Evaluation Method of Test Productivity and Reasonable Allocation for Long Horizontal Wells in Deep-Water Faulted Sandstone Oilfield in West Africa

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Abstract. For deep-water faulted oilfields, long horizontal wells are arranged crossing the fault to improve the single-well controlled OOIP and productivity. At the stage of development plan implementation, in order to verify the well productivity, productivity tests were carried out for all drilled wells. In view of the loose reservoir, high productivity, multiple test chokes and short test time, we chose EGINA oilfield which is a deep-water faulted sandstone reservoir in West Africa, as the research target. Considering the sealing of faults and the superimposed relationship of sand bodies, four injection-production connection modes were established. A test productivity evaluation method with multi-level chokes was formed for long horizontal wells in deep-water faulted sandstone reservoirs. In addition, reasonable allocation for long horizontal wells was proposed for four connection modes. According to the practice in EGINA Oilfield, the evaluation method of test productivity and reasonable allocation for the long horizontal wells are reasonable and reliable, and can serve as a guide for similar long horizontal wells in deep-water faulted sandstone oilfields.

Keywords: Deep-water oilfield · Faulted oilfields · Turbidite sandstone · Horizontal well · Productivity test · Productivity evaluation

1 Introduction

Since the 1990s, a lot of oil & gas fields of deep-water turbidite reservoirs have been discovered. They are mainly distributed in the Campos Basin in South America, Gulf of Mexico Basin in North America, the South China Sea, and the Niger Delta in West Africa. The deep-water turbidite reservoirs have become a hot point in oil & gas exploration and development [1]. The Lower Congo Basin and the Niger Delta Basin are the focus areas for the exploration and development of deep-water turbidite reservoirs, and have been deeply studied by scholars at home and abroad. The research field covers the deposition mechanism [2, 3], deposition model [3, 4], and deposition

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characteristics and evolution rule [1], channel distribution and configuration characteristics [5–7], connectivity mode and connectivity [8, 9], waterflooding pattern and water injection scheme optimization [10] and so on.

The cost of drilling and completion for a single well in deep-water oilfields is nearly 100 million US dollars, and we usually apply the development strategy of "less wells and high production rate". For deep-water faulted oilfields, in order to improve single well controlled OOIP and productivity, the well pattern of long horizontal wells crossing fault is adopted. At the stage of development plan implementation, in order to ensure the oil wells' productivity, all the oil wells productivity is tested after drilled, so that we can take subsequent measures when the test productivity is much lower than forecasted. Due to the high productivity and loose reservoirs, in order to prevent sand production during test process, multiple test chokes are adopted. At the same time, considering the test cost, crude oil storage and other factors, the productivity test time is usually very short, so it is difficult to accurately evaluate the productivity. Therefore, it is very necessary to establish an accurate productivity evaluation method with multiple test chokes of long horizontal wells crossing faults. At present, the research results of the test productivity evaluation for oil wells are mainly concentrated in the in,

In the shallow water oilfields, a lot of researchers pay much attention to time correction coefficient [11–13] and interlayer interference coefficient [14] of test productivity evaluation. However, in deep-water faulted sandstone reservoirs, a few of researchers studied the productivity test process and on-site operations [15] in aspect of test productivity evaluation. There are few studies on the productivity evaluation method with multiple test chokes and reasonable allocation for long horizontal wells.

In view of the loose reservoir, high productivity, multiple test chokes and short test time, we chose EGINA oilfield which is a deep-water faulted sandstone reservoir in West Africa, as the research target. Considering the sealing of faults and the superimposed relationship of sand bodies, four injection-production connection modes were established. A test productivity evaluation method with multi-level chokes was formed for long horizontal wells in deep-water faulted sandstone reservoirs. In addition, reasonable allocation for long horizontal wells was proposed for four connection modes. According to the practice in EGINA Oilfield, the evaluation method of test productivity and reasonable allocation for the long horizontal wells are reasonable and reliable.

2 EGINA Basic Information

EGINA oilfield is located in the deep-water contract area of OML130 in West Africa, which is about 160km away from Port Harcourt port in the north (see Fig. 1), and the water depth ranges from 1150 to 1750 m [16, 17].

The EGINA oilfield is an anticline heavily complicated by faults. The sedimentary facies of the reservoir is deep-water turbidite fan, and the lithology of the reservoir is fine-coarse sandstone. Its main ingredients are quartz and feldspar. Agbada formation is the targeted reservoir which include many kinds of gravity flow deposits, such as massive slump, gravity flow channel, overflow bank deposit, sedimentary lobe, channel and lobe complex and channel lags. The deep-water gravity channel and lobe forms the main reservoir. Because the reservoir is not deeply buried, so it loosely cements and weakly compacts. As a result, it has medium-high porosity and high permeability. The oil quality is good. It has medium density and low viscosity.

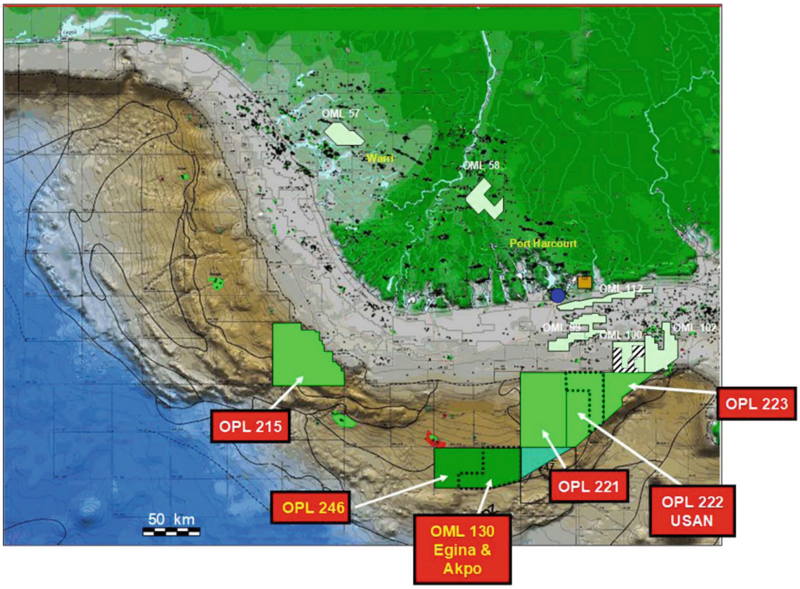


Fig. 1. EGINA field location [17].

3 Injection-Production Connection Mode

The faults developed densely, and multi-phase channels deposited staggered in the EGINA oilfield. Therefore, the connection modes and connectivity between injection and production wells are complex and diverse. The conventional connection mode affected by a single dominant factor of a fault or reservoir is no longer applicable in this oilfield.

Aiming at this problem, considering the sealing of faults and the superimposed relationship of sand bodies, four injection-production connection modes have been established, including: overlapped sand bodies connection, sand bodies connection across unshielded faults, sand bodies connection across shielded faults and sand bodies connection across sealing faults, as shown in Fig. 2. The qualitative evaluation of those connectivity are very strong, strong, medium and poor, which provides a basis for allocation and injection of development wells.

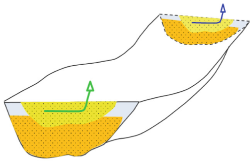
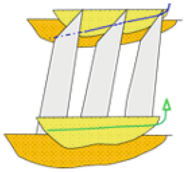
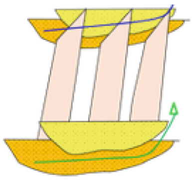
Connection mode	Mode diagram	Connectivity
overlapped sand bodies connection		very strong
sand bodies connection across un-shielded faults		strong
sand bodies connection across shielded faults		medium
sand bodies connection across sealing faults		poor

Fig. 2. Four injection-production connection modes in EGINA oilfield

4 Evaluation Method of Test Productivity for Long Horizontal Wells

In order to obtain the oil well productivity and flowback drilling fluid, all the oil wells were tested for productivity. However, the sandstone reservoir is unconsolidated, so the choke size or drawdown pressure is increased step by step during testing, which can serve the purpose of preventing sand production [15]. As a result, all the oil wells productivity test are carried out with multi-level test chokes, besides the test time is short due to high-test cost. It is difficult to determine the productivity using the conventional methods.

4.1 Test Productivity Evaluation Procedure

To evaluate the well test productivity reasonably, we proposed test productivity evaluation procedure:

(1) Interpretation of pressure build-up well test for long horizontal wells with multi-level chokes in faulted reservoirs, we can obtain reservoir physical parameters, reservoir and fault distribution characteristic parameters. That is to say, the reservoir and boundary parameters are acquired according to the oil well pressure build-up interpretation.
(2) Combined with reservoir physical parameters and fault block boundary characteristics, productivity models of long horizontal wells in faulted reservoirs are established.
(3) Determine the pseudo-steady state time of long horizontal well with multi-level chokes. When evaluating test productivity, it is first necessary to clarify whether the tested chokes at all levels are at pseudo-steady state, to select a suitable productivity evaluation method. For complex faulted reservoirs, based on the productivity mathematical model, the productivity test can be simulated to calculate the time reaching pseudo-steady state.
(4) Choose an appropriate method to evaluate the test productivity. If there is a test choke that reaches the pseudo-steady state, the test productivity is evaluated by the conventional method. If none of the test chokes has reached the pseudo-steady state, firstly use the test data of the last choke to calculate the productivity index, and then use the Horner simulation method [18] to calculate the equivalent test time of the last choke. If the equivalent test time is longer than the time to reach the pseudo-steady state, the productivity index obtained from the last choke is the well productivity; otherwise, the productivity index at pseudo-steady state is obtained by the correction of productivity model.

4.2 Applications Example

The oil well P-4 in EGINA oilfield is chose to test productivity evaluation. P-4 location is shown in Fig. 3. P-4 was conducted productivity test by 10-level chokes, and the total test time is 27.4 h. Its productivity test curve as shown in Fig. 4. The procedure of test productivity evaluation (Sect. 4.1) is used to evaluate test productivity of P-4.

Firstly, pressure build-up test of P-4 is interpreted and acquired reservoir physical parameters, reservoir and fault distribution characteristic parameters. Then, productivity model of P-4 is established according to the reservoir physical parameters and fault parameters. Thirdly, the time reaching pseudo-steady state is 51 days which is calculated by the model. So none of the test chokes has reached the pseudo-steady state. At last, the equivalent test time is calculated by Horner simulation method, it is 9.7 h. Therefore, the productivity index at last choke is corrected by the productivity model, and the productivity index at pseudo-steady state is 1503 m^3/d/MPa.

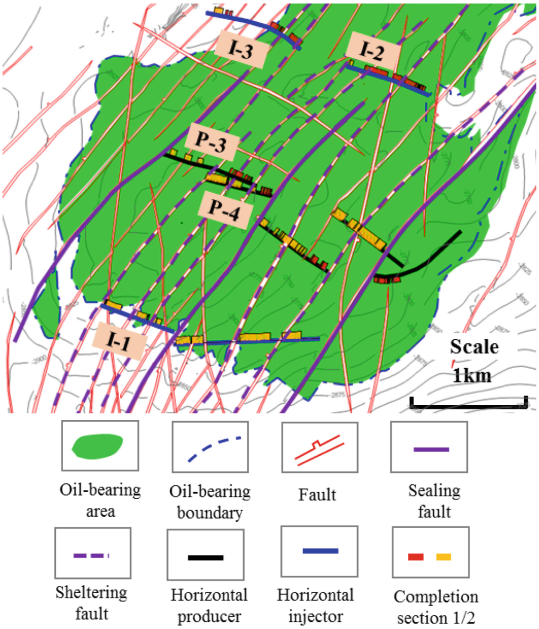


Fig. 3. Well location of P-4

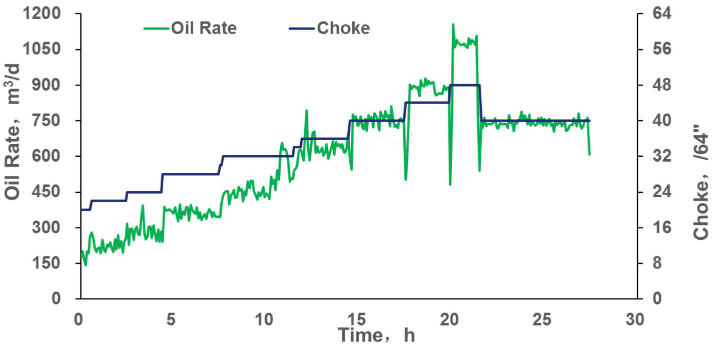


Fig. 4. P-4 productivity test curve.

5 Reasonable Allocation Method for Long Horizontal Wells

In order to achieve balanced and efficient development and avoid premature flooding for each fault block, the oil reservoir numerical model is used to measure the recovery factor under different oil recovery rates considering the connection mode between injection and production wells in Sect. 3. The reasonable oil production rate of the each fault block is determined, which guide the reasonable production allocation for the oil wells. The reasonable oil recovery rates of four connection modes are shown in Table 1.

Table 1. The reasonable oil recovery rates of four connection modes

Connection mode	Recovery rate, %
overlapped sand bodies connection	11–14
sand bodies connection across unshielded faults	8–10
sand bodies connection across shielded faults	7–8
sand bodies connection across sealing faults	5–6

The production allocation results is applied in EGINA oilfield, which guided it to rapidly rise to the peak production capacity of 200,000 barrels in five months. Up to now, there is no water breakthrough for all the fault blocks.

6 Conclusion

(1) Considering the sealing of faults and the superimposed relationship of sand bodies, four injection-production connection modes were established, including overlapped sand bodies connection, sand bodies connection across unshielded faults, sand bodies connection across shielded faults and sand bodies connection across sealing faults in EGINA oilfield.
(2) In view of the loose reservoir, high productivity, multiple test chokes and short test time, a test productivity evaluation method with multi-level chokes was formed and reasonable allocation was proposed for long horizontal wells based on four connection modes. According to the practice in EGINA Oilfield, the evaluation method of test productivity and reasonable allocation are reasonable and reliable.

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