The operation conditions are becoming more challenging.

In US +80% of the sucker rod failures are associated with Fatigue or Corrosion-Fatigue.
Corrosion Fatigue Resistant Sucker Rods
Development Premises

Operating Conditions
- Harsh environment, CO₂, H₂S, Chlorides
- High cyclic loads, temperature, pressure
- Water cut

Available options
- Standard industry steels
- Inhibition
- Lower strength material and oversized string design

+80% results in CF failures

R&D Inputs
- Develop a new series of Sucker Rods specially designed to:
  - Increased corrosion-fatigue resistance
  - Capable to handle high loads
  - Released at a market level price
**Corrosion Fatigue Resistant Sucker Rods**

**Development Process: Steel Design**

- **Ultra Clean Steel**
  - Highly controlled raw material
  - Low Residuals:
    - Low P
    - Limited S & O

- **Chemical Composition**
  - Low Carbon
  - Micro Alloying: Cr, Mo, Nb, B, Ti

- **Microstructure**
  - Resulted in:
    - Fine grain/packet size distribution
    - Fine precipitates with high spherical shape factor
    - Low dislocation density

- **Heat Treatment**
  - Full martensitic structure (95%)
  - Tempered Martensite
  - Fine Ferrite Grains
  - Very fine Carbides

**AlphaRod™**
Corrosion Fatigue Resistant Sucker Rods
Metallurgical Concept

Normalized and Tempered rods Standard Structure

AlphaRod™

- Full martensitic structure (95%)
- Tempered Martensite
- Fine Ferrite Grains
- Very fine Carbides

Perlite
Bainite

Sept. 12-15, 2017
2017 Sucker Rod Pumping Workshop
Corrosion Fatigue Resistant Sucker Rods
Microstructure - Standard Rod vs AlphaRod™

- **Standard Rod**
  - 500x Center
  - Grain size ~15 μm
  - 500x Surface

- **AlphaRod™ CS**
  - 500x Center
  - Grain size ~4 μm
  - 500x Surface

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Corrosion Fatigue Resistant Sucker Rods
Metallurgy Effect

- Toughness
- Microstructure
- Fatigue Endurance Limit
- Corrosion Fatigue

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Fracture toughness is a property which describes the ability of a material containing a crack to resist fracture.
Corrosion Fatigue Resistant Sucker Rods

Testing: Toughness

Increased toughness compared to Standard grades
Corrosion Fatigue Resistant Sucker Rods

Introduction to Fatigue Failures

Paris Law

- Region I: No Propagation
- Region II: Stable Crack Growth
- Region III: Rapid Crack Growth

Log (da/dn) = c(ΔK)^n

Transition
Low Crack Growth

ΔK_{th}

Log ΔK

Threshold

Nucleation
Crack growth
Final failure
Corrosion Fatigue Resistant Sucker Rods
Testing: Fatigue Nucleation and crack growth rate

Paris Law

Region I
No Propagation

Region II
Stable Crack Growth

Region III
Rapid Crack Growth

Transition
Low Crack Growth

\[ \log(\frac{da}{dn}) = \log(c) + n \log(\Delta K) \]

\[ \Delta K_{th} \]

Fatigue crack growth:
- Experim.; Best fit (Paris Law)
  - AlphaRod\textsuperscript{TM} CS DS (4330M): \[ \frac{da}{dN} = 9.82 \times 10^{-10} (\Delta K)^{3.28} \]
  - N&T 4330, Gr. D: \[ \frac{da}{dN} = 2.84 \times 10^{-9} (\Delta K)^{3.18} \]

Threshold:
- Experim.; Best fit for threshold
  - AlphaRod\textsuperscript{TM} CS DS (4330M): \(
  \Delta K_{th} = 9.46 \text{ MPa.m}^{0.5} \)
  - N&T 4330, Gr. D: \(
  \Delta K_{th} = 7.61 \text{ MPa.m}^{0.5} \)

Stress intensity factor range, \( \Delta K \) (MPa.m\(^{0.5}\))

25\% Increased Threshold
Corrosion Fatigue Resistant Sucker Rods

Introduction to Fatigue Failures

**S-N curve**
(Stress Applied vs. Cycles until Failure)
Corrosion Fatigue Resistant Sucker Rods
Testing: Fatigue Limit in Air

Improved fatigue resistance compared to Standard grades

Improved fatigue resistance compared to Standard grades
Corrosion Fatigue Resistant Sucker Rods

Lab test validation: Corrosion-Fatigue (CF)

CO₂

• Liquid Solution simulating formation water: pH~5.5
• **Gas: CO₂ + N₂**
• Temperature: 140F
• Pressure: 450psi
• **Partial Pressure CO₂: 145psi**
• **Loading: Mod Goodman @SF 1**
  ~150% D, ~85% UHS
• Cycling frequency 20 cycles/min
  (10 to 30 days each test)

H₂S

• Liquid Solution: pH~4.5
• **Gas: 100% H₂S**
• Temperature: 77F
• Pressure: 14psi
• **Partial Pressure H₂S: 14psi**
• **Loading: Smax=Mod Goodman @SF 1= ~150% D, ~85% UHS**
• Cycling frequency 20 cycles/min (10 to 30 days each test)
Mechanical Properties

- YS (0.2% offset): 110 Kpsi (758 MPa)
- UTS: 125 Kpsi (862 MPa)
- Elongation (2"): 10% Min
- Impact Toughness (CVN@20°C): 133 ft-lb (180 J)

Better Corrosion Fatigue Performance in CO₂

- 2x vs DA & KD
- 3x vs HS

The Best Corrosion Fatigue Performance in H₂S

- 4x vs KD & UHS
- 8x vs DA & MMS
Modified Goodman Diagram

**Corrosion Fatigue Resistant Sucker Rods**

AlphaRod™ can be found for simulation in SROD & RODSTAR (latest versions)

Or by using MMS or UHS rods @ SF 0.9

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**Standard grades**

- API C 1530
- API K 4621
- API D 4142
- API DS 4320/30
- HS 4138 - HS 4330

**AlphaRod™ grades**

- AlphaRod™ CS

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**Graph**

- **Smax (Ksi)**
- **Smin (Ksi)**

* Service Factor 1
**AlphaRod™ Accessories** are manufactured with the same **QUALITY Standards and SPECIFICATIONS** than AlphaRod™ Sucker Rods in order to reach the same **Microstructure and Corrosion Fatigue Performance**

<table>
<thead>
<tr>
<th>Coupling</th>
<th>Size</th>
<th>Run life (days)</th>
<th>Corrosion Rate (gr/mo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>1&quot;</td>
<td>136</td>
<td>147</td>
</tr>
<tr>
<td>AlphaRod™ CS</td>
<td>1&quot;</td>
<td>112</td>
<td>17</td>
</tr>
</tbody>
</table>

**Case Study:**

88% **Corrosion Rate Reduction**

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Corrosion Fatigue Resistant Sucker Rods
Field Validation

AlphaRod™ - Trial Wells

+70% of them already reach target and 10 of them triple previous run time

44 strings/tapers installed in US

Sept. 12-15, 2017

2017 Sucker Rod Pumping Workshop
Concluding Remarks

The new steel notably increases the run life in corrosive environments (CO$_2$, H$_2$S) at high loads (Capable of working up to Modified Goodman Diagram for HS @ SF 0.9).

AlphaRod™

6 years of R&D program

Steel Design  
Lab Testing  
Field Validation
Questions?

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