Well site facilities Onshore Conference
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Adjustable choke design to handle erosion

The leader in choke technology
100 years + of production process evolution

Far from Titusville in 1859 the last 25 years of production evolution brought us...

- Shale oil & gas production
- SAGD Process
- Cyclic steam process
  - More aggressive “Well management programs”
  - Increasing sand volume being used
  - Resisting temptation to reduce flow back time
  - More demanding well stimulation techniques

Today’s producer have to handle more aggressive process conditions.

- Sand and organic erosion (up to 15%)
- High temperature (700°F+)
- Higher pressure (15K and 20K)
  - Creating Initial higher pressure delta with often supersonic speed conditions
- High flow rates over a wide range of pressure conditions true well life.
  - Maintaining flow rate with a delta reducing by over 3000psi over well depletion cycle.
- Hydrate formation, that’s always fun...
- And yes.. Sand.. Did we say sand?
Evolving demands

Sand is proving to be the new enemy …

- Coated, man made or natural, it’s all the same. Evil.
- A common denominator for all unconventional O&G production, sand erosion is costly in multiple ways;
  - Down time
  - Lost of production
  - Difficult implementation of the well management program
  - High parts and maintenance cost
    - High cost of ownership

While operation wants more from the choke…

- Controllability
- Repeatability
- Reliability
- Long life trim
- Long term shut off capabilities
- Increase up-time
- Low cost of ownership

**Fact:** Your production choke valves are your primary control elements, and a major determinant in your ability to achieve profitability.

- Every production choke designs has merits,
- But they also have limitations when faced with sand…let’s review…
Needle and Seat Choke (Circa 1925)

Flow

Results of sand erosion

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M.O.V Wafer Choke (Circa 1950)

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Results of sand erosion

Hydrate
M.O.V Choke (Circa 1950)

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Results of sand erosion

Flow
Plug and Cage Choke  (Circa 1975)

Flow

Results of sand erosion

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External sleeve design (evolving since 2000)

Advance technology

Evolved trim designs

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Results of sand erosion
Erosion Performance Comparison: Adjustable Chokes

Velocity Magnitude (m/s)

Primary Wear
Secondary Wear

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Design Criteria: Driving Factors

- **Pressure** – API 6A Energy Distortion & ASME Methods, Material Mechanical Properties.
- **Temperature** – API 6A Temp Class, Annex G Derating, Material Mechanical Properties, etc.
- **Corrosion** – Sweet and Sour, NACE MR0175
- **Erosion** – Velocity, Energy, Material
- **Flowrates** – Adjustability, Flow Coefficient (Cv), Choked flow, etc.
- **Controllability** – Cv curve, Adjustment Resolution, etc.
- **Cavitation** – F/I factor
- **Hydrate Formation** – X/t factor
- **Automation** – Safety, Monitor, Labor, $$$
- **Cost** – Cost of Ownership

The science behind the design
Continuity Equation: (V-A)

- Conservation of Mass:

\[
\dot{m}_1 = \dot{m}_2 \\
\rho_1 V_1 A_1 = \rho_2 V_2 A_2 \\
V_1 A_1 = V_2 A_2
\]

Incompressible Fluid

\[
\frac{V_1}{V_2} = \frac{A_2}{A_1} \\
A_1 > A_2 ; \ V_1 < V_2
\]
Bernoulli’s Principle: Venturi Effect (P-V)

- Conservation of Energy:
  - Kinetic $\leftrightarrow$ Potential
  
  $V\uparrow \rightarrow P\downarrow \quad P_1 > P_2 \quad V_1 < V_2$
  
  $V\downarrow \rightarrow P\uparrow$

$\Delta P = P_{in} - P_{out}$
Gay-Lussac’s Law: Joule-Thomson Effects (P-T)

- Conservation of Energy: Internal ↔ Potential

- The pressure exerted by a gas is directly related to the Kelvin temperature.

- V and n are constant.

\[
\frac{P_1}{T_1} = \frac{P_2}{T_2}
\]

\[T_1 < T_2 \; ; \; P_1 < P_2\]

- The act of reducing the pressure of gas flow through a restrictor results in a phenomenon known as the Joule-Thomson Effect.

- Cooling occurs because work must be done to overcome the long-range attraction between the gas molecules as they move farther apart during the expansion process.
Trim Life Prediction Model

- Erosion = Function (Fluid Kinetic Energy, Subject Material)
  - Fluid Kinetic Energy: $E_k = \frac{1}{2} mV^2$
  - Subject Material: Primary & Secondary Wear Areas
Erosion Control

Erosion Management

- **Energy Management**
  - Impingement – Energy dissipation

- **Velocity Management**
  - Valve Internal Design – Slower is better

- **Material Management**
  - Hardness + Corrosion resistance
Velocity Control

**Body Velocity**
Velocity must be acceptable for alloy or stainless steel material.
Typical hardness Rc 22

**Orifice Velocity**
Tungsten Carbide Trim allows high acceptable velocity.
Typical hardness RA 94

**Inlet Velocity**
Inlet velocity must be acceptable for alloy or stainless steel material.
Typical hardness Rc 22

**Trim Exit Velocity**
Velocity must be acceptable for alloy or stainless steel material.
Typical hardness Rc 22

The science behind the design
Erosion management

**Upstream**
- Longer Deadband
- Larger Choke Size
- Larger Body Inlet Bore or End Connection

**Vena Contracta**
- Proper sized ports (Minimum Perimeter)
- 2 or 4 ports
- Harder Materials (>Ra 94 5CB TC)

**Downstream**
- Larger Choke Size - Larger Cage ID
- Larger Body Outlet Bore or End Connection
- Body Outlet TC Wear Sleeve
- HES Choke

The science behind the design
Empirical data demonstrates that fluid impingement will effectively dissipate 25% or more of the energy.
Trim Design

Trim Dead Band

- Protects seat surface from high velocity fluid associated with trim ports
- Increases body annulus area for reduced velocity

Design evolution

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Retaining Sleeve

- Protects body from fluid velocity and potential erosion
- Eliminates the need for wetted body threads
- Facilitates ease of service with no special tooling.
- Allows self-aligning trim components
Deflection lip on collar separates throttling surface from seating surface for prolonged shut-off.

Metal to Metal seat surfaces provide extended Class 5 shut-off.
Tungsten Carbide

- To be able to contain the energy and provide suitable erosion resistance tungsten carbide is used for the trim components
  - **Hardness being the feature of interest,** it should be known that not all carbide grade are equal.
- Carbide grade should be manufactured from binder consisting of Cobalt, Nickel, and Chromium.
Trim Material – Erosion

**Erosion Test Results**

<table>
<thead>
<tr>
<th>Material</th>
<th>K1C (MPa*m^0.5)</th>
<th>Material Loss (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master Flo 5CB (Ra 94)</td>
<td>2.25</td>
<td>9.27</td>
</tr>
<tr>
<td>Sandvik DC05 (Ra 93)</td>
<td>3.41</td>
<td>9.91</td>
</tr>
<tr>
<td>Commercial Grade 6% Co (Ra 93)</td>
<td>4.35</td>
<td>10.18</td>
</tr>
<tr>
<td>Commercial Grade 6% Ni (Ra 91)</td>
<td></td>
<td>17.36</td>
</tr>
</tbody>
</table>

**Test Specifications:**
- 1% Sand Slurry
- Upstream P = 2000 psi
- ΔP = 850 psi
- Flow Rate = 123 gpm
- Port V = 256 Ft/Sec
- Duration = 26 Hours

**Corrosion Testing**

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>K1C (MPa*m^0.5)</th>
<th>MATERIAL</th>
<th>K1C (MPa*m^0.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC05</td>
<td>0.594</td>
<td>DC05</td>
<td>0.594</td>
</tr>
<tr>
<td>6% Ni</td>
<td>0.777</td>
<td>6% Ni</td>
<td>0.777</td>
</tr>
</tbody>
</table>

**Test Specifications:**
- 10% HCl with H2S and CO2
- 50°C
- 168 Hr Test
Erosion Calculation: Trim Life Prediction

Max. (Worst) Case Scenario
- Max. Pressure/Pressure Drop
- Max. Temp
- Max. Oil Flow Rate
- Max. Gas Flow Rate
- Max. Velocity
- Min. Trim Life

Where sand depletion over time will increase life cycle exponentially.
F_L or X_t (Pressure Recovery) Factor

- Provides a correlation between pressure drop and lowest pressure point in the valve (P_VC)

- Lower P_VC means lower temperature

\[ F_L = \frac{P_1 - P_2}{P_1 - P_{VC}} \]

i.e. the higher F_L number, the lower the risk of cavitation
In order to best mitigate hydrate formation and cavitation, the “vena contracta” and recovery factor information is crucial and more predictable.
Choke Trim Designs For Different Applications

Standard 4-port
- General Purpose
- Excellent For Erosion Control
- Good Controllability
- Available In SS, Stellite Or Tungsten Carbide

Custom Multi-port
- Reduction In Noise
- Improved Controllability On Startup
- Available In SS Or Tungsten Carbide

2-stage
- Available In Standard And High Pressure Drop
- Good For Cavitation Control
- Good For Noise Control
- Available In Stellite Or Tungsten Carbide

Labflo
- Excellent For Noise Control
- Excellent For Cavitation
- Liquid, Gas And Multi-phase Applications
- 3 Distinct Pressure Drop Configurations along Travel
- Available In Tungsten Carbide

Laminate 4-port
- Used In High Impact Applications To Reduce Catastrophic Failure (Tested To Withstand 300 J Energy)
- Absorbs Impact Energy In Outer Cage; Soft Core Between Cages Acts As A Crack Arrester
- Continuous Bond Technology Maintains Structural Integrity
- Available In Tungsten Carbide

Well Cleanup
- Used In High Impact Applications To Eliminate Catastrophic Failure
- Absorbs Impact Energy In The Stainless Steel Outer Cage
- Recommended For Flowback And Well Cleanup Operations
- Proprietary 5CB Tungsten Carbide On All Erosion Sensitive Areas
### Conclusion

#### Trim design comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>POS</th>
<th>MOV</th>
<th>N&amp;S</th>
<th>P&amp;C</th>
<th>C&amp;S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjustable</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Shut Off Capability</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Jet Impingement</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Energy Dissipation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throttling = Sealing surface</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Hi-speed Jet into Body Outlet</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>F/ and/or Xt Factor</td>
<td>Lo</td>
<td>Lo</td>
<td>Lo</td>
<td>Med</td>
<td>Hi</td>
</tr>
<tr>
<td>Torque/Thrust Requirements</td>
<td>N/A</td>
<td>Hi</td>
<td>Lo</td>
<td>Lo</td>
<td>Lo</td>
</tr>
<tr>
<td>Rotating Stem (Stem Seal)</td>
<td>N/A</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Custom Trim</td>
<td>No</td>
<td>Kinda</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Control Resolution</td>
<td>No</td>
<td>Bad</td>
<td>Bad</td>
<td>Good</td>
<td>Good</td>
</tr>
</tbody>
</table>

*The Leader in Choke Technology*
Conclusion

- Process conditions are getting more demanding.
  - More sand downhole during frac
  - Higher flow rates
  - Increase emphasis on controllability and repeatability to meet well program demands.
  - Cost containment against sand erosion effects taking a front seat.

- Advance trim design and materials advantages…
  - With its ability to control velocity at the trim, the external sleeve design provides;
    - Long trim life
    - Lowest cost of ownership
    - Increase Up-time
    - Improved controllability and repeatability
    - Long term shut off capability
    - Proving itself to be best defense against the effects of sand erosion.

End.