The Influence of Interlayer on the Expansion of Steam Chamber of Oil Sand SAGD Development

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Abstract. The steam-assisted gravity drainage (SAGD) technology is currently a more effective frontier technology for the exploitation of heavy oil, and it has a better development effect than other exploitation methods. The formation and expansion of the steam chamber is the key to SAGD technology, and the interlayer is an important influencing factor. Therefore, it is of great significance to study the influence of the interlayer on the expansion of the steam chamber and the effect of SAGD development during the oil sand SAGD development process. In order to study the influence of the interlayer on the expansion of the steam chamber during the oil sand SAGD development process, a double-horizontal well SAGD physical experiment simulation experiment was carried out using the experimental device of the thermal recovery physical simulation system. The influence of interlayer on the expansion law of the steam chamber during the SAGD development of dual horizontal wells is studied. Studies have shown that the interlayer inhibits the longitudinal development of the steam chamber, and the steam chamber is forced to expand laterally along the interlayer to form a steam chamber similar to an inverted triangle. The steam chamber is fully developed in the area below the interlayer, but the steam chamber cannot break through the interlayer.

1. Introduction
Double-horizontal well SAGD refers to the use of parallel well layout, and the gas injection well is above the production well. The steam injected from the upper horizontal well heats the crude oil in the upper oil layer through the latent heat of vaporization, forming a steam cavity in the middle of the oil reservoir. Since the steam injection well is directly above the oil production well, the steam cavity covers the oil layer above the oil production well and follows the continuous steam the injection expands outwards and exchanges heat with the heavy oil and ultra-heavy oil in the reservoir. At the same time, the viscosity of the heated crude oil decreases, so that the viscosity of the solid bitumen oil is reduced at high temperature to become flowable crude oil. Driven by gravity, the heated flowable crude oil, along with formation water and steam condensate, migrates downwards into the bottom horizontal production well and is produced [1]. The mechanism of mudstone interlayer on SAGD development is that the interlayer only hinders the upper crude oil, and it only hinders the exchange of materials and does not hinder the transfer of heat [2, 3]. The physical interlayer hinders the upward development of the SAGD steam chamber and forces the steam chamber to expand laterally along the interlayer [4].
This research aims at the expansion of the steam chamber during the development of SAGD, and studies the influence of the interlayer on the expansion of the steam chamber.

2. Physical Simulation

2.1. experiment apparatus
The three-dimensional thermal model is shown in Figure 1. The material of the model is 316 stainless steel, the internal size of the model is 50 × 40 × 15 cm, the pressure resistance limit of the model is 10 MPa, and the temperature resistance is 300 °C. The inside of the model is sealed by a sealing ring and a graphite sealing tape. There are heat insulation boards around the model to simulate the heat loss of the formation. The entire model is placed in a temperate box to supplement heat loss. The display on the temperate box can display the real-time temperature and pressure inside the model. The temperature profile inside the model is detected by temperature sensors. There are 297 temperature sensors in the model, which are evenly distributed inside the model, and the distance between each sensor is 5 cm. The number of horizontal wells is 2, and the distance from the bottom row of horizontal wells to the bottom of the model is 4 cm. An electric heating device is installed in the steam injection well and the pipeline along the route. During the experiment, the heating temperature of the device is consistent with the temperature of the steam generator, so that the steam enters the oil reservoir and still maintains a steam state.

2.2. Experimental program
According to the actual permeability and thickness of the interlayer, two experimental models are designed. As shown in Figure 2, it includes a homogeneous experimental model without interlayers and a heterogeneous physical experimental model with interlayers located at the upper 1/3 of the model and with a permeability of 20 mD and a thickness of 2 cm.
2.3. Experimental procedure
Before the implementation of the SAGD physical simulation experiment, preparations such as sand packing, saturated model with formation water, saturated oil, and aging for 12 hours. The complete SAGD physical simulation experiment process is divided into 2 stages.

The first stage is the preheating stage of the steam cycle. Both the steam injection well and the production well are slotted Φ6 pipelines, and the outer sides are respectively wound with unslit Φ3 pipelines. Steam is injected from the inlet end and flows through the spiral pipeline to heat the formation near the well. Flows out from the outlet end; because the preheating pipeline is not perforated, there is no fluid exchange between the wellbore and the formation, and heat is transferred by heat conduction. The preheating is stopped until the midpoint of the two wells reaches 70-80 °C, and the first stage finished.

The second stage is the production stage of SAGD with dual horizontal wells. The circulation preheating pipeline is closed, steam is injected from the upper steam injection well, and the heated crude oil and condensed water flow into the production well under the action of gravity. Throughout the experiment, the production well is directly connected to the atmosphere, the temperature of the injected steam is maintained at 200-220 °C, and the steam injection rate is constantly adjusted to keep the temperature difference between the production well and the steam injection well at 5-40 °C; Collect the produced liquid at each moment for oil-water separation, the temperature was recorded of different points inside the model at different times, then temperature contour map via postprocess software SURFER was drawn.

3. Result and discussion
For the model without interlayer, the steam chamber was shown in Figure 3. After steam is injected, the area around the injection well was heated. The viscosity of the crude oil will drop significantly and flow into the production well under gravity. The subsequent steam will occupy the original heavy oil space, making the steam chamber gradually expand.
Figure 3. Temperature distribution and steam chamber growth at different time for no interlayer model

It can be seen from the Figure 3 that the steam chamber rapidly expanded upward in the first 100 minutes; the upward expansion rate of the steam chamber in 400 minutes gradually decreased. Continuing to simulate development for 1200 minutes, the steam chamber no longer develops upwards, but slightly expands laterally. At the end of the experiment, the steam chamber was concentrated in the middle of the model, which was elongated, and most of the top and sides of the model were not swept. During the SAGD development process, due to the steam gravity overriding, the steam chamber is mainly developed vertically, but the heat dissipation is severe during the steam floating process, and the steam cavity cannot grow up indefinitely, and it is difficult to break upward after expanding to a certain height.

The expansion of the steam chamber when there is an interlayer is shown in Figure 4. Due to the steam overlay, the steam chamber initially develops faster, while the lateral expansion is slower. Before the steam chamber reaches the top of the model, the steam chamber overlaps as a whole. At 200 min, the steam chamber expands to 2/3 of the height of the model (interlayer). Due to the ultra-low leakage rate of the interlayer, the steam chamber first expands laterally. Finally, after 1600 minutes of steam injection, due to the obstruction of the ultra-low permeability interlayer, the steam could not break through the interlayer, and only the universe broke through the interlayer.
Figure 4. Steam chamber growth and temperature distribution for model with interlayer

Figure 5. Oil production rate curve
The Figure 5 compares the oil production rate and the recovery factor over time under different interlayer conditions. As can be seen from the figure, at the beginning of SAGD production, the initial oil production rate is very high due to the preheating of the crude oil between the injection and production wells to the vicinity of the production well, and the oil production rate continues to decrease as time increases. In addition, the oil production rate and recovery factor in the experiment with interlayer are far less than those without interlayer. By comparing the recovery factor of model with and without interlayer, it is found that the presence of interlayer obviously affects gravity drainage, and the degree of recovery with interlayer is much smaller than that without interlayer, the recovery factor of the non-interlayer model and the interlayer model were 41.94% and 35.78%, respectively.

4. Conclusion
In the SAGD process, when there is no interlayer, the steam chamber mainly develops vertically, and the horizontal expansion is small. The steam chamber is elongated, and the recovery rate of the steam chamber increases rapidly in the vertical development stage.

When an interlayer exists, the steam chamber first develops longitudinally. When the steam reaches the interlayer, the low permeability interlayer will hinder the longitudinal expansion of steam. The steam is difficult to continue upward and starts to expand horizontally. Due to the barrier of the ultra-low permeability interlayer, the steam chamber cannot penetrate the interlayer. But the heat passes through the interlayer.

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