding groundwater infiltration and oil and gas leakage to reduce the heat loss from the rock formation. Yang, Lin et al [5]. Experiments were designed to simulate high-temperature oil shale extraction under in situ water-free conditions to verify the feasibility of an underground freeze wall testbed for in situ oil shale extraction and to provide technical support for the use of natural air cooling energy for cooling underground freeze walls. Li, Shumin et al

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[6]. The buffer distance of the permafrost wall was simulated and analyzed using ANSYS numerical simulation software, and it was concluded that the buffer distance of the permafrost wall has less influence on the temperature field in the central heating area of the oil shale, and the optimal conclusion was reached when the buffer distance is 40m combined with the optimization from the cost perspective.

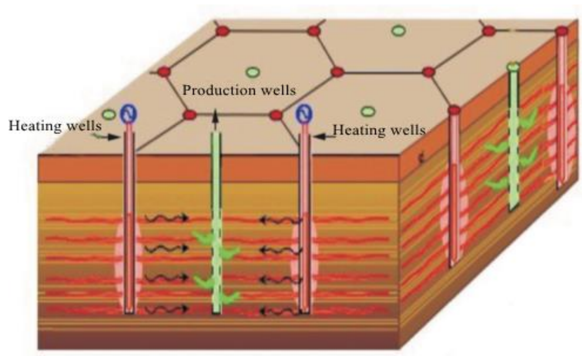

Fig. 2 Schematic diagram of Shell's ICP technology [7]

2.1.3. Exxonmobil ElectrofracTM Technology

The ElectrofracTM process starts with hydraulic fracturing of shale formations using parallel horizontal Wells. The conductive medium is filled into the cracks of oil shale layer to form heating unit. The conductive medium transfers heat to the shale formation by conduction, which causes the pyrolysis of the caseous roots within the shale formation and the resulting oil and gas is extracted to the surface through the recovery well. The U.S. Department of Energy study noted that the operation of this technology can simultaneously produce an associated mineral, sodium bicarbonate, which reacts with heat to form sodium carbonate as a byproduct [8]. Liu Dexun et al. concluded that the hydraulic fracturing process of the technique on the rock formation can increase the permeability of the rock formation and facilitate the extraction of dense rock resources, and the technique also produces sodium carbonate as a by-product, which is economically efficient but environmentally polluting [9].

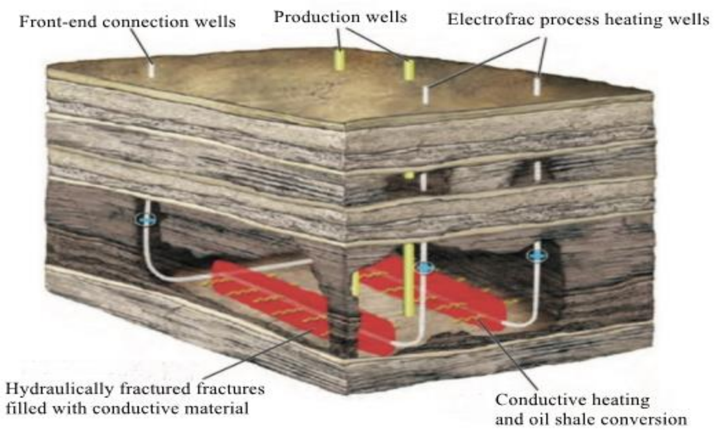

Fig. 3 ElectrofracTM technology from ExxonMobil [10]

2.1.4. EGL in-situ mining technology

This technology mainly uses convection and reflux heat transfer principles to heat oil shale. The technology consists of two main components: the heating system and the oil recovery system. The heating system is a closed annular system consisting mainly of several parallel horizontal

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wells. High temperature natural gas or propane or dry distillation gas is passed into the annular system to bring in heat to heat the oil shale formation [11]. The vertical wells are mainly used to collect the hydrocarbons generated by pyrolysis and transport them to the surface.

2.2. U.S. Bureau of Land Management RD&D Program (Research, Development & Demonstration)

Wang Youping and others pointed out that in order to promote the development of shale oil extraction technology and large-scale commercial development in the United States, the U.S. Bureau of Land Management (BLM) conducted the first and second rounds of bidding for RD&D project pilot areas (Research, Development & Demonstration) in June 2005 and November 2009. The oil shale in-situ technologies that are relatively mature and have been awarded RD&D pilot areas by the BLM include Shell ICP technology, Chevron CRUSH technology, U.S. shale oil CCR technology, and ExxonMobil Electrofrac technology [12].

3. Problems and solutions of in-situ oil shale mining process in China

3.1. Problems

3.1.1. Significant security issues

Some oil shale mines, especially small mines, lack capital and technology, and their safety facilities are far inferior to those of large and medium-sized mines. Water permeation accidents, mine gas accidents, and chip gang and roof accidents often occur. [13] Lightly, it causes loss of property, and seriously, it causes casualties or even major casualties.

3.1.2. Weak research base for oil shale

The level of research in China needs to be greatly improved, both in terms of oil shale genesis, properties and development and utilization [14]. Taking Wanfang database as the data source, for example, the number of literature appears in the search of "coal combustion" is 76,703, the number of literature appears in the search of "oil and gas resources" is 56,608, and the search of "oil shale Only 5130 documents appear in the search for "oil shale", which is less than 10% of the conventional oil and gas resources. This shows that there is very little research on oil shale porosity, permeability, physical and chemical properties of oil shale on environmental chemical composition, and its mining application.

3.1.3. Oil shale mining process is a serious environmental pollution

At present, oil shale mining has significant environmental problems, such as serious water consumption, groundwater pollution, methane leakage, and induced geological disasters. Among them, water resources consumption and groundwater pollution are very prominent. During the extraction process, hydraulic fracturing technology consumes a large amount of freshwater resources. According to the U.S. Environmental Protection Agency, the water consumption of each horizontal well is generally about 7600 to 9000 m3, while in southwest and northwest China, where the geological conditions are complex, the water consumption will reach 10000 to 24000 m^3 [3].

Table 1. The average water consumption of shale gas well in USA

Shale Name	Total per well/m^3	Drilling Water consumption/m^3	Drilling water to total volume/%	Fracturing water consumption/m^3	Fracturing water to total volume/%
Barnett Shale	10100	1500	14.9	8600	85.1
Fayetteville Shale	11225	225	2.0	11000	98.0
Haynesville Shale	13980	3780	27.0	10200	73.0
Marcellus Formation	14600	300	2.1	143	98.0

The fracturing fluid used in oil shale exploitation usually includes water, sand and related chemicals such as drag reducer, fungicide, scale inhibitor, clay stabilizer and surfactant [4].

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After fracturing, part of the fracturing fluid will be discharged to the surface and the remaining part will remain underground permanently. After fracturing, the fracturing return fluid, due to its long contact with the reservoir, not only retains the original chemical substances, but also mixes with phenols, ketones, grease, heavy metals, microorganisms bacteria, suspended organic matter, natural radioactive substances and other pollutants [15], the complexity of the return fluid composition brings a major challenge to the treatment and secondary use of sewage, and also exacerbates the degree of environmental pollution of groundwater and the difficulty of management.

3.1.4. The technology of dry distillation is still immature

The dry distillation technology of oil shale mainly adopts endothermic dry distillation. In order to make full use of oil shale of different particle sizes (lumpy granular, powdered), it is often necessary to equip multiple dry distillation furnaces at the same time, which is more complicated in terms of technology and equipment and increases the cost; in addition, the oil and gas generated by dry distillation of powdered oil shale will bring out more dust when it comes out of the furnace, which is also difficult to handle. Through the analysis of different heating methods in situ mining technology, the electric heating technology is characterized by mature technology and easy control, but the heating speed is slow and easy to cause a large amount of heat loss, higher cost, and the generated oil and gas pressure is low, resulting in lower oil and gas recovery rate. Fluid heating technology is characterized by faster heating rate of oil shale and the fractures produced generally do not close due to fluid pressure, resulting in faster export of produced oil and gas; the fluid is not easy to control during the heating process, and it is easy to form a short circuit of fluid, i.e., the fluid flows too fast and flows out of the formation before heat exchange with the oil shale. RF heating technology is characterized by strong penetration of the generated heat and faster heating rate; however, it is more technically difficult and costly.

Research on the environmental impact of new processes for in situ pyrolysis of oil shale is blind and lacking in a systematic way [15]. The majority of researchers have used the ICP technology from Shell as the background for their research on the disturbance of the geological environment by in situ pyrolysis of oil shale, but the ICP warming process is very slow and the heat loss is huge, which makes it difficult to be applied on a large scale.

3.1.5. Limitations of the oil shale power industry

Direct combustion power generation is economically competitive from the perspective of energy utilization. At present, the technology of burning oil shale for power generation includes direct combustion technology of pulverized coal furnace and fluidized bed combustion technology, but there are four major problems of burning oil shale in pulverized coal furnace that have not been solved: (1) the metal corrosion of the radiating heating surface in the furnace chamber is serious and the life span is short; (2) the convection heating area is large, the ash plugging is serious, and the heat transfer efficiency is low; (3) the powder system often explodes, which is very unsafe; (4) when the heating value of oil shale is lower than 8374 kJ/kg, it needs to spray oil to help combustion, which is not economical. The bubble fluidized bed combustion technology has some limitations due to low combustion intensity, large space occupation, large bed area, difficult to handle structure, low thermal efficiency and poor environmental index. Therefore, the oil shale power generation industry has not been able to develop.

3.1.6. The main problems for refining crude oil

As world oil prices continue to rise and economies become more dependent on crude oil, there is a global boom in shale oil refining. Shale oil is mainly produced by extracting oil shale to the surface through open pit or mine, crushing and above-ground dry distillation, and then developed and utilized. This technology has a history of more than 200 years and is relatively

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mature, but the limitations of this technology are relatively large, in addition to the inability to extract oil shale in cities and under important buildings, the damage to the ecological environment is also very serious and unavoidable, mainly in the following aspects: (1) Serious ecological and water quality damage. Whether it is open pit mining or underground mining, the groundwater level needs to be lowered below the level of the oil shale containing layer, and for mining 1 m^3 of oil shale, generally 25 m^3 of groundwater needs to be pumped out. The pumped groundwater must precipitate solid particles in the water before it is discharged into rivers and lakes, but mining water greatly increases the sulfate content in surface water and groundwater. (2) The pollution of ash residue is inevitable. Oil shale obtained through direct mining is used to refine shale oil or burned directly, and this process will produce a large amount of ash residue, which will seriously pollute the environment and endanger human production and life. (3) Direct mining accounts for more. Once reclaimed it cannot be fully restored. (4) High-quality oil shale in China is mainly concentrated in the middle and deep layers, and the traditional process for the development of middle and deep oil shale becomes uneconomical due to the increase of extraction cost [16].

3.1.7. Oil shale process development is limited by many constraints

The development of oil shale process is promising, but it is greatly limited by the current technology and mining methods. The main ones are: (1) Economic cost constraints. Traditional extraction requires stripping the oil shale minerals to the surface and then crushing them for use, resulting in too many steps - extraction, transportation, processing, refining, reprocessing, transportation, and environmental remediation - to compete with other energy sources. This is the main reason why the oil shale industry has faded from history in the past 50 years. (2) Environmental constraints. The processing of oil shale is similar to the processing of organic fossils such as coal, and the process of reuse inevitably brings great pollution to the environment and damages the natural ecology, sometimes even irreversibly. (3) Atmospheric pollution. In the process of oil shale mining, processing, dry distillation or combustion, a large amount of SO_2, NO_X, CO_X, HCl, H_2S, CH_4, phenols and other harmful substances will be generated and released into the atmosphere, which seriously affects the quality of the atmosphere. (4) Dust pollution. In the mining and crushing stage, dust is the main pollutant, and is released into the atmosphere with the mining and transportation process. The process of dry distillation or combustion will also produce a large amount of dust, and adsorb a large number of harmful metal elements and organic substances, which will settle to the surface and cause serious harm to plants and organisms in a large area. (5) Water and soil pollution. The development and utilization of oil shale resources requires a large amount of water resources in almost every stage. The extraction process requires the extraction of groundwater, and various industrial effluents, such as cooling water and leachate, are produced in the process of oil shale or ash accumulation. These effluents contain high levels of organic pollutants, such as phenols and oils, which flow into surface water or soil and disturb the water and soil balance, as shown in 3.1.3 above. (6) Occupy a lot of land. Both methods of off-site extraction of oil shale resources will occupy a large amount of land, and even cause surface subsidence. Most of the extracted oil shale has to be piled up on the surface, and most of the processing waste, except for a few backfills, is piled up on the surface, which occupies a lot of land and cannot be disposed of for a long time, causing serious damage to arable land and vegetation [17].

3.2. Solution

3.2.1. Recycling of wastewater, waste gas and ash generated by dry distillation

The wastewater, waste gas and ash produced by dry distillation are recycled and reused. Using new technology and new patented equipment, low calorific value gas is used as fuel for boilers and gas generators to produce steam and electricity, and the dual goals of clean emission of waste gas and clean secondary energy can be achieved by primary purification of waste gas;

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waste water is treated by oil separation and sedimentation and then all used for production recycling, which fundamentally reduces the use of fresh water; waste residue from dry distillation can be applied to the construction industry as block and The waste residue from dry distillation can be used as filling material for blocks and hollow bricks in the construction industry, and the analysis and demonstration of small particle shale for fluidized bed boiler combustion, etc. [18].

3.2.2. Gas management at working face

When the oil shale collapse will release alkane, alkene, alkyne, hydrogen, hydrogen sulfide and other gases, gas management is difficult; the working face over oil and gas wells have the possibility of abnormal oil and gas gush, there is the risk of gas, oil and gas coupling disaster, gas explosion impact is huge, can be through the corner of the two-way staggered step buried pipe extraction mining gas, over oil and gas wells special treatment, two top plate directional segmentation hydraulic pre-fracturing [19] and other technologies for gas management at the working face.

3.2.3. Improving the legal system and strictly regulating shale oil and gas exploration

According to the shale gas exploration and development process, we clarify the various aspects of the shale gas development process that may cause environmental pollution and ecological damage, strengthen environmental monitoring during the shale gas drilling project, fully implement environmental protection-related requirements, and provide feedback on effective environmental protection information to ensure that its impact on the environment is within the carrying range and so on [20]. The relevant environmental protection departments in China should first clarify the main department for environmental management of shale gas, and at the same time examine whether the existing laws, regulations and policy norms are feasible for the environmental issues of shale gas, and make up for the current deficiencies by formulating and introducing special legal documents for environmental management of shale gas extraction as soon as possible [21].

3.2.4. Learning from the experience of other great examples

At present, Shell, Exxon I Mobil and EGL are at the forefront of research on in-situ extraction technology, among which Shell ICP technology is the most mature and has been tested in the field. The principle of this technology is: using electric heaters to heat the underground oil shale layer to speed up the natural maturation progress of the casein, so that the organic casein in it can be pyrolyzed to produce oil and gas, and then by adding H2 to obtain ultra-clean light oil and gas. The application of ICP technology depends on the depth and thickness of the oil shale deposits and the conditions of the groundwater deposit.

The technology consists of the following four processes: (1) Establishing a freeze wall: To prevent the flow of formation water into the extraction area and prevent the dispersion of oil and gas products. The freeze wall consists of freeze wells, a closed pipe network connecting the freeze wells and a frozen surrounding rock medium. A series of wells are drilled around the extraction area with a spacing of about 3m, and a closed circulation system is installed in the freezing wells. -45℃ freezing fluid is injected into the circulation system, which is circulated in the closed system to freeze the groundwater around the system and the subsequent rock media together, forming a freezing wall; (2) Heating shale formations: After the formation of the freeze wall, production wells are used to drain groundwater from the production area and inject it into the formation outside the freeze wall. Then, multiple heating wells are drilled within the freeze wall and electric heaters are installed into the heating wells to heat the oil shale formation; (3)Extraction of dry distillation oil and gas: After heating the oil shale layer, with the heating, the oil, gas, vapor and non-hydrocarbon gases produced flow together into the production wells, which are transported through the production wells to the surface processing unit for oil, gas and water separation, and then the separated oil and gas products are

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transported to the corresponding processing units for further processing; (4)Restoration work: groundwater, above-ground soil and vegetation in the extraction area, etc.

In early 2004, Shell heated the oil shale formation in the test area, producing 1,700 barrels of light oil in August 2005, along with associated gas, before shutting down the heater and ceasing production shortly thereafter. Currently, Shell ICP technology has been developed to the second generation, called E-ICP. 2006 saw the preparation of an E-ICP test plan and an application to obtain three oil shale development, test and demonstration blocks in Colorado for field testing, which is currently in the heating phase [22].

4. Summary and Outlook

(1) Oil shale in-situ mining technology mainly adopts convection heating method, and will explore diversified heating methods in the future to improve oil shale mining efficiency and develop a green and efficient mining process.

(2) The horizontal gap of the shale formation has a significant impact on the extraction process of oil shale, which needs to be explored in a more specific and comprehensive manner.

(3) The limited scale of shale oil in-situ extraction project trials and the limited number of projects that have been granted exclusive test areas have hindered the development of the shale oil in-situ extraction process.

(4) The continuous improvement of the known extraction process and the discovery of the unknown extraction process is the direction we must always strive for. In our country, through continuous learning from the experience of advanced examples, as well as through the continuous discovery of problems and solutions in the mining process, oil shale mining technology is being improved, while the environmental problems generated should not be ignored, the mining process can not just pursue technology and production, but should be led by the scientific concept of development, must be combined with environmental protection, plus support for safety and low security, focus on pilot experiments, strengthen in situ Mining integration, all-round reduction of the surrounding atmosphere, soil geology, groundwater and other environmental breakthroughs, strengthening the treatment and improvement of damage to the environment, as early as possible to establish environmental protection first, circular development of mining mode, in the use of oil shale resources while reducing the impact on the environment to a minimum.

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