INJECTION CONFORMANCE IN CO_2 FLOODS

Presented by Baker Hughes Water Management

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12/13/13

CO_2 Conference- Midland, TX

Difference between Water and CO_2 Flooding

CO_2 flooding

- Initial reservoir pressures encountered are higher
- Injectant is corrosive
- More expensive
- Mobility ratios are higher
- Fractured/vuggy carbonates exhibit early breakthrough in secondary and tertiary recovery
- Rock dissolution leading to increased permeability
- Acts as a good tracer

What do you need for a successful CO_2 flood?

- Uniform permeability $\longrightarrow$ Improved sweep
- Temperatures less than 250 ºF
- High API oil
- Success rates mimic water flood response
- Adds 5-15% of OOIP to ultimate recovery
  - High S_{or} post -water flooding

What can be changed?

Carbon Dioxide and Enhanced Oil Recovery report by National Energy Technology Laboratory http://www.netl.doe.gov/

Decreased sweep efficiency

Early CO_2 breakthrough leads to

- Well head freezing
- Higher OPEX
- Conversion of CO_2 floods to WAG floods to manage costs
- High GOR’s across field

Characteristics of Permian Basin reservoirs

Advantages

- Low geothermal gradient makes the pressure required for CO_2 miscibility with oil lower
- High degree of geological continuity between wells
- Reasonable injectivities
- Lengthy waterflood history with high S_{or}

Disadvantages

- High permeability in vuggy and fractured carbonates
- Early breakthroughs

Carbon Dioxide and Enhanced Oil Recovery report by National Energy Technology Laboratory http://www.netl.doe.gov/

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Examples of CO_2 floods treated with polymer gels

- SACROC
- Weyburn, Saskatchewan
- Rangely Field, CO
- Means San Andres
- Denver Unit
- Wellman Unit
- Wertz, WY
- Vacuum Field, NM
- Salt Creek, TX and WY
- Mississippi
- SSAU
- Hockley Co, TX
- Ward Co, TX
- Cochran Co, TX
- Gaines Co, TX
- Andrews Co, TX

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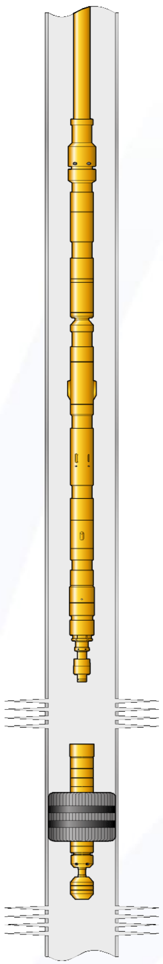
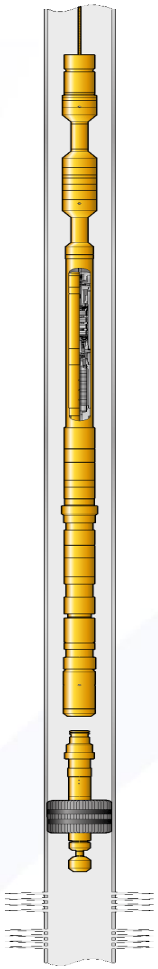
CONFORMANCE OPTIONS

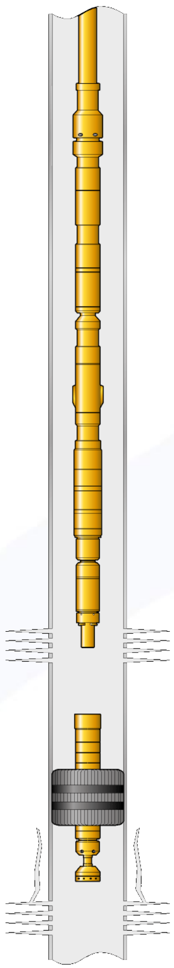
Mechanical Water Shut-Off (WSO) Options



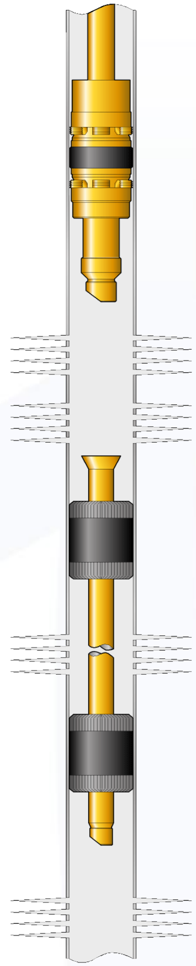
Retrievable Bridge Plug



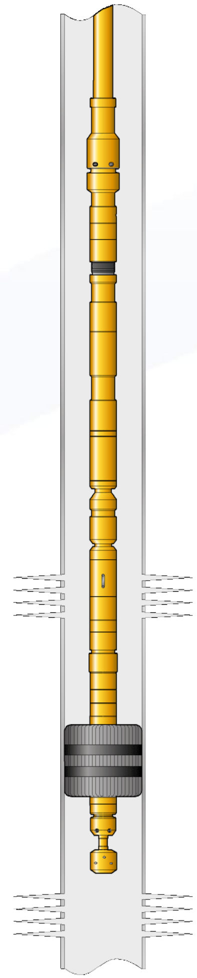
Permanent Bridge Plug



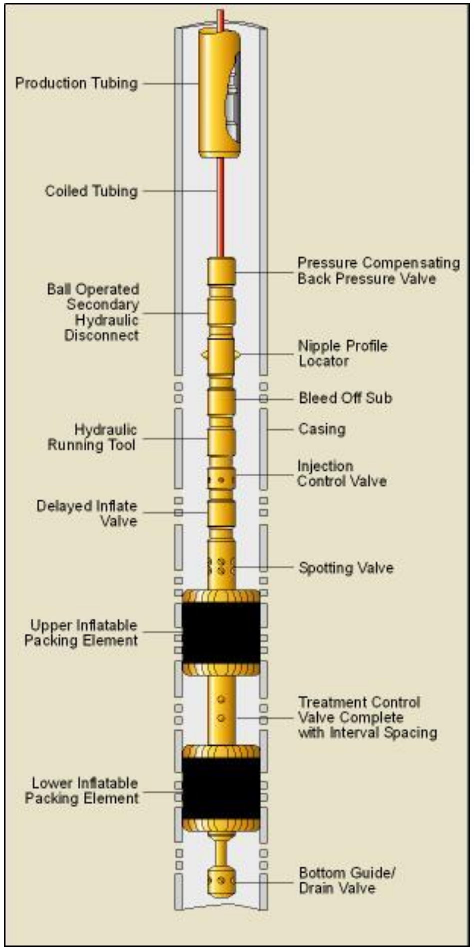
Cement Retainer



Straddle System



Retrievable Packer



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Cement Solutions- Near Wellbore Isolation

- Portland Cement
- Ultrafine Cement
- Foamed Cement
- Acid-soluble Cement

Advantages of Gel Treatments

- Crosslinked polymer gel solution (gelant) can penetrate deep in the reservoir to improve areal and vertical sweep
- Gel not affected by CO_2 or H_2S exposure
- Large volume treatments are relatively inexpensive
- Minimal well intervention – most treatments bullheaded

Chemical Conformance Solutions

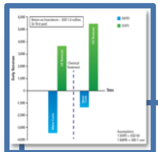
Medium/High Molecular Weight Gel

Application

- Reservoir conformance technology
- Water floods
- CO_2 floods
- Injection wells for improved sweep
- Production wells for favorable WOR

Candidates

- Naturally fractured reservoirs
- Temperature rating 200ºF
- High temperature gels (up to 300° F available)



Benefits

- Modify flow in reservoir
- Improved sweep patterns
- Improved ultimate recovery
- Reduced water and CO_2 production
- Usually does not require isolation
- Minimal equipment needed

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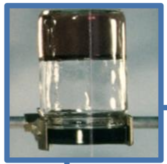
Chemical Conformance Solutions

Low Molecular Weight Gel

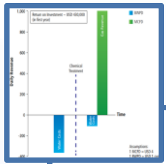
Application

- Zone abandonments
- Casing leak repairs
- Behind pipe channels
- Chemical liner to seal open hole



Candidates

- Near-wellbore treatments
- Temperatures up to 230°F
- Sandstone / Carbonate



Benefits

- Penetrates reservoir
- Eliminates permeability
- Easy cleanout and minimal equipment needed

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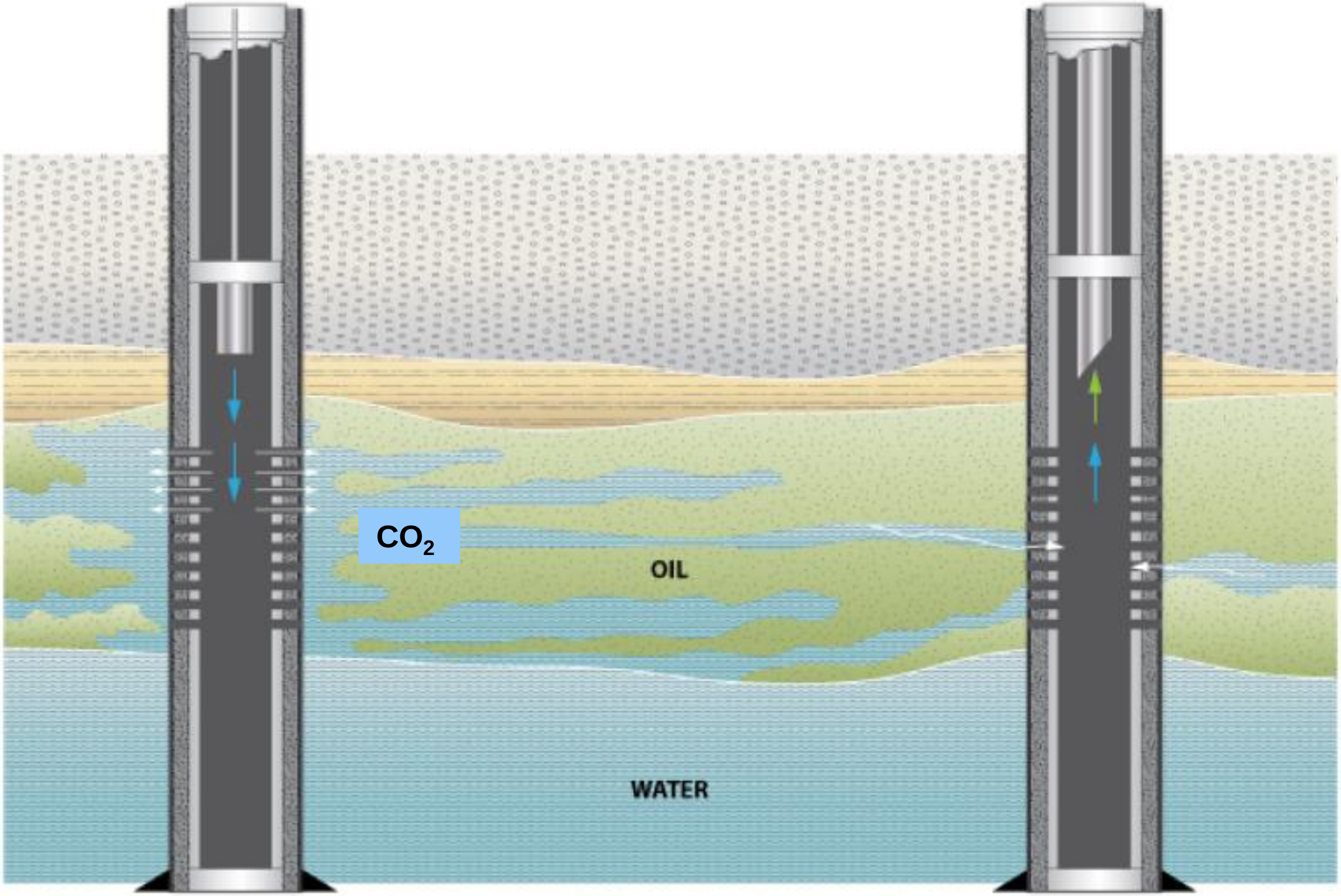
Thief zones and viscous fingering



Injection Wells – Basic Design Thoughts

- More volume is better – its proven!

- Polymer volume must be balanced by gel concentration
  - How quick is the breakthrough to the producer?
  - What is the thief interval height?
  - What is the spacing?
  - What is the injection rate and pressure?

- What are the pattern economics?
  - How quick did the wells respond and decline in the waterflood?
  - The throughput volume of the waterflood response is one indicator of polymer volume necessary
  - How much money do you want spend?

Injectivity Index Model

- Based on 40+ polymer treatments for a major Permian operator in a CO_2 WAG flood
- Reservoir is a limestone reef complex with an assortment of secondary porosity features
- Formula – Barrels/Day/PSI = Injectivity Index
- Used for high-rate/low-pressure injectors
- Also used for producers based on step-rate testing

Polymer Volume Estimates Based On Injectivity Index

Injectivity Index	Volume/Concentration
Less than 2	1,000-2,000 bbls MMW with lower polymer loadings
Less than 4	4,000-5,000 bbls MMW with mid-range loadings
10-20	10,000 bbls MMW with higher-range loadings
20-60	18-20,000+ bbls MMW/HMW with high-loadings

SPE 39612- Gel treatments in Rangely CO_2 flood

- Large CO_2 miscible WAG flood in NW Colorado
- Decline in oil production with increase in OPEX
- High perm features and fracture pathways responsible for poor sweep – Sandstone reservoir
- Technologies tried with mixed success
  - Selective injection
  - Straddle packers
  - Pattern re-alignment
  - Cement Squeezes etc.

Near wellbore treatments not effective

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Range of polymer gel treatment responses

- Forty-four wells treated
- No apparent impact on injection or production
- Oil rate increase
- Reduction in water
- Reduction in gas
- Areal sweep improvement
- Reduction or elimination of oil decline rate
- Improved pattern CO_2 retention and utilization
- Smoothing of production

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Why is smoothing production beneficial?

- Save on artificial lift costs
- Enables improved lift sizing and operation
- Surface separation equipment upsets minimized
- Pressure spikes on gathering lines reduced

These are not included in typical treatment evaluation

SPE 39612. Hild, G.P. and Wackowski, R.K.

Total and Average Incremental Production/Year

	Total Incremental Production (BPD. MCFPD)				Average Incremental Production (BPD. MCFPD)			Job Success	
District	**Oil**	**Water**	**Gas**	**# Jobs**	**Oil**	**Water**	**Gas**	**#**	**%**
1	210	1650	550	10	21	165	55	9	90
2	235	450	1230	9	26	50	137	8	89
3	120	300	800	7	17	43	114	4	57
4	60	1130	370	4	15	283	93	3	75
Total	625	2930	2950	30	21	98	98	24	80

SPE 39612. Hild, G.P. and Wackowski, R.K.

1994- 1996 Polymer Gel Treatment Program Economic Results

Investment	$2,060,500	**Incremental recovery**	685,000 bbls
Rate of return	365%	**Success rate**	80%
Payout	8 months	**Water handling cost**	$0.19/ bbl
D.P.I	3.63	**CO_2 handling cost**	$0.29/ mcf
Net present value	$3,226, 000	**Project life**	3 years

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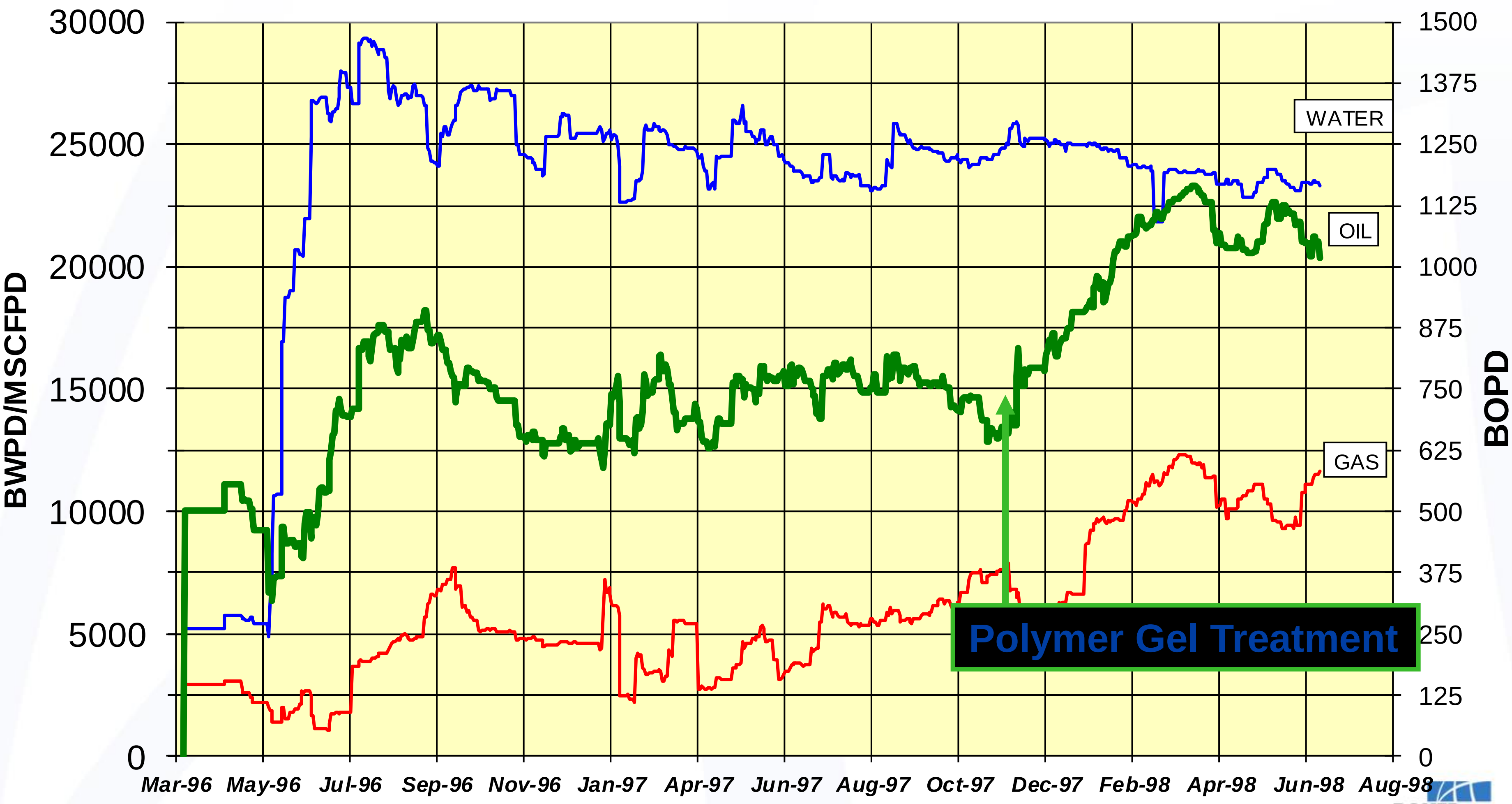
ROZ Performance after Main Pay Conformance



Final thoughts/ Challenges

- SPE 27825 - Wertz Field, WY (1994)
- SPE 35361
- SPE 39612

Rangely Field, CO (1998)

CO_2 conformance papers are 15-20 years old despite hundreds of successful treatments performed

- Gel treatments are proven to be low-risk, long-term and cost effective