Integration of Geomechanics, Stress Field and Reservoir Production to Predict Dynamic Fractures Behavior of a Tight Sandstone Reservoir*

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Abstract

The unconventional reservoirs, such as tight sandstone reservoirs in the Ordos Basin of China, have received widespread attention over the past two decades for the deepening of petroleum knowledge and incessant technology progress. Along with long-term water flooding in these reservoirs, the dynamic fractures are identified by the production performance, tracer test, microseismic data, etc., and their behaviors are summarized as the opening, extending and reclosing. An integrated study was conducted which integrates geomechanics, stress field, reservoir characteristics and production to describe dynamic fractures and optimize the development of reservoir. Controlled by the geomechanics and paleo-stress field, the natural fractures develop in the reservoir with their state originally closed or filled. Subsequently due to high pressure near the wellbore area of injection wells, the closed or filled natural fractures are reactivated, constantly extend, controlled by the in-situ stress field, and may reclosed under the decreasing pressure of moderate injection.

The complexity of the dynamic fractures is influenced by lithology-based geomechanics, the difficult to determine paleo and current stress field, varied production measures and history, which are necessary to predict dynamic fractures behavior. In this study, an integrated approach is proposed and applied to a tight sandstone reservoir in the Changqing Oil Field as a case study. The geomechanics model is first built up to predict potential natural fractures distribution under the paleo-stress field. These fractures are evaluated to determine the existence and behaviors of dynamic fractures based on the analysis of production performance and current stress field. The behaviors of dynamic fractures are determined by tests and benefit the optimization and adjustment for this tight sandstone reservoir development.
Integration of Geomechanics, Stress Field and Reservoir Production to Predict Dynamic Fractures Behavior of Tight Sandstone Reservoir

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Apr. 4, 2016
Outline

- Overview

- Dynamic Fractures
  - Forming mechanism
  - Features identification
  - Distribution prediction

- Conclusions
Overview

**A Domestic Oilfield**

**Changqing Oilfield**

**Oilfield Property**

- **Major layer:** Chang 61 members in the Yanchang Formation
- **Sedimentary:** Delta facies
- **Buried depth:** 1100~1300m

![Porosity, Permeability, Water Cut, Recovery Percent](chart.png)
Increasing water cut and extremely low oil production;
- Serere water-flooding in major layer
- Water flooded goes along with the directions of fractures

**Overview**

Production Performance

Reservoir Profile

Water flooding Map
Overview

- No fracturing of injection well;
- Indication of fracture features in logging, well testing and production;
- Permeability Interpretation reaches 10 times more than core-analysis.

### W25-05 well testing

- **Formation Pressure:** 20.61 MPa
- **Formation Factor:** 213.0 mD·m
- **Effective Permeability:** 21.1 mD
- **Fracture Half-length:** 221 m

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Log-Log plot: $dp$ and $dp'$ [MPa] vs $dt$ [hr]

FMI Logging (W16-155)
Outline

➤ Overview

➤ Dynamic Fractures
  • Forming mechanism
  • Features identification
  • Distribution prediction

➤ Conclusions
Yanshan and Xishan Period Paleo stresses make two types of fractures:

**Yanshan Period: NW**

**Xishan Period: NE**

From Lianbo Zeng
Forming Mechanism

1. Stress Field (Paleo)

Outcrop Observation (25 miles, July, 2012)
1. Stress Field (Current)

Influenced by new tectonics movement, maximum of current stress NE 70

From Chinese Academy of Sciences
Forming Mechanism

1. Stress Field (Current)

Influenced by new tectonics movement, maximum of current stress NE 70°
Forming Mechanism

2. Geomechanics

Lithology: fine sandstone/siltstone > muddy/calcareous > mudstone

Thickness: more thick → increasing frac interval → less frac density
2. Geomechanics (Experiment)

Objectives: geomechanic intensity parameters of different lithology

Content: rock acoustic and intensity via simulating actual underground condition

Condition: formation pressure 30MPa, pore pressure 10MPa/13MPa/20MPa
Forming Mechanism

2. Geomechanics (Experiment)

Fracture Extension Pressure

\[ P_{tip} = \sigma_{H} \min + \sqrt{\frac{\pi U E}{2(1 - U^2)r_f}} \]

Lithology: siltstone > fine sandstone > calcareous sandstone

Results of Geomechanics Experiment

<table>
<thead>
<tr>
<th>Well</th>
<th>Lithology</th>
<th>Depth</th>
<th>FP/PP (Mpa)</th>
<th>( \sigma_1 ) (Mpa)</th>
<th>E (GPa)</th>
<th>( \mu )</th>
<th>( E/(1-\mu^2) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>WJ16–159</td>
<td>Calcareous Sandstone</td>
<td>1025.67</td>
<td>10/5</td>
<td>159.4</td>
<td>22.02</td>
<td>0.28</td>
<td>23.894</td>
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<tr>
<td>WJ16–158</td>
<td>Fine Sandstone</td>
<td>1026.4</td>
<td>10/5</td>
<td>107.8</td>
<td>16.15</td>
<td>0.179</td>
<td>16.686</td>
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<tr>
<td>WJ16–155</td>
<td>Siltstone</td>
<td>1035.1</td>
<td>10/5</td>
<td>102.6</td>
<td>14.96</td>
<td>0.176</td>
<td>15.436</td>
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<tr>
<td>WJ16–155</td>
<td>Fine Sandstone</td>
<td>1038.1</td>
<td>10/5</td>
<td>95.6</td>
<td>17.68</td>
<td>0.268</td>
<td>19.052</td>
</tr>
</tbody>
</table>

CP — Confining Pressure
\( \sigma \) — Compressive strength
\( \mu \) — Poisson’s ratio
PP — Pore Pressure
E — Young modulus
Forming Mechanism

3. Injection Performance

- Local stress changes during injection-production process
- Cumulative water injection pressure exceeds fracture pressure

Initial stage of development

Combination of facies, fractures and current development
Outline

- Overview

- **Dynamic Fractures**
  - Forming mechanism
  - Features identification
  - Distribution prediction

- Conclusions
1. Geology Features

High-angle Fractures, mostly unfilled, NE direction 71°~85°

Outcrop Observation

Core Observation (W16-155)

FMI Logging (W16-155)
# 2. Geophysics Features

Logging Response: Low RT, High AC, abnormal GR, PNN flooded indication

<table>
<thead>
<tr>
<th>Layer</th>
<th>D/m</th>
<th>SP/mV</th>
<th>AT10/(Ω.m)</th>
<th>AT20/(Ω.m)</th>
<th>AT30/(Ω.m)</th>
<th>AT60/(Ω.m)</th>
<th>AT90/(Ω.m)</th>
<th>AC/(μs/m)</th>
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<tr>
<td>C611-1</td>
<td>30</td>
<td>80</td>
<td>10</td>
<td>10</td>
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<td>10</td>
<td>10</td>
<td>300</td>
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<tr>
<td></td>
<td>50</td>
<td>170</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>175</td>
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<td>10</td>
<td>10</td>
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<td></td>
</tr>
</tbody>
</table>

Interpretation:
- PNN logging: Low RT, High AC, abnormal GR, PNN flooded indication

Fracture Logging Response (W20-064)

Oil Flooded

Water 35.1 t/d
Features identification

3. Production Performance

- Correspondence between injection and production process
- **Oil Wells**: significant rising of water cut and increasing liquid production
- **Injection Wells**: abrupt aggrandizement of water absorbing capacity
Features identification

4. Testing and monitoring

- Well Testing suggests fracture flow features
- Tracer Testing displays flow orientation NE60°~70°

Formation Pressure: 20.61 MPa
Formation Factor: 213.0 mD·m
Effective Permeability: 21.1 mD
Fracture Half-length: 221 m
4. Testing and monitoring

- Water absorbing profile: spike-type and growing
- Water index curves: turn-points indicates generation of fractures
Outline

- Overview

- Dynamic Fractures
  - Forming mechanism
  - Features identification
  - Distribution prediction

- Conclusions
Distribution prediction

1. Natural Fractures

- **Calibration** between core-observation and well logging
- **Screening** of favorable parameters on fractures (GR, AC/DEN/RILD)
- **Identification** of Natural Fractures by Neural Network Approach

![Calibration between core-observation and well logging](image1)

![Screening of favorable parameters on fractures](image2)

![Identification of Natural Fractures by Neural Network Approach](image3)
Distribution prediction

1. Natural Fractures

- Lithology-facies
- Paleo-Stress Field
- Maximal Curvature
- Fractures Intensity
- Fractures Density
Distribution prediction

2. Artificial Fractures

Current Stress Field Recovery

Artificial Fractures Model

Wells’ Young modulus

Poisson’s ratio Profiles

Artificial Fracturing Simulation
3. Dynamic Fractures

Dynamic Fractures Model

Production Testifying
4. Numerical Simulation

Bypass
\[ \sigma_1 = T_0 \]
Capture
\[ |\tau_\beta| < S_0 - \mu \sigma_{by} \]
4. Numerical Simulation

Distribution prediction

4D Dynamic Fractures Behavior
Outline

- Overview

- Dynamic Fractures
  - Phenomenon
  - Forming mechanism
  - Identification methods
  - Characterization and Prediction

- Conclusions