WELL PRODUCTIVITY ASSESSMENT THROUGH COMPUTATIONAL FLUID DYNAMICS APPLIED TO NEAR-WELLBORE & WELLBORE MODELLING

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Outline

- **Objective**
  - Background and Motivation
    - What is Computational Fluid Dynamics – CFD
    - Why to use it for wellbore and near-wellbore modelling
    - Hydraulically fractured wells
  - Asymmetric Damage in horizontal wells
  - Completion fluid displacement in a horizontal well
  - Final comments
Objective

To share the concept of detailed wellbore and near-wellbore modelling through the use of computational fluid dynamics, specifically finite volumes and to highlight its relevance for production optimisation and drainage architecture design.
As indicated by Yildiz (SPE 82249), the long-term productivity of oil and gas wells is influenced by many factors. Among these factors are petrophysical properties, fluid properties, degree of formation damage and/or stimulation, well geometry, well completions, number of fluid phases, and flow-velocity type.
Background and motivation

- Well inflow performance $\rightarrow$ Forecast production

Impact of sand face completion/well geometry: Drainage architecture

Impact of formation damage
Background and motivation

Henry Darcy (1853)

\[ Q = \frac{-kA (P_b - P_a)}{\mu L} \]

Analytical Equations

- Fundamental conservation equations of momentum and continuity
- Closure terms
- Well geometry
- Boundary conditions
- Assumptions on: fluid properties, petrophysical properties, fluids saturations, formation damage degree
Background and motivation

- Analytical models - Case adapted to the model and not the model adapted to the case
- Important decisions related to production enhancement operations taken on the base of oversimplifications
- Lack of comprehensive workflows for inflow performance estimation
- Multiphase flow complexities and non-Darcy effects are usually neglected
50% RETURN PERMEABILITY DECREASE WHAT DOES IT MEAN?
Background and Motivation

- Laboratories can produce great detail on depth, magnitude and mechanisms of damage for any rock/fluid combination simulating near wellbore phenomena.

- There is nowhere for this information to go – the detail is lost.

- Fit the damage to the model (…instead of the model to the damage).

- The so-called “skin factor”, is solely perceived as a fudge factor, a matching factor, something that goes into the equation but we don’t really know what it is.

- Unfortunately, when formation heterogeneities, complex well geometries, complex sand face completions and particular formation damage intensities are present, analytical solutions are difficult or impossible to obtain.
Background and Motivation

• This lack of adequate modelling leads to gross generalisation on the magnitude, depth and impact of damage and thus on any well inflow prediction

• No adequate models for near-wellbore

• For horizontal wells…required coupled well-porous media models

IMPROVED WORKFLOWS REQUIRED
Background and Motivation

- How important is to have a model which captures the relevant physic that will drive the well’s productivity?

- How much investment is on risk?

- Is the flow dynamics completely intuitive under every proposed sand face completion scenario?

- Do we believe on the importance of comprehensive workflows?...

Only we can decide when it is important to go further.
What is CFD?

**Computational Fluid Dynamics** is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flow.

- Approximate solutions
- Honours mass, momentum and energy conservation equations
- Based on space and time
- CFD uses the growing computing power of modern computers to allow engineers to accurate predict solutions without making arbitrary simplifying assumptions
Why to use this detailed modelling for wellbores and the near-wellbore area?
Why CFD?

- Finite Volumes
- Flexible, comprehensive
- Wellbore and near-wellbore area, including damaged zones, perforations at real scale, screens, horizontal wells, hydraulic fractures, open hole, naturally fractured reservoirs
- Coupled well-porous media modelling
- Steady state cases
- Transient cases
Why CFD?

Mesh for coupled well-porous media case
Why CFD?

Mesh for cased and perforated 60 deg phasing
Why CFD?

Mesh for cased-perforated 90 deg phasing
Applications

HYDRAULICALLY FRACTURED WELLS
Hydraulically fractured wells

When designing a hydraulic fracture, the objective is?

a) Knowing how many sacks of proppant will be required?
b) How many stages will we pumped?
c) Which fluids will be used?
d) None of the above?
Hydraulically fractured wells

The answer is “d”

What is really important to determine is:

“The fracture characteristics which will provide the highest and sustainable production increase based on practical limitations”

The lack of technology has moved the approach towards designing the treatment first and then having a very high level result on what the production increase is going to be (…fast calculations!)

Vincent [SPE 119143] has pointed out that “although computing tools have improved, as an industry we remain incapable of fully describing the complexity of a hydraulic fracture, reservoir and fluid flow regimes
<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Permeability (md)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>S1 k = 100 md</td>
</tr>
<tr>
<td>5</td>
<td>S2 k = 10 md</td>
</tr>
<tr>
<td>12</td>
<td>S3 k = 50 md</td>
</tr>
<tr>
<td>8</td>
<td>S4 k = 90 md</td>
</tr>
<tr>
<td>15</td>
<td>S5 k = 70 md</td>
</tr>
</tbody>
</table>

Select optimum sand face completion (vertical well + fracs, deviated well +fracs...)

Hydraulically fractured wells
Hydraulically fractured wells

- **Base case**
  - Only perforations, 60 deg phase on S1 and S5 zones.
  - Poor drainage for the middle section is observed

Pressure Profile (Pas)
Hydraulically fractured wells

- Perforations+ Fracture @ S3 layer (Fracture & one of the perfs planes)
Hydraulically fractured wells

- Perforations+ Fracture @ S3 layer
- Incremental inflow capacity ~60% compared with the only-perforations option

Pressure Profile (Pas)
Hydraulically fractured wells

- Impact of Perfs + Frac at S1 layer

Pressure Profile (Pas)

Velocity Profile (m/s)
Hydraulically fractured wells

- Impact of Perfs + Frac at S1 layer

Velocity Vectors (m/s)
Hydraulically fractured wells

- Only perforations, 60 deg phase on S1, S4 and S5 zones.

Pressure Profile (Pas)
Hydraulically fractured wells

- Perforations + S4 Fracture
- Potential propagation to water zone

![Pressure Profile (Pas)](image)
Hydraulically fractured wells

- Perforations + S2 Fracture

Pressure Profile (Pas)
Hydraulically fractured wells

- Perforations + S2 & S4 Fractures

Transverse fractures

Fracture planes perpendicular to presented plane

Pressure Profile (Pas)
Hydraulically fractured wells

\[ \frac{\partial P}{\partial L} = \frac{\mu v}{k_d} + \beta \rho v^2 \]

(Darcy)

(Non-Darcy)

(Forchheimer Equation)
In the Forchheimer equation the first term represents viscous flow and the second term denotes the flow governed by inertial forces. Instead of turbulence, the non-Darcy flow is caused by inertial forces arising from the fluid flowing through curvilinear flow paths having periodical expansions and contractions of pore spaces. The flow paths in porous media can be conceptually illustrated by Figure 7.
Hydraulically fractured wells

Inertial losses

(a) tortuous flow paths

(b) expansions of pore space

(c) contractions of pore space
Hydraulically fractured wells

Technical

Highly detailed modelling

Practicality

- Selection of optimum perforation strategy for fracturing

- Influence on the fracture design regarding optimum fracture geometry

CONSISTENCY
Applications

ASYMMETRIC DAMAGE IN HORIZONTAL WELLS
Asymmetric Damage

Horizontal well

Preservoir = 4.47E07 Pascal

Undamaged Reservoir

Mud Cake

Damaged Zone

K = 1000 mD

K = 10 mD

K = 100 mD

Pwf = 4.42E07 Pascal

TRUE PICTURE FROM HEEL, TOE, TOP AND BOTTOM
Asymmetric Damage
Asymmetric Damage
Asymmetric Damage

Velocity Vectors for coupled well-porous media model
Asymmetric Damage

Pressure Profile for coupled well-porous media model
Asymmetric Damage

Technical

Highly detailed modelling

Practicality

- Mud selection

- Sand Face completion selection
Applications

DRILLING TECHNIQUE SELECTION
WELL PRODUCTIVITY
Drilling Technique Selection

Evaluation of drilling techniques for a naturally fractured reservoir

1) Overbalanced?
2) MPD?
3) Underbalanced?
Objective

To evaluate formation damage potential by comparing the following options:

- Underbalanced drilling (UBD)
- Managed pressure drilling (MPD)
- Conventional drilling with simple water based mud system (and post drilling acid stimulation options)
Drilling Technique Selection

Geometry: Well model meshed
Drilling Technique Selection

Geometry: Well model details

Enhanced permeability zones

Damage zones

Well

Matrix Permeability zone

Matrix Permeability zone

Enhanced permeability zone
Drilling Technique Selection

Results

Pressure profile of the UBD Case
Drilling Technique Selection

Results

Pressure profile of the Mixed Metal Oxide Case & Clean up
Drilling Technique Selection

Results

Pressure profile of the MPD Case
Drilling Technique Selection

Technical

- Highly detailed modelling

Practice

- Supports operational decisions on the selection of the optimal drilling technique → well productivity

CONSISTENCY
The use of CFD is a powerful engineering tool, providing core information which enhances the decision making process for the sand-face completion design and formation damage impact understanding. This detailed modelling provides deep understanding of the dynamics in the near-wellbore and the well itself.

Visualization of potential drainage profiles provides a comprehensive view of the impact of the well’s performance. These models represent a way for having more comprehensive views towards achieving technical excellence.

The use of detailed sand-face completion modelling, reduces the need of introducing “skin” factors to account for the complexities associated with the flow in the near wellbore area, and prevents the formation damage to be seen as a fudge factor.
Final Comments

THE BOUNDARIES

understanding

effort
Final Comments

Turning from having points of view...

Points of view

Viewing points

to having viewing points.
Final Comments

Evolving to a more comprehensive view
THANK YOU!