Analyzing the Correlations in Generalization of the Reservoir Information in a Well Completion Design Optimization using ICD’s along the Horizontal section of a Wellbore

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Introduction

EQUALIZER™ – Operating Envelope
EQUALIZER™ – Technology Portfolio
EQUALIZER™ – Design & Diagnostics Overview
EQUALIZER™ – Flow Performance Characteristics
EQUALIZER™ – Applications

- Key technical factors that are affecting the horizontal well completions

- Determining the potential actions to be taken in order to improve the influx and therefore maximize the benefits of horizontal wells.

- Analyzing horizontal wells applications using a reservoir simulator in order to understand the well completion effects on the reservoir behavior.
Why do we need Flow Control Devices?

Optimum Deliverability

Barrier

UNEVEN PRODUCTION
Challenges facing production from long horizontal wells

- Uneven pressure drawdown along the wellbore due to long horizontal section (heel to toe effect)
- Permeability heterogeneity along open hole section
- Different mobility ratios of oil, gas and water
- Reservoir pressure difference along open hole section
Baker Hughes as an Industry Leader in ICD Installations

EQUALIZER Technology

- Enhanced hydrocarbon recovery by delaying the onset of water or gas breakthrough by equalizing inflow along the length of a long horizontal lateral section.

- Field Proven

- Over 3 million feet installed in sand control and non-sand control applications
  - + 60,000 ICD Joints Downhole
  - + 600 miles

- + 1000 wells worldwide:
  - Norway, Canada, Saudi Arabia, Mexico, China, Russia, Indonesia, India, UAE, etc.
EQUALIZER™
Operating Envelope
Uneven Production from a Horizontal Lateral

Sections of the lateral are favored for production due to the influence of:

- Frictional pressure drop in the completion string
- Variations in $K_v$ and $K_h$ along the wellbore
- Variations in fluid composition and mobility
- Non-uniform reservoir pressure along the lateral length
Physical phenomena in Horizontal Well

The Challenge: Water / Gas / Steam Breakthrough

- Evenly production
- Downhole Water and Gas Control
- Optimum pressure drop distribution
- Well completion fit to the reservoir need

- Improve well performance
- Improve reservoir performance
- Understand reservoir behavior

- Homogeneous Formation
- High Permeability At Heel
- High Permeability at Toe
- Alternating High-Low Permeability Strata

- Improve performance
- Improve reservoir performance
- Understand reservoir behavior

- Pr > 2000 psi
- Pb > 0.7 Pr
- K > 1 Darcy
- μ > 1 cP
- Water Cut < 30%

- Pr < 1000 psi
- Q < 1000 stbd
- GOR > 3000 scf/stb

- Pr > 2000 psi
- Q > 1000 stbd
- μ > 1 cP
EQUALIZER Technology Portfolio

Sand Control Screen Type
- BakerWeld Jacketed Sand Screen
- Excluder2000 Premium Mesh Screen
- BakerWrap Wrap-on-Pipe Screen

Non-Sand Control (Consolidated Formation)
- EQUALIZER-CF

ICD (Inflow Control Device)
- EQUALIZER HELIX

Accessories
- RE Packer (Reactive Element)
- MPas Packer
- MTV (Multi Tasking Valve)
- Sliding Sleeve

EQAULIZER Select
Types of Flow Control Devices

Frictional Geometry

Big flow area, low velocity, viscosity sensitive

\[ \Delta P = \frac{128\mu LQ}{\pi d^4} \propto \mu Q \]

Restriction Geometry

Small flow area, high velocity, partially viscosity insensitive

\[ \Delta P \propto \frac{\rho (\frac{Q}{A})^2}{\rho Q^2} \]

Autonomous Geometry

Varies; big flow area, low velocity, viscosity insensitive

\[ \Delta P \propto a_2 Re^{b_2} + \left( a_1 Re^{b_1} + a_2 Re^{b_2} \right) \left( 1 + \left( \frac{Re}{t} \right)^c \right)^d \]
PICD Geometry Types

- **EQUALIZER HELIX**: Helical-channel PICD design creates the desired flowing pressure loss via friction as fluid passes through the channel(s).

- **EQUALIZER SELECT**: Field-adjustable version of the hybrid ICD. The desired flow restriction setting is controlled by selection of the quadrant which is open for flow.

<table>
<thead>
<tr>
<th>PICD Type</th>
<th>BHI Offering</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube</td>
<td>N/A</td>
<td>Tube PICDs have smaller flow area and induce high fluid velocity, and are less sensitive to viscosity than helical systems. However, they are susceptible to plugging and erosion.</td>
</tr>
<tr>
<td>Orifice</td>
<td>N/A</td>
<td>Orifice PICDs have smaller flow area and induce high fluid velocity, and are less sensitive to viscosity than helical systems. However, they are susceptible to plugging and erosion.</td>
</tr>
<tr>
<td>Helical</td>
<td>EQUALIZER HELIX™ PICD</td>
<td>Helical PICDs have the advantages of larger flow area and low velocity, but do not perform well when handling multi-phase flow.</td>
</tr>
<tr>
<td>Field Adjustable Hybrid</td>
<td>EQUALIZER SELECT™ PICD</td>
<td>Hybrid PICDs have large flow areas and low velocity and are highly viscosity insensitive. Field Adjustable Hybrid PICDs provide the performance of the standard Hybrid, and the pressure drop rating can be set at the rig site based on reservoir conditions encountered while drilling.</td>
</tr>
<tr>
<td>Hybrid PICD with sliding sleeve</td>
<td>EQUALIZER SELECT PICD with sliding sleeve</td>
<td>The Hybrid PICD with sliding sleeve enables shut off of compartmented zone to stop water influx detected by production logging or DTS sensors. Sleeve is closed using coiled tubing.</td>
</tr>
</tbody>
</table>
Visualizing the Flow Path

- **Equalizer HELIX**
  - Un-Perforated Base Pipe
  - Screen Cartridge Sandstone Formations
  - Helical Flow Channel Allowing a Predefined Production Rate Per ICD

- **Equalizer™ CF**
  - Debris Filter Carbonate Formations
  - Holes that allow fluid into basepipe

- **Equalizer SELECT**
What Do We Design For?

- No plugging over the life of the well
- Minimal or no erosion
- Sufficient pressure drop to equalize flow over well life
- Greater economic efficiency
Decision Making Process

1. Determine the need for Sand Control
2. Establish Minimum Number of Flow Control Devices using Critical Velocity
3. Determine Screen/Barrier Length
4. Establish Maximum Number of Devices using Performance Curves
5. Determine Packer Number and Placement
6. Model Performance over the Life of the Well
The Need for Modeling

1. Input data from client
2. Build quick look one well ICD "shoe box" model in Reveal.

Model set-up
- Determine size of ICDs & screen for the hole size
- Generate perm profile along well
  - Generate rel perm
  - PVT Data

ICD Simulation
- Compartmentalization
- FRR
- # of ICDs
- Location of ICDs

Design modification

Quick Look analysis complete
- Full ICD simulation

Chance you're making a good decision
Data & evidence
ICD completion design requires careful modeling of several parameters including:

- Fluid saturations
- Variations in fluid properties
- Reservoir pressure
- Production drawdown
- Flow rates at the sand face and into the completion
- Variances in permeability along length of the wellbore
- Maximum flow rate per joint to not exceed the erosion velocity
- Minimum flow rate per joint to promote flow control
- Minimum pressure drop through the completion to control the reservoir fluids
- Effect of compartmentalization of the pay zone
Compartmentalization in ICD completions

Heterogeneity and ICD completion design

- Uniform Sandstone
- Layered Sandstone
- Carbonate Reservoir
- Highly Fractured Carbonate

Number of Compartments vs. Heterogeneity and PI CD Pressure Setting
EQUALIZER™
Flow Performance Characteristics
Appropriate ICD type selection based on anticipated flow characteristics

\[ \Delta p_{liq} = K \rho_i \left( \frac{v_{liq}^2}{2g_c 144} \right) \]

\[ \Delta p_{liq} = K \rho_i \left( \frac{q_{liq}^2}{2g_c 144} \right) \frac{1}{A^2} \]

\[ K = \left( \frac{\Delta p_{liq}}{q_{liq}^2} \right) \left( \frac{1}{\rho_i} \right) A^2 (2g_c 144) \]

\[ K = \left( \frac{\Delta p_{liq}}{q_{liq}^2} \right) \left( \frac{1}{\rho_i} \right) A^2 (2g_c 144) \]

\[ Re = \frac{d \rho_i V_{sl}}{\mu_i} \]

\[ K = f(Re) \]

The reservoir fluid type would determine which flow performance characteristic must be used.
Adjustable Hybrid Design Flow Performance Characteristic
Low flow velocity design and high flow area to avoid erosion & plugging issues
The Flow Resistance Rating impact on the flow performance
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Applications
A Variety of Applications

- Reservoir type: sandstone & carbonate
- Well Type: producer & injector & storage wells
- Fluid Type: oil & gas
- Completion type: Standalone or Gravel pack
- Single or Multi lateral
- Well Deviation: horizontal or vertical (long interval – thickness and high permeability contrast)
- SAGD
Single lateral Sandstone – Water Control
ICD Controlling water in Oil producer in a sandstone formation
Single lateral Sandstone – Water/Gas Control
ICD controlling water and gas in Oil producer

01/30/2010 (29,960 days)

Gas Saturation (fraction)

0.8
0.64
0.48
0.32
0.16
0
PICD

Standard Screen

1600’ horizontal

02/09/2010 (30,250 days)

Gas Saturation (fraction)

0.8
0.64
0.48
0.32
0.16
0
PICD

Standard Screen

04/11/2010 (30,881 days)

Oil Saturation (fraction)

0.800016
0.640149
0.480282
0.320415
0.160537
0
PICD

Standard Screen

02/07/2010 (27,789 days)

Gas Saturation (fraction)

0.8
0.64
0.48
0.32
0.16
0
PICD

Standard Screen

3200’ horizontal

6400’ horizontal

Standard Screen

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Case 1 – Stand-alone Screens Completion (Does not illustrate actual well path)

Case 2 - Equalizer Select ICD with Gravel Pack

1. packer and 32 ICD joints of the same sequence (excluding bullhead) repeated to heel

Equalizer Select

- Equalizer Select resistance increases by flowing through more stages
- FRR Available: 0.8, 1.6, 3.2, 6.4

Well Results

ICD Oil Production

Barefoot Oil Production

Barefoot Water Production

ICD Water Production
Questions ???