Protecting your Reservoir: How Bacteria can Contaminate, the Introduced Risks and How to Develop a Program to Control Them

Ken Wunch – Energy Technology Advisor
Joe Moore – Senior Research Scientist

DuPont Microbial Control
Overview

I. Sources of Reservoir Contamination
II. Risks of Microbial Contamination to Reservoir, Production & Asset Integrity
III. Current Microbial Control Technologies
IV. Risk Assessment - Field Audits
V. Risk Mitigation
I. Sources of Reservoir Contamination

Populations:
- Mainly aerobic, freshwater organisms but higher salinity, produced water reinjection is becoming more common
- Reservoir-tolerant anaerobes present & surviving:
  o Salinity appears most important in limiting reservoir growth
  o Temperature is secondary – documented growth in 140°C reservoirs
- Spores on proppants

Processes:
- Tanks/trucks moved from site to site
- Coiled Tubing fluids flushed into reservoir
- Cleaning process questionable
- Drilling mud recycled

I. Sources of Reservoir Contamination

Proppants:
- Widely variable levels of contamination
- Evidence suggest that spores survive proppant mining/drying

<table>
<thead>
<tr>
<th>Sample</th>
<th>Total Bacteria</th>
<th>Total SRP</th>
<th>Total Archaea</th>
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</table>
I. Sources of Reservoir Contamination

Wells are NOT clean when completion begins

- Some organisms proliferate rapidly in downhole conditions
- Shut-in times after drilling and after completion influence growth

![Downhole Diagram]

- Residuals From Drilling
- Endemic Organisms?
- "Frac Hits"
I. Sources of Reservoir Contamination

Conclusions:

– Any fluids or substances injected into the reservoir during drilling or completions have the potential to carry microbes with it
– Fluids from neighboring wells can also be a source of microbial contamination
– Reservoirs are not sterile – “Life Finds a Way”
– Proactively managing contamination in injection fluids will mitigate subsequent risks

What are the risks of microbes in the reservoir?
Bowtie Risk Management

Proactive Management

- Risk Assessment
  - Modeling or Testing
  - Selection and Deployment of Appropriate Barrier

- Preventative Barrier
  - Confirmation that Barriers are Performing as Designed

- Barrier Assurance

Event

Reactive Management

- Reactive Barrier
  - Remediation e.g.
  - H₂S Scavenging
  - Biocide

- Reactive Barrier Assurance

Undesirable Consequence

- Undesirable Event e.g.
  - MIC, Souring

- Confirmation that Barriers are Performing as Designed

- - HSE Incident
  - - Production Incident
II. Risks of Microbial Contamination

Oilfield Microbial Growth

- Water
- Bugs (Bacteria, Archaea, Extremophiles)
- Microbial Control Problem Triangle
- Food
  - Simple hydrocarbons
  - Frac Fluid Polymers/Gels
  - Source Water Nutrients
II. Risks of Microbial Contamination

- **Souring**
  - Devalues hydrocarbon
  - Health & Safety
  - Corrosion
  - FeS – Formation damage
  - FeS – Biofilm development

- **MIC**
  - Asset damage
  - Biofilm formation
  - Corrosion – acids/H₂S

- **Biofouling**
  - Biofilm – flow path plugging
  - Biofilm – wettability
  - Reduced flow/recovery

**What are the impacts to operations?**
II. Risks of Microbial Contamination

Reservoir Souring

- Sulfate and thiosulfate reducers metabolize or “eat” carbon sources and “breathe in” sulfate/thiosulfate and “exhale” H$_2$S

Impacts

- Health & Safety
- Corrosion
- Scale – FeS
- Higher CAPEX – equipment replacement
- Higher OPEX – interventions and H$_2$S scavengers
- Loss of Revenue – shut-ins and devaluation

Sulfate-reducing bacterium Desulfovibrio vulgaris; the bar in the upper right is 0.5 micrometer long
II. Risks of Microbial Contamination

Microbiologically Influenced Corrosion (MIC)
- CMIC (Chemical) – metabolic products (sulfide, organic acids) trapped under biofilm/scale at metal surface
- EMIC (Electrical) – direct uptake of electrons from metallic iron

Impacts
- Health & Safety
- Loss of Primary Containment (LOPC) in tanks and pipelines
- Higher CAPEX – equipment replacement (ESPs, rod pumps)
- Higher OPEX – corrosion inhibitors, biocides
II. Risks of Microbial Contamination

Biofouling & Decreased Production
– Microbial control value propositions historically focused on prevention of corrosion or souring
– Biofilm growth in proppant packs block fluid/gas transport and reduces conductivity
– Conductivity loss will have a negative economic impact on production
– Microbial control strategies to control biofilm growth in the reservoir will enhance production

Proof of Concept (POC) ➔ Lab Studies ➔ Field Studies
II. Risks of Microbial Contamination - POC

Biofilm Growth on Proppants

II. Risks of Microbial Contamination - POC

Scanning Electron Micrographs of Biofilm Growth on Proppants

No Biofilm

Biofilm (3 days)
II. Risks of Microbial Contamination - POC

Scanning Electron Micrographs of Biofilm Growth on Proppants

No Biofilm

Biofilm (3 days)
II. Risks of Microbial Contamination - POC

Biofilm Growth in Response to Pressure

II. Risks of Microbial Contamination - POC

Biofilm Impact on Production - Modeling


8% biofilm coverage leads to 50% loss in gas flow
II. Risks of Microbial Contamination - POC

Shale GeoBioCell – Proppant Packing

A. Shale GBC with 100 mesh proppants
B. Micro-channel of shale GBC with proppants
C. and D. Higher magnification of the microchannel showing proppants

Note – No confining (reservoir) pressure on channel or proppant pack

Biofilm formation tracked through imaging using
- Stereoscope V16
- Multiphoton LSM 710
II. Risks of Microbial Contamination - POC

Hydraulic Resistance after Inoculation

After 3 & 5 days of incubation, flow was completely obstructed in Shale GeoBioCell
II. Risks of Microbial Contamination - POC

Scanning Electron Micrographs of Proppant Ejected from Channel

Extracellular matrix fibers of biofilm encapsulated in iron sulfur crystals

Proppant

Microbes
II. Risks of Microbial Contamination

Lab Studies – Ongoing Work with Stim-Lab
II. Risks of Microbial Contamination

Lab Studies – Experimental Plan

– Load shale conductivity cells with proppant. Use standard industry parameters:

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<th>Proppant type</th>
<th>40/70 mesh Northern White Sand</th>
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<tr>
<td>Proppant loading</td>
<td>1 lb/ft²</td>
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<tr>
<td>Pressure</td>
<td>2,000 psi</td>
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</table>

– Establish baseline conductivity over 48 hr using 2% KCl solution
– Inoculate with organisms isolated from shale wells
– Shut in for 7 days
– Repeat conductivity experiment with fouled cell

– Result: Comparison of conductivity before and after organism growth
II. Risks of Microbial Contamination

Lab Studies – Qualitative Results

– After inoculation, conductivity cells with added bacteria were darker, due to sulfide production and iron sulfide (FeS) formation.
II. Risks of Microbial Contamination

Lab Studies – Quantitative Conductivity Results

– Inoculation with shale-dwelling bacteria resulted in 10-20% loss in proppant pack conductivity

– Industry Reservoir Model suggests a loss of ~6000 bbl oil over the first 180 days of production

Actively Looking for Partners for Field Studies
II. Risks of Microbial Contamination

Conclusions:

- Uncontrolled biofilm growth in the reservoir and production equipment may reduce well productivity, produce H\textsubscript{2}S & FeS, and cause corrosion

- Biofilm demonstrated to grow rapidly on proppants in lab-stimulated shale fractures which can reduce conductivity by 10 - 20% and reduce production by 1,000 barrels per month

- Iron sulfide (FeS) mineral growth, caused by microbiological souring, was demonstrated to block flow channels beyond biofilm growth and can further impact production processes

- Proactively managing biofilm growth will mitigate subsequent risks

**What barriers do we use to prevent these risks?**
III. Current Microbial Control Technologies

Barriers to Mitigate Risks in Hydraulic Fracturing:

1. Biocides
2. Nitrate
3. Non-Chemical Devices
III. Current Microbial Control Technologies

Evaluation of Biocide Attributes

- All biocides are not created equal
- No biocide “silver bullet” exists
- Selecting a biocide is not a “check the box” exercise!
III. Current Microbial Control Technologies

Surface Active Compounds
- Cationic quaternary ammonium biocides
  - ADBAC, DiDAC, TTPC
  - Cocodiamine, PHMB ("quat-like")
- Commonly used as hard surface disinfectants

Benefits
- Effective at low doses (10-25ppm)
- Excellent high pH and temp stability
- Biofilm penetration

Limitations
- Shale/sandstone adsorption
- Reactivity with anionic fluid additives (hPAM)
- Less effective in hard and saline waters
- Foaming
- Emulsification
- Variable biodegradation profiles
- High aquatic toxicity

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<th>Active Ingredient</th>
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<tr>
<td>AQUCAR™ 742</td>
<td>42.5% Glutaraldehyde, 7.5% ADBAC</td>
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<tr>
<td>AQUCAR™ 714</td>
<td>14% Glutaraldehyde, 2.5% ADBAC</td>
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<tr>
<td>AQUCAR™ 7140 LT</td>
<td>14% Glutaraldehyde, 2.5% ADBAC – freeze stable</td>
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</table>
III. Current Microbial Control Technologies

Oxidizers

- Inorganic, reactive biocides
  - ClO$_2$, bleach, peroxide
  - Peracetic acid, performic acid (breakdown to peroxide)
- Commonly used for disinfection and treatment of industrial/potable water
- Used for preparation of topside injection water sources

Benefits

- Extremely fast kill
- Effective at low doses (1-5ppm)
- Residuals easily measured in the field

Limitations

- No residual kill due to high reactivity
- React with chemical additives in functional fluids
- Highly corrosive
- Can form persistent halogenated disinfection byproducts
III. Current Microbial Control Technologies

2,2-dibromo-3-nitrilopropionamide (DBNPA)

- Widely used in oilfield applications
- Many non-oilfield uses
  - Industrial water treatment
  - Consumer product decontamination
  - Manufacturing plant hygiene

Benefits

- Extremely fast microbial kill
- Non-corrosive at end-use levels
- Excellent speed of kill and additive compatibility balance (as compared to oxidizers)
- Fast abiotic degradation

Limitations

- Fast abiotic degradation
- Incompatible with sulfides
- React with oxygen scavengers (bisulfite)

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<td>AQUCAR™ DB 100</td>
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<td>AQUCAR™ DB 20</td>
<td>20% DBNPA (l)</td>
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<tr>
<td>AQUCAR™ DB 5</td>
<td>5% DBNPA (l)</td>
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</table>
III. Current Microbial Control Technologies

Tetrakis (hydroxymethyl) phosphonium Sulfate (THPS)

- Widely used in oilfield applications
- Commonly used in offshore water flooding

**Benefits**
- Moderate high pH and temperature stability
- Dissolves iron sulfide deposits
- Relative low aquatic toxicity
- Rapid kill and preservation activity

**Limitations**
- Reactivity with anionic fluid additives (hPAM)
- Adsorption to shale
- Reacts with oxygen scavengers (bisulfite)
- Incompatible with sulfides
- Forms inactive THPO in the presence of oxygen
III. Current Microbial Control Technologies

Glutaraldehyde

- Widely used in oilfield applications
- Many non-oilfield uses including medical sterilants, animal biosecurity and cooling towers
- Commonly blended with quats (synergy)
  o Glut/quat (6:1 ratio)
  o Most commonly used oilfield biocide treatment

Benefits

- Rapid kill and preservation activity
- Moderate high pH and temperature stability
- Readily biodegradable
- Efficacious in sour water

Limitations

- Reacts with oxygen scavengers (bisulfite)
- Incompatible with primary amines

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<td>AQUCAR™ GA 50</td>
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<tr>
<td>AQUCAR™ GA 25</td>
<td>25% Glutaraldehyde</td>
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</table>
III. Current Microbial Control Technologies

2-bromo-2-nitro-1,3-propanediol (Bronopol)

- Many non-oilfield uses
  - FDA approved for indirect food contact
  - Industrial water treatment

Benefits
- Good balance between quick kill and length of protection
- Available as a solid and liquid
- Compatible with fluid additives

Limitations
- Rapid hydrolysis occurs at high pH and temperature
- Reacts with oxygen scavengers (bisulfite)
- Incompatible with sulfide

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<th>Active Ingredient</th>
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<td>AQUCAR™ BP 100 (s)</td>
<td>99% Bronopol</td>
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<tr>
<td>AQUCAR™ BP 30 (l)</td>
<td>30% Bronopol</td>
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</table>
III. Current Microbial Control Technologies

**Tris(hydroxymethyl)nitromethane (THNM)**

- Slowly degrades to the active biocidal chemistry (formaldehyde)
- Traditionally used for water-based material preservation (coatings, household products)
- Provide long-term protection, but slow initial microbial kill (poor “kill study” results)
- The parent molecules possess no antimicrobial activity and must degrade to provide microbial kill

**Benefits**

- Effective at high temperature
- Effective at high salinity
- Compatible with fluid additives
- No rock adsorption
- Readily biodegradable
- Low mammalian and aquatic toxicity

**Limitations**

- Reacts with oxygen scavengers (bisulfite)
- Formaldehyde released will scavenge sulfide
III. Current Microbial Control Technologies

4,4-dimethyloxazolidine (DMO)
- Hydrolysis degrades to the active biocidal chemistry (formaldehyde)
- Traditionally used to preserve paints and industrial products
- Provide long-term protection, but slow initial microbial kill (poor “kill study” results)
- The parent molecules possess no antimicrobial activity and must degrade to provide microbial kill

Benefits
- Effective at high temperature
- Effective at high salinity
- Compatible with fluid additives
- No rock adsorption
- Readily biodegradable
- Low mammalian and aquatic toxicity

Limitations
- Reacts with oxygen scavengers (bisulfite)
- Formaldehyde released will scavenge sulfide

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<tbody>
<tr>
<td>AQUCAR™ A 78</td>
<td>78% DMO</td>
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</tbody>
</table>

![Chemical structure of 4,4-dimethyloxazolidine (DMO)](image)

Antimicrobial Efficacy
Compatibility
Increasing Length of Protection
Increasing Speed of Action
III. Current Microbial Control Technologies

US Biocide Regulations

- In the US, the EPA has significant oversight responsibilities for biocides
- Mandated by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
  - Same law that governs pesticides and herbicides applied to food crops
- Biocides must be registered and are subjected to rigorous testing by the manufacturers
- Manufacturers propose applications and use limits for products
- EPA evaluates data and uses to ensure the product will not harm people or the environment when used as directed
- Only registered biocides allowed to be applied and can only be used as directed on the label
- EPA FIFRA has enforcement process and can issue fines and incarceration for violations
III. Current Microbial Control Technologies

Nitrates

- Non-biocidal
- Competitive inhibition – nitrate stimulates nitrate reducing bacteria (NRB) to outcompete SRB
- Typically used in conventional waterflooding to control souring

Benefits

- Non-biocidal and not regulated by EPA

Limitations

- Only limits souring – can stimulate biofouling and corrosion
- Effective with constant treatments, not as a one-time dose during completions
III. Current Microbial Control Technologies

Non-Chemical Devices

- Doesn’t use chemicals
- Use mechanisms such as UV light, sonication, shear to kill organisms

Benefits
- Not regulated by EPA

Limitations
- No protection beyond initial kill
- Bacteria rebound quickly
- Typically low throughput
- Energy intensive
- Ineffective against moderate or high organism loads
- Reduced efficacy in turbid or saline water
III. Current Microbial Control Technologies

Potential New Technologies

– Enzymes – biological catalysts for souring, MIC or biofouling control
– Probiotics – introduction of favorable organisms to control harmful ones
– Phages – introduction of viruses that infect and kill bacteria

Risks & potential barriers are identified.
How do we assess the risks in the field?
IV. Risk Assessment – Field Audits

Overview of a Field Audit

- Risk Assessment - collect field samples to enumerate bacterial contamination entering the system and measure how it changes through major stages & processes
- Qualify risk by assigning “traffic light” threat levels to quantification
- Barrier Assurance - evaluate performance of incumbent barriers to mitigate risks
- Provide recommendations for improvements
### IV. Risk Assessment – Field Audits

#### Enumeration Methods for Barrier Assurance

<table>
<thead>
<tr>
<th>Method</th>
<th>Pros</th>
<th>Cons</th>
</tr>
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<tbody>
<tr>
<td>Culture vials (&quot;Bug Bottles&quot;)</td>
<td>• Detects organisms that are viable in the original sample</td>
<td>• Defined media can only culture small subset of organisms</td>
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<tr>
<td></td>
<td>• Inexpensive</td>
<td>• Only semi-quantitative</td>
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<tr>
<td></td>
<td>• Commonly used in the oilfield</td>
<td>• Delayed results (1-4 weeks)</td>
</tr>
<tr>
<td>Adenosine Triphosphate (ATP)</td>
<td>• Quick results (minutes)</td>
<td>• High ATP reads do not necessarily correlate to problematic organisms</td>
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<td></td>
<td>• Can detect unculturable organisms</td>
<td>• Chemistry or physical properties of sample may interfere with assay</td>
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<tr>
<td>qPCR</td>
<td>• Can detect unculturable organisms</td>
<td>• Expensive</td>
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<td>• Can be customized to detect specific groups of organisms or metabolic processes</td>
<td>• Requires specialized training and equipment</td>
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<td>• Currently difficult to perform in the field</td>
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</table>
IV. Risk Assessment – Field Audits

Metagenomics

– Qualitatively evaluate taxonomy of sample populations

– Example* – trend reservoir population changes over time in correlation with salinity changes

– Basin specific models to assess impact of microbes on production primary deliverable of MAPFRAC (Microbes Affecting Production in Fracturing Systems) Project

*Daly, Wilkins, Wrighton, et al. (2016) Microbial metabolisms in a 2.5-km-deep ecosystem created by hydraulic fracturing in shales. Article # 16146 Nature Microbiology
IV. Risk Assessment – Field Audits

General Field Audit Results from U.S. Completions

- Microbial audit during hybrid frac completions in Anadarko Basin
- Reservoir temperature ~ 90°C
- Field used ClO₂ upstream of frac tanks and 0.500 gpt (500 ppm) glut/quat (15% active) biocide at the blender

Legend

- **Bug Bottles**
  - ≥3: 2
  - 1
  - 0
  - SRB: Sulfate-Reducing Bacteria
  - APB: Acid Producing Bacteria

- **qPCR**
  - >10⁵
  - 10⁻³⁻¹⁰⁻⁵
  - 10⁻²⁻¹⁰⁻³
  - <100

- **ATP**
  - >10³
  - 10⁻²⁻¹⁰⁻³
  - <10

General Field Audit Results from U.S. Completions

Samples from frac pond were heavily contaminated

Frac water holding tanks

Proppant storage units

Blender

Other frac chemistries (biocide, buffer, x-link, FR, etc.)

Pressure pumping

Well head

Frac pond

ClO₂ treatment

Gel Hydration

Frac water holding tanks

ClO₂ treatment of the source water was initially effective

Not tested

Not tested

Increased contamination upon gel hydration

Coalesced water was highly contaminated

Glut/quat treatment effectively reduced microbial counts

Guar and FR harbored some microorganisms

Proppant inputs showed little contamination

# bottles tested:

FOS copies/mL

qPCR

mg ATP/mL

SigB Bacteria

SRB: Sulfate-Reducing Bacteria

APB: Acid Producing Bacteria
IV. Risk Assessment – Field Audits

Drillout Fluids

– Drillout water is a field-relevant glimpse of if the well was properly decontaminated
– ~ 3 weeks between completions and drillout

– Drillout flowback was clean at multiple points along lateral
– Coiled tubing drill fluid introduced contamination into the reservoir
IV. Risk Assessment – Field Audits

Produced Fluids

- 1 month: produced water remained clean
- 3 months: produced water showed a significant increase in microbial counts
- Metagenomics data shows growth of *Thermosipho, Desulfomicrobium* (both sulfide producers) & *Thermoanaerobacter* (thiosulfate reducer)

- Glut/quat treatment in the blender effectively decontaminated the well for several weeks
- Microbial control program was not optimized for extended downhole protection
IV. Risk Assessment – Field Audits

Using Metagenomics for Contamination Source Tracking

<table>
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<tr>
<th>Microorganisms</th>
<th>H₂O drill mud</th>
<th>oil drill mud</th>
<th>source H₂O</th>
<th>pre-CI₂O₂</th>
<th>post-CI₂O₂</th>
<th>tank solids</th>
<th>pre-hydration</th>
<th>post-hydration</th>
<th>proppant</th>
<th>SW frac</th>
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<td>Caldanaerobacter</td>
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<td>Marinilibiaceae</td>
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**Sulfidogenic**

- not detected
- 0.0-0.5%
- 0.6-5.0%
- 5.1-20.0%
- 20.1-30.0%
- 30.1-40.0%
- 40.1-50.0%
- > 50.0%
IV. Risk Assessment – Field Audits

Using Metagenomics for Contamination Source Tracking

Drill Muds Are a Source

Thermoanaerobacter
Thermotoga
Desulfomicrobium
Thermosiphon
Desulfotomaculum
Desulfibacter

Unclass. Clostridiaceae 1
Hypnocyclicus
Ruminococcaceae
Unclass. Peptococcaceae
Defluviitalea
Proteiniphilum
Caldicoprobacter
Caldanaerobacter
Marinilabiliae

Drillout Introduces Sulfidogenic Bacteria

Dirty Water Tanks Negate ClO₂ Treatment

not detected
0.0-0.5%
0.6-5.0%
5.1-20.0%
20.1-30.0%
30.1-40.0%
40.1-50.0%
> 50.0%
IV. Risk Assessment – Field Audits

Conclusions:

Risk Assessment
- Input water is highly contaminated
- Microbial contamination in frac water tanks is widely variable, but frac fluid is only as clean as the dirtiest tank
- Guar stimulates downstream microbial growth
- Drilling fluids and coiled tubing drill fluid introduced uncontrolled contamination into the reservoir

Barrier Assurance
- Protection provided by ClO$_2$ is short-lived and essentially negligible
- 500 ppm (0.5 gpt) glut/quat was able to decontaminate the well and provide initial reservoir protection for several weeks
- Preventive barriers can only be added during completions so barrier assurance conclusions can only inform the next well completions
- Biocide application strategy should be optimized based on desired length of downhole protection
IV. Risk Assessment – Field Audits

Operator Actions Based on Recommendations:

1. Reevaluated and discontinued application of ClO$_2$
2. Increased glut/quat usage at blender
3. Agreed to evaluate glutaraldehyde and long-term preservative biocide

How do we develop a risk mitigation program to maximize production and deliver high-quality hydrocarbons?
V. Risk Mitigation – Preventative Barriers

Proactive Management

- Risk Assessment
  - Modeling or Testing
  - Selection and Deployment of Appropriate Barrier

- Preventative Barrier
  - Confirmation that Barriers are Performing as Designed

- Barrier Assurance
  - Undesirable Event e.g. -- MIC, Sourcing

Reactive Management

- Reactive Barrier
  - Confirmation that Barriers are Performing as Designed
  - Remediation e.g.
    - H₂S Scavenging
    - Biocide

- Reactive Barrier Assurance

Undesirable Consequence

- HSE Incident
- Production Incident
V. Risk Mitigation – Preventative Barriers

Uncontrolled Microbial Growth – Economic Impact

- **Economic Impact**
  - **Souring related**
    - Less valuable, sour hydrocarbon
    - H₂S scavenger purchase
    - H₂S exposure (health & safety)
    - Iron sulfide treatments
    - Shut-in well downtime
  - **Biofouling related**
    - Reduced production rates
    - Shut-in well downtime
  - **MIC related**
    - Loss of containment
    - Asset repair/replacement

- **Cost of Biocides**
  - Safe shipment & handling
  - Regulatory compliance
V. Risk Mitigation – Preventative Barriers

Antimicrobial Treatment Phases of Hydraulic Fracturing:

Three Phases
1. **Prepare** the Water
2. **Decontaminate** the Well
3. **Protect** the Formation/Reservoir
V. Risk Mitigation – Preventative Barriers

Optimized Biocide Treatments for Hydraulic Fracturing

“Prepare” Phase Treatments
Primary attribute = **Speed**

- **Topside microbial kill**
  - Limited biocide–microbe contact time, demands **rapid kill** activity, rather than chemical stability

  Additional desired attributes
  - Minimal corrosiveness

“Decontaminate” Treatments
Primary attribute = **Compatibility**

- **On-The-Fly**
  - Must keep fluid clean after introduction of other components and remove residual drilling wellbore contaminants.

  Additional desired attributes
  - Reactivity balance between quick kill and long-term

“Protect” Phase Treatments
Primary attribute = **Endurance**

- **Downhole microbial kill**
  - Chemical **stability** and **availability**, allowing the biocide to act on microbes at the right time

  Additional desired attributes
  - High temperature and salinity stability
  - No rock adsorption
V. Risk Mitigation – Preventative Barriers

Comparative Efficacy of Oilfield Biocide Chemistries
V. Risk Mitigation – Preventative Barriers

Field & Lab Results that have Informed our Recommendations

1. Quats & THPS are neutralized and ineffective downhole in the presence of shale

V. Risk Mitigation – Preventative Barriers

Field & Lab Results that have Informed our Recommendations

2. Oxidizer protection is short-lived and cannot control downstream contamination
3. Glut/Quat treatment at the blender decontaminates & preserves frac fluid short-term
V. Risk Mitigation – Preventative Barriers

Field & Lab Results that have Informed our Recommendations

- Recent Permian Audit

Week 1 lower salinity input water = Higher initial bioload

ClO₂ reduces contamination both weeks.

Regrowth occurs in week 2
Organisms have adapted

Glut/Quat provides complete decontamination both weeks.
V. Risk Mitigation – Preventative Barriers

Field & Lab Results that have Informed our Recommendations

– Recent Permian Audit

qPCR avoids ATP’s detection bias toward aerobic organisms. Detects organisms that cause problems downhole.

Week 2 regrowth in hydration unit is higher than source water.

Glut/Quat reduces bioload both weeks.
V. Risk Mitigation – Preventative Barriers

Field & Lab Results that have Informed our Recommendations

4. Preservative chemistries extend reservoir protection

- Field study at 25 well pads with 72 total wells tested
- Glut (125 ppm) + DMO (150 ppm) coinjected
- SRB, APB & ATP monitored in produced water for 90 days
- Excellent control over bacteria (>93% of samples <10^2/ml)

V. Risk Mitigation – Preventative Barriers

Field & Lab Results that have Informed our Recommendations

4. Preservative chemistries extend reservoir protection

- Initial Challenge (Drilling and Fracturing)
- Challenge 2 (Drillout)
- Challenge 3 (Frac hit)

Simulated laboratory shale reservoirs
- Pressure (1000 - 2500 psi)
- Temperature (95 – 160 F)

Filled with Simulated Injection Fluids...
- 1-3% TDS water
- 1,000 ppm anionic hPAM

...and solids/formation materials...
- Dense sediments of 40-100 mesh sand and 6-100 mesh Wolfcamp Shale

...locked in for 10 weeks, periodically measure H₂S
V. Risk Mitigation – Preventative Barriers

Questions that Need to be Addressed:

– Do you understand the threats to your field?
– Is your company proactive or reactive?
– What are you trying to protect?
– What are the recommended preventative barriers?
V. Risk Mitigation – Preventative Barriers

Do you Understand the Threats to your Field?

– Scrutinize the operation and evaluate where you may contaminate equipment or the reservoir
– Perform basic microbial testing on injected fluids or equipment that may be contaminated
– Routinely monitor production to ensure selected barriers are performing as intended
– Perform an audit if preventative barriers are failing
V. Risk Mitigation – Preventative Barriers

Is your Company Proactive or Reactive?

– A proactive microbial control program is holistically more cost effective
– Often sacrificed when completion cost and not production is prioritized
– A proactive microbial control program must be executed during completions
V. Risk Mitigation – Preventative Barriers

What are you Trying to Protect?

– The reservoir and resultant first months of production; your assets
– Prioritize chemistries that “Protect the Reservoir” and “Decontaminate the Well”
– Ensure barriers “do no harm”
V. Risk Mitigation – Preventative Barriers

What are the Recommended Preventative Barriers?

- Glut/Quat blends added at the blender are the workhorse of the industry and will provide several weeks of cost-effective protection.
- The addition of a “Protect the Reservoir” chemistry such as DMO will extend the production of high-quality hydrocarbons.
- DMO or THNM are excellent choices to preserve a well during a prolonged shut-in and can offer months of microbial control to prevent souring, corrosion or biofouling.
References


• Daly, Wilkins, Wrighton, et al. (2016) Microbial metabolisms in a 2.5-km-deep ecosystem created by hydraulic fracturing in shales. Article # 16146 Nature Microbiology.


