Can Water Guide Economic Performance?

Preferential water producing zones in tight oil systems: Insights for exploitation

Decision Driven Data Collection and Analysis

Making Water Data More Valuable by Pantano & Franks
Reservoir Dynamics Drive Economics

- Know what is being produced! 
  - Identify formation vs fracturing water using stable isotopes

- Know where fluids are coming from! 
  - Allocate produced water to specific formations/facies with Strontium isotopes

- Learn what helps or hurts production! 
  - Employ historical archives of continuous monitoring to optimize operations

- Actively improve HC recovery! 
  - Use inline metering water properties to react real time to changes in chemistry
Laterals in Cross Sectional View

- Middle Bakken Lateral
- Three Forks Lateral

Gamma Ray
Bulk Volume Oil

API_WellNo
33105038070000
33105038080000
33105038090000
33105038100000

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Archived data illustrates 1 out of 4 Good? Can we learn to get 3 out of 4 Good?
Reservoir Dynamics From Flow Rates

- **Frac Hit?**
- Drop in HC production when nearby 3 wells came online

Daily Oil Rates

Daily Water Rates

Spike in produced water rate when nearby 3 wells came online
• First MB well lost > 100 K BOE by new wells
  • Stable Isotope data could have revealed where and when stimulation came back
  • Residual Salts Analysis (RSA) could have shown which facies were contributing water
  • Continuous Density (SG) and EC (1/Rw) could have shown real time switching from one source another
  • Integrating 1-3 with stimulation and operation events increase chance of improved recovery factors (RF)

Best time to plant a tree is 50 years ago, second best is NOW! (proverb)
Know what is being produced!

- Identify formation vs fracturing water using stable isotopes

**Cum Stimulation Water Recovered For SE MB Lateral**

- **Cum Stimulation Water Recovered**
- **Cum Water (BBL)**

**Injected 190,000 Barrels**

- **100 %**
- **50 %**
- **0 %**

**Northern wells create pressure drop which increases amount of fracturing water recovered**

**Pure Formation approximately +6**

**Pure Stimulation Water Signature < -15**

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Completion Water Accounting Robust and Accurate

- **Produced Water Sample 18**
  - Due to squeeze for scale

- **Flow Back Sample 10**

- **Flow Back Sample 1**

- **Stimulation Water**
  - 50%

- **Completion Surface Water**
  - δ¹⁸O: -17%
  - TDS: 0.1 g/l

- Deep Basin Brine
  - δ¹⁸O: +5%
  - TDS: 220 g/l

- 6 Days
- Produced Water Samples 1-20**

- 600 Days

Stable isotopes identify fresh water treatment
TDS of sample 230,000 mg/l → due to scale dissolution
Know where fluids are coming from!

- Allocate produced water to specific formations/facies with Strontium isotopes

Geophysics detects energy events not connectivity of fluids!

Need to have method to identify where formation fluids are originating.

Composition of major components are more robust than trace.
Residual Salt to Facies Water Chemistry

1. 20 grams crushed internal chunk of core
2. 20 ml Distilled Water
3. Lab

Concentration of the Leachate = $C_{Lx}$

$$FW_x = C_{Lx} \left( \frac{V_L}{\phi . S_W . V_C} + 1 \right)$$

Eq. 1

Where:
- $FW_x$ = Concentration of constituent X in the formation water (mg/l).
- $C_{Lx}$ = Concentration of constituent X in the leachate (mg/l).
- $V_L$ = Volume of leachate (cm$^3$).
- $V_C$ = Volume of core (cm$^3$).
- $\phi$ = Fractional porosity of core.
- $S_W$ = Fractional water saturation of core.


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Know where fluids are coming from!

- Allocate produced water to specific formations/facies with Strontium isotopes
Know where fluids are coming from!

- Allocate produced water to specific formations/facies with Strontium isotopes

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Flow Meter Data Improves Ability to Learn

- Ratios of the flow rates of the different phases identify events that could be managed differently.
- Look backs on historic data indicate opportunities for behavior to be repeated or avoided.

Learn what helps or hurts production!

• Employ historical archives of continuous monitoring to optimize operations
Learn what helps or hurts production!

- Employ historical archives of continuous monitoring to optimize operations

Coriolis Mass Meter

Valuable Oil-Gas-Water Separator Data

EasyClosedLoopCalibrator

EC Probe

Gas Water Separator

Temperature

Water Density

Mass Flow

30 Minutes

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SG with EC Improves Real Time Salt Content of Produced Water from +/- 20% to +/- 10%
EasyClosedLoopCalibrator Ideally brings it down to +/- 2%
Actively improve HC recovery!

- Use inline metering water properties to react real time to changes in chemistry

Real time data to avoid costly events

Inline calibrated with grab samples illuminate dynamics for real time actions.

Grab samples alone are good for long term trends.
Extra Dimension Constrains Fluid Flow Dynamics

Seismic Attribute to conceptualize difference in pressure compartments
Water Surveillance Illuminates Fluid Communication to Improve Well Economics

Water samples at well head under different operating conditions identify facies. Technique requires multi-component mixing model. Density (SG) and/or Rw Inline flow measurements at well or pad level can assist understanding subsurface.

High Porosity and Water Saturation

Water chemistry of unique rock water interactions of good storage unit

Excess Pressure

https://info.drillinginfo.com/category/bakken/
1) Bakken Oil pushed by Lower Three Forks Water

Simplified conceptual model
Three Forks Oil pushed Lower Three Forks Water

1) Bakken Oil pushed by Lower Three Forks Water
2) By passed Three Forks Water

Simplified conceptual model
### Economics

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost USD$</th>
<th>Equivalent # bbl oil</th>
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<tbody>
<tr>
<td>Mass Meter</td>
<td>$20,000</td>
<td>2,000</td>
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<tr>
<td>EC Meter</td>
<td>$8,000</td>
<td>800</td>
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<tr>
<td>Water Samples and Analysis</td>
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<td>Lab Calibration</td>
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<tr>
<td><strong>Total per Well</strong></td>
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# bbl oil assumes $10/bbl profit

Meter cost includes installation and data management (vendor variable)

Meter cost do NOT include credit due to replacement

Residual Salts Analysis for Formation Identification $90,000 for 400 square miles

Approximately $40 K/well

Or

4K bbl to avoid lost of 100’s K bbl
Summary

1. Stable Isotope data reveal where and when stimulation water is produced.
2. RSA shows facies that contribute water and variability between formations (different Rw in shales?)
3. Inline meters show real time switching of water storage units
4. Integrating 1-3 with stimulation and operation events increase chances for improved recovery!
Acknowledgements

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Zhiyong He

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George Williams et. al.

Material Testing Group.

Mike Geddes,
Applied Technical Sales, LLC
Direct: 406 245-1144,
atsalesmt@gmail.com
Extra Slides

Possible to answer specific questions. Not updated with latest information.
Establish Protocol, Best Practices & Caveats

- Density from Coriolis meter provides timely actionable information – Electrical Conductivity meter inexpensively increases reliability
- Stable isotopes are used to determine contributions of drilling, stimulation, and maintenance water to water sample.
- Strontium isotope is very robust indicator of facies.
- Residual salts analysis from core needs refinement in four areas:
  1. Know how to capture salts
  2. Know which elements come from reactive portion of rock
  3. Know porosity for sample
  4. Know correct water saturation for sample

- Density (Specific Gravity) inline meter
- Electrical Conductivity (Resistivity of Water (Rw)) inline meter
- Cations:
  - Na+ (sodium)
  - K+ (potassium)
  - Ca++ (calcium)
  - Mg++ (magnesium)
  - Sr++ (strontium)
  - Si (silicon)
  - Li++ (lithium)
  - Ba++ (barium)
  - B (boron)
  - Fe++ (iron)
  - NH4+ (ammonium)
  - Zn++ (zinc)

- Anions:
  - Cl- (chloride)
  - Br- (bromide)
  - I- (iodide)
  - SO4-- (sulfate)
  - HCO3- (bicarbonate)
  - CO3 (carbonate)

- Isotopes:
  - Oxygen and Hydrogen Isotopes (δ18O, δD)
  - Strontium Isotopes (87Sr/86Sr)

- Other:
  - pH
  - Specific Gravity (measured)
  - Resistivity or Conductivity (measured)
  - Total Dissolved Solids
  - Total Suspended Solids (filter, weigh, and save for possible XRD)
  - Salt precipitate from a well. XRD then digested and chemically analyzed.
Correcting Density for Standard Conditions

Flow velocity decreases with time.

The slower fluids move the more they are cooled from reservoir temperature > 200 F

Water becomes more dense with cooler temperatures.

Or, hot water is less dense.
Modern Meter Data Provides Better Signals

Produced Water Density @ 60 F (g/cc)

- Correction of density of water to standard conditions illustrate dynamics of reservoir due to pressure decline and also operation events.

- Opportunities for behavior to be repeated or avoided

- Use inline metering water properties to react real time to changes in chemistry

Actively improve HC recovery!

Frac Water Recovery
New Wells Start

Subsurface Disturbance or Operational Events?

Days Since SE MB online

1.170
1.180
1.190
1.200
1.210
1.220
1.230
1.240

200 300 400 500 600 700

SE MB Lateral

Pantano.john@gmail.com
Actively improve HC recovery!

- Use inline metering water properties to react real time to changes in chemistry

Water Density at Field and Standard Conditions

Gaps in field data due to separator and well dynamics

Signal

Noise and Signal
Know where fluids are coming from!

- **87Sr/86Sr atom ratio**
  - Depth (ft bgl):
    - Bakken
    - LBS
    - Middle Bakken PW
    - Middle Bakken RSA
    - Three Forks
    - UBS Lew an
    - Upper Bakken Shale RSA

- **Distance in feet (1000)**
  - Depth in feet (1000):
    - 0
    - 40
    - 80
    - 120
    - 160
    - 200
    - 240

- **DEM**
  - Surface Unconformity
  - Santonian
  - Aptian
  - Callovian
  - Carboniferous
  - Charles
  - Mission Canyon?
  - Bakken
  - Three Forks
  - Upper Bakken Shale RSA

- **Formation**
  - Bakken
  - LBS
  - Middle Bakken PW
  - Middle Bakken RSA
  - Three Forks
  - UBS Lew an
  - Upper Bakken Shale RSA

Make Water Data More Valuable by Pantano & Franks

Contact: Pantano.john@gmail.com
Operation of Oil-Gas-Water Separator: Untapped Source of Real Time Data

Accurate oil production measurement provides insight into well performance and often times can be used for allocation of royalties. Precise level control and flow meters that require minimal maintenance enable accurate measurement. Emerson provides a wide range of level technologies including traditional displacers as well as advanced guided wave radar technologies unaffected by product density changes. Flow meter diagnostics can be used to detect gas carry-under and water in oil contamination allowing for improved control and verification of separator performance.

Flow Meter = FIT
Measures density and temperature of fluid continuously!

Level Control Valve = LCV

Level In Tank = LIT

Oil

Water


Making Water Data More Valuable by Pantano & Franks
Core Results Indicates Fresher Water In Shales

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<th>Formation</th>
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<th>Dilution</th>
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Source from United States Geological Survey 2019
Strontium Isotope Fingerprint Formation Fluid

Hypothetical Residual Salt Analysis

Produced Water $^{87}\text{Sr}/^{86}\text{Sr}$ Isotope Ratio

- Middle Bakken RSA
- Three Forks RSA

- Stimulation Water

Depth (ft)

Three Forks RSA

Middle Bakken RSA

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Inline Density (SG) and/or EC(Rw) allows for real time insights! Bulk water properties surrogate for laboratory results

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Integrate 310  
Mass Balance, Logs, Flowback, Seismic & Production

Outliers 320  
Detect and Reject Outlier

Rectify/Adjust 330  
Modify Rw, Sw, porosity, TDS

Generate Finger Print 340  
Isotopes, Ratios & Concentrations

Produced Water 350  
Pressure, Phases, Composition, Volumes

Historic Actions 360  
Completions, Operations

Trail and Error 370  
Change Completions, Change Operations

C – O – H isotopes of Salts Core and Produced Water (Alkalinity – CH4 – Dissolved CO2

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USGS Data Illustrates Spatial Trends

https://pubs.er.usgs.gov/publication/70190270

https://pubs.er.usgs.gov/publication/70190270
Mappable Water Illustrate Spatial Variability

3D View with attribute draped on base TF
If you want to go quick look at same things, if you want to go far go together (African)