USING GELS TO REDUCE EXCESS WATER PRODUCTION IN FRACTURED PRODUCTION WELLS

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**PROBLEM:** Most designs for water shutoff gel treatments have been strictly empirical—possibly contributing to erratic success rates.

**OBJECTIVE:** Provide an engineering-based method to design and analyze gel treatments in production wells where fractures or fracture-like features are the conduit for excess water production.
During gelant injection into a vertical well, gelant:
• Flows far down the fracture length,
• Leaks off a short distance into the porous rock.
After returning the well to production, the gel:
• Must reduce $k_w$ much more than $k_o$,
• Act as a much greater barrier to water than oil,
• Don’t want to damage flow in the fracture itself.

*SPEPF (Nov. 1998) 223-229.*
Example assuming:
Leakoff distance = 0.5 ft in all zones, $F_{rro} = 20$, and $F_{rrw} = 500$.

Equivalent resistance to flow added by the gel
• In oil zone: 0.5 ft x 20 = 10 ft.
• In water zone: 0.5 ft x 500 = 250 ft.

*SPEPF* (Nov. 1998) 223-229.
STEPS IN THE PROCEDURE

1. Collect needed data:
   \( \Delta p, q_o, q_w, h_o, h_w, k_o, k_w, \phi_o, \phi_w, \mu_o, \mu_w, L_f, S_{or} \)

2. Estimate external drainage distance: \( L_e \)

3. Estimate the degree of gelant penetration in various zones: \( L_{po}/L_{pw} \)

4. Find residual resistance factors: \( F_{rrw}, F_{rro} \)

5. Calculate oil & water productivity versus gelant volume.

6. Determine optimum gelant volume.
2. ESTIMATING AN EXTERNAL DRAINAGE DISTANCE

\[ L_e \approx \frac{1}{2} \text{ the distance to the nearest well}, \text{ or} \]

\[ L_e = \Delta p \frac{k A}{[887 q \mu]} \]

Equation can be applied for the water zone(s), the oil zone(s) or both.

- \( L_e = \) total distance in ft (external drainage distance)
- \( \Delta p = \) pressure drop in psi (\( \Delta p \) from \( L_e \) to the fracture face before gel placement)
- \( k = \) permeability in md (for water or oil)
- \( A = \) flow area in ft\(^2\) (\( A = 4 L_f h_f \) for a 2-wing fracture)
- \( q = \) rate in BPD (for water or oil)
- \( \mu = \) viscosity in cp (for water or oil)
3. Degree of Gelant Penetration
[In oil zone(s) relative to water zone(s)]

\[ \frac{L_{po}}{L_{pw}} = \frac{\{1+(F_r^2 - 1) \frac{(k_o\phi_w)}{(k_w\phi_o)}\}^{0.5} - 1}{(F_r - 1)} \]

\( F_r \) is resistance factor (effective viscosity)

For water-like gelants \((F_r = 1)\):

\[ \frac{L_{po}}{L_{pw}} = \frac{(k_o\phi_w)}{(k_w\phi_o)} \]

For viscous gelants \((F_r > 20)\):

\[ \frac{L_{po}}{L_{pw}} \approx \left[\frac{(k_o\phi_w)}{(k_w\phi_o)}\right]^{0.5} \]
FRACTURED PRODUCER PROBLEM 1
ESTIMATING GELANT LEAKOFF DISTANCES

A vertical well intersects a two-wing fracture (half-length=50 ft). This fracture cuts through an oil zone that was 24 ft high, a water zone that was 24 ft high, and a separating shale barrier of 2 ft. For the oil zone, \( k_a = 100 \) md, \( k_{ro} = 0.9 \), \( k_{rw} = 0.1 \), \( S_{or} = 0.3 \). For the water zone, \( k_a = 500 \) md, and no \( S_{or} \) was present. \( \phi = 0.2 \) in both zones. \( \mu_{\text{water}} = \mu_{\text{oil}} = 1 \) cp. 600 bbl of a 20 cp-gelant are injected. How far do you expect the gelant to penetrate into each of the two zones?

\[
L_{po}/L_{pw} \approx \left[ \frac{(k_{o}\phi_{w})}{(k_{w}\phi_{o})} \right]^{0.5} = \left\{ \frac{90(0.2)}{[500(0.2)(1-0.3)]} \right\}^{0.5} = 0.5
\]

\[
V = 600 \left( \frac{350}{62.4} \right) = 3365 \text{ ft}^3
\]

\[
V = 4L_f \left[ h_{w}\phi_{w}L_{pw} + h_{o}\phi_{o}L_{po} \right] = 4(50)[24(0.2)L_{pw} + 24(0.2)0.7L_{po}]
\]

\[
L_{pw} = 2.6 \text{ ft (water zone)} \quad L_{po} = 1.3 \text{ ft (oil zone)}
\]
Water residual resistance factor = Water mobility before gel placement / Water mobility after gel placement

\[ F_{rrw} = \frac{(k/\mu)_{\text{water before gel}}}{(k/\mu)_{\text{water after gel}}} \]

= permeability reduction to water

Oil residual resistance factor = Oil mobility before gel placement / Oil mobility after gel placement

\[ F_{rro} = \frac{(k/\mu)_{\text{oil before gel}}}{(k/\mu)_{\text{oil after gel}}} \]

= permeability reduction to oil
DARCY’S LAW FOR LINEAR FLOW IN SERIES

\[ \Delta p_{\text{total}} = \Delta p_{\text{fracture}} + \Delta p_{\text{gel bank}} + \Delta p_{\text{brine/oil bank}} \]

\[ \Delta p_{\text{total}} = \left[ 887 \frac{q}{\mu} / (k A) \right] \left[ F_{rr} L_p + (L_e - L_p) \right] \]

- \( F_{rr} \) = residual resistance factor in the gel bank
- \( L_p \) = distance of gel penetration in ft (e.g., from the fracture face)
- \( L_e \) = total distance in ft (external drainage distance)
- \( \Delta p \) = pressure drop in psi
- \( q \) = rate in BPD
- \( \mu \) = viscosity in cp
- \( k \) = permeability in md
- \( A \) = flow area in ft\(^2\) \((A = 4 L_f h_f\) for a 2-wing fracture\)
FRACTURED PRODUCER PROBLEM 2
PREDICTING OIL & WATER RATES AFTER GEL

For the well in Problem 1 (600 bbl gelant, \( L_{pw} = 2.6 \) ft, \( L_{po} = 1.3 \) ft, \( L_f = 50 \) ft, \( h_o = h_w = 24 \) ft, \( k_w = 500 \) md, \( k_o = 90 \) md, \( \mu_w = \mu_o = 1 \) cp), before gel placement, the well produced 5000 BWPD and 900 BOPD; \( \Delta p = 1000 \) psi. Lab studies indicated that the gel should provide \( F_{rrw} = 1000 \) and \( F_{rro} = 100 \). What water and oil rates are expected after the gel treatment if \( \Delta p \) remains 1000 psi?

Estimate external drainage distance, \( L_e \):

\[
q = \frac{4 \Delta p \ k \ L_f \ h}{(887 \ \mu \ L_e)}
\]

\[
5000 = \frac{4(1000)500(50)24}{[887(1) \ L_e]}
\]

\[
L_e = 541 \ ft
\]

\[
q = \frac{4 \ \Delta p \ k \ L_f \ h}{{887 \ \mu \ [F_{rr} \ L_p + (L_e - L_p)]}}
\]

\[
q_{\text{water}} = \frac{4(1000)500(50)24}{[887(1)[1000(2.6)+(541-2.6)]]} = 862 \ BWPD
\]

\[
q_{\text{oil}} = \frac{4(1000)90(50)24}{[887(1)[100(1.3)+(541-1.3)]]} = 727 \ BOPD
\]

Summary: Water: 5000 to 862 BWPD  Oil: 900 to 727 BOPD
FRACTURED PRODUCER PROBLEM 3
INCREASED $\Delta p$ INCREASES OIL & WATER RATES

For the well in Problem 2, what water and oil rates are expected after the gel treatment if the pressure drawdown is 2000 psi after the gel treatment instead of 1000 psi?

\[ q = 4 \Delta p \frac{k L_f h}{887 \mu [F_{rr} L_p + (L_e - L_p)]} \]

\[ q_{\text{water}} = 4(2000)500(50)^{24} / \{887(1) [1000(2.6)+(541-2.6)]\} \]
\[ q_{\text{water}} = 1724 \text{ BWPD after} \quad \text{versus} \quad 5000 \text{ BWPD before} \]

\[ q_{\text{oil}} = 4(2000)90(50)^{24} / \{887(1) [100(1.3)+(541-1.3)]\} \]
\[ q_{\text{oil}} = 1454 \text{ BOPD after} \quad \text{versus} \quad 900 \text{ BOPD before} \]

Summary: 600 bbl treatment, $\Delta p$ after gel =2X $\Delta p$ before gel
Water: 5000 to 1724 BWPD    Oil: 900 to 1454 BOPD
When 600 bbl of gelant were injected, $L_{pw}=2.6$ ft and $L_{po}=1.3$ ft, and the actual post-treatment water and oil rates were 1000 BWPD and 1700 BOPD, respectively, when the post-treatment pressure drawdown was 2000 psi. What were the ACTUAL \textit{in situ} $F_{rrw}$ and $F_{rro}$ values?

\[ q = 4 \Delta p \, k \, L_f \, h \left/ \left\{ 887 \, \mu \left[ F_{rr} \, L_p + (L_e - L_p) \right] \right\} \right. \]

\[ 1000 = 4(2000)500(50)24 / \{887(1) \left[ F_{rrw} \,(2.6) + (541-2.6) \right] \} \]

$F_{rrw} = 1874$ ACTUAL \hspace{1cm} versus 1000 lab value

\[ 1700 = 4(2000)90(50)24 / \{887(1) \left[ F_{rro} \,(1.3) + (541-1.3) \right] \} \]

$F_{rro} = 25.6$ ACTUAL \hspace{1cm} versus 100 lab value
## FRACTURED PRODUCER PROBLEMS

Effect of gelant volume on oil & water production

### Pressure drawdown = 2000 psi

\[ F_{rrw} = 1874 \quad F_{rro} = 25.6 \quad L_f = 50 \text{ ft} \quad L_e = 541 \text{ ft} \]

<table>
<thead>
<tr>
<th>Gelant, bbl</th>
<th>BWPD</th>
<th>BOPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10000</td>
<td>1800</td>
</tr>
<tr>
<td>300</td>
<td>1818</td>
<td>1749</td>
</tr>
<tr>
<td>600</td>
<td>1000</td>
<td>1700</td>
</tr>
<tr>
<td>1200</td>
<td>526</td>
<td>1611</td>
</tr>
<tr>
<td>2400</td>
<td>270</td>
<td>1457</td>
</tr>
</tbody>
</table>
Pressure drawdown = 2000 psi

F_{rrw} = 1874  \quad F_{rro} = 25.6  \quad L_f = 50 \text{ ft}  \quad L_e = 541 \text{ ft}

Volume of gelant injected, bbl

BWPD

Water

Oil

1000 BWPD

1700 BOPD

BOPD

10000

15000

20000

10000

15000

20000

Volume of gelant injected, bbl
SIMPLE BENEFIT ANALYSIS: \( \text{$/day benefit} = (\text{water treatment cost}) \times (\text{BWPD reduction}) - (\text{oil price}) \times (\text{BOPD reduction}) \)
DEALING WITH COMPLICATIONS

What if you don’t know: $k_w$, $k_o$, $h_w$, $h_o$, A, or $L_f$?

This information can often be extracted from production and well history data, specialized tests, and/or from well behavior during gelant injection. See SPE 77411.
SUMMARY

• Gels that reduce $k_w$ more than $k_o$ have great utility in treating fractured production wells.

• An engineering-based method is available to design and analyze these treatments.

• The method REQUIRES accurate pressure measurements before and after (and ideally, during) the gel treatment.