PETROLEUM EXPLORATION AND DEVELOPMENT
Volume 39, Issue 6, December 2012
Online English edition of the Chinese language journal

Cite this article as: PETROL. EXPLOR. DEVELOP., 2012, 39(6): 764–772.

RESEARCH PAPER

Propagation and control of fire front in the combustion assisted gravity drainage using horizontal wells

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Abstract: The propagating characteristics of combustion fronts and coke zones in the combustion assisted gravity drainage process were studied using 3D physical simulation experiments. The main mechanisms and factors affecting stable propagation of the combustion fronts were discussed. The experimental results show that the propagation of combustion front can be divided into startup stage, radial expands stage and moving forward stage. The top oil layer is ignited first at the startup stage. Ignition temperature, ignition time and air injection rate are the key parameters for successful ignition. At the radial expanding stage the combustion front grows in size and expands radically and downwards like a funnel, and the air injection rate should match the area of combustion front. After the combustion front propagates beyond the "toe" position, the burning zone would advance along the horizontal well at a certain angle. The controlled gas override and gas seal of the coke in the horizontal well contributes significantly to the overall stability of the process. In field pilot testing, well pattern, ignition parameters and regime of injection and production should be optimized to ensure the stable propagation of the combustion front.

Key words: combustion assisted gravity drainage; horizontal well; combustion front; propagating characteristic; physical simulation

Introduction

The combustion assisted gravity drainage using horizontal wells is a new technology for heavy oil development [1–2], which combines the horizontal well and in-situ combustion technique. Breaking the upper limit of crude oil viscosity and expanding the application [3–6] scope of fire flooding, it is expected to play an important role in the development of heavy oil and ultra heavy oil in thick layers.

At present, the relevant reports about it are rare in China for study on this technique has been started late. Scholars abroad have mainly focused on study on the mechanism of the drainage, oil recovery, oil upgrading, and well pattern, etc. [5–11]. While there is little study on the three-dimensional propagation characteristics of combustion front in oil drainage process, key control parameters and methods, especially no study reports about the potential risks[12] and how to prevent these risks, which will limit the application and promotion of the technique in oil development.

In view of the above situation, the author studied the propagation characteristics of temperature field and coke zone in combustion assisted gravity drainage process by using 3-D physical simulation experiments, analyzed the key controlling parameters and stably propagating mechanism of combustion front in different stages. The results have instructive significance for keeping the stability of drainage process and avoiding channelling of injected air into the toe of horizontal wells.

1 Experiment apparatus and experiment procedures

1.1 Experiment apparatus

3-D fire-flooding physical simulation experiment apparatus consists of injection system, producing system, measuring & controlling system, and physical model (Fig. 1). Injection system is made up of an injection pump, a piston vessel, an air compressor, a gas flowmeter, and gas bottles. Measuring & controlling system, including hardware and software, is used to collect and process temperature, pressure and flow rate data. Producing system can separate and measure the liquid and gas produced from the model. The 3-D sand-packed model is installed with insulating materials and heating device outside, and uniformly placed 4-layer thermocouples inside. The temperature fields of different oil profiles can be obtained by

Received date: 27 Mar. 2012; **Revised date:** 25 Aug. 2012.
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Foundation item: Supported by the National Major Science and Technology Project "Research and Application of In-Situ Combustion Technology" (2011ZX05012-002)

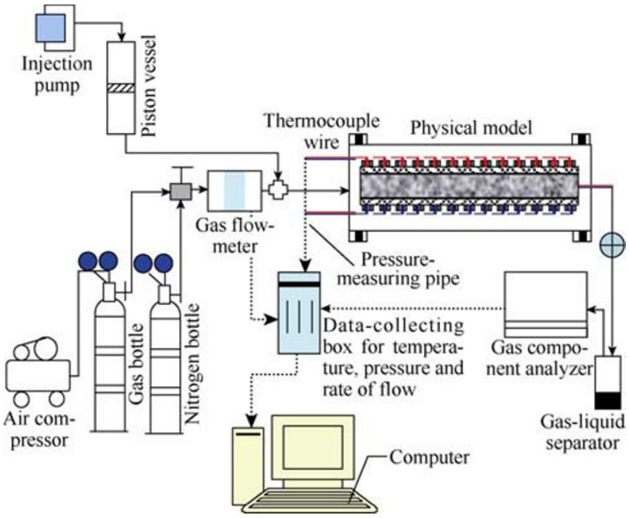

Fig. 1 3-D physical simulation system for in-situ combustion

the inversion software. The propagating process of combustion front can be judged from the temperature fields at different time.

Two physical models of different sizes are designed for the experiment. The well patterns are shown in Fig. 2. The inner size of model I is 400 mm×400 mm×150 mm. A vertical air injection well (with igniter) is set in the middle of the sidewall, and a horizontal well is set at the bottom of the model. The distance between the toe of the horizontal well and the air injection well is 50 mm. The inner size of model II is 600 mm×400 mm×150 mm, and model II is 1.5 times of model I in volume. The air injection well in model II is set in the middle, 100 mm from the sidewall, and the horizontal well is also set at the bottom of the model. The distance between the toe of the horizontal well and the air injection well in model II is also 50 mm.

In the previous experiments, the air injection well was perforated at the entire oil layer, which easily led to combustion front breaking through the horizontal well and destroying the well [13]. Hence, the air injection well was only perforated at the upper 1/2 of the oil layer in this series of experiments.

1.2 Experiment procedures

The 3-D fire-flooding experiment includes the following procedures: (1) Experiment preparation. According to the geologic conditions of target reservoir, the porosity, permeability and saturation of 3-D model were designed, and based on this, fluids and core preparation, fluids physical property test, transducer calibration and igniter test were done. (2) Model packing. This process mainly includes model well/igniter installation, transducer installation, pressure test, core packing, saturating the core with water and oil. The oil used in the experiments is 12 090 mPa·s at 50 °C in viscosity, which is super heavy in actual reservoir temperature of 18 °C. The packed model is homogeneous, with the porosity of 39% and the oil saturation of 84%. (3) Fire-flooding experiment. Turned on the igniter to preheat the oil layer, at the same time nitrogen was injected in stead of air to prevent low temperature oxidation. When the temperature around the igniter well reached a specific value (350 °C in general), the injected gas was turned to air to ignite the layer. The whole fire-flooding process includes ignition with slow injection of gas, increasing injection rate, stable fire-flooding and stopping injection. The injection pressure was maintained at 0.6 to 0.8 MPa, and the air injection rate was controlled at 5 to 20 L/min.

2 Physical simulation experiments of three-dimensional fire flooding

2.1 Experiments using model I

The propagation characteristics of combustion front at the

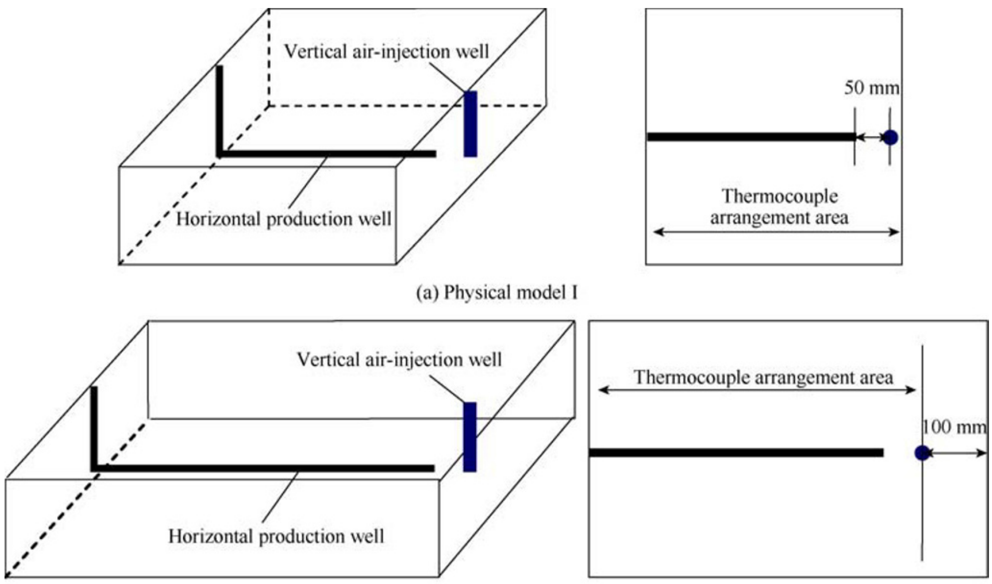

Fig. 2 Distribution of wells in 3-D fire-flooding model and corresponding well pattern