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A feasibility study on in-situ heating of oil shale with injection fluid in China

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ABSTRACT

The reserves of oil shale are over 5 times as many as the current natural proven recoverable oil reserves in the world. It has huge potential but it is hard to obtain economic efficiency because of its low oil length and exploration difficulty. This research combines theory and experiment, evaluates the exploitation of in-situ heating of oil shale with injection fluid, which have the characteristics of high oil length, large productivity and short production cycle. For the oil shale layer with high oil length (> 18%), the oil price shall at least reach 105 $/bbl (18% oil length) to maintain 10% of the internal rate of return; for the oil shale with low oil length (3.5–18%), the oil price shall at least reach 377 $/bbl (5% oil length) to maintain 10% of the internal rate of return. At present, only the oil shale with high oil length (> 18%) can be exploited for in-situ heating of oil shale with injection fluid in China.

1. Introduction

Oil shale is a kind of sedimentary rock containing solid combustible organic material, which is generally known as oil or Kerogen, presenting taupe brown or black. The natural oil shale is extremely low with permeability and low porosity under natural conditions. Kerogen is stored and integrated with oil shale in solid form. The internal bedding of oil shale is fully in closed state underground. In all fossil fuel, if reserves are converted to calorific value, oil shale is in the second place, after coal; the reserves of oil shale are fairly large worldwide, and if converted to oil shale, it may reach more than 40 billion ton, which is over 5 times as many as the current natural proven recoverable oil reserves in the world. It is a great potential energy source and an internationally recognized alternative of traditional oil resources (Zhaojun et al., 2006; LiShuyuan and Qian, 2012). China is rich in oil shale resources and the new evaluation data of China oil shale resources from 2003 to 2006 indicate that the oil shale is broad in China and spread over 47 basins of 20 provinces (cities and districts). The gross reserves are nearly 47.6 billion ton, which is 1.5 times the reserves of conventional petroleum resource, ranking No. 4 in the world (Taiyuan University of Technology, 2006). The oil length of China oil shale (Gang-Fu et al., 2006; Yu-Hong et al., 2009; Yun-lai et al., 2009; Li, 2012) is above average. The oil shale with 5–10% oil length and more than 10% oil length account for 37% and 18% of the country's oil shale resources, respectively, mainly focusing on 3.5–18%.

The conventional exploration method of oil shale (Dexun et al., 2009) includes opencast mining and underworkings mining. Opencast mining involves digging in the open and mining oil shale ores directly, which occupies a large amount of land and causes severe pollution in the surroundings at the same time; underworkings mining involves making underworkings and mine oil shale ores by rock drill. The produced oil shale ores are piled on the ground, which also occupies a large amount of land. Both exploration methods need to reduce the groundwater level to the position below the oil shale layer, so that they do not damage the nearby farmland and forest.

The process technology of in-situ conversion by underground heat conduction (Zhiqin, 2006) is to drill the heating well in oil shale layers and heat them. Heavy oil and gas are released from Kerogen. Through enrichment formation, elimination, change of phase state and other changes of the lighter component of tight carbon fraction, more hydrogen-rich compound is converted from liquid to gas. The light hydrocarbon under the ground flows to the nearby production well by natural or artificial fracture. The extraction efficiency of original carbon under the ground can reach 65–70% by this technology. According to different heating sources, it may be divided into ICP technology (electric heating) and IVE technology (gas heating in hot weather). The IVE technology may water a great quantity of precious natural gas resources and it requires constructing gas pipeline with high costs; if the hot steam is injected, the injection device is huge, with high daily cost, large floor space and poor economic performance. Furthermore, the main thermal degradation temperature of oil shale is from

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350 °C to 850 °C, and it is really difficult to heat the ground to that temperature. The heat loss for downhole injection is large and the economic benefit is poor. However ICP technology (Rangel-German et al., 2004) has a simple heating method, convenient construction, high heat efficiency and small floor area. The heater temperature may reach above 1000 °C and the heating temperature can be controlled, which is an advantageous mining method.

The research of this paper is based on the following ideas: first of all, simulate the temperature distribution of in-situ heating of reservoirs. Obtain the weight loss ratio of reservoirs at different temperatures by experiment and derive the formula of weight loss ratio at different temperatures. According to the fitting formula of weight loss ratio, calculate the productivity of oil shale produce by reservoirs at different temperatures, the production value of oil shale, the electric energy required by heating reservoirs and the requested electric charge. The production value of oil shale shall minus the electric charge, fees of well drilling and other costs. Evaluate the economic value of in-situ heating of oil shale by the internal rate of return and net present value method.

2. Physical model

The object of study is 20 width × 20 height oil shale layer of 216 mm wellbore diameter. Considering the layer symmetry, 2D is studied, as shown in Fig. 1. $r=0$ is hole center, and the semi-diameter of the wellbore is 108 mm. The top and bottom of oil shale are other layers. The shaft lining is the injection side for the injection fluid. The well strings are used to control fluid injection only to enter the injection part with an arrow mark. At the same time, the heating device is installed in that location, which increases the fluid temperature of the well to 1123.15 K and remains at the same temperature by adjusting the power and voltage.

The well depth of this oil shale layer is 500 m from the top, the temperature is 308.15 K and the geothermal gradient is 3°/100 m. The initial temperature distribution of this oil shale layer is

$$T_o = -0.03z + 308.75 \quad (1)$$

where z is the thickness of oil shale, whose value ranges from 0 m to 20 m, belonging to the normal pressure system. The initial pressure distribution is

$$P_0 = 9800(500+z) \quad (2)$$

Due to the uneven temperature upon heating, the fluid density in porous media is changed. Hence, buoyancy flow would be taken into account in this study. The computational formula of buoyancy flow is

$$F = 1000 \times 9.8\beta(T - T_o) \quad (3)$$

where β is the thermal expansion coefficient of fluid, $1/K$ is 0.04342; T_0 is the initial temperature of layer, K; T is the temperature of oil shale layer; and K is the transient value of temperature upon heating.

3. Numerical model (Table 1)

Brinkman equation and heat transfer equation by porous media are used to simulate heat transfer and fluid flow. Speed coupling is achieved by fluid flow (Anwar Hossain and Wilson, 2002).

Fluid flow:

$$\begin{cases} \frac{\mu}{K}u + \nabla P - \nabla \cdot \frac{\mu}{\varepsilon}(\nabla u + (\nabla u)^T) = \rho g \beta (T - T_c) \\ \nabla \cdot u = 0 \end{cases} . \quad (4)$$

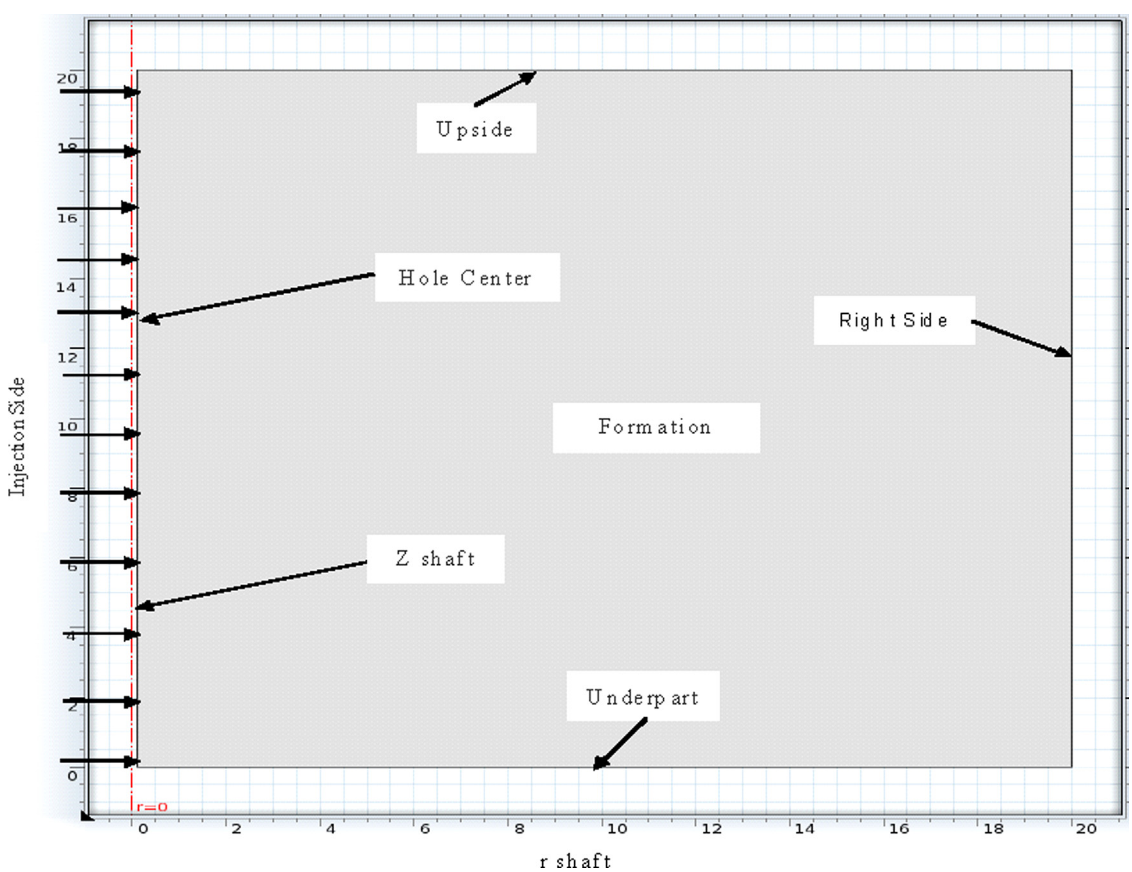

Fig. 1. Physical model diagram.

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