Can Polymers Reduce S_{or} Below that for Waterflooding?

S_{or} Reduction by Polymers: Why Are We Talking About This? – DAQING!

Wu et al. SPE 109228, Wang et al. SPE 127453

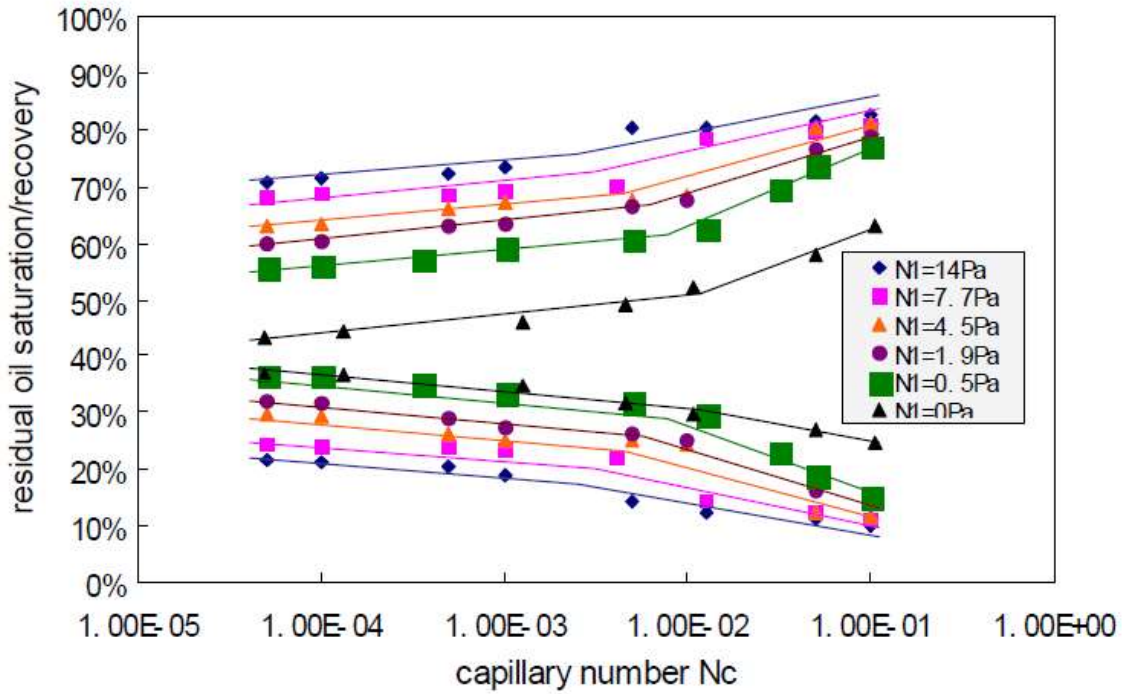


Fig.4 The relation curve of the recovery/residual oil saturation vs. the capillary number of the binary displacing system

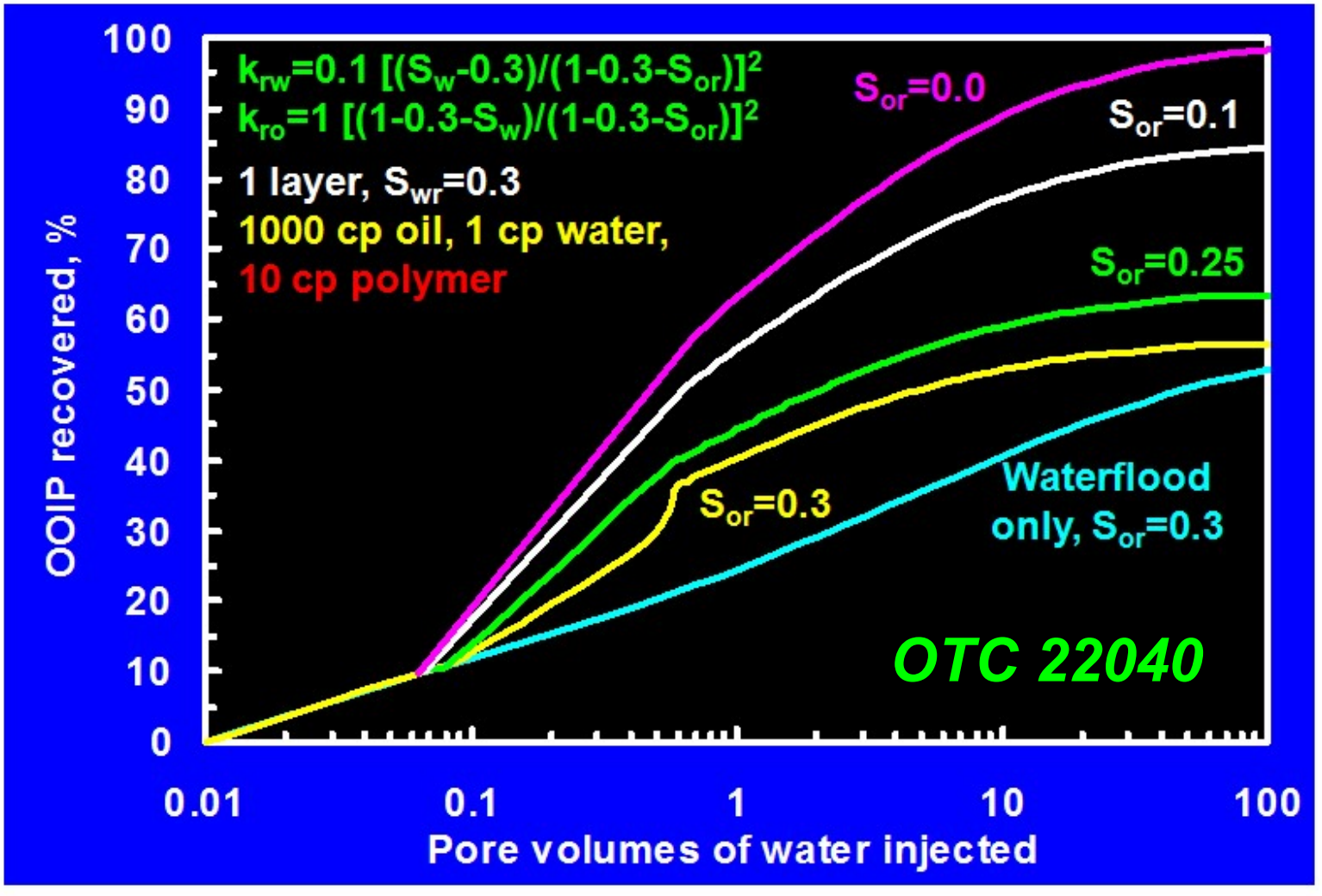
Wang et al. (SPE 144294) reported 20% OOIP EOR from injecting 150-300-cp HPAM into >5600 wells (10-cp oil) versus 12% OOIP EOR for 40-cp HPAM.

S_{or} Reduction by Polymers: Bottom Line

1. It does matter—even for viscous oils.
2. Primarily, true S_{or} reduction has been seen in non-water wet cores.
3. Most (but not all) seem to agree that the effect occurs mostly at higher velocities with high Mw HPAM.
4. Seems to happen in some rocks/reservoirs but not others.
5. Debate still rages about the cause and whether it is a real/usable effect.

Can viscoelastic polymer solutions reduce the S_{or} below that for waterflooding?.

1. Daqing says yes; UT Austin says maybe not.
2. Does it matter for viscous oils? (yes)



PREVIOUS LITERATURE: Water- Wet Cores

- Conventional wisdom within the petroleum industry is that the ultimate residual oil saturation (S_{or}) for a polymer flood is the same as that for a waterflood (Tabor 1969, Lake 1989).
- Polymers have a negligible effect on oil-water interfacial tension, so no reduction of S_{or} is expected, compared with waterflooding.
- Several previous literature reports are consistent with this view in water-wet cores, especially with Berea and Bentheim sandstone (Schneider and Owens 1982, Pusch et al. 1987, Wreath 1989).

LITERATURE:

Cores not water wet

- Wang: Daqing HPAM solutions reduced S_{or} from 36.8% (with waterflooding) to 21.75% (for polymer flooding) using a constant capillary number under oil-wet, weakly oil-wet, and mixed-wet conditions.
- Schneider and Owens (1982): HPAM reduced S_{or} in oil-wet cores up to 8.4%.

Water-wet cores

- Zaitoun and Kohler (1987, 1988): PAM reduced S_{or} by 3% in water-wet Berea and Vosges sandstones. In Bentheim sandstone, Pusch et al. (1987) saw 1% to 4% reductions in S_{or} with xanthan and a sugar solution.
- Differences might not be significant.

PREVIOUS LITERATURE: Water- Wet Cores

UT Austin View for Water-Wet cores

- During polymer flooding, Huh and Pope (2008) observed S_{or} reductions (relative to waterflooding) ranging from 2 to 22 saturation percentage points using heterogeneous Antolini cores. For heterogeneous cores, two effects could appear to make the S_{or} lower after a polymer flood than after a waterflood. First, if insufficient water is flushed through the core to displace mobile oil from less-permeable pathways, one could be misled by the high water cut to believe that the core was near S_{or}. Improved volumetric sweep during a subsequent polymer flood could rapidly produce a small spike of mobile oil from the less-permeable pathways. SPE 113417, 179683.

PREVIOUS LITERATURE: Water- Wet Cores

UT Austin View for Water-Wet cores

- For polymer flooding in a secondary mode (no prior waterflood), a lower S_{or} is reached because oil ganglia stay connected longer and drain pores of oil more effectively. SPE 113417

UT Austin, Bentheimer cores, 120-cp oil

- At low velocities, the endpoint residual oil satuation was the same for waterflooding and polymer flooding. SPE 179683 and SPE 179689.
- Reductions in S_{or} are seen when flooding with HPAM solutions at high velocities (Deborah numbers). SPE 179689

UT Austin SPE 187230 (Erincik et al. 2017)

- Unusually low S_{or} attained by injecting high-salinity polymer solutions after low-salinity polymer solutions.

- Explanation for the effect is currently unknown.
- Relevance to field applications is currently unknown.

- Experiments were performed at relatively high pressure gradients and rates.
- A controversial EDTA-hydrosulfite pre-treatment was used.
- The brine contained no divalent cations.

SPE 169681 (Vermolen et al. 2014)

- For 300-cp crude, no reduction in S_{or} occurred for HPAM rates up to 3 ft/d.
- For 9-cp crude, reduction of S_{or} can be seen, especially with viscous elastic HPAM solutions and higher rates.

SPE 174654 (Clarke et al. 2016)

- Argue that "elastic turbulence" is responsible for the apparent "flow-thickening" of HPAM solutions in porous media.
- Also argue this effect results in reduction of S_{or} because fluctuating flow field destabilizes trapped oil drops.
- Onset (flow velocity) of flow thickening
  - Decreases with increased polymer Mw.
  - Increases with increased rock permeability.
  - Is independent of polymer concentration.

Papers on S_{or} Reduction Using Polymers

1. Wang Demin et al. SPE 153070, 146473, 144294, 127453, 114335, 109228, 101950, 88456, 72123.
2. UT Austin. SPE 113417, 169037, 179683, 179689, 187230.
3. Cottin et al. SPE 169692.
4. Vermolen et al. SPE 169681, IPTC 17342.
5. Urbissionva et al. *JCPT* 49(12) 2010: 49-56.
6. Schneider and Owens. SPE 9408.
7. Kohler and Zaitoun. SPE 16274, 18085.
8. Clarke et al. SPE 174654.
9. Azad et al. SPE 193771, 195687, 201122, 204212.
10. AlSofi, Ayirala et al. SPE 184163, 200251.
11. Souayeh et al. SPE 208581.

Bottom Line: Most (but not all) seem to agree that the effect occurs mostly at higher velocities with high Mw HPAM.

Views on S_{or} Reduction Using Polymers

1. It is due to viscoelasticity of HPAM solutions.
   A. Does not explain results where S_{or} reduction occurs at low capillary numbers.
   B. If true, it means the phenomenon is largely irrelevant to oil recovery in field applications (because high velocities are needed to bring out the viscoelasticity).
2. It is an artifact of either having heterogeneous cores or unfavorable mobility ratio.
   A. May not explain results where S_{or} reduction occurs at low capillary numbers in homogeneous cores.
   B. May not explain the 20% OOIP EOR at Daqing field.
   C. Recent Daqing papers (SPE 210298 and 200084) now doubt the earlier high-concentration polymer claims .
3. Could it be due to wettability alteration by polymer?

Some Papers Indicating that Polymers Can Make Rock More Water-Wet

1. SPE 16274 and 18085 (Zaitoun and Kohler, IFP).
   A. Polymer adsorption shifted the water relative permeability curve down.
   B. Polymer adsorption shifted Sor to lower values.
2. SPE 184163 and 200251 (Aramco).
   A. Polymer adsorption on some reservoir rocks reduced contact angle more than low-sal alone.
   B. In one case, low-sal/polymer recovered as much oil as surfactant polymer flooding (~20% OOIP).
3. SPE 208581 (Qaboos University, Oman)
   A. Mineral dissolution and polymer adsorption on calcite substantially altered wettability.

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