Studies of Fractures; Induced and Natural and their Implications for Primary Production, Waterflooding and EOR

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Executive Summary; Why We Worry About Fractures?

• Primary Recovery Reserve Estimation – How will matrix drain? + will gas and water be associated with primary production
• Screw up sweep in waterfloods and worse in CO$_2$ Floods + maintain injectivity
• Ruin stimulation designs (hydraulic fracturing for stimulation)
Executive Summary;

But are Natural and Injection Induced Fractures all Bad?

No, there is significant benefits

Depends on

✓ Structural location/mechanical properties
✓ Fracture connectivity
✓ Matrix permeability
✓ Proactive flood management
Organization of talk

1. Executive Summary
2. Natural Fractures Description/ Identification
   - Structural location/mechanical properties
   - Fracture connectivity
3. Difference between hydraulically induced fractures vs. injection fracture (waterflood / EOR)
4. How are waterflood/ EOR (CO$_2$) Injection Induced Fractures caused?
5. Reversibility of induced fractures in waterfloods and EOR
6. Conclusions
Credit where credit is due

• A lot of people have put this picture together I am just summarizing it
  • See references in the back
Experience and Observations from 53 Countries and hundreds of reservoir studies; Rule of Thumb

- ~50% of reservoirs have open fractures initially
- ~50% of reservoirs have closed fractures initially
- 95% of injection projects have open fractures near injectors
- Some high permeability reservoirs are not affected by fractures
- Low permeability (Kair < 10 md) reservoirs are affected by fractures

The amount of fracturing is more prevalent in carbonates
Natural Fractures
Fractures are ever present in Sedimentary Rocks

- **Outcrops** → almost always have some fractures present
- **Lost drilling mud**
- **Water oil ratio, GOR, CO₂ floods and inter-well tracer studies**
  - *Very quick fast breakthrough in the direction of maximum horizontal stress* ($Sh_{max}$)
- **Fall off tests** → presence of linear flow even in non fractured reservoirs
- **Polymer and gel treatment** injection pressures are much lower than theoretical radial matrix flow
Fractures Description/ Identification

- Fractures are present in most sedimentary rocks except ductile rocks like halites, anhydrites and some shales.
- For natural fractures spacing varies with lithology and presence? location of structural features (faulting and structural highs bending).
- Thinner beds often more intensely fractured zones.

Figure 3.25. Brecciated fault trap.
What controls natural fractures?

- Dolomite 3 ft fracture spacing
- Limestone 1 ft fracture spacing

Example of fracture spacing changing with lithology

Top of structure

https://www.bing.com/images/search?view=detailV2&ccid=w%2fhEtK4L&id=A7ECFD4D24AD11593AB587C2321E1726CD3951B3&thid=OIP.w_HEtK4Lplzesd03BbR2xgErEs&q=bent+ruler+image&simid=608025521124216351&selectedIndex=0&ajaxhist=0
Example of Direct Observation of Fractures

Differences in fracture spacing and orientation between zones

Mechanical Properties

More shale zones act as termination points

Spraberry Fracture System Schematic

Average fracture spacing
3.17 ft (N42E)

Average fracture spacing
1.62 and 3.8 ft (N32E and N80E)

Pay zone, 5U
Siltstone, Vshl<15%, f>7%

Non-pay zone, 2U, 3U, and 4U
Siltstone+Dolomite, Vshl<15%, f<7%

Gamma Ray Response

Pay zone, 1U
Siltstone, Vshl<15%, f>7%

Sand layer 1U (10 ft)

Shale layer (140 ft)

Sand layer 5U (15 ft)

150 ft.

Example of Direct Observation of Fractures

Differences in fracture spacing and orientation

Between zones

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What controls natural fractures?

Lisbon field Alaska (Chevron)

Faulting

RB examples
- Alaska
- Rocky Mountains (USA+ Can.)
- Columbia, Ecuador, Cuba
- Iran, Iraq

Alaska; Mega scale fractures are often associated with water/gas invasion (Alaska, Canadian Rocky/foothill), South America

Off shore fields North Sea see Rate correlations between wells 4 miles away with <1 one month leg K. Heffer SPE 130734
What controls the presence of natural fractures?

- Lithology
  - Carbonates ↑
    - Dolomites vs. Limestones
  - Sandstones ↓
- Mechanical properties
  - Thin beds
  - Brittleness
  - Ductility
- Faults
- Top of structure
Hydraulic fracturing vs Injection Induced Man-made Fractures: **Growth Rate**

- **Hydraulic fracturing (high pressure, fast rates); done in hours (110’s ft/ hour)**

- **Waterflood or CO\(_2\) induced fracturing (lower pressure, slower rates) → caused be temperature and particulate matter (plugging) growth in days and years (~1ft/day)**

Injection of low viscosity fluids, such as water/CO\(_2\), differs dramatically from traditional high viscosity fracture completion fluids, leak-off rates much higher in gas and waterfloods.
Hydraulic Fracturing vs. Waterflood/Injection Induced Fracturing

- Fracture leak off controlled
- Temperature controlled

Leak off very low

hydraulic fracturing for stimulation
How do Waterflood or Injection Induced Fractures Grow? It is Leak-off Dependent

Water Leakoff controlled process

Large amount of viscous crossflow in (high permeability) case

Fracture does not grow

Fracture grows

Small amount of viscous crossflow in (low permeability) case
How do Waterflood or Injection Induced Fractures Grow?

- low leak off case
  - low permeability

- High leak off case
  - High permeability

Very Very Poor Sweep

Very good Sweep/ Good injectivity
Arrow drawn by RB; induced fractures grow to interwell distances

Fractures don’t grow

Unconventional Reservoirs

Conventional Reservoirs

Tight Gas or Tight Oil Sandstone

Conventional Oil or Gas Reservoirs

Shale

Limestone

*Natural Gas from Coal

Extremely Tight

Very Tight

Tight

Low

Moderate

High

Permeability (mD)

0.0001

0.001

0.01

0.1

1.0

10.0

100.0

Poor

Quality of Reservoir

Good


Permeability Classification Permeability (mD)

Very low < 0.01

Low 0.01 – 1

Average 1 – 100

High 100 – 10000

Very high > 10000

* Natural Gas from Coal reservoirs are classified as unconventional due to type of gas storage.
Experience and Observations from 53 Countries and hundreds of reservoirs

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95% of injection projects have open fractures near injectors

Some high permeability reservoirs are **not** affected by fractures

low permeability (Kair < 10 md) reservoirs are **affected** by fractures

Natural fractures or plains of weakness; water/EOR fluids connect

Injector wellbore
Why do I believe in injection induced fractures? Dynamic data evidence

• Lack of sensitivity of injection pressure to injection rate

✓ Water oil ratio, GOR, CO$_2$ floods and inter-well tracer studies

  ✓ Very quick breakthrough in the direction of maximum horizontal stress $S_{h\text{max}}$
This is extremely common 95% of injection wells

Time *(intervals every 5 minutes)* or monthly data
How common is this behaviour; lack sensitivity or pressure to rate $\rightarrow$ very common
Wainwright field, sandstone waterflood reservoir pressure constant

Injection Pressure increase; Very common after decreases in water injection rates
How are waterflood/ EOR (CO$_2$) Injection Induced Fractures caused?

- Small temperature changes
- Initial pressure depletion
- Injecting dirty water

Map View of Near wellbore region

Fracture system length and volume depends upon pore pressure. Temperature and damage on fracture
Recap

• Natural Fractures are effected by structure (FAULTS), mechanical properties and lithology

• Most Natural Fractures are not important but 1%-10% of fractures are critically important → highly connected fracture systems

• Pressure pumping hydraulic fractures generally use very low leak-off fluids to extend fractures → growth rates are very fast

• Injection Induced Fluid are high leak-off fluids → growth rates are slow

• Injection of cold water relative to formation temperature and injecting dirty water extends fractures
Conclusions

• Natural fractures are controlled by structure, mechanical properties and lithology
• Waterflood induced fractures have both a positive and a negative effect on waterflood performance
• Water and CO$_2$ injection widens existing fracture systems and connects otherwise discontinuous natural fractures or heterogeneities
• Waterflood induced fractures are not simple linear features but very likely complex fractures
• Waterflood induced fractures have often a very subtle “fracture pressure”
Conclusions

- Injection Induced Fractures and growth is effected by
  - injection rate
  - the duration of the excess pressure and the amount of leak-off to the non-fractured rock
- Cooling of the formation can cause fracturing
- Heterogeneities
- Particulate matter (dirty water)
- Presence of ductile layers/inclusions (salt, anhydrite, plastic shales)
- Erosional or chemical alteration of fracture surfaces
Lack of sensitivity of injection pressure to injection rate (some references)

- Injection fracturing in line drive waterflood Danish North Sea SPE 94049 Maersk
- Relationship between Azimuths of Flood Anisotropy and Local Earth; K.J. Heffer + A. B. Dowokporb
- Stresses in Oil Reservoirs analysis of the injection test for a waterflooding terra tek SPE-13130
- Modeling the Propagation of Waterflood-Induced Hydraulic Fractures SPE-7412
  - Danish North Sea
  - North Sea, Texas, Montana, Florida, Canada, etc.; 36 case studies;
  - Offshore
  - Western Canada
Lack of sensitivity of injection pressure to injection rate (some references)

- effect of fractures on waterflood case study SPE-1423
- Identification of induced hydraulic fractures in waterfloods SPE 59525
- G. Warren CIM Petroleum Society 95-11
- J. Andrews SPE 900949
- Injectivity; Characteristics of EOR Polymers; R.S. Seright et al oct. 2009 SPERE
- The Impacts on Waterflood Management of Inducing fractures in Injection Wells in the Prudhoe Bay ,Alaska SPE 16358

- Oklahoma
- Howard Glasscock Field of West Texas
- Western Canada
- East Coast (Offshore) Canada
- USA
- Alaska
- waterflood induced fractures Valhalla N. Sea

Also see references in back
More references


- Closing the Lab-Field Gap - A look at near-wellbore flow regimes and performance_SPE 27774


- N Sea Settari A., SPE 24912
More references

- Martin Felsenthal and Howard H. Ferrell; Fracturing Gradients in Waterfloods of Low-Permeability, Partially Depleted Zones, JPT JUNE, 1971

- "Low-cost monitoring of inter-well reservoir communication paths through correlations in well rate fluctuations: case studies from mature fields in the North Sea" SPE 130734; looked at 7500 well pairs

- Richard Baker, Tim Stephenson, Crystal Lok, Predrag Radovic, Robert Jobling, and Cameron McBurney; Analysis of Flow and the Presence of Fractures and Hot Streaks in Waterflood Field Cases; SPE 161177; looked at >1000 well pairs