Innovation and Application of Numerical Simulation Technology for Bohai Heavy Oil Thermal Recovery

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The purpose and significance of Bohai heavy oil thermal recovery

Thermal numerical simulation technology innovation

The application effect
First, the great potential of Bohai heavy oil thermal recovery

- **Bohai special heavy oil reserves development situation**
  - 738 million tons for future production
  - 92.31 million tons for cold production
  - 9.06 million tons for thermal recovery

- **Bohai oilfield**
  - Rich in heavy oil reserves
  - Proved reserves: 560 million tons
  - 3P geological reserves of crude oil viscosity greater than 350 cp: 840 million tons

- **Thermal recovery production**
  - Accounts for 15% to 55% of total production
  - Large potential for thermal recovery

- **Development experience**
  - NB 35-2 Multi-thermal Fluids cyclic stimulation
  - LD 27-2 cyclic steam stimulation

- **Heavy oil reserves**
  - **NB** 35-2: 14.93 million tons
  - **LD** 27-2: 15.01 million tons
  - **Liaohai-1**: 9.81 million tons
  - **Liaohai-2-C**: 1.96 million tons
  - **Liaohai-2-A**: 5.14 million tons
  - **Liaohai-2-B**: 3.09 million tons

- **Heavy oil production**
  - Bohai Oilfield: 0.4% (2018)
  - Shengli Oilfield: 15% (2018)
  - Liaohai Oilfield: 55% (2018)
  - Liaohai Oilfield: 7% (2018)

- **Special heavy oil cold production**
  - Poor development experience
  - Necessary to adopt thermal recovery

- **Current production**
  - Bohai Oilfield: 8.26 Mt
  - Shengli Oilfield: 2.04 Mt
  - Liaohai Oilfield: 1.95 Mt

- **Future production**
  - 4.65 Mt for Bohai oilfield
  - 4.71 Mt for Shengli oilfield
  - 1.25 Mt for Liaohai oilfield
Second, numerical simulation technology is essential for heavy oil thermal recovery.

**Offshore heavy oil thermal recovery characteristics**

- Large well spacing
- Special development method
- Heat injection equipment limit

The thermal recovery well spacing are 3 to 4 times of onshore oil fields.

**Thermal development**

- Pressure field
- Temperature field
- Viscosity field
- Saturation field
- Thermal property field

On the mechanism of Thermal recovery, thermal development needs to consider temperature field, viscosity field, thermal property field, etc. Conventional water injection development can be combined with reservoir engineering method and numerical simulation method. Due to multi-field coupling, numerical simulation has become an important predicting method in thermal recovery.

- First implement the Multi-thermal Fluids cyclic stimulation development test
- At present, the equipment can only provide heat for 1~2 wells at the same time.
The forecasting capacity of heavy oil thermal development has been greatly improved, and five oilfields thermal recovery plan have been reviewed.

- Steam stimulation
- Local thermal recovery
- Single reservoir type
- Multi-thermal fluid
- Overall thermal recovery
- Multiple reservoir types

- The application of numerical simulation technology for different thermal recovery methods and scales in different reservoir types has been realized.
Four problems

(1) The biggest difference between thermal recovery simulation and conventional water flooding simulation is the description of “heat”. How much influence does each thermal property parameter have on development forecast? Is there any change in the characteristics of thermal recovery of heavy oil offshore?

(2) How to choose the development method of offshore heavy oil thermal recovery?

(3) How to improve the precision of the prediction results for thermal recovery forecast?

Porous media flow characteristics? How to choose the thermal method?
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The application effect
First, the rock compressibility coefficient temperature sensitivity

Problem 1: the difference in the development effect of hot and cold production under large well spacing is small.

- The thermal production well spacing in the onshore oilfield is small, and the developing radius is in the hot zone;
- The offshore thermal production well spacing is large, and the developing radius is divided into hot zone and cold zone;
- Experiments show that the higher the temperature, the larger the pore compressibility;
- With a constant compressibility factor, the difference in recovery between thermal recovery and depletion is small.

![Graph showing compressibility coefficient vs. temperature](image)

Experimental results of temperature effect on compressibility coefficient.
The experiment shows that the compressibility coefficient is also affected by many factors such as the number of cycles of steam stimulation, porosity, temperature and pressure. A dynamic compressibility coefficient technique considering reservoir physical properties is proposed firstly. 

With the increase of temperature and porosity, rock compressibility coefficient increases. Rock compressibility coefficient decreases with the increase of huff and puff rounds.
Second, special / super heavy oil start-up pressure equivalent simulation

Problem 2: the actual cold production of the super heavy oil field has no production, but the oil can be produced in numerical simulation.

In the model, the initial production of cold production is 37 m³/d.

Test overview:
In February 1993, the LD-1 well was tested and no production was obtained.
In October 2008, the LD-2 well was tested and no production was obtained.
From October to November 2013, LD-3 well test, also no production.

This is mainly due to the fact that the start-up pressure at different temperatures is not taken into account in the model.
The low temperature relative permeability curve is changed, so that the production is zero under the initial temperature. The high temperature relative permeability curve keeps the same. The simulation results after adjustment are consistent with the actual thermal recovery test, which greatly improving the simulation accuracy.
Third, the rapid decision-making technology of cyclic stimulation

Problem 3: The Bohai oilfield has conducted multi-thermal fluid cyclic stimulation and CSS tests.

How to quickly choose the development method?

- The heat enthalpy value of steam stimulation is significantly higher than that of multi-fluid, and the viscosity reduction effect is better than that of multiple heat fluid. The multi-fluid has better pressure holding effect;
- We studied the effects of oil layer thickness, crude oil viscosity, permeability, $K_v/K_h$ value and rhythm on the cyclic stimulation development. It is believed that the viscosity of the crude oil and the thickness of the oil layer are the primary factors affecting the development effect.
- Considering the combination of viscosity and thickness changes, numerical simulations are carried out to draw different patterns of throughput.

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<th>Advantage</th>
<th>Steam stimulation</th>
<th>Multiple thermal fluid throughput</th>
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<tr>
<td>The thermal enthalpy value is significantly higher than that of the multi-component thermal fluid, and the heating and viscosity reduction effect near the near well is better than the multi-component thermal fluid.</td>
<td>Expand heat wave area, increase energy and maintain pressure, increase elastic energy</td>
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Fast decision making with different cyclic methods

- **1000 mPa·s**
  - Steam huff and puff
  - Multi-thermal Fluids Huff and Puff

- 30m
- 20m
- 10m

Viscosity of Underground Crude Oil, mPa·s

Cum. Oil production, 10^4 m³

**Cumulative Oil Production**

- **Cumulative Oil Production**
  - Steam huff and puff
  - Multi-thermal Fluids Huff and Puff
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The application effect
The technique have been approved by Tianjin branch company and applied in the preliminary project of heavy oil thermal production such as LD5-2N.

The technical achievements have been successfully applied in oilfields such as LD21-2 and JZ23-2, supported domestic heavy oil thermal recovery.

Improve the numerical simulation accuracy of the Canadian oil sands, and help CNOOC's overseas asset development to reduce costs and increase efficiency.

### Status

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<th>Undeveloped heavy oil field</th>
<th>Exploring geological reserves</th>
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Thanks!