IOSR Journal of Pharmaceutical Science Invention
ISSN (Online): 2319 – 6718, ISSN (Print): 2319 – 670X
www.ijpsi.org
Volume 1 Issue 1 ǁ December. 2012 ǁ PP.01-07

Research on In-situ Oil Shale Mining Technology

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***ABSTRACT*:** *Shortage problems of traditional resources, such as petroleum, coal, natural gas etc, is getting worse and worse and the price is rising constantly, which provides advantages for oil shale industry. The development of oil shale mining technology has aroused wide attention. Based on different ways of heating, this paper introduces the technological process and development of electric heating in-situ exploitation technology, convection heating in-situ exploitation technology and radiation heating in-situ exploitation technology in detail. In addition, advantages and disadvantages of these technologies are also discussed. Finally, development trend and prospect of oil shale in-situ exploitation technology is described.*

Index Terms—*Oil shale, Shale oil, In-situ Exploitation.*

I. BACKGROUND

Oil shale is dense layered flammable sedimentary rock with organic and high ash and it belongs to saprogenic coal. Its color ranges from light-grey to dark brown and it contains ash over 40%, which is its main difference from the coal, and oil content over 3.5% [1], which is its main difference from the carbonaceous shale. Natural oil shale's permeability and porosity is extremely low. When temperature is raised, its porosity will increase [2].

The oil shale resource in the world is tremendous. As the statistics published by the《Oil and Gas》showed, the reserve of the oil shale in the world is nearly trillion tons [3], which is far more than that of the petrol. Oil shale is often used as generate electricity, heating and the production of shale oil and chemical products. In recent years, as oil price continues to rise, how to use oil shale to produce shale oil is gaining wider attention and research.

Shale oil can be produced via retorting technique, which has two forms, that is aboveground and underground. Aboveground retorting technique has some shortcomings, namely, low utilization rate, heavy pollution, small-scald, high cost, large occupation of land area and low recovery rate [4-5]. Generally, oil shale buried in 300m cannot be developed, while this part occupies a large proportion of the oil shale resource [6]. Therefore, underground retorting technique is getting into the researcher's field of vision gradually.

Underground retorting technique (in-situ technology) means that heat the oil shale which was buried under the ground directly without exploiting it out, and exported the oil and gas to the ground. This method can be used for exploiting the oil shale that is buried in the deep layer and be of high thickness. Besides, it still has several advantages as follows, high quality, high oil recovery rate, less coverage of area and green. Many foreign corporations and research institutes have made a lot of studies, and they have seen the result preliminary. It's necessary for us to perfect the underground retorting and develop the in-situ exploitation technology, to provide theoretical and technical reserves for the future development of oil shale resources [7-8].

I. TECHNOLOGY OF IN-SITU EXPLOITATION

There are three key problems about this technology: ① Problem of heating. Kerogen must be converted into flexible oil and gas. Therefore to make decomposition occur within a reasonable time, enough heat should be provided in a chunk of region; ② Problem of exploitation. Considering natural oil shale's extremely low porosity and permeability, we must increase them to extract oil and gas; ③ Problem of environment. The oil shale after dry distillation mustn't bring improper environmental or economic burden. According to different ways of heating, in-situ exploitation can be divided into three technologies including conduction heating, convection heating and radiation heating [9-10].

II. CONDUCTION HEATING TECHNOLOGY

A. Shell Oil Corporation's ICP technique

Principle of ICP technique (as shown in Fig. 1) is that heat is transferred into oil shale strata through electric heater to heat and crack to make kerogen in the oil shale transform into high grade gas and then transport oil and gas

to the surface. This technology is just used in experiment and still not be commercially developed depends upon many factors.

Process: To prevent ground water from inflowing into exploitation area, frozen wall should be constructed firstly. We ought to drill a series of wells around exploitation area to set up annular closed pipeline system and then inject freezing liquid of forty five degrees Celsius below zero (ammonia) to freeze ground water nearby to form peripheral frozen wall for that the water would not be polluted. Afterwards, ground water within exploitation area should be carried away though dredging dried well to reduce consumption of energy during the heating process. Heating well should be drilled with the heating rod been installed on it to heat kerogen to get high grade oil and gas and then they will be transported to the surface through production well.

Characteristics:① Electric heating process is complicated and more faults are difficult to be eliminated; ②Heating device with low efficiency is wasteful of power, which brings about high cost; ③Oil and gas with minor migration agent is hard to be extracted.

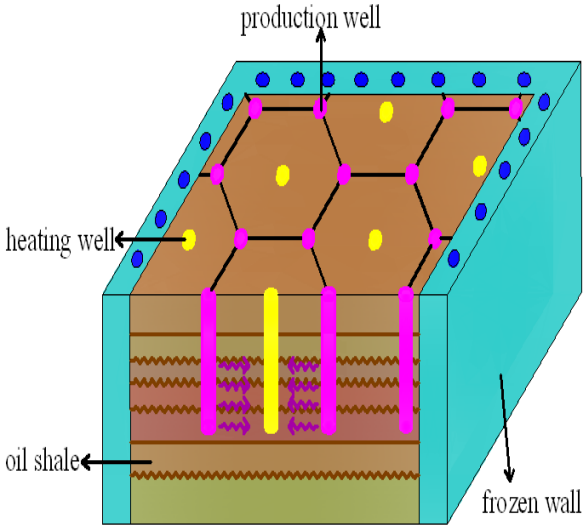

Fig. 1. Shell Oil Corporation's ICP technique

B. Exxon Mobil Corporation's Electrofrac TM technique

The company participates in development of oil shale since 1960 and now mainly research in-situ exploitation technology. By investigating more than 30 processes, they proposed ElectrofracTM unique that has been experimented and get satisfactory result (as shown in Fig. 2).

Process: At first, make the shale formation fractured horizontally by horizontal wells. Afterwards put conductive medium into those fracture to heat, and then we can get oil and gas.

Characteristics: ①Fracturing technology can raise permeability of shale; therefore oil shale with high density can be exploited; ②It is easy to pollute the ground water; ③Efficiency is improved because of the special way of heat conduction.

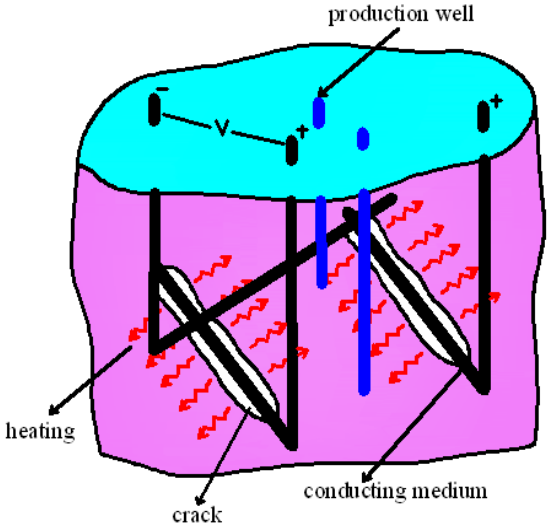

Fig. 2. Exxon Mobil Corporation's Electrofrac TM technique

C. GFC technique of IEP Corporation

Process: Take advantage of high temperature fuel cell stack to heat shale formation to get oil and gas (as shown in Fig. 3). At the beginning of heating, extra gas should be filled into cell stack as fuel and when it is normal, it will be autarky [11].

Characteristics: ①Heating temperature is equality and efficient; ②By arousing temperature to make fluid pressure be increased to 710～1420kPa to fracture shale formation to improve porosity and permeability; ③ Generated energy is not only autarky but also used to produce electric energy; ④ It produces a few of pernicious substance such as NO_X, SO_2 because it produces energy by electric reaction.

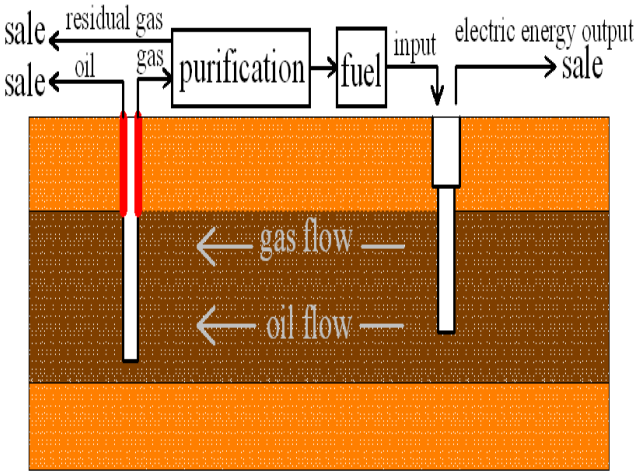

Fig. 3. GFC technique of IEP Corporation

III. CONVECTION HEATING TECHNOLOGY

A. Convection heating by high temperature hydrocarbon gases of Taiyuan University

Process: Space a group of wells and connect them by fracturing and then exchange heating well and production well. Inject 400～700 ℃ hydrocarbon gases into shale formation through heating well to heat kerogen to produce oil and gas and extract them by water or hypothermal gas to the surface (as shown in Fig. 4).

Characteristics: ①By fracturing shale formation we can get huge fracture that can connect all wells, which improves its permeability and increases production efficiency; ②Vapor whose specific heat is low is substituted by hydrocarbon gases whose specific heat is high and then heating velocity is increased; ③ The method of exchange heating well and production well at intervals contributes to uniform temperature.

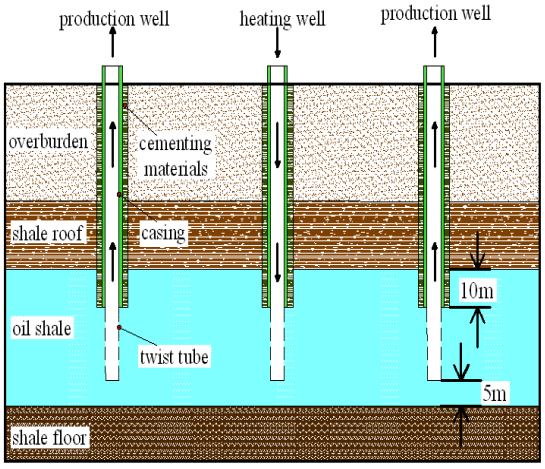

Fig. 4. GFC technique of IEP Corporation

B. CRUSH technology of Chevron Company

In 2006, CRUSH technology that is mainly use hyperthermia CO_2 to heat shale formation is invented by Chevron Company and Los Alamos National Laboratory (as shown in Fig. 5). The technology needs a lot of water and must be produced at hand, which brings about a great deal of pollution [12].

Process: Fracture shale formation to increase contact area of CO_2 and kerogen and then inject CO_2 to fracture to get oil and gas.

Characteristics: ①Contact area of CO_2 and kerogen is improved; ②The use of CO_2 can improve percent recovery of shale oil; ③Cost is low and pollution is small due to the use of single vertical nonreversing well.

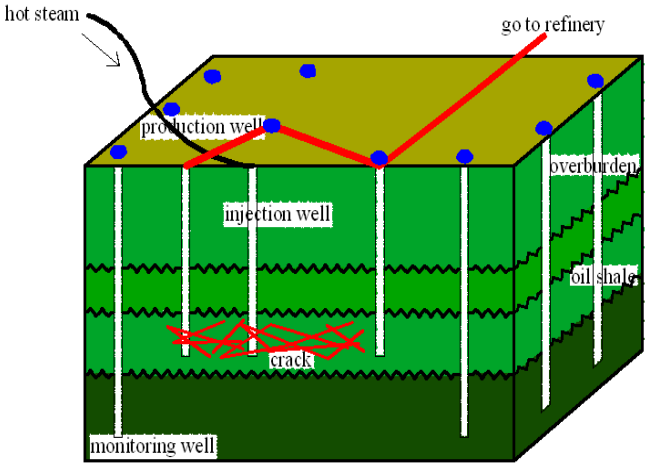

Fig. 5. CRUSH technology of Chevron Company

C. Air heating technology of Prtroprobe

Process: First pass the compressed air and the dry distillation gas into the burner, when heated to a certain temperature, and part of the oxygen is consumed, the mixed gas will be sent into the layor to heat the oil shale, which makes some of org matter turns into hydrocarbon gas. Then export the hydrocarbon gas on to the ground, we can get the light oil after condensating the hydrocarbon gas that has been taken out (as shown in Fig. 6).

Characteristics: ① The compressed air which is in a high temperature can fracture the oil shale in the layor, and increase the porosity of the oil shale, then the hydrocarbon gas can be exported out of the layor more easily; ② The process has four kinds of products, they are hydrogen, methane, light oil and water. ③ Some light hydrocarbon gas get burned in the burner, helping to heat the air that will be passed into the layor; ④ Carbon dioxide gas will be returned to the layor, which is environmental and brings low air pollution; ⑤The oil shale in the deep layor is approached even as deep as 900m; ⑥ The oil shale's original structure still keeps 94%～99% integrity, avoiding the ground collapse.

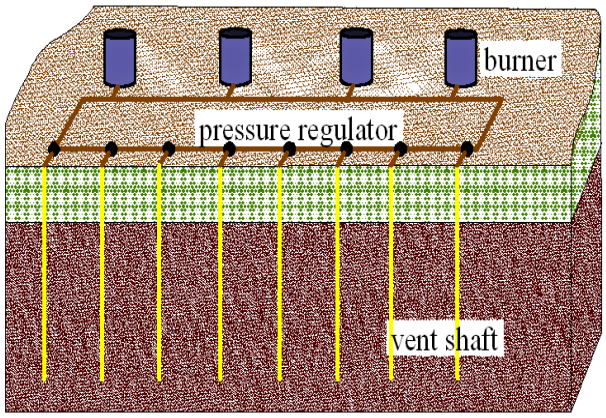

Fig. 6. Air heating technology of Prtroprobe

D. IGE technique of MWE

Process: Hyperthermal steam should be injected into shale formation to heat it and get oil and gas that ought to be extracted, condensed and recovered. Separate non-condensable gas after being heated to some temperature should be injected into formation to exchange with oil shale to realize circulation (as shown in Fig. 7).

Characteristics: ① Avoid viscosity because it is only involved in air flow; ② Cost is low and pollution is small because of use of single vertical central well; ③ Only explicating oil shale in more than 150 meters depth and 8 meters thickness can we get better economic benefit.

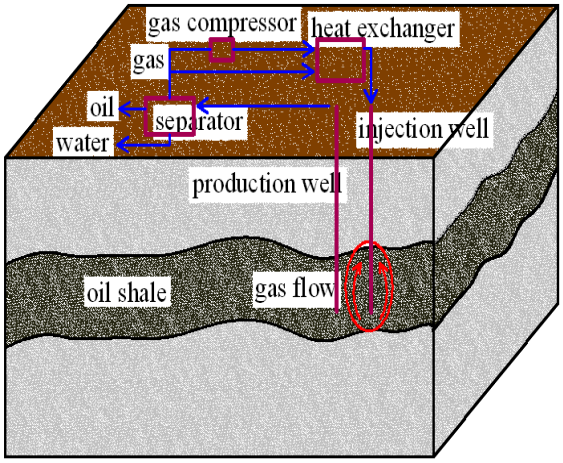

Fig. 7. IGE technique of MWE

IV. RADIATION HEATING TECHNOLOGY

A. RF/CF technology introduction of Raytheon

As the expert in RF field, Raytheon has made a perfect combination of his RF and CF which is from Hyde Park, the other expert in CF field. By this in-situ technology, oil shale is heated by CF, and critical CO_2 drives the liquid and gas out (as shown in Fig. 8).

Process: RF/CF is a patent technology that combined radio frequency heating and critical liquid driving [13]. The oil industry equipment drills and sends radio frequency antenna or transmitter to the oil shale. The ray energy from antenna or transmitter heats the oil shale, and critical CO_2 drives the oil to well, then the oil is pumped to ground to condensate and storage. The CO_2 is separated and pumped to well to use again.

Characteristics: ① High oil recovery rate. By using RF/CF technology, 4～5 units' power is produced by consuming 1 unit power. It has higher economic benefits than ICP technology, which produces 3.5 units power by consuming 1 unit power; ② The oil industry equipment is used to drill oil well in oil shale. RF antenna or transmitter is sent down to the underground and emits ray to heat the oil shale; ③ Crude oil is extracted and driven to well by injecting critical CO_2; ④ Selective heating mode. It will heat the specified field quickly to the aim temperature.

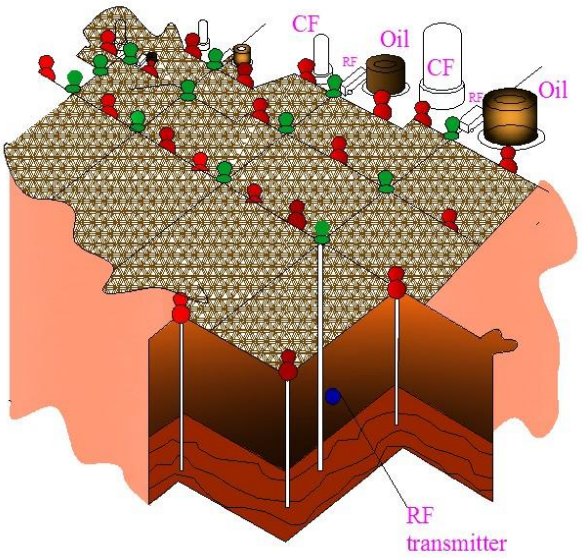

Fig. 8. RF/CF technology introduction of Raytheon

B. RF technology introduction of LLNL

The RF heating technology has been researched by America Illinois Institute of Technology in the late of 1970s. Vertical combination electrode was used to heat the shale slowly. It needs lots of time to diffuse the heat by conduction. To avoid this defect, LLNL used radio frequency to heat the shale. The RF has a strong penetrating power and can be controlled easily (as shown in Fig.9).

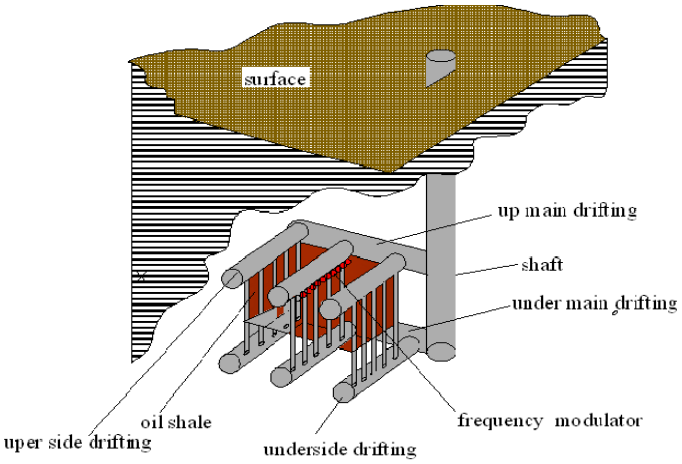

Fig. 9. RF technology introduction of LLNL

V. CONCLUSIONS

In a word, because the speed is slower and it takes more time, the system of conduction heating is easy to loss great heat, which consumes much energy and takes a lot of money. What's more, the technology is complex, low recovery and has much fault that is difficult to eliminate, which decrease further the application prospect. In contrast, the speed of convection heating is faster, but most of fluids will outflow from formation before they do not exchange heat with oil shale, resulting in improving cost and being hard to control. Although the penetrating power of radiation heating whose heating speed is fast and that takes little time is high, its cost is high and it has big technical difficulty.

Field test has confirmed that the technology of in-situ electric heating is fine and has good prospect .But the technology in china is basically placed in the blank appearance. According to the characteristics oil soil is deep burial and low grade, China should greatly study and develop the technology of in-situ electric heating, which provides technical reserve for national large-scale exploitation in the future.

After the organic matter among oil soil is heated to the given temperature, it will be cracked. Besides, the whole formation will change many parameters, for example rock structure, construction, stress distribution,material composition and so on. So the technologies which are well spacing, temperature control, transporting shale oil gas with high temperature, electronic information controlling, insulation and so on are the main developing direction on the father in-situ retorting.

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