History Matching – what is sufficient HM for prediction/well planning

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Outline

- Introduction and Challenges
- Clear objectives and Fit for purpose models
- Quality assurance of History Match
- Stepwice process and how to make the HM process efficient
- Summary
Why do we History Match our Models?

- Objective is to improve models and their predictability
- Integrate all data
- Continuous reservoir description to reduce uncertainty
The objective is to forecast the future production with as little uncertainty as possible.

Provide integrated models with reduced and quantified uncertainty.
Challenges with Simulation models

- History Matching becomes more and more challenging with increasing number of wells and years on production

- Applicability of a FFM depends very much on:
  - Detail level required
  - Field Maturity

- Despite acknowledging all information acquired during the production period, there seems to be a limit for how accurate a flooding or recovery factor can be determined by simulation.

![Diagram showing the relationship between increasing level of detail and maturity of the field, with phases such as Early phase, Plateau period, Ramp up, and Tail End. The diagram also includes columns for Change in drainage strategy, Long term prognosis, and Short term prognosis, indicating the transition to Well planning.]
Challenges for modelling mature oil fields

- Predictability for very mature fields require accuracy of a few percent points of RF
- Gas fields are generally less complex to model

<table>
<thead>
<tr>
<th>Field</th>
<th>Fraction of recoverable oil extracted</th>
<th>% units oil remaining to be recovered</th>
<th>+/-30% confidence on remaining correspond to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statfjord</td>
<td>99 %</td>
<td>0,5 %</td>
<td>0,2 %</td>
</tr>
<tr>
<td>Gullfaks</td>
<td>96 %</td>
<td>2,6 %</td>
<td>0,8 %</td>
</tr>
<tr>
<td>Oseberg</td>
<td>94 %</td>
<td>3,9 %</td>
<td>1,2 %</td>
</tr>
<tr>
<td>Fram</td>
<td>85 %</td>
<td>7,0 %</td>
<td>2,1 %</td>
</tr>
<tr>
<td>Heidrun</td>
<td>81 %</td>
<td>8,1 %</td>
<td>2,4 %</td>
</tr>
<tr>
<td>Gjøa</td>
<td>72 %</td>
<td>8,4 %</td>
<td>2,5 %</td>
</tr>
<tr>
<td>Ekofisk</td>
<td>82 %</td>
<td>8,9 %</td>
<td>2,7 %</td>
</tr>
<tr>
<td>Visund</td>
<td>71 %</td>
<td>11,3 %</td>
<td>3,4 %</td>
</tr>
<tr>
<td>Snorre</td>
<td>75 %</td>
<td>11,4 %</td>
<td>3,4 %</td>
</tr>
<tr>
<td>Skarv</td>
<td>40 %</td>
<td>25,6 %</td>
<td>7,7 %</td>
</tr>
</tbody>
</table>

Data from NPD fact pages
Profile Application and Fit for Purpose model

Objective has to be clear

- Expectation has to be realistic
- Predictive power has to be accessed
- What is expected to be predicted?
  - Oil Rate
  - Gas rate
  - Free gas production
  - Condensate production
  - Water production
  - Pressure development
  - Contact movements
- Will it be assisted by other methods
  - Decline
  - Observed experience

What is the decision to be taken?

- FFM
  - Business plan and prognosis
  - Change/modify Drainage strategy
  - Capacity and pressure constrains
  - Well planning
- Sector models
  - Well planning (model based/no-model data)
  - WAG injection
  - Compositional effects
  - Polymer injection
  - Thin oil zones
  - Injection containment
Methods of HM

- Manual (Single model)
- Computer assisted (Multiple models)
- Sector models (some time used to correct FFM)
Examples of acceptance criteria

- Matching criteria's have to be evaluated and selected for each field
  - Engineering judgement and evaluation is required to adjust acceptance criteria
- Uncertainty in observations are often underestimated.
- Run sensitivities to understand impact

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Uncertainty/Accepted deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil rates, Water rates Gas Rates</td>
<td>+/- 10-15%</td>
</tr>
<tr>
<td>Fault multiplyers</td>
<td>+/- 1-2 log10 cycles</td>
</tr>
<tr>
<td>RFT</td>
<td>+/- 10% relative, forten more than real uncertainty in measurement (0.1 bar)</td>
</tr>
<tr>
<td>Pressure match</td>
<td>+/- 5-10 bar, smaller acceptance for large volumes</td>
</tr>
<tr>
<td>Porosity</td>
<td>5% units</td>
</tr>
<tr>
<td>NTG</td>
<td>+/- 10-15%</td>
</tr>
<tr>
<td>Isopac trends</td>
<td>+/- 10%</td>
</tr>
<tr>
<td>4D Seismic</td>
<td>++++</td>
</tr>
</tbody>
</table>
Quality assurance of history matching results

- Visualize, check & make sure that simulation model is initialized with a stable initial state and all model properties (porosity, permeability, initial water saturation, relative permeability data, end-point saturations, fluid properties, well data, etc) are consistently setup

- Use plotting and visual inspection/QC
  - Historical oil, water and gas rates
  - Measured/observed RFT/PLT data
  - Pressure/saturation distribution in the reservoir vs time
  - Comparison with seismic attributes for flooding and reservoir quality

- Apply History Matching Index (HMI) for quantitative analysis of history matching results (in Excel or using specialised software) and check if the difference between the observed and simulated dynamic behaviour is within specified uncertainty

- Visualize, check, and communicate all modifications made with G&G personnel, and make sure that all modifications made are realistic

\[
HMI_{gf} = \left[ \frac{1}{n} \sum_{i=1}^{n} \left( \frac{w_{gf} \ C_{gf} - H_{gf}}{H_{gf}} \right) \right]^{1/2}
\]

One should not spend time to make thousands of simulations to achieve better match than the uncertainty range in the observed data warrants
Test acceptance – visual inspection

- Evaluate deviation on history matched
- For Assisted History Matching, AHM
  - Acceptance – Use actual uncertainty in the measurements as starting point.
- How well does the model represent the physics ongoing in the reservoir?
- Is the spread acceptable?
- What is the controlling constrain in prediction, water handling, lift, gas capacity etc.
History Match Quality

- Modelling quality should be well understood
- Drill down to identify weaknesses and areas and wells having issues
  - Well-by-well presentation
  - Region-by-region presentation
History Match Analysis tool

- Calculates History match index and identifies issues
Stepwise history matching process
Common tuning and matching parameters

- Start with the big rocks first
- Start with a limited number of matching parameters

<table>
<thead>
<tr>
<th>History matching steps</th>
<th>Modifiers</th>
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<tbody>
<tr>
<td>1 Match average reservoir pressure (during analysis phase focus on delta pressure/depletion)</td>
<td>Pore volume, rock compressibility, fault transmissibility, permeability, aquifer parameters/pressure support, vertical/lateral communication.....</td>
</tr>
<tr>
<td>2 Match RFT pressures</td>
<td>Pore volume, rock compressibility, fault transmissibility, permeability, aquifer parameters/pressure support, vertical/lateral communication.....</td>
</tr>
<tr>
<td>3 Match average GOR and WCT</td>
<td>Fault transmissibility, vertical/lateral communication, relative permeability, facies proportions</td>
</tr>
<tr>
<td>4 Match well GOR and WCT</td>
<td>Relative permeability, fault transmissibility, vertical/lateral communication, well PI, near wellbore permeability</td>
</tr>
<tr>
<td>5 Match/quality check well PLT, open hole logs and tracer data</td>
<td>Relative permeability, fault transmissibility, vertical lateral communication, well PI, near well bore permeability</td>
</tr>
<tr>
<td>6 Match well shut in pressures</td>
<td>Reservoir communication, near well bore connectivity</td>
</tr>
<tr>
<td>7 Calibrate wells for predictions</td>
<td>Well PI, skin factor</td>
</tr>
</tbody>
</table>
Reflections on Assisted History Matching

How to make the AHM process efficient – lessons learned

<table>
<thead>
<tr>
<th>Learnings</th>
<th>Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Understanding the reservoir, field experience and uncertainties</strong> in the reservoir properties and observed data are fundamental prior to optimisation start-up</td>
<td><strong>Too much focus on optimization settings rather than focusing on the reservoir understanding and reservoir uncertainties involved.</strong></td>
</tr>
<tr>
<td>Confidence in the reservoir model and that it represents physics has to be established.</td>
<td><strong>Many wells with complex trajectory, long production history and large number of uncertainty parameters</strong></td>
</tr>
<tr>
<td>Start with low number of uncertainty parameters and the most important ones, analyse the results, and add/remove uncertainties</td>
<td></td>
</tr>
<tr>
<td>History matching process should not to be considered as a pure optimisation process. It is a combination of reservoir understanding and careful uncertainty assessment with wide range of optimisation methods provided in the AHM software</td>
<td>New uncertainties added without analysing the results from previous optimisation loop</td>
</tr>
<tr>
<td></td>
<td>Base case simulation model not checked &amp; no sensitivities performed to understand importance of uncertainty parameters selected</td>
</tr>
</tbody>
</table>
Always remember why we are doing history match!

- **Have to look at prediction too** – not enough to look at match quality
- Run predictions as part of the QC
- Predictability can be checked by testing on the last part of history
- Test historical performance on real production constraints, i.e. Inlet pressures, capacities etc
- Check gap at transition from history and prediction
Handling Uncertainty
Multiple vs Single realizations

- Multiple realizations enables handling of uncertainty in the predictions
- Uncertainty in prediction is difficult to handle for single realization HM

![Graph showing multiple models history match compared to single models history match.](image-url)
Avoid risk of predictability by local history matching

- Match at well level is often an issue. It can be tempting to introduce local powerful measures to improve the match.
- This will often result in reduced predictability.

- Property modelling and geo-modelling per area
- Modelling of thief zones
- Local variations HM using Relperms
Summary

Predictive models

- Clear and realistic objectives focusing on decision
- Fit for purpose model Representing Reservoir Physics
- Set acceptance criteria. Understanding Reservoir and uncertainties
- Use Stepwise approach. Test acceptance criteria and apply judgement
- Test model in prediction mode
- Compare with alternative methods
There’s never been a better time for good ideas