Production enhancement and uncertainty reduction by optimum use of flow control devices

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Presentation outline

- Introduction to the advanced completion technology
- Active ICV (Interval Control Valves)
- Passive ICD (Inflow Control Devices)
- Autonomous FCD (Flow Control Devices)
Introduction
Reactive control of multi-zone production

Reactive

• Decisions are based on system’s current condition
• Short-term objectives: → Improve current Production
• React quickly to unexpected events with:
  1. Well intervention or
  2. ICVs/Autonomous FCD: which introduce extra complexity, risks and limits to the number of zones
Introduction
Proactive control of multi-zone production

**Proactive**
- Starts during early production period to mitigate future problems.
- Long-term objective: Increase Total Oil Recovery
- Uses a reservoir model of unknown quality
- Computationally demanding
- Requires reservoir simulation and production modelling skills
- ICVs, ICDs, AFCDs
Technology development
Advanced Well Completion (Downhole Flow Control) types

Passive Control
- Inflow control devices (ICD)
  - Many types
    - Tube
    - Orifice
    - Slot
    - Nozzle
    - Helical
    - EQUIFLOW
    - FloReg & Fluxrite
    - Hybrid EQUILAIZER
    - ResFlow, ResInject
    - Production EQUILAIZER
    - Labyrinth
    - ICD

Active
- Inflow/Interval Control
  - Valves (ICV)
    - hydraulic control
    - Electric control
    - Electro-hydraulic
      - on/off
      - discrete positions
      - infinitely variable

New developments
- Laminar \( \Delta P \sim \mu Q \)
- Turbulent \( \Delta P \sim \rho Q^2 \)

- AICD
  - Restrict unwanted fluid flows
- AICV
  - Stop unwanted fluid flows
Active Control (ICVs)
Providing a flexible real time control of zonal production

Challenges in proactive optimisation of ICVs:

1. Large number of control variables
   - Number of controlled elements times production time.
   - Example (A real-field case study): 4 years control period, 4 control steps per year (control every 3 months), 12 ICVs → 192 variables

2. Uncertain numerical reservoir models calculate oil/water production forecast (objective function)

✓ Fast and efficient in-house optimisation algorithm developed (SPE-167453).
Problem Definition:
Impact of Reservoir Model Uncertainty on Proactive Optimisation using single realisation

The optimum control scenario is calculated using a **single realisation** (e.g. base-case).

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**Proactive optimisation**

Base-case

This control scenario provides optimal performance for the base-case model (or realisation).

**Proactive optimisation**

**Optimum control scenario**

**Base-case**

**This control scenario provides optimal performance for the base-case model (or realisation).**

**However,** this control strategy is highly unlikely to provide optimal performance when applied to (all) other reservoir model realisations.
Solution:
Developed Approaches for Proactive Optimisation under Uncertainties (Robust Optimisation)

- A modified objective function is defined as mean of a reasonable ensemble of realisations.
- Search for a control scenario which improve all realisations (to some extent)

Optimum control scenario obtained using Robust Mean Optimisation is applied to all realisations:
- Increased mean (maximum added-value)
- Reduced uncertainty

Non-optimum performance in some realisations

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  - ΔP ~ ρQ²

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Advanced Well Completions in Heterogeneous Reservoirs

- Horizontal wells have extended reservoir-well contact
- This results in uneven inflow profile in Open-Hole (OH) wells
- Early water breakthrough
- Decreases oil recovery
- Well out-flow & surface separation problems

\[ \Delta P_{\text{Reservoir}} \]
\[ \Delta P_{\text{ICD}} \]

- ICD completion reduces the open hole’s inflow rate variation
- The pressure drop across an ICD is position & flow rate dependant
- Analytical & well simulators provide a snapshot of the well inflow performance
- Reservoir Simulators quantify the value equalising the well’s inflow performance

Courtesy of Halliburton
Optimising & Quantifying the Value of an ICD completion
Analytical modelling of the performance of a specific well

• The analytical model of an ICD completion in heterogeneous reservoirs is described
• The inflow distribution is quantified and designed

Birchenko et al. 2012, dx.doi.org/10.1016/j.petrol.0121.06.022
Definition of the Terms used in Selection of ICD-completion to compromise the improved inflow rate profile and the increased completion pressure losses

Dimensionless Parameters:

- **Productivity Ratio (PR)**
  
  How much well productivity is sacrificed

- **Inflow variance (IV)**
  
  Level of reservoir heterogeneity

- **Inflow Equalisation (IE) = \frac{IV_{ICD}}{IV_{OH}}**

  How successful is the ICD-completion
ICD-completion performance Type Curves for Heterogeneous Reservoirs

- Each IE value has a unique type curve that relates IV to PR
- ICD completion strength determines PR & IE

Example:
- Reservoir heterogeneity $\equiv 0.6$ IV$_{OH}$
- Recovery increases with IE = 0.3
- Achieved with new PR = 0.20

More heterogeneous reservoirs require larger reductions in Productivity Ratio for given level of IE
Case study
Adjusted Completion Design When the Well Log shows More Heterogeneous K distribution than was initially assumed in the well completion model

The updated model is more heterogeneous than the original model.

Original design (using initial model)
Keep the original ICD size in the updated model
Adjusted ICD size in the updated model

SPE 175448-MS
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Autonomous Flow Control Devices (AFCDs)

Commercial or with reported engineering development

*SPE 159634*  
*SPE 166285*  
*SPE 169233-MS*
The target is to understand

Optimum completion configuration

\[ \delta P = \left( \frac{P_{\text{mix}}}{P_{\text{cal}}} \right)^{2} \cdot \left( \frac{\mu_{\text{cal}}}{\mu_{\text{mix}}} \right)^{y} \cdot a_{\text{AICD}} \cdot q^{x} \]

Detailed discussion in [SPE 170780-MS]
Is the optimum AFCD performance similar for different reservoir types and oil/water/gas properties?

Maximum recovery within white boxes

- Colour = oil recovery (red is more)
- \((Y)\) = restriction to 100% water/gas (equiv. diam. mm)
- \((X)\) = restriction to 100% oil (equiv. area mm\(^2\))

- AFCD performance trend is similar
- Optimum AFCD performance areas due to:
  - Reactive vs. Proactive Control
  - “Good Water”
Field Study: AFCD-completion vs. ICD-completion
Impact of reservoir uncertainty

Optimum design for an existing AFCD

- 4 joints per wellbore segment.
- 3 AFCDs per joint.

- Confirmed AFCD Performance Trend
- Evaluated role of Uncertainty

8.6% more recovery

- Heavy oil/water
- 3 Multi-Lateral wells
Downhole Flow Control Completion: Added value

- Improve production control
- Improve production in uncertain conditions
- Improve project economics
The authors wish to thank:

1. The 2nd Inwell Flow Surveillance and Control Seminar organising committee and the session chairmen for the opportunity to give this presentation.

2. The research leading to these results received partial funding from the European Union’s Seventh Framework Programme managed by REA-Research Executive Agency [http://ec.europa.eu/rea](http://ec.europa.eu/rea) (FP7/2007-2013) under grant agreement No. FP7-SME-2013-2-605701.

3. Funding was also provided by the sponsors of the “Value of Advanced Wells” Joint Industry Project at Heriot-Watt University.

4. Schlumberger Information Systems are also acknowledged for providing access to their software
Thanks For Your Attention.