[PS]Invasion and Reservoir Damage in Tight Reservoirs: Options of Avoiding and Stimulation Based on Damage Mechanisms*

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Abstract

Formation (reservoir) damage is normally thought of as being equivalent to “skin damage”. However, it is not always identifiable by skin measurements or calculations. Formation damage should be defined as any barrier to production within the confines of the near wellbore reservoir or wellbore completion interval that restricts maximum natural production of fluids or gases. One author states, “Formation Damage is simply any process, which would cause a reduction in the productivity and/or injectivity.” Barriers to production are normally thought of as being artificially induced during drilling, completion (cementing, perforating, hydraulically fracturing) or production (workovers), but they are also often naturally induced by the flow of native clays or fines within the reservoir, or by a natural oil wet condition of the rock.

An industry misconception exists that formation damage is not (or of less) concern in tight (low permeability) reservoirs. Gas/oil permeability can be reduced to a great extent due to the invasion of the liquid phase of the drill in or completion fluid. Deep invasion depths, enhanced by capillary forces, have been documented. Effect on productivity depends on the depth to which the formation damage occurs. The same situation can occur in hydraulically fractured formations. This emphasizes how important avoiding formation damage can be.

Primary damage mechanisms and factors that have a significant influence in tight gas reservoirs include mechanical damage to formation rock, water blocking, relative permeability reduction around the wellbore resulting from filtrate invasion and fluid leak-off into the formation during hydraulic fracturing. Formation damage may also result from physical, chemical or biological conditions, i.e., plugging of the pores with muds, formation fines, native clays, bacteria or scale precipitates, cement filtrate invasion, changing the wettability of the formation with surfactants, or by changing the water saturation of a formation with invasion of water from an extraneous source.

The discussion covers methods and tools to avoid, remediate formation damage resulting from various damage mechanisms to which tight reservoirs are subjected, and focuses on hydraulically fracturing. We conclude that avoiding and remediating are the most important issues to be resolved during exploitation of tight reservoirs, and every effort should be made to minimize both the severity and the depth of formation damage.

Invasion and Reservoir Damage in Tight Reservoirs: Options of Avoiding and Stimulation Based on Damage Mechanisms

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ABSTRACT

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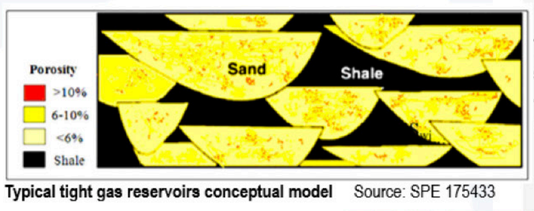
The Tight Gas Reservoir

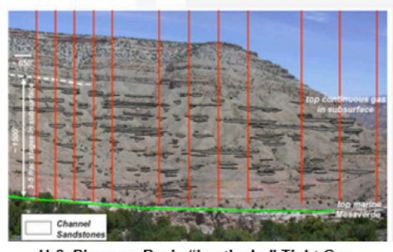
- **Tight Gas** – Reservoir with permeability **<0.1 md** (US Tax – non technical)
  Low Perm **<5 md**, found in every gas-producing Basin in world **"Tight are Unconventional"**
- **Unconventional (Holditch Definition)** – "Well that cannot be produced at economic rates nor recover economic volumes of gas unless the well is stimulated by a **large hydraulic fracture treatment or** produced by a **horizontal well** / multilateral wells."
- **No Typical Tight Gas Reservoirs:**
  - Deep or shallow
  - High-pressure or low-pressure
  - High-temperature or low-temperature
  - Blanket or lenticular
  - Homogeneous or naturally-fractured
  - Single layer or multiple layers



Tight Sand formations are stacks of isolated lenses of sand bodies - separated by shale layers

Typical tight gas reservoirs conceptual model Source: SPE 175433

- **Gas** sourced in another formation, **migrates** and **trapped** (like conventional gas) into formation where found
- Majority **Tight** (low perm) reservoirs are **Gas Bearing** marine/ fluvial **sandstones** & **siltstones -** some **marine carbonates**
- Primarily **dry gas** production; some can produce water



U.S. Piceance Basin "Lenticular" Tight Gas

"Formation Damage" Overview

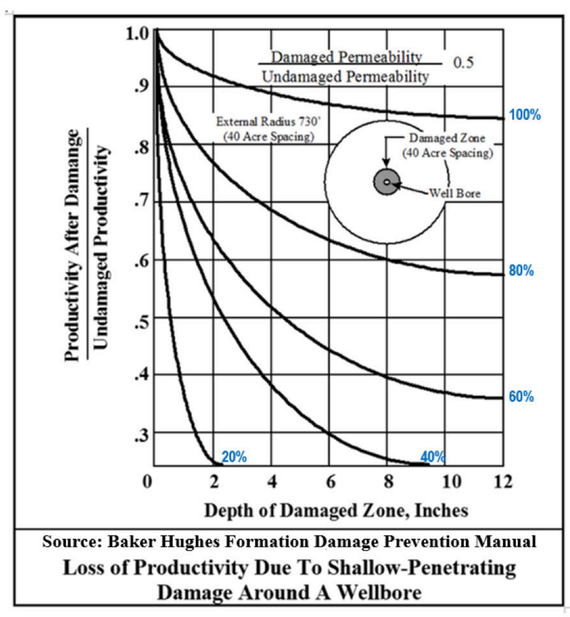
- Normal Definition – Formation Damage = Skin
- Should be Defined – "Any barrier to production within the confines of the near wellbore or wellbore completion interval that restricts maximum natural production of fluids or gases"
- A Simple Definition – "Formation Damage is simply any process, which would cause a reduction in the productivity and/or injectivity"
- Barriers to production normally thought to be Artificially Induced during:
  - Drilling (Fluids)
  - Completion (Cementing, Perforating, Hydraulic Fracturing)
  - Production (Workovers)
- Also often Naturally Induced:
  - Flow of Native Clays/Fines within reservoir
  - By natural Oil Wet condition of rock
- Industry Misconception: Formation Damage is not (or of less) concern in Tight (low permeability) reservoirs
- Gas/Oil permeability can be reduced to Great Extent by invasion of liquid phase of Drill In or Completion fluid
- Deep Invasion depths enhanced by Capillary Forces documented
- Same situation can occur in hydraulically fractured formations

Effect of Formation Damage on Well Productivity

- Most forms of Formation Damage reduce native permeability of a formation
- Evaluate Formation Damage/Remediation potential using Multi-Discipline Analysis
- Use Reservoir models to study effect of reduced permeability on well productivity
- Figure to Right shows this effect as related to depth of Formation Damage

Examples:

- Reduction of perm of 50% surrounding the wellbore by thickness of 2 inches reduces Productivity by 7%
- If Perm reduction is 12 inches thick, Productivity is reduced by 14%
- By same analysis, if perm is reduced by 90% for a distance of 12", result is 62% loss in well Productivity
- Therefore, if well should produce 1.0 MMcfd, if perm is reduced by 90% for a distance of 12", then well will only produce 380 Mcfd of gas
- Example emphasizes the importance of Avoiding Formation Damage

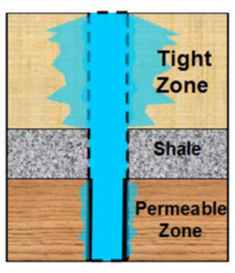


Source: Baker Hughes Formation Damage Prevention Manual
Loss of Productivity Due To Shallow-Penetrating Damage Around A Wellbore

Estimating Reduction in Well Productivity Based on Depth of Damaged Zone, Vertical Well

- Reservoir models normally used study effect of reduced permeability on Well Productivity
- Empirical Graph can Estimate Reduced well Productivity vs. Formation Damage

Example:
If Perm reduced by 90% for distance of 12",
Then Well Productivity reduced by 62%
1.0 MMcfrd potential well reduced to 380 Mcfd



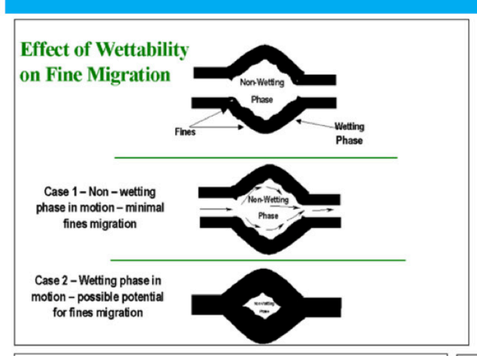
Depth (stylized) Water Invasion Damage in Tight Gas Reservoirs
Source: SPE 142284

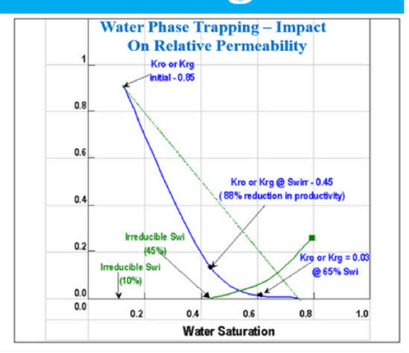
Damage Mechanisms in Tight Formations

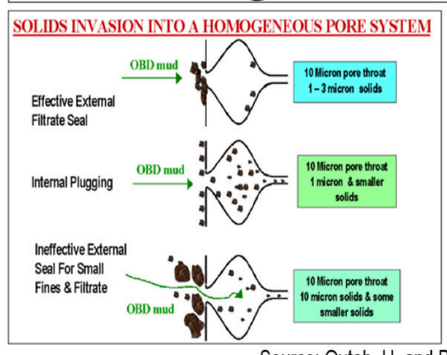
- Several different forms of Formation Damage can occur during - Drilling, Completion (Stimulation) and Production
- Damage Mechanisms essentially fall into three major Categories:
  1. MECHANICAL
  2. CHEMICAL
  3. BIOLOGICAL

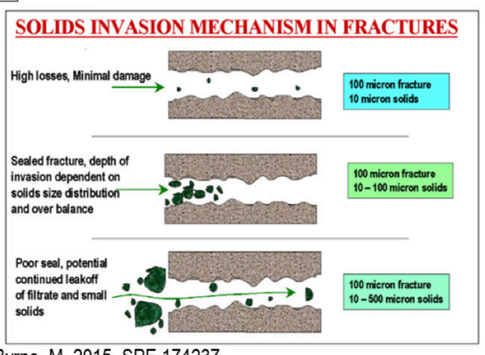
1. Mechanical Formation Damage tends to be the Most Significant for Tight Gas reservoirs – divided into three major types:
   - Fines Migration
   - Phase Trapping (Water Blocking - Relative Permeability Effects)
   - External Solids Invasion
2. Chemical Formation Damage divided into two types:
   - Rock – Fluid incompatibilities
   - Fluid – Fluid incompatibilities
3. Biological Formation Damage often over-looked due to delayed appearance, two types:
   - Aerobic (requires continuous O_2 source)
   - Anaerobic (does not require O_2 source)

Mechanical Formation Damage





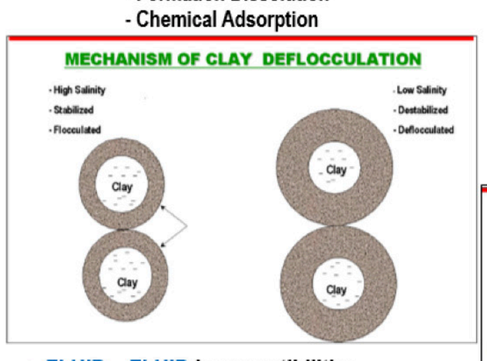


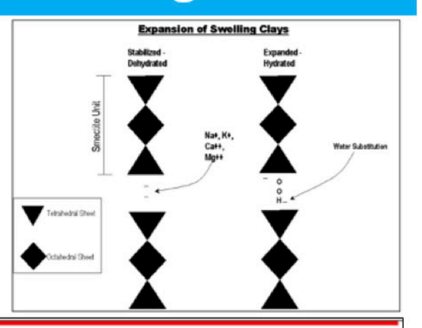


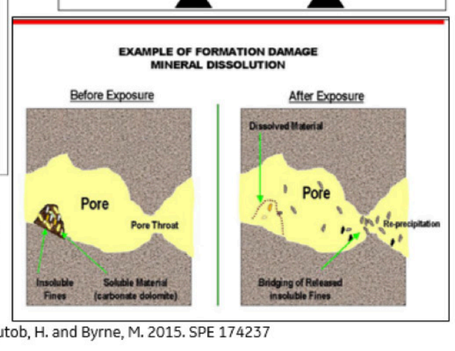
Source: Qutob, H. and Byrne, M. 2015. SPE 174237

Chemical Formation Damage

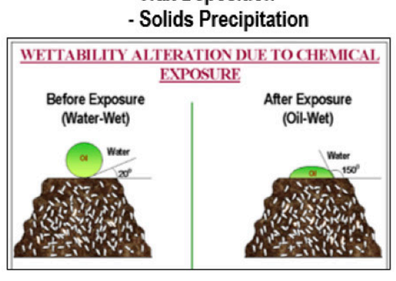
- FLUID – ROCK (Particle) Incompatibilities
  - Clay Swelling
  - Clay Deflocculation
  - Formation Dissolution
  - Chemical Adsorption







- FLUID – FLUID Incompatibilities
  - Wettability Alterations (Fluid Invasion)
  - Wax Deposition
  - Solids Precipitation

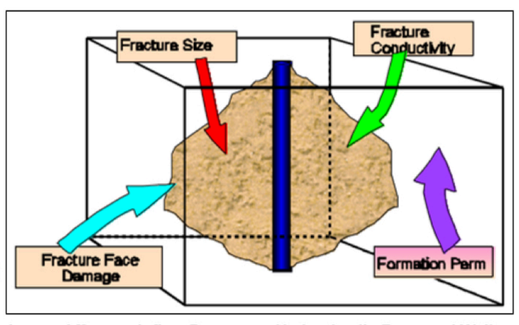


Source: Qutob, H. and Byrne, M. 2015. SPE 174237

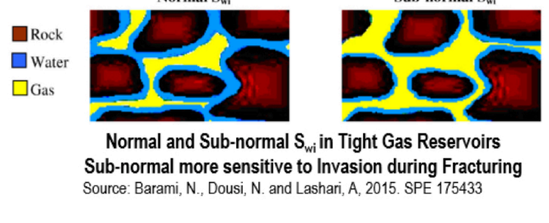
- Wax Deposition may not be true Formation Damage, but Inherent Problem
- Solids Precipitation affected by Temperature & Pressure, Primarily associated with Oil and not Gas

Hydraulic Fracturing Formation Damage

- Hydraulic Fracturing treatments can generate significant increases in well productivity, and remove/bypass some forms of Formation Damage
- Fracturing Fluid Invasion is one of the main damage mechanisms:
  - Occurs in permeable zones & natural fractures
  - Leads to serious permeability reduction in rock matrix, NF or in hydraulic fracture wings
  - Can result in Reduction of long term Production Performance due to:
    * Liquid Phase Trapping and Clay Swelling
    * In Rock Pores next to the Fractures
- Formations with Sub-normal initial S_{Wi} significantly more sensitive to damage caused by water invasion during Fracturing
- Formation Damage from Fracturing also caused by:
  - Proppant embedment
  - Gel filter cake at fracture face
  - Gel residue in proppant pack



Issues Affecting Inflow Damage in Hydraulically Fractured Wells
Source: Bennion, D., Thomas, F. et al. 2000. SPE 59753



Normal and Sub-normal S_{wi} in Tight Gas Reservoirs
Sub-normal more sensitive to Invasion during Fracturing
Source: Barami, N., Dousi, N. and Lashari, A. 2015. SPE 175433

Minimizing/Preventing Formation Damage During Drilling

Drilling Mud and Formation Damage

- Mud may damage productive zone such that it will not produce, or produce at reduced rate
- Mud Components that cause formation damage during Drilling are:
  - Invasion of Mud Particles into formation
    - Clays
    - Cuttings
    - Weighting & Lost Circulation Materials

    Mud Particles plug pores, NFs, or any flow paths where particles and fluid move
  - Invasion of Mud Filtrate into formation
    - Viscosified Fluids
    - Surfactants
    - Water & Oil

    Mud Filtrate may change formation wettability, deposit precipitants, mobilize, shrink or swell native clays, increase water saturation or restrict flow (other means)

Minimizing/Preventing Formation Damage During Drilling

- Special Designed Drill In Fluids (low fluid loss, + bridging agents/clay stabilizers, organic/OBM)
- Controlling Drilling Parameters
- Remove w/Acidizing Treatments or By-pass with perforations (if not planning to frac well)
- Air, Gas or Foam Drilling (if possible)
- Advanced Drilling Techniques – suite of tools and techniques
  - Managed Pressure Drilling
  - Underbalanced Drilling
  - Coiled Tubing Drilling
  - Through Tubing Rotary Drilling
  - Subsea Through Tubing Drilling

Remediation of Formation Damage During Fracturing

- Strong Capillary Forces in tight formations, impede fracture fluid recovery, form multi-phase flow in damage zone making invaded fracture fluid harder to remove – resulting in Well Productivity Reduction
- Use low-damage Frac Fluid Additives
- Lab experiments showed significant Conductivity Loss after water flow in Barnett cores; caused by shale fracture surface "softening" after exposure to water
- Open Hole completion may show higher productivity than Cased Hole perforated system
- Use gaseous-based (energized) frac fluids, Foam, CO2, Propane in certain Formations
- Optimize Time and Velocity of Flowback (reduced choke sizes)
- Modelling: fracture fluid invasion, proppant embedment, layer, gel filter cake residue at fracture face, and gel residue inside fracture may only reduce well productivity by very small amount in Shale Gas reservoirs
- Remove damage due to Phase Trapping by:
  - Increasing drawdown pressure (Artificial Lift)
  - Reducing interfacial tension, water/oil or water/gas (Alcohols, Surfactants, Solvents)
  - Changing physical geometry of pore system (Acidizing)
  - Remove trapped water (Artificial Lift, Evaporation, N_2)
  - Use Breakers in Fracture Treatment Design

Conclusions & Recommendations

- Majority of Low Permeability Reservoirs are Gas Bearing
- Formation Damage is a significant concern in Tight (low perm) Reservoirs
- Formation Damage can occur during Drilling, Completion (hydraulic fracturing), or Production of Tight Reservoirs
- Drilling Mud may damage productive zones such that they will not produce or produce at Reduced Rates
- Mechanical Formation Damage tends to be Most Significant for Tight Gas Reservoirs (esp. Liquid Phase Trapping)
- Use Methods/Tools to Avoid/Remediate Formation Damage

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