Sand Production: Exclusion, Management, Encouragement

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Two Basic Approaches

SAND EXCLUSION

- Screened Completions
  - Screens, filters, etc.
  - Slotted liners
  - Gravel packs
  - Frac-and-pack

- Screenless Completions
  - Oriented perforations
  - Gradient and rate control
  - Horizontal wells
  - Open holes

SAND MANAGEMENT

- Encouraging sand influx
  - Heavy oil production
  - Completion approaches

- Living with sand influx
  - Sand Management concept
  - Evolution of an oil well

- Deliberate sand clean-up
  - A workover and testing approach for wells
“Sand” vs “No Sand”

- I - “no sand” (i.e.: below detection limit)
- II - “episodic sand” (occasional bursts)
- III - “continuous sand”
- If II and III help make a lot more oil, sand becomes an “asset”
- Can II and III be “managed” at acceptable risk?
Decisions, decisions, decisions

What to do about sand?
New technologies?
New concepts?

Sand Exclusion
* Screens & Liners
* Packs & Fracs
* Well control methods

Sand Management
* Production rate control
* How much sand?
* New surface facilities

Encouraging Sand
* For heavy oils only?
* As a completion method?
* As a workover method?

Production rate increases, sand handling needed

Sanding risks lower, completion costs increase

Quantitative answers use risk analysis: data, experience, etc. are needed to make optimum economic decisions.
Maracaibo Example

- Unconsolidated strata
- Normally pressured
- Clay (kaolinite)
- Some asphaltene in heavier oils (<30°API)
- Sand production will increase oil rates
- Reduced workovers
- Offshore? Onshore?
- Analysis suggested sand influx is best $$

Courtesy: PDVSA
Many Maracaibo reservoirs are evidencing sanding as they mature

- Gravel packs, screens… have problems
  - Substantial loss of production is common
  - Kaolinite and fines tend to block the wells
  - Installation is expensive, & workovers costly

- Most of the reservoirs are offshore
  - Limited platform area, but shallow calm sea…
  - A “great fear” of sand influx exists

- Many fields are well past peak production
E.g. Gravel Packing or not?

- What is the cost of a gravel pack?
- By how much does it reduce production?
- How often will you have to do workovers?
- Is a gravel pack really the right technology for your field?
- What are the options?

Diagram:
- 7” steel casing
- 3½” slotted liner -0.012” slots packer
- 20-40 mesh gravel
- Perforated interval
Sand Management

- When can we live with “some” sand?
  - When oil rates are thereby enhanced
  - If sand management costs are modest
  - If well and facility risks can be managed

- There are costs and risks involved
  - Allowing sand influx is more “risky”
  - Facilities modification required
  - Constant surveillance is needed to manage risk

- Is it applicable in high gas rate wells?…
Flow and Sand Velocity

- Critical diameter (µm)
- Depth (m/MD/RKB)

**Flow rates:**
- 2000 m³/d
- 1500 m³/d
- 500 m³/d

**Tubing and perforations**

Courtesy: Geomec S.A.
Sanding and Geomechanics

- Sanding is a **Rock Mechanics** Issue
- The important geomechanics factors are:
  - The tensile and shear strength of the reservoir
  - The in situ stresses and pore pressures
  - The hydrodynamic drag forces on the matrix
  - Alteration of rock properties (damage)
  - Alterations of stresses and pressures with time
- Understanding the physics is vital
- The best completion strategy is vital
- Well production management is vital
Why is Physics Important?

- If you understand the mechanics, you have an excellent chance of choosing the right option for your wells.
- If you don’t, you will choose a solution that is too conservative:
  - Large expense
  - Reduction in oil production capacity
  - Expensive workovers

- SAND EXCLUSION IS ONLY ONE POSSIBLE ANSWER AMONG MANY!
**Geomechanics Impact Flow Path**

**Screening and Analysis**

- First-order screening (geology, case histories)
  - Geomechanics assessment
    - Geophysical logs
    - Petrophysical evaluation
    - Stress history
  - Impact assessment
    - Well modeling
    - Reservoir modeling
  - Mitigation options
    - Pressure maintenance
    - Completions options
    - Production practice

- Risk assessment
  - Second-order screening
  - Production predictions
- Cost-benefit analysis
- Decision making
  - Experience base
  - Learning and teaching
- Cost of options
  - Ranking cost + effect
Damaged Zones

- Cohesion damage
- Introduction of a “flaw”
- Focusing of flow paths
Damage From Perforating

Using a Mohr-Coulomb plot to illustrate damage

Although conceptual, the MC idea to express loss of shear strength from cohesion loss in perforating is important.
Fines Production

Throat blockage

Fines mobilized by:
- Δ geochemistry
- Δp (drag force)
- depletion strains

Usually fines less than 1/20th mean grain size

Fines production is not sand production. If you try to stop all sand production, you will also reduce oil production substantially.
Fines or Formation?

Typical North Sea case of fines migration

Cumulative Percentage

Grain Diameter (micron)

Produced fines

Whole formation (core)

Courtesy: Geomec S.A.
Continuous Sand Influx

- Used in CHOPS – Cold Heavy Oil Production with Sand – for viscous oils)
- A valuable, low-risk production strategy in UCS with viscous oils and gas in solution
- Entire matrix is produced (not only fines)
- Typical rates are from 0.25 to 10% sand by volume of the dead liquids
- Sanding increases well productivity, eliminates fines or asphaltenes blockages
- Must cope intelligently with sand
Continuous Sand Production

As much as 10% sand by volume liquids

Yielded and channeled zone generated by large-scale sanding

In CHOPS, sand comes in continuously (but at a highly variable short-term rate) with the viscous oil. Typically, 0.25 – 4% sand influx in Canada heavy oil ($\mu = 500 – 15,000$ cP).
Typical North Sea case: Sand burst grain size

- Produced sand
- Whole formation (core)
Intermittent Sand Bursts

- Occur in poorly consolidated sands, perforated high rate oil and gas wells
- Bursts are “self cleaning” events, and tend to remove near-well flow impediments (“skin”)
- Beneficial effects on Q, fewer interventions
- Lower CAPEX for well completions
- Higher risks because of episodic sand influx
- Facilities must be designed to handle sand
Sand Bursts

- Sanding in high rate oil wells in poorly consolidated sandstones comes in “bursts”

A burst may be from a few kg to as much as 100 kg. 

Bursts may occur every few days to every few weeks.

sand rate, g/m³

mini-bursts

sharp rise time

slow decay

10-100 min

time

A burst may be from a few kg to as much as 100 kg
The Seepage Force on Grains

The hydrodynamic or seepage force

Seepage Force

\[ F = sA_w \cdot \frac{\partial p}{\partial l} \]

The pressure gradient leads to a seepage force that destabilizes individual sand grains or groups of grains.
Hydrodynamic Drag

- Also called “seepage force”
- Results from $\Delta p$, $\therefore$ is proportional to gradient

$$ F = sA\omega \frac{\partial p}{\partial l} $$

$\rightarrow A =$ cross-sectional area of grain or “chip”
$\rightarrow w =$ a measure of grain diameter
$\rightarrow s =$ a shape factor to account for geometries

- Gradient is directional (vector), $\therefore F$ coaxial
- Sand must be pre-weakened (sheared, dilated, lost cohesion) to be able to be plucked by $F$…
Conditions Around a Tunnel

-convergent flow

σ_r'

σ_θ'

seepage force

Rock matrix

rock matrix

colloquial flow

spalling

F

F

damaged rock

4-D Sand Management
Perforation Tunnel

Wellbore

\( \sigma'_r = 0 \)

Damaged zone (low c)

Intact formation

Convergent flow region

Zone of highest seepage force
If the rock is very weak in cohesion (pre-weakened), the drag force overcomes the tensile strength at a free face, where the rock is unconfined.

If the rock is weak in shear, higher stresses caused by drawdown can lead to shearing and loss of strength (cohesion damage).

If the rock strength can be preserved, or even enhanced, the risk of sanding can be reduced substantially, but at a cost!
Rock Strength

Mohr-Coulomb plot of stresses

- Shear stress ($\tau$)
- Normal stress ($\sigma'$)

Strong rock
Weak rock

Good cohesion
Poor cohesion

Y_1
Y_2

Rock strength
Rock Strength (I)

- It is possible to reduce sanding risk by increasing the strength of the rock
  - Increase the cohesion
  - Increase the confining stress
  - Reduce the shear stress

- Many sand exclusion methods are based on these three basic concepts
Methods to increase the strength include:
- Resin treatment of weak layers, squeezes
- Placing gravel-packs to maintain $\sigma_3'$
- Use Frac-and-pack & other fracturing methods to re-stress the sand and maintain $\sigma_3'$
- Maintain high water-flood pressures to avoid increasing $\tau$, reducing $\sigma_3'$, or losing cohesion
- Use expanding screens to maintain $\sigma_3'$
Weakening of Sand

- Drilling damage can reduce cohesion and cause dilation near the borehole
- Perforation damage can generate a large zone in which the cohesion is destroyed and the rock “granulated”
- Too aggressive production can trigger disruption of fabric, weakened zone
- Depletion can change stresses
- Thermal shocking (injection well), others??
Strengthening Weak Sands

- Add cohesion, restress, minimize damage
- Cohesive methods
  - Resin injection, several approaches
  - Silicate injection
  - Resin-coated sand use in fracturing and Frac-Pack
- Restressing methods
  - Fracturing
  - Frac-Pack methods
  - Radical ideas (expand a steel liner in the wellbore?)
  - Hybrid Completion
Scale Effects, Tunnel

stable

unstable
Do you want to reduce the risk of sanding?

- Use small diameter entry ports
  - Sand will form stable arches behind the casing
  - Smaller diameter, the more stable the arch

- Use deep penetration charges
  - Larger flow area, lower local gradients
  - Smaller tunnel diameter, greater stability

- Reduce perforation density
  - Smaller damaged zones that do not overlap

- Oriented perforations in the stress field
Resin Squeeze

(furans, silicates, epoxies, etc…)

Low k bed – poor contact
Intermediate k, OK
High k, deep penetration
Selective Resin Squeeze

Used in wells on Sand Management if one seriously troublesome zone must be isolated.

Costly, and also reduces productivity index.
Liners are susceptible to scale and plugging

Openings are sized and shaped using various empirical criteria

Open hole
Slotted liner

Cement
**Open-Hole & Liners, Screens**

- Placement of a sized (slotted) filter liner

- Advantages
  - Easy to place in long open holes
  - Good sand exclusion is provided

- Disadvantages
  - Liner can collapse (formation often does)
  - Slotted liners often plug and develop scale
  - Erosion of liners is common
  - As always, reduction in PI usually develops
Screens Inside Cased Holes

Screens are prone to scale, erosion, and plugging with fine-grained minerals, but intervention is relatively easy.

A carefully sized screen is placed inside a cased, perforated well.
Inclined Well Design

12-1/4" HOLE

Rev. 9-5/8"
36 Lb/Ft.
J-55, BTC @ 800'

8-1/2" HOLE

KOP @ 3121' (MD)

Entry Point @ 4432' MD / 4133' TVD , INC= (60,04º)
DIR =233.87° Azimuth

Prepacked Screen, thermal design 3-1/2",

Hydraulic Packer @ 4212' (MD) @ 60°

Target: BACH-02 Sand, (ZONES 1,2,3)

Rev. 7", 23 Lb/ft., N-80, BTC @ 5099'

Final depth: 5099' MD, 4466' TVD
Direction: 235°Az, Final angle: 60°

Courtesy: PDVSA, Bachaquero Field
Screens, Slotted Liners, Filters

- Physical exclusion of the particles

- Advantages
  - Some fines can still flush through
  - Reduces sanding risk to almost zero

- Disadvantages
  - Not usually a selective process
  - Usually reduces PI and susceptible to erosion
  - Provides a substrate for chemical scale
  - Pore throat plugging not eliminated
  - Interventions can be extremely costly
Fracturing Methods

Fracture propped by resin-coated sand

Increase in $\sigma_3$
Fracturing Using Zone Exclusion

Sand not perforated

Very weak, high-k sand

Resin-coated sand

Increase in $\sigma_3$
High Proppant Fracturing

Treatment pressures

vertical stress

least principal stress

virgin reservoir pore pressure

“Frac-and-pack”

Proppant concentration

time (constant pumping rate)
High Rate Fractures

- Fat fractures, close to hole
- Extra wings
- Proppant forced between casing and rock, sometimes called the halo effect, verified in 1999
- Frac & pack, high rate fracs, high µ fracs

\[ \sigma_3 \]

\[ \sigma_{\theta} \text{ increases!} \]

\[ \sigma_r \text{ increases!} \]
Selective Perforating

Often bad zone is high k zone as well
Well models cannot handle this
Full numerical model needed
Economic analysis is required

Sensitive zone left unperforated;
now, it cannot produce sand
Formation cross-flow

This is a risk-reduction strategy, not guaranteed exclusion.
Phasing of Perforations

Which phasing to use?

Principal Stresses

\[ \sigma_1 > \sigma_2 > \sigma_3 \]

\[ \sigma_{hmin} = \sigma_3 \]

This is a risk-reduction strategy, not exclusion.
Spacing of Perforations

Fewer perforations:
Higher $\partial p/\partial r$ at each perf = greater sand risk
No overlap of damage zones = less sand risk

More perforations:
Lower $\partial p/\partial r$ at each perf = less sand risk
Overlap of damage zones = greater sand risk

This is a risk-reduction strategy, not exclusion.
Oriented Perforations?

![Graph showing sand stability index versus well inclination for different well azimuths](image)

- **Well Azimuth: E**
- **Well Azimuth: N60E**
- **Well Azimuth: N30E**
- **Well Azimuth: N**

*Oriented perfs*

*Courtesy: Geomec S.A.*
Open-Hole Gravel Pack

After placement, intervention is almost impossible.
Gravel may tend to scale, perforations plug with fines.

- Open casing or tubing
- Placed gravel, $D_{50} \sim 6 \times D_{50}$ of sand
- Cement
- Open hole may be reamed to larger dia.
Open-Hole Gravel Pack

- Filling the hole with a carefully sized gravel

- Advantages
  - Highly effective in long horizontal wells
  - Technology has improved greatly recently

- Disadvantages
  - Positive skins (+5 - +10) always develop
  - Removal impossible, chemical treatment hard
  - Requires re-drilling a hole if blocks
  - Does not prevent fines and mineral scale
Inside-Casing Gravel Pack

After placement, intervention is extremely difficult. Gravel may tend to scale, perforations plug with fines.

Placed gravel, $D_{50} \sim 6 \times D_{50}$ of sand

Open casing or tubing

Cemented and perforated casing
Well Placement to Avoid Sand

Vertical fractures placed to overcome low $k_v$

- Need good flow models
- Need good fracturing

Bed susceptible to sand production

- $k_h$
- $k_v$

4-D Sand Management
Horizontal Well Placement

- Avoid the sand producing layer entirely
- Advantages:
  - Sanding risk greatly reduced by avoidance
- Disadvantages:
- Problems if \( k_h \gg k_v \) (e.g. if \( k_h = 10k_v \))
  - Only works if the weak layer is easily identified and consistent in the reservoir
  - Installation of vertical fractures is expensive
  - Still doesn’t eliminate skin and scale problems
Reducing Gradient

This is a risk-reduction strategy, not exclusion.
Predictions

- Sand strength analysis based on geomechanics
- Correlated to log data
- Expressed in terms of critical well drawdown
- Used to identify the most critical layers
- Used to design the completion approach
- Used to assess well management and risks
Economics and Risk

$---------------------------------$$

ECONOMIC FACTORS

- Production Rate
  - Effect of screens on Q
  - Q and reduction of $\partial p/\partial r$

- Completion Costs
  - CAPEX for installing gravel packs, screens...

- Intervention Needs
  - Frequency of workovers
  - Scale and fines

RISK FACTORS

- Sand erosion risk
  - Surface facilities
  - Safety issues

- Well impairment risk
  - Plugging the well?
  - Casing loss?

- Sand handling requirements
  - Separation, storage, disposal
Lessons Learned

- Reducing risks of sanding may mean reducing oil recovery rates, higher completion costs, higher workover costs
- Careful geomechanics analysis and $-risk analysis is needed to choose the right approach
- For example: is an open-hole completion (with a slotted liner) perhaps the best way?
  - Less rock damage (reduced sanding risk…)
  - Reduced gradients (higher exit area)
  - Very low-cost option, likely better PI as well
  - You can later re-complete if you really need to…