Real-Time Performance Analysis of Water-Injection Wells

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Presentation Outline

• Methods for Monitoring Injection-Well Performance

• Proposed Methodology:
  ✓ Calculation of Pressure Inside Waterbank
  ✓ Hall Integral Derivative

• Proof of Methodology with Geomechanical Simulations

• Field Examples

• Concluding Remarks
Current Injection-Well Monitoring Methods

- Conventional Hall Plot (1963)
- Hearn Plot or Reciprocal Injectivity Index (1983, 2005)
Hall Method

\[ p_{wf} - p_e = \frac{141.2i \mu w B}{kh} \left[ \ln \left( \frac{r_e}{r_w} \right) + s^* \right] \]

**Hall Integral**

\[ \int (p_{wf} - p_e) dt \]

**Cumulative Injection**

- Plugging
- Fracturing
Hall Method & Hearn/RII Method

Slope Analysis: Silin et al. 2005

\[ \frac{p_{wf}}{i_w} \]

\[ m = \frac{p_{wf} - p_e}{i_w} \]

RII Method: Abou-Sayed et al. 2005

\[ \frac{1}{i_w} \]

\[ (p_{wf} - p_e)/i_w \]

Injected Volume
Proposed Methodology

\[ D_{HI} = \alpha_i W_i \left\{ \ln \left( \frac{r_e}{r_w} \right) + s^* \right\} \]

Hall Integral & Derivative

Cumulative Injection

Plugging

Matrix Injection

Fracturing
Geomechanical Simulation; Formation Parting With Cold-Water Injection

$i_w$, STB/D

$T$, °F

$x_p$, ft

$\rho_{wf}$, psia

Time, days

0 50 100 150

0 50 100

0 10,000 20,000 30,000

0 50 100

0 5,000 5,200 5,600 5,800

0 100 200 300

0 40 80 120

0 5,000 5,200 5,400 5,600 5,800
Estimating Water-Bank Radius and Pressure

\[ r_e(t) \rightarrow p_e(t) \]

\[ p_e \text{ psia} \]

\[ r_e \text{ ft} \]

\[ \begin{array}{c|c|c|c|c|c|c} \hline \text{Time, days} & 0 & 20 & 40 & 60 & 80 & 100 & 120 \\ \hline p_e & 5,000 & 5,050 & 5,100 & 5,150 & 5,100 & 5,050 & 5,000 \\ \hline r_e & 0 & 20 & 40 & 60 & 80 & 100 & 120 \\ \hline \end{array} \]
Interpreting Data w/ Modified-Hall & Skin Methods

Cumulative Injection, STB

HI, HID
psi-D

Start of Fracing

Hall Plot
Numeric Derivative
Analytic Derivative

Start of Fracing

HI, HID
psi-D

HI, HID
psi-D

Start of Fracing

Analytic Derivative
Numeric Derivative

Cumulative Injection, STB

Time, days

0 20 40 60 80 100 120

0 20 40 60 80

0 5,000 5,300 5,600 5,900

0 1.0E+04 2.0E+04 3.0E+04 4.0E+04

0 1.0E+04 2.0E+04 3.0E+04 4.0E+04

$\rho_{wf}$ psi

$\psi$ psi
Simulating Formation Plugging w/Variable Skin

$p_{wf}$ psia

$PSS$

$pe$ psia

$Transient$

$iw$ STB/D

$re$ ft

Start of Plugging

Time, days
Interpreting Data w/ Modified-Hall & Hearn Methods

- HI, HID
- psi-D

- Cumulative Injection, STB

- Start of Plugging

- $D_{HI}$

- $\Delta p/i_w$
- psi-D/STB

- Start of Plugging
Injection-Well Response in Diatomite Reservoir

$p_{wf}$ psia

$i_w$ STB/D

Time, days
Injection-Well Response in Diatomite Reservoir

- $i_w$ (STB/D)
- $p_{wf}$ (psia)
- $p_e$ (psia)

Time, days

- $r_e$ (ft)
Injection-Well Response in Diatomite Reservoir

HI, HID
psi-D

Cumulative Injection, STB
Injection in a Carbonate Reservoir

\[ i_w \] (STB/D)

\[ \rho_{wf} \] (psia)

\[ \rho_e \] (psia)

\[ r_e \] (ft)

Time, days

Transient
Injection in a Carbonate Reservoir

Start of Fracing

Hall Plot
Derivative

HI, HID
psi-D

Cumulative Injection, STB

Δp/i_w
psi-D/STB

Variable Pe
Constant Pe

Cumulative Injection, STB
Injection in a Sandstone Reservoir

Sharma et al., 2000, SPEPF

$i_w$ STB/D

$p_p$ psia

Cumulative Injection, STB

HI, HID psi-D

Filter Change

Acidizing

$D_{HI}$
Matrix Acidizing in a Carbonate Reservoir

Zhu & Hill 1998, SPEPF
Concluding Remarks

• Conventional Hall Method Works Best in Cases Where Oil/Water-Interface Pressure ($p_e$) of Moving Bank Changes Minimally

• Variable $p_e$ & Analytic HID Formulations Developed

• When Used in Tandem With Hall Integral, HI-Derivative Curve Provides Unambiguous Diagnosis of Well’s Performance Status

• Proposed Method Applicable in Wells Injecting Water in Various Formations & Equally Effective in Monitoring Matrix Acidization