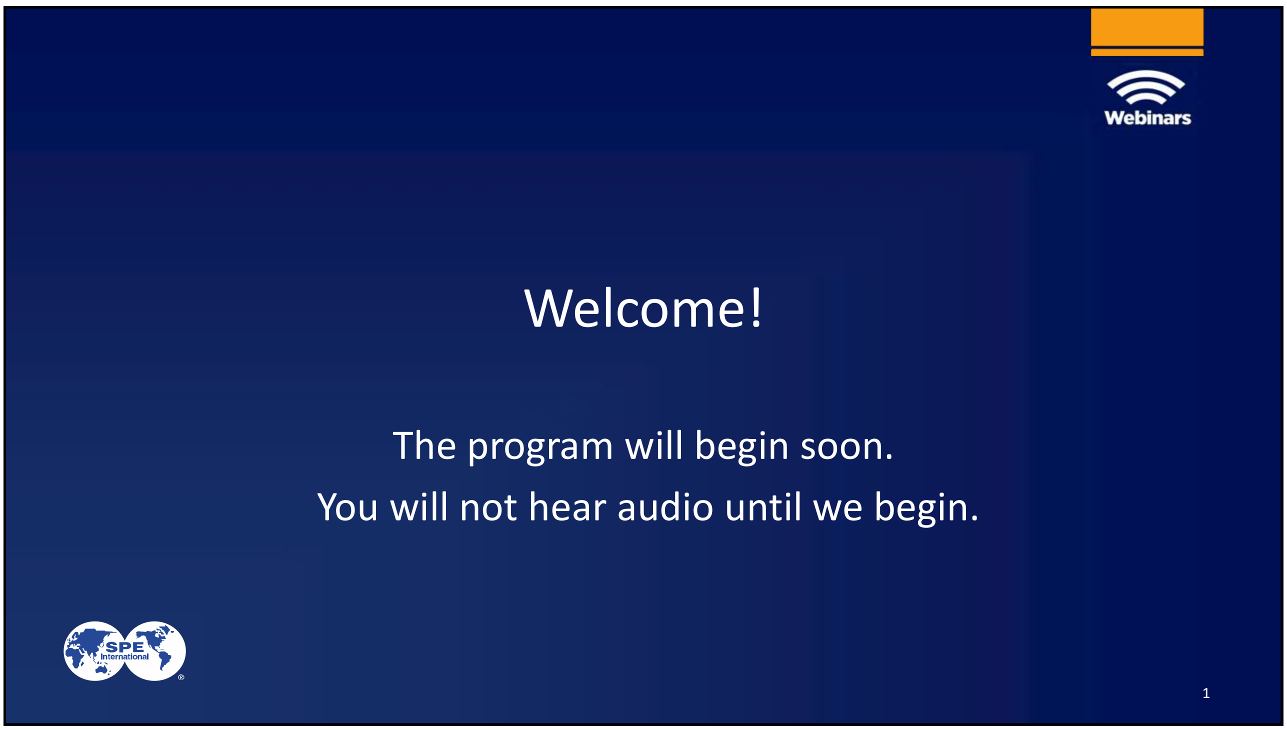
Webinars
Welcome!
The program will begin soon.
You will not hear audio until we begin.
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1

Flood Management: Solving Conformance or Sweep Efficiency Problems

Webinars

Water Lifecycle and Strategy Technical Section

David D Smith
President and Principal Advisor
Oilfield Conformance Consulting LLC

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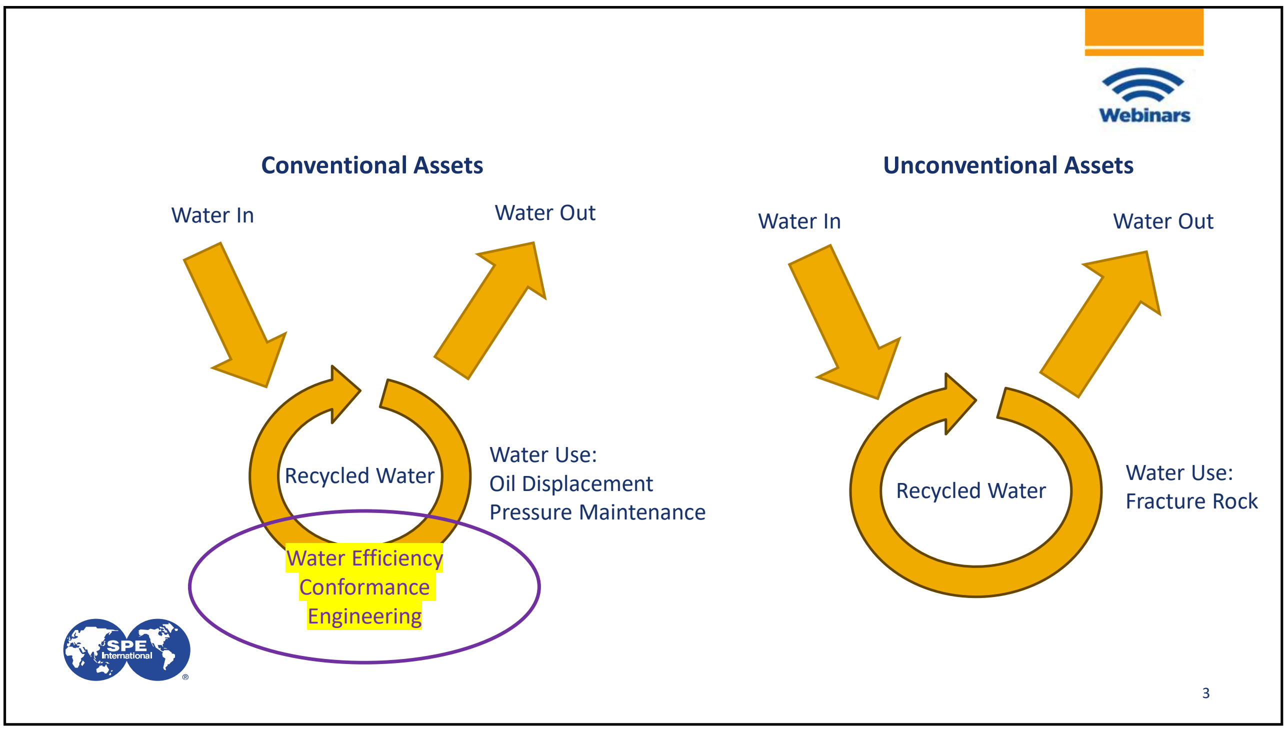
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Conventional Assets
Water In
Water Out
Recycled Water
Water Use:
Oil Displacement
Pressure Maintenance
Water Efficiency
Conformance
Engineering
Unconventional Assets
Water In
Water Out
Recycled Water
Water Use:
Fracture Rock
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3

Objectives of this Presentation

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- Provide a definition for Conformance Engineering.
- Discuss experiences on solving conformance problems.
- Review methods for solving conformance or sweep efficiency problems.
- How successful are we, and how successful can we be at executing Conformance Engineering efforts and solutions?
- What does it take to do better when it comes to Conformance Engineering?

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Conformance Engineering: Definition

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The process of utilizing reservoir and wellbore information to understand the flood sweep efficiency performance, and then use that understanding to make adjustments to the flood which results in improved oil recovery?

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WHY DO WE FAIL?

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- Early 90's - Conformance Study
  - Evaluation of 200+ Water and Gas Shut Off's
    - Success rate of ~ 60%.
  - Completed evaluation of failures:
    - ~70% of failures attributed to misunderstanding of the problem and/or reservoir
    - ~30% of failures attributed to inability of solution to control the problem.
- **BOTTOM-LINE – We fail because we don't fully understand the problem.**

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Conformance Engineering – Process Approach

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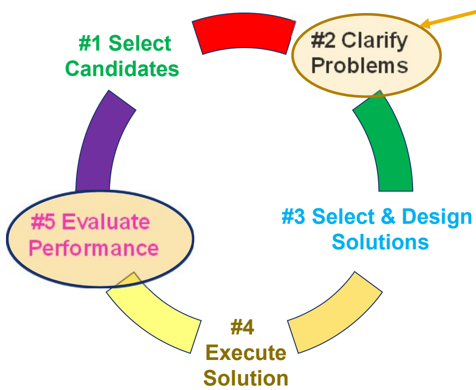
Candidate Selection: Identify the Symptoms



Spend 80% of your effort here.

Experience Indicates:

Assumptions lower success rate.

Success rate improves with better problem understanding.

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Learn from the Process

7

7

Candidate Selection

I have a water problem. - No you Don't

- You have a symptom - you need to understand the problem.
- What are your other symptoms or anomalous and irregular behaviors?
  - Lower than anticipate Recovery Factor, with higher than anticipated WOR/GOR
  - Rapid Breakthrough
  - Injection or Production Profile Issues
    - All fluid going into or coming from a discreet point
    - Out of Zone Injection or Production
  - VRR < 1 or > 1 with no pressure response.
  - Etc. Etc.

Conformance Engineering – Problem Analysis Elements: Reservoir & Wellbore

Webinars

- Reservoir Characterization – Initial Conditions
  - Initial Reservoir Characterization – Depositional Environment
  - Structural trap mechanism
  - Post deposition alteration / natural fracturing etc.
  - Basic Reservoir Rock and Fluid properties Ø, K, S_o, S_w … etc.
- Reservoir Monitoring - Performance - Fluid Data Review
  - Injection and Production Volumes
  - Pressure data (static and dynamic)
  - Trend Analysis - Find and characterize performance anomalies
- Reservoir Testing - Active Analysis – Current Condition
  - Induce change – monitor and analyze response
- Reservoir Modeling – Evaluate potential changes
  - Final or current characterization
  - Evaluate Potential Response
  - Test Assumptions

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- **How does fluid move through the reservoir and why?**

9

Conformance Engineering – Problem Analysis Elements: Reservoir & Wellbore

Webinars

- Wellbore Characterization – Initial conditions
  - Completion type (Cased Hole, Open Hole. Slotted Liner, GP etc. … etc.)
  - Layered isolation mechanism
- Wellbore Monitoring – how do we change things
  - Event History – Stimulations (Acidizing, Fracturing, Scale Sqz … etc.)
  - Other Mechanical Modification (Lift changes, Plugs or Patches … etc.)
- Wellbore Testing - Active Analysis – Current Conditions
  - Induce change – monitor and analyze response
  - Downhole Logging / Monitoring
- Wellbore Modeling
  - Evaluate flow potential
  - Understand lift mechanics

- **How does the Wellbore both Past and Present interact with the Reservoir?**

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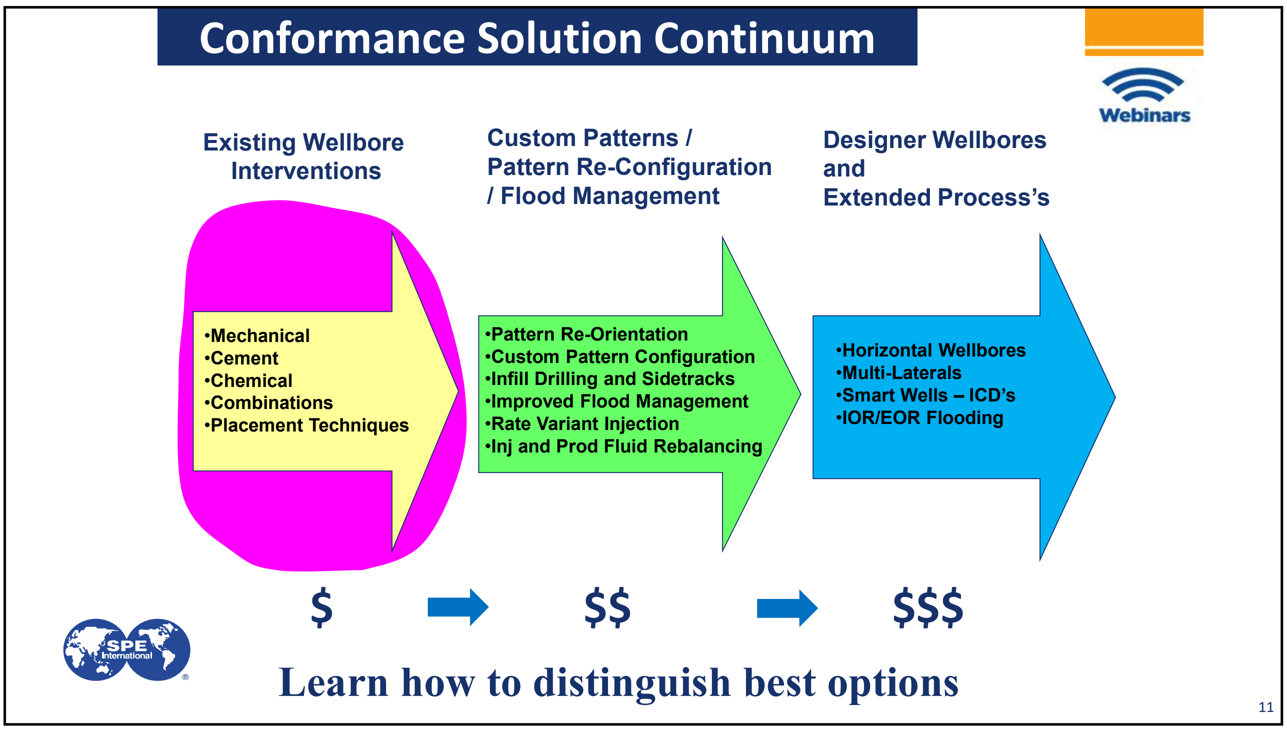
Conformance Solution Continuum
Webinars
Existing Wellbore Interventions
Custom Patterns / Pattern Re-Configuration / Flood Management
Designer Wellbores and Extended Process's
•Mechanical
•Cement
•Chemical
•Combinations
•Placement Techniques
•Pattern Re-Orientation
•Custom Pattern Configuration
•Infill Drilling and Sidetracks
•Improved Flood Management
•Rate Variant Injection
•Inj and Prod Fluid Rebalancing
•Horizontal Wellbores
•Multi-Laterals
•Smart Wells – ICD's
•IOR/EOR Flooding
$
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$$$
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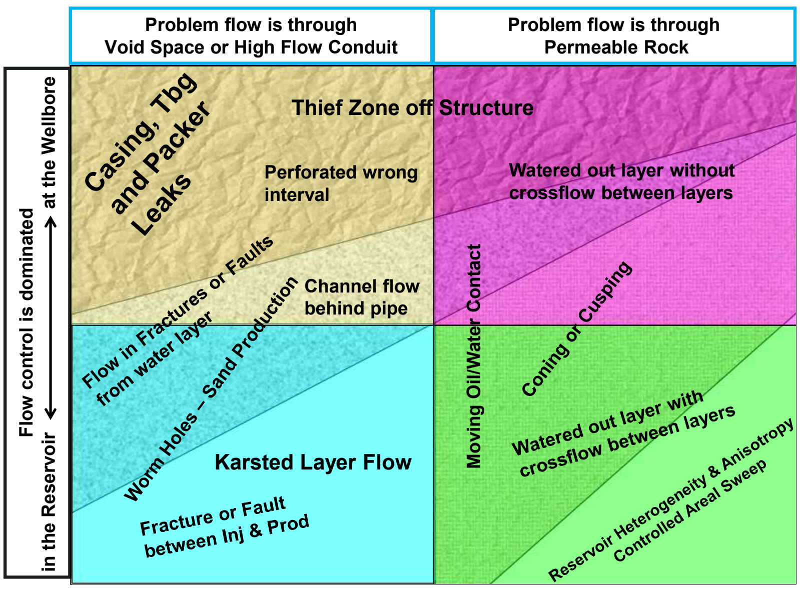
Learn how to distinguish best options
11

11

CONFORMANCE PROBLEM MATRIX



Mechanical Solution | Cement / VS Fillers | Chemical / Sealant Gel Systems

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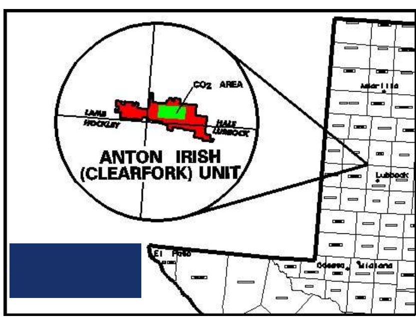
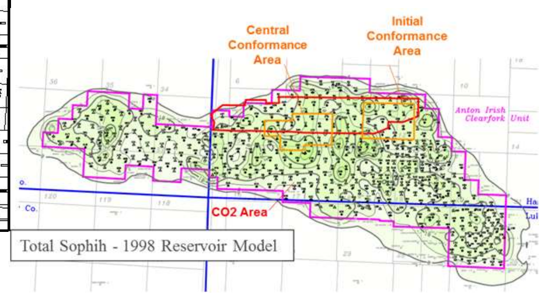
The Successful Evolution of Anton Irish Conformance Efforts

SPE #103044 and 6th International Conference on Production Optimization





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Results – TOTAL – 5 WELLS

FLUID	Rate Prior to SI	Average Rate After Treatment	Rate as of March 2006
OIL (BOPD) H2O (BWPD) GAS (MCFPD)	<< 297* 6400 35000+ * * Est Gas Rate & Last good oil rate.	494 4250 4500* Combined initial rate impact.	317 4400 5100*

- Prior to generating improved problem understanding
  - ~20 Solutions attempted over 15 Years with 0% Success
- After improved problem understanding
  - 5 Solutions executed over 3 Years with – 100% Success

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SPE- 179649
Comprehensive review of fracture control for conformance improvement in the Kuparuk River Unit - Alaska.

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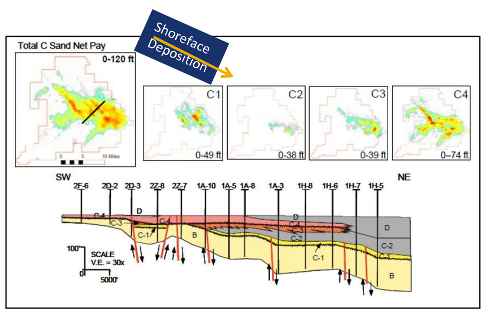

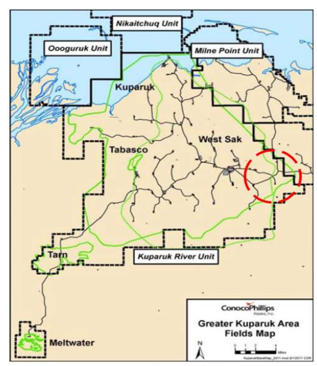

Area of study is distal edge of C-sand in the eastern edge of the Kuparuk field.

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Kuparuk Geology – Fracture Characterization

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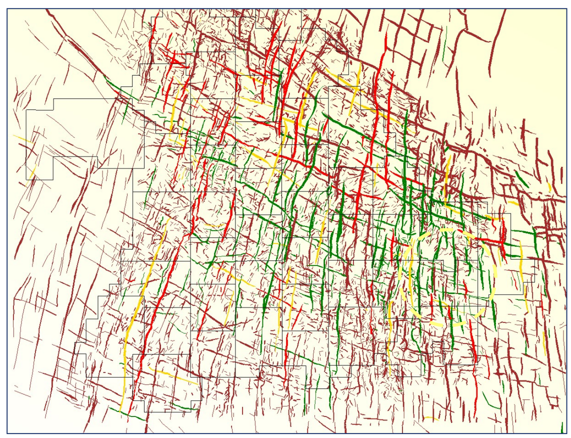
- Over 6,000 mapped faults
- Green lines are confirmed conductive or transmitting faults
- Bright Red lines are confirmed sealing or non-conductive faults
- Dark Red lines are faults that we have not been able to establish their conductive nature.



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KRU Inj 1 -- Wellbore Diagram

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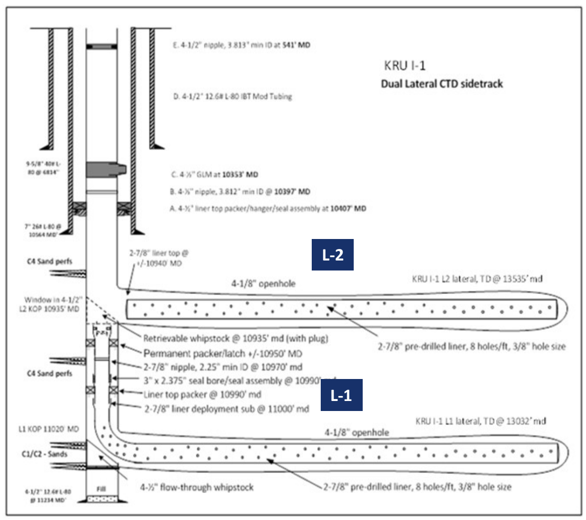
- **Original wellbore slant injector - drilled in Dec-1999.**
- **Original injector - very low rate.**
- **CTD sidetracked Nov-2004**
  - **increase reservoir contact**
- **Horizontal dual lateral injector - pre-drilled liners**
- **Profiles run 2007 and 2009**
  - **75% to 80% of the injection is going down L2 lateral.**
  - **Once SI there is potential for cross-flow from L2 to L1**



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KRU Inj 1 – Tracer Breakthrough Relationship

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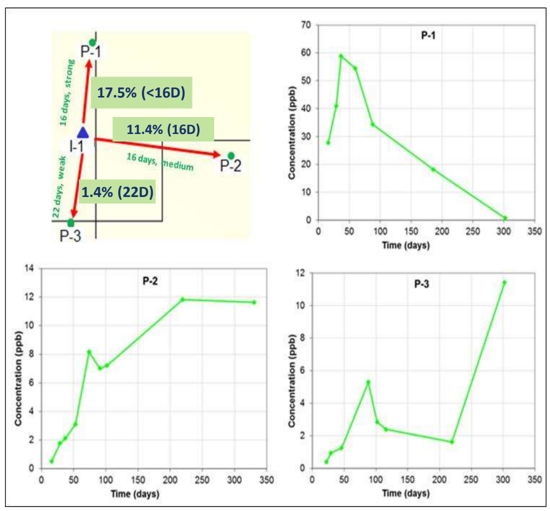
- **Tracer breakthrough data only defines nature of direct path.**
- **Tracer does not establish:**
  - a) actual volume of the system.
  - b) volume required to control the system.



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Problem Characterization

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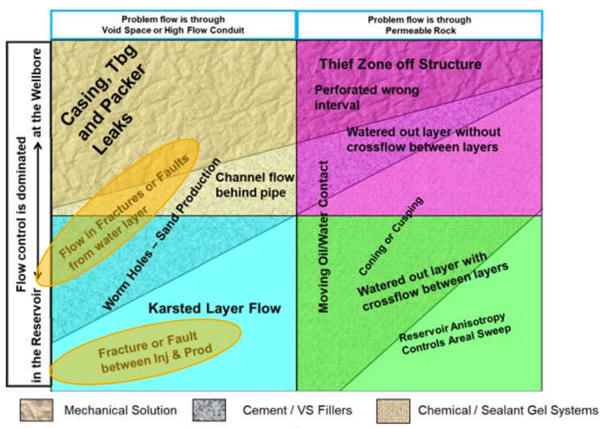
- Inj 1 - rapid communication with 3 production wells (P-1, P-2 and P-3).
- Flow expected through some form of VSC (void space conduit) – natural fracture
  - Majority of Injection in L-2
  - Rapid inter-well tracer breakthrough
  - MI injection-production cycling.
- Completion analysis shows potential to mechanically isolate L-1 from any treatment material.



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Basic Treatment Procedure and Pumping Response

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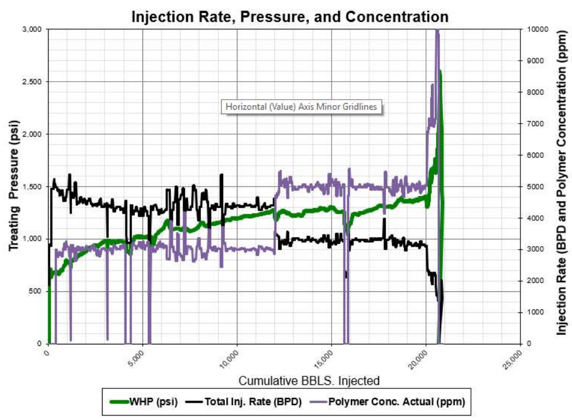
1. Isolate L-1 lateral with inflatable bridge plug.
2. Check injectivity to confirm L-1 is isolated.
3. Pump High Molecular Weight (HMW) polymer gel with X-linker to fill VSC .
   - Designed for a desired rate at max pressure.
4. SI for 48 to 72 Hrs - allow gel to X-link.
5. Test injectivity.
6. Gradually return well to Injection.
   - Ultimately, increase to max pressure. (evaluate for injectivity reduction)
7. Pull inflatable bridge plug – return L-1 to injection.



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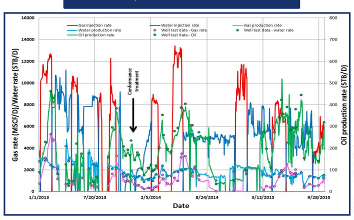
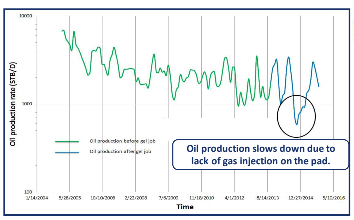
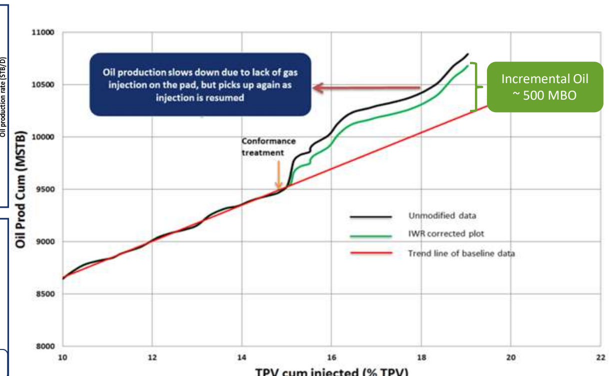
POST SOLUTION ANALYSIS
Pattern Area Injection Efficiency Plot

Noisy Production Data







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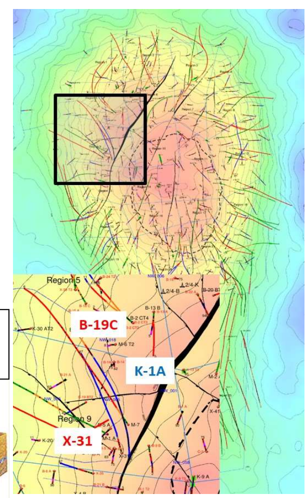
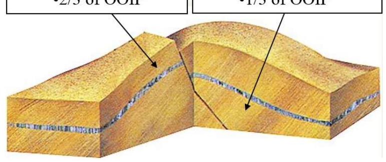
SPE-190209
Identification, Problem Characterization, Solution Design and Execution for a Waterflood Conformance Problem in the Ekofisk Field – Norway
Or
K-01A - A Conformance Control Case History

- **OOIP of ~7 billion STB**
- **Fractured chalk**
- **Two main formations**
- **Matrix permeability from 0.1 to 10 mD**
- **First production in 1971**
- **Long waterflood history**



Ekofisk Formation
- 300 - 500 ft thick
- 2/3 of OOIP

Tor Formation
- 300 - 500 ft thick
- 1/3 of OOIP



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Understanding the Problem -- Problem Diagnostics

- Initial problem indicators
  - Injection and production events /changes
  - Temperature response
  - Water chemistry analysis
- Problem clarification diagnostics
  - Injection profiles
  - Temperature logs
  - Step Rate Tests (SRT)
    - Pressure Transient Analysis (PTA)
  - Inter-well tracer
    - Tracer concentration & breakthrough timing
  - Interference tests
  - Gel emulation test
  - Geologic and Geophysical interpretation

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Problem Identification and Problem Understanding Summary

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K-01A
STIM/First Inj.

Pressure support for challenged regions (B-19)

K-01A Open

Tracer Injection

B-19 First Prod.

Water zone isolated with packers

Breakthrough X-31

Lost 2400 bopd

K-01A SI

After 16 days of Injection

X-31
Tracers

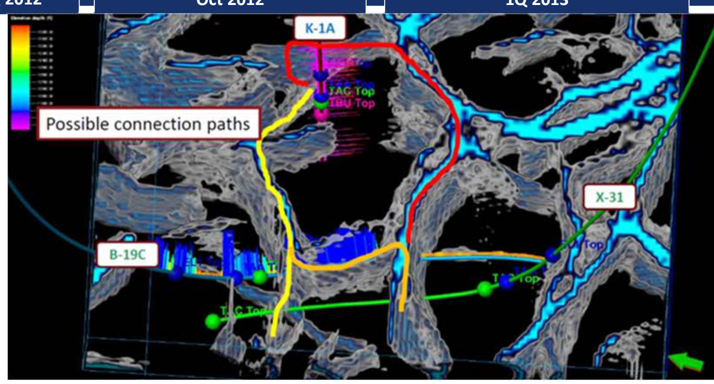
90 minutes response time

B19
Tracers

3 weeks response time

16 days

Aug 2012 | Oct 2012 | 1Q 2013



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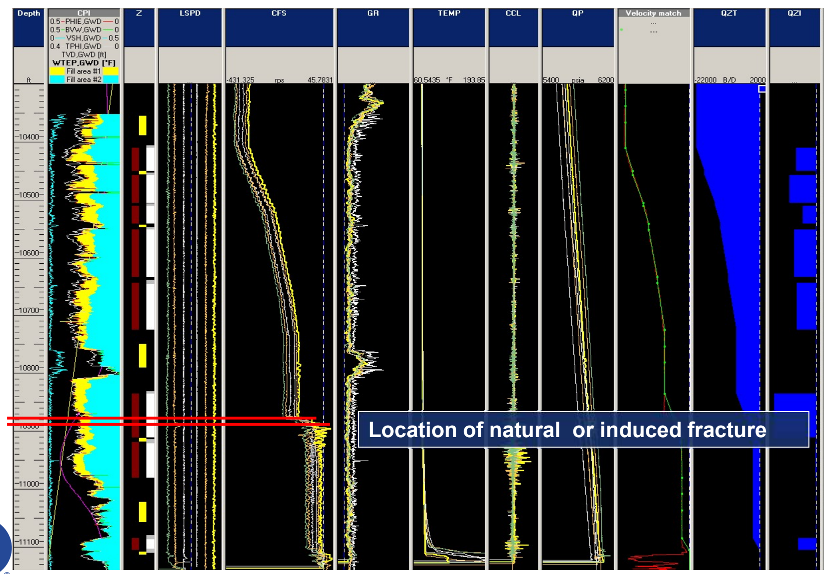
PROBLEM CHARACTERIZATION AND DIAGNOSTICS

K-01A Injection Profile



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Conformance solution in K-01A – Basic principles

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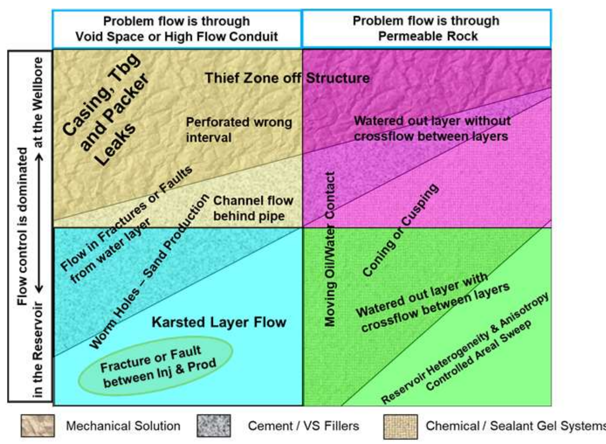
- **Solution Selection - Void Space Filler (VSF)**
  - VSC is swept and has little or no value
    - Do not damage matrix or tight fractures in process
  - Fill as much of VSC as possible – product needs to stay in VSC
- **Best opportunity to fill a VSC is the first time.**
  - Problem character requires strength and volume
  - Other concerns (Protect offset wells)



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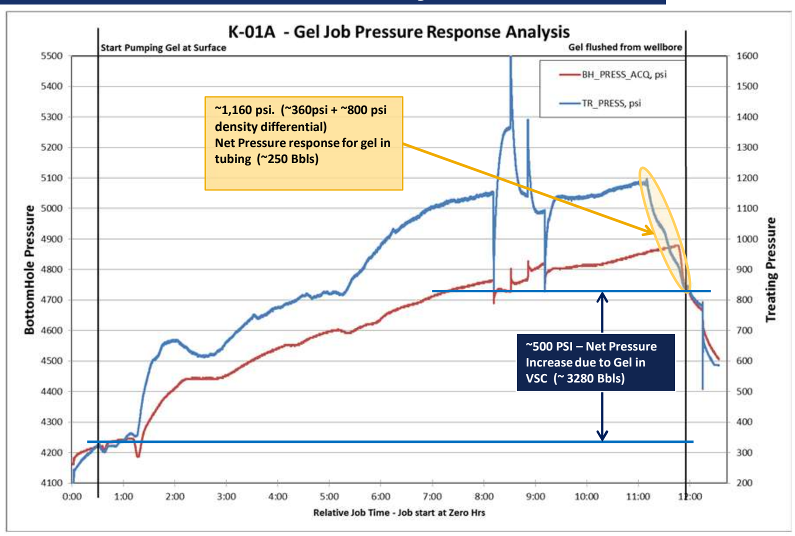
K-01A Gel-Cement emulation job – Results



- Confirmed large volume of fracture network and general character of VSC.

Gel-Cement emulation convinced management of need for large volume VSF.

Solution Execution: Nitrified cement operation

Largest single volume of nitrified cement in oil industry

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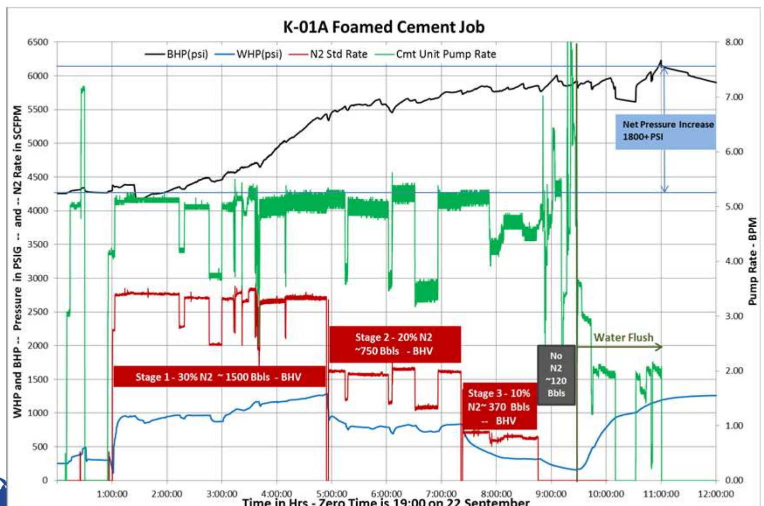

Job Pumped Sept 22, 2014

Design Volume:
3000 Bbls BHV
(BHV – Bottomhole Volume)

Executed Volume:
2740 Bbls BHV

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Overburden response due to pressure increase around K-01A

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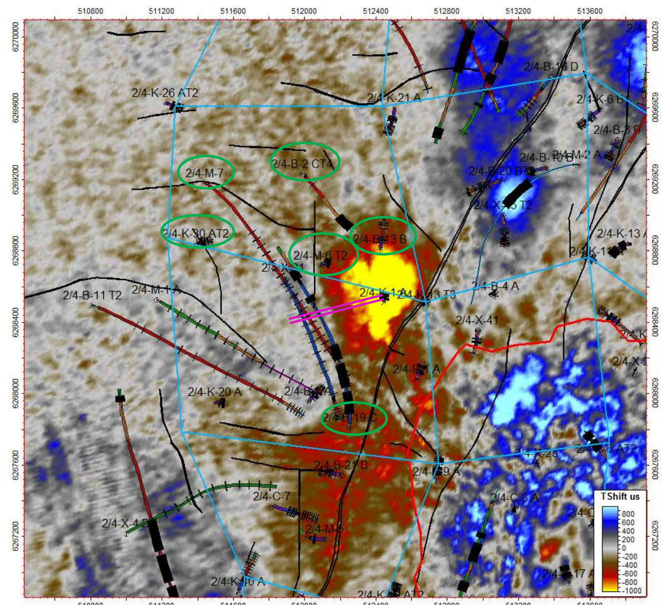
4D –Seismic Imaging



Delta Time Steps
July / 2015
April / 2016

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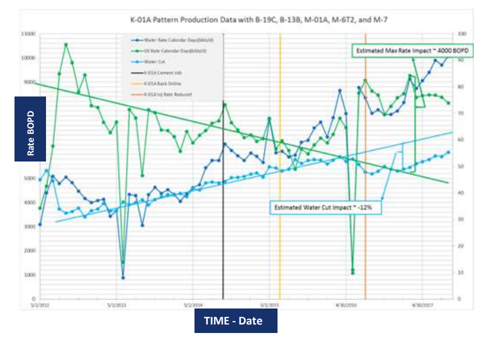
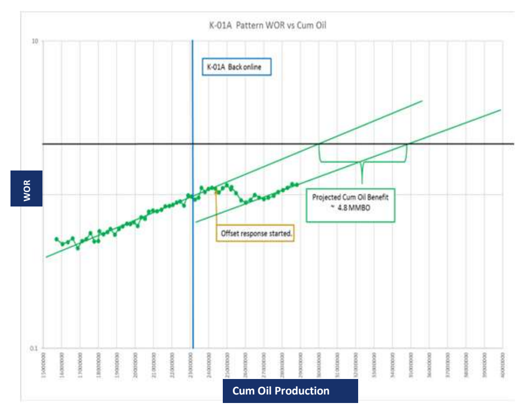
2/4-K-01 A Treatment Benefits





- **Peak incremental oil rate ~ 4000 STB/D.**
- **Total cum oil expected from life of project: ~ 4.8 MMSTB**
- **K-01 A - Successful conformance treatment which led to incremental oil production and salvaged wells**
- **Initiation for a bigger conformance program in Norway**

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Conformance Benefit Analysis

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- Direct Rate Benefit
- Indirect Rate Benefit
- OpEx Savings

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Conformance Benefit Analysis

- **Direct Rate Benefit – Area of Influence**
  - Producer Treatments – simple
  - Injector Treatments (Key is area of influence)
    - Offset Producers
    - Multiple Injectors often show broader influence.

- $Q_{od} = Q_{oa} - Q_{oi}$

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Conformance Benefit Analysis

- **Indirect Rate Benefit –** Real Oil rate increase as a result of replacing the capacity once occupied by the undesirable or cycled fluid.
  - **Passive Fluid Replacement**
    - Occurs in all types of fields with central gathering systems and no active program for managing marginal wells.
    - % Replacement Factor is low 20% to 10% or less.
    - Replacement Fluid comes in at Field Average WOR and/or GOR.
  - **Active Fluid Replacement**
    - Occurs in all types of field where facility limitations mandate an active program for managing marginal wells.
    - % Replacement Factor is higher 40% or greater – extreme case can be 100%
    - Replacement Fluid is considered to be brought in at the marginal WOR or GOR. (i.e. ratio where well is considered un-competitive).

Conformance Benefit Analysis

- **% Facility Utilization Factor – F_{Uf}**
  - **F_{Uf} - This factor should only be applied to the limiting remaining fluid stream capacity. (i.e. either Water or Gas/CO2)**
  - **RWOR or RGOR – denotes the replacing fluid WOR or GOR**
  - **$Q_{oid} = F_{Uf}((Q_{wi} - Q_{wa})+Q_{od})/(1+RWOR_r)$ or $F_{Uf}(Q_{gi} - Q_{ga})/(1+RGOR_r)$**

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Conformance Benefit Analysis

- **OpEx Savings Benefit – $ benefit realized by not handling recycled or undesirable fluid.**
  - Operating expense savings is only realized on the fluid that is not replaced!!
  - Increased oil rates must also be back out of fluid limiting system. Remove Q_{od} & Q_{oid}
  - $(1 – F_{Uf})$
  - Cw and Cg = Cost to handle lifecycle of water or gas

- **Trick (Show OpEx Savings as equivalent oil rate benefit)**
  - Divide OpEx Savings ($/Day) / Net Rev/Bbl ($/Bbl) = Q_{oe} (EBOPD)

- **For WSO - $Q_{oes} =(1- F_{Uf})*(Q_{wi} – Q_{wa} – Q_{od} – Q_{oid})*C_w /N\$_{PBO}$**
- **For GSO - $Q_{oes} = (1- F_{Uf})*(Q_{gi} – Q_{ga})* C_g] / N\$_{PBO}$**

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Conformance Benefit Analysis

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Production Well Treatments

- **Often better Economics**
- **Peaks early but can drop off rapidly**
- **Easy to define direct rate benefit**

Injection Well Treatments

- **Rate and Economics are delayed and difficult to evaluate or observe.**
- **Peak is broad and/or increasing. It is often expected to last much longer**
- **Often difficult to define direct rate benefit.**
  - Pattern or Area of influence:

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Conformance Benefit Analysis with Econmics

Total Rate Equivalent Rate Benefit = $Q_{od} + Q_{id} + Q_{oes}$

Need Rate and Price Forecast to Generate Economics

Used simple annual decline rate applied to total incremental benefit

- Used 10% decline for base case and doubled natural decline rate to 20% for incremental benefit to accommodate for water rate return.

Used oil price forecast of flat $50/Bbl

Used cash flow discount rate 10%

Truncated benefit at 10 years – Limited life of solutions

Simplistic Economic Value Example

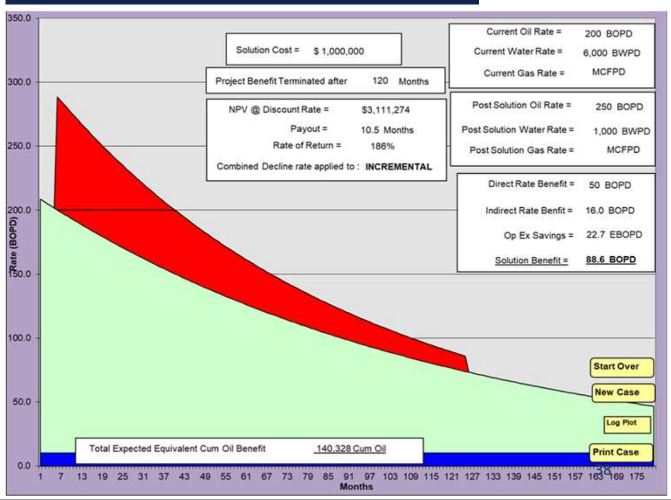
Table 1.	Example WSO values for a typical conformance problem	
	Rates before solution execution	Rates after solution execution
Oil Rate	**200**	**250**
Water Rate	**6000**	**1000**

Key Economic Parameters

Puf =	$0.20	per bwpd	Cost of handeling undesired fuid
Fuf =	10%		Facility Utilization Factor
RWOR =	30		This is the field average WOR.
Oil Price =	50.00	$/BO	Field Oil Price adjusted for gravity etc.
Net Rev Price =	39.45	$/BO	Net Rev Price - {Royalty, Adv and Sev Tax}

Note:

- 25.6 % of Total Benefit is from Op Ex Savings
- 18.0 % of Total Benefit is from indirect rate benefit
- Only 56.4% of Total Benefit is from direct rate benefit.
- If you don't account for the benefit from removing the water from the system, you lose a significant portion of the true benefit.



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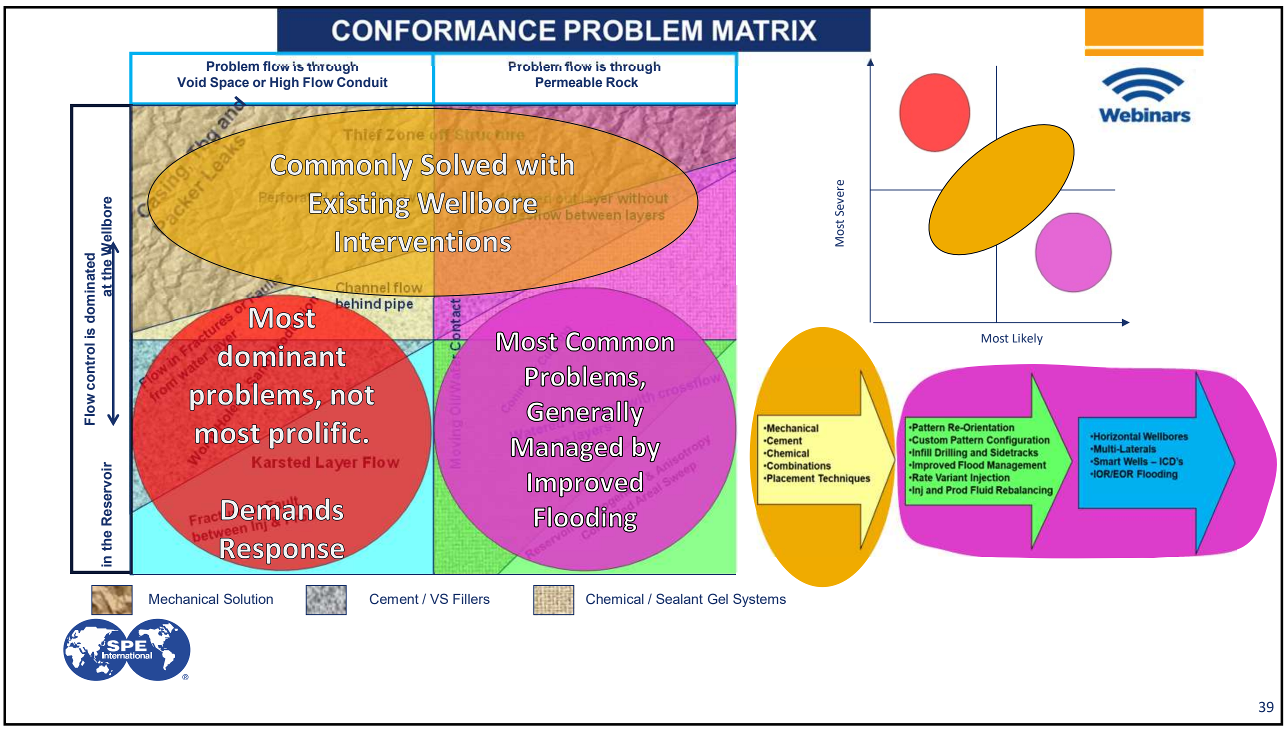
CONFORMANCE PROBLEM MATRIX
Problem flow is through Void Space or High Flow Conduit
Problem flow is through Permeable Rock
Flow control is dominated at the Wellbore
in the Reservoir
Commonly Solved with Existing Wellbore Interventions
Most dominant problems, not most prolific.
Demands Response
Most Common Problems, Generally Managed by Improved Flooding
Channel flow behind pipe
Karsted Layer Flow
Most Severe
Most Likely
Webinars
•Mechanical
•Cement
•Chemical
•Combinations
•Placement Techniques
•Pattern Re-Orientation
•Custom Pattern Configuration
•Infill Drilling and Sidetracks
•Improved Flood Management
•Rate Variant Injection
•Inj and Prod Fluid Rebalancing
•Horizontal Wellbores
•Multi-Laterals
•Smart Wells – ICD's
•IOR/EOR Flooding
Mechanical Solution
Cement / VS Fillers
Chemical / Sealant Gel Systems
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DISCUSSION REVIEW – How can we improve?

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- Improve solution success rate by utilizing a process approach and prioritizing problem understanding prior to designing a solution.
- Recognize that conformance problems are often different than originally anticipated.
  - Avoid assumption or be careful to try and test your assumptions.
  - VSC are more prevalent than we might suspect and dominate when they occur.
- Utilize solution continuum and problem/solution matrix to help define the best solution options for the defined problem character.
- Recognize wellbore history and overall operational conditions often control solution options.
- Improve time and focus on training (not necessarily teaching more mentoring):
- Incorporate solution performance analysis to improve problem understanding and potential future treatment designs. (review validity of assumptions)
- Incorporate better benefit analysis to properly value conformance solution work.
  - Don't undervalue your conformance efforts.

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REFERENCES

Webinars

- 2023 JPT – Article Series: April, June, August and ? - October. "Flood Management: Solving Conformance or Sweep Efficiency Problems" - Parts 1 thru 4.
- SPE-103044: 6th International Conference on Production Optimization: The Successful Evolution of Anton Irish Conformance Efforts.
- SPE-169073: An Overview of Conformance Control Efforts for the West Sak Field on the North Slope of Alaska.
- SPE-179649: Comprehensive Review of Fracture Control for Conformance Improvement in the Kuparuk River Unit - Alaska.
- SPE-190209: Identification, Problem Characterization, Solution Design and Execution for a Waterflood Conformance Problem in the Ekofisk Field – Norway
- SPE-201302: Case History of Conformance Solutions for West Sak Wormhole/Void Space Conduit with a New Reassembling Pre-Formed Particle Gel RPPG.

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Questions?

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