1. Gel treatments (of any kind) are not polymer floods.
2. Crossflow makes gel placement challenging.
3. Adsorbed polymers, weak gels, and suspensions of gel particles plug low-k rock by a greater factor than high-k rock.
GEL TREATMENTS ARE NOT POLYMER FLOODS

Crosslinked polymers, gels, gel particles, and “colloidal dispersion gels”:

• Are not simply viscous polymer solutions.

• Do not flow through porous rock like polymer solutions.

• Do not enter and plug high-k strata first and progressively less-permeable strata later.

• Should not be modeled as polymer floods.
Distinction between a blocking agent and a mobility control agent.

For a mobility control agent, penetration into low-k zones should be **maximized**.

For a blocking agent, penetration into low-k zones should be **minimized**.
Gel Placement in Heterogeneous Systems with Crossflow

Ideal Near-Wellbore Treatment

Ideal Far-Wellbore Treatment

Reality

Water  Oil  Gel

SPE 24192
CROSSFLOW MAKES GEL PLACEMENT MORE DIFFICULT!!!

Crossflow in a two-layer beadpack. SPE 24192
Xanthan solutions displacing water; $k_1/k_2 = 11.2$.

- 0-ppm xanthan, 1 cp
- 200-ppm xanthan, 3 cp
- 500-ppm xanthan, 8 cp
- 1000-ppm xanthan, 23 cp
- 2000-ppm xanthan, 75 cp

Layer 1
Layer 2

Xanthan
Water
USE OF A WATER POSTFLUSH WITH A WATER-LIKE GELANT

(a) Injection of a Water-like Gelant
(b) Injection of a Water Postflush Prior to Gelation
(c) Shut-in during Gelation
(d) Water Injection after Gelation

### USE OF A WATER POSTFLUSH WITH A WATER-LIKE GELANT

**ADVANTAGES**
- High injectivity could be maintained after gelation.
- Incremental oil could be recovered quickly.

**LIMITATIONS**
- The gel treatment will not help much beyond the greatest distance of gelant penetration.
- Sufficient gelant must be injected.
- Long gelation times are needed in unfractured wells.
- Gelant resistance factor should not exceed that for water.
- Gelant resistance factor should not increase during gelant placement.
- Transverse dispersion may limit the idea to thick formations.
Sophisticated Gel Treatment Idea from BP

In-depth channeling problem, no significant fractures, no barriers to vertical flow:

- BP idea could work but requires sophisticated characterization and design efforts,
- Success is very sensitive to several variables.

BRIGHT WATER—A VARIATION ON BP’s IDEA (SPE 84897)

- Injects small crosslinked polymer particles that “pop” or swell by ~10X when the crosslinks break.
- “Popping” is activated primarily by temperature, although pH can be used.
- The particle size and size distribution are such that the particles will generally penetrate into all zones.
- A thermal front appears necessary to make the idea work.
- The process experiences most of the same advantages and limitations as the original idea.
KEY QUESTIONS DURING BULLHEAD INJECTION OF POLYMERS, GELANTS, OR GELS

• Why should the blocking agent NOT enter and damage hydrocarbon productive zones?

• How far will the blocking agent penetrate into each zones (both water AND hydrocarbon)?

• How much damage will the blocking agent cause to each zone (both water AND hydrocarbon zones)?
GELANTS FLOW THROUGH POROUS ROCK; GELS DO NOT

Gelant flows freely like a polymer solution

Partial gel formation

MOBILE GELANT
IMMOBILE GEL
FLOW DIRECTION

Gel filling all aqueous pore space
1-day-old 0.25% HPAM gel plugs the core face in a 7.2 darcy core

1-day-old gel: 0.25% HPAM, 0.0208% Cr(III) acetate, 41°C, 7.2 darcy polyethylene.

First section

Second section
1-day-old 0.2% HPAM gel plugs the core face in a 9.6 darcy core

1-day-old gel: 0.20% HPAM, 0.020% Cr(III) acetate, 41°C, 9.6 darcy polyethylene.
1-day-old 0.15% HPAM gel plugs the core face in an 8.5 darcy core.

1-day-old gel: 0.15% HPAM, 0.015% Cr(III) acetate, 41°C, 8.5 darcy polyethylene.
4-day-old 0.15% HPAM gel plugs the core face in a 1.57 darcy core.

Gel: 4-day-old 0.15% HPAM, 0.015% Cr(III) acetate, 1% NaCl, 0.1% CaCl$_2$, 41°C. 1570-md fused silica. 100 cm$^3$/hr (7 ft/d).

Section 1 (2 cm length)
Section 2 (9.6 cm length)
Section 3 (1.9 cm length)
4-day-old 0.15% HPAM gel plugs the core face in a 1.57 darcy core

1570-md fused silica.
Injection rate = 100 cm³/hr (7 ft/d).

Gel: 0.15% HPAM, 0.015% Cr(III) acetate, 1% NaCl, 0.1% CaCl₂
4-day-old 0.15% HPAM gel plugs the core face in a 1.57 darcy core

Injection rate = 100 cm³/hr (7 ft/d).
Brine: 1% NaCl, 0.1% CaCl₂,
Core: 1570-md fused silica.

Section 1, 2 cm

Section 2, 9.6 cm

Section 3, 1.9 cm
Al(III)-citrate-HPAM gels act like other gels.

300-ppm HPAM, 15-ppm Al(III) as citrate, 0.5% KCl, 41°C, 707-md Berea sandstone 15.8 ft/d (6.7 PV/hr) injection rate.

DOE/BC/14880-10 (March 1995) 51-64.
A 1-day-old Cr(III)-acetate_HPAM gel with 0.5% HPAM can extrude through a 28 darcy sand pack, but dp/dl is ~ 200 psi/ft!!!
Adsorbed polymers, “weak” gels, particle suspensions, and “dispersions” of gel particles reduce $k$ in low-$k$ rock more than in high-$k$ rock.

Adsorbed HPAM $M_w = 5.5 \times 10^6$
20% hydrolysis.
Sandstone rock.

Vela et al. SPEJ (April 1976), 84
Contrary to some claims, adsorbed polymers, “weak” gels, and gel “dispersions” can harm flow profiles!!!
USE OF PARTICULATES -- Problems

- Particles are not all the same size.
- Pores are not all the same size.
- Some particles will enter most or all pores.
- Permeability reduction may be greater in low-k pores than in high-k pores.
Could allow a low-mobility foam to form in high-k zones but not in low-k zones.

Much lab work needed to identify the foam.

Aqueous phase must not contain a gelant.

Foam must be persistent in the high-k zone.
PHYSICAL REALITIES FOR IN DEPTH PROFILE MODIFICATION

RANDY SERIGHT, New Mexico Tech

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