Automatic History Matching  
On The Norne Simulation Model  
Eirik Morell - TPG4530 - Norwegian University of Science and Technology - 2008

Abstract
This paper presents the result of an automatic history match study on the Norne Field. The study was done using commercially available tools, SIMOPT and ECLIPSE from Schlumberger.
Gradzone analysis was done to improve the workflow of the history matching process.
Actual field water production data was fitted using SIMOPT.

Introduction
History matching is usually the most complex part reservoir simulation. Over the years it has been a manual trial and error procedure that requires great knowledge about the actual field. The purpose of history matching is to ensure some degree of legitimacy to the flow simulation model. This process is non-unique meaning that it can have several solutions. The basic of history matching is to modify the simulation model’s flow parameters, such as permeability, porosity and transmissibility, in order to make the model simulate produce similar results as the real field.
Production- and pressure data are collected from the actual field and feed into the simulation model as history production or pressure readings. Based on the misfit between simulated data and real field data changes to the simulation model are made.
The increase in computing power along with software development has resulted in several releases of software aiding the history matching process. The most successful tools are based on gradient methods.1 These methods make use of the gradient of the objective function. This function is representation of the misfit between observed- and simulated data.

Problem description
Norne simulation model has a small degree of misfit. However, some wells are poorly matched. Wells introduced in 2006 seem to be the worst. Problem areas are to be detected. Relying production data a sensitivity analysis is done, the effect of fault transmissibility is studied, followed up by a Gradzone analysis of horizontal permeability.
Furthermore the effect of 4D history matching is discussed.

Norne
Discovered in December 1991, the Norne field is located in the Norwegian Sea. It’s a good quality oil reservoir with a 110 m thick oil column with a 75m gas cap. Initial oil in place is 106.6 millions Sm3, where 90 millions Sm3 is recoverable. The reserves are distributed in 4 provinces: Norne C; Norne D; Norne E; Norne G, whereas 97% of the OIP is located in Norne C, D and E and the remaining 3% in Norne G.2
Oil production started in 1997 and gas production started in 2001. As of December 2007; cumulative oil produced is 77 millions Sm3, amounting 86% of recoverable reserves, and cumulative gas produced is 5 billions Sm3.3
Norne reservoir simulation model
The Norne field production has been studied using a 3D three-phase full field black-oil model, based on a geological model from 2004. It’s a fine grid system, 46 x 112, with 22 layers using grid blocks between 80-100m. Hysteresis for WAG period is included, making the model CPU consuming.

Results of the simulation model

Fig. 2 – GOR in green & WCT in blue vs. Time

Fig. 3 – GOR in blue & GORH in pink vs. Time

Fig. 4 – WCT in blue & WCTH in pink vs. Time
Sensitivity analysis

Using a 0.005 error margin SIMOPT produce the RMS (Root Mean Square) values displayed in table 1. The top row shows the overall match between the simulated and observed data. The RMS total is quite low meaning that the overall history match of the field is good. This confirms the general impression given by studying GOR and WCT, in figure 3 and 4 respectively.

Table 1’s second and subsequent rows display a breakdown of RMS values for individual wells. The values are ordered descending, where low value is preferable, meaning that well E-3AH and B-1BH is the worst match while B-4H is the best match.

Wells located in segment C are dominating table 1.

Table 1 - RMS analysis, 0.005 error margin

<table>
<thead>
<tr>
<th>Name (i)</th>
<th>Domain (j)</th>
<th>RMS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>GLOBAL</td>
<td>29.14</td>
</tr>
<tr>
<td>WWCT</td>
<td>E-3AH</td>
<td>64.26</td>
</tr>
<tr>
<td>WWCT</td>
<td>B-1BH</td>
<td>73.15</td>
</tr>
<tr>
<td>WWCT</td>
<td>E-2AH</td>
<td>68.37</td>
</tr>
<tr>
<td>WWCT</td>
<td>D-3AH</td>
<td>35.26</td>
</tr>
<tr>
<td>WWCT</td>
<td>B-3H</td>
<td>34.03</td>
</tr>
<tr>
<td>WWCT</td>
<td>B-4D</td>
<td>31.52</td>
</tr>
<tr>
<td>WWCT</td>
<td>E-3CH</td>
<td>30.97</td>
</tr>
<tr>
<td>WWCT</td>
<td>B-1H</td>
<td>26.90</td>
</tr>
<tr>
<td>WWCT</td>
<td>E-1H</td>
<td>25.76</td>
</tr>
<tr>
<td>WWCT</td>
<td>D-1H</td>
<td>25.56</td>
</tr>
<tr>
<td>WWCT</td>
<td>D-2H</td>
<td>24.15</td>
</tr>
<tr>
<td>WWCT</td>
<td>D-4AH</td>
<td>23.77</td>
</tr>
<tr>
<td>WWCT</td>
<td>B-4B</td>
<td>17.72</td>
</tr>
<tr>
<td>WWCT</td>
<td>E-2H</td>
<td>17.05</td>
</tr>
<tr>
<td>WWCT</td>
<td>D-1CH</td>
<td>12.15</td>
</tr>
<tr>
<td>WWCT</td>
<td>D-4H</td>
<td>12.02</td>
</tr>
<tr>
<td>WWCT</td>
<td>E-3H</td>
<td>11.62</td>
</tr>
<tr>
<td>WWCT</td>
<td>B-2H</td>
<td>13.20</td>
</tr>
<tr>
<td>WWCT</td>
<td>E-4AH</td>
<td>7.87</td>
</tr>
<tr>
<td>WWCT</td>
<td>D-3BH</td>
<td>7.54</td>
</tr>
<tr>
<td>WWCT</td>
<td>K-3H</td>
<td>7.27</td>
</tr>
<tr>
<td>WWCT</td>
<td>B-4H</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Figure 6 displays observed data in pink and simulated data in blue. The difference in production start as well in magnitude is significant.

Figure 5 and 6 display watercut for the worst matched wells in the model. They purpose an opposite problem. Figure 5 display simulated water cut greater than reported whereas figure 6 display simulated watercut lower than reported. E-3AH is located in segment E, while B-1BH is located in segment C.

A closer inspection of the RMS values for wells in segment C shows that they tend to simulate less watercut than reported. Thus segment C is the area of interest to improve.
Designing a regression problem

Well B-1BH was completed in January 2006 located in Norne C-segment. It’s located in grid blocks i=8, j=26-31, z=13.

A visual inspection shows that faults affecting pattern of flow around B-1BH are C_10, C_21, C_26 and C_27.

Figure 8 shows that fault transmissibility for C_26 and C_27 is largely negative correlated. This may pose a problem, making the regression ill-posed.

The other off-diagonal elements are low to medium negative correlated, meaning that they probably will improve the match. Thus transmissibility of C_10, C_21, C_26 and C_27 will be the parameters to vary in the regression.

Removing production data for all segments except C-segment produce RMS values displayed in table 2.

Table 3 display a reduction of RMS values after 3 regression runs. A comparison of RMS values before and after regression is illustrated in figure 9.
Gradzone analysis

In the previous section faults, as regression parameters, were chosen based on visual inspection. SIMOPT offers an option to identify regions in the reservoir most affected by the objective function.\(^1,5\)

\[
f = \frac{1}{w_i} \left( \frac{\alpha_i - c_i}{\sigma_i} \right)^2
\]

\(^{(1)}\)

It’s a time consuming process, but it allows a new type of region selection based on parameter variation.

Horizontal permeability were investigated in C-segment, area i=5-18, j=14-38, z=10,13,15 using 75 Gradzone parameters. Parameters are scattered according to figure 10. Different layers are used in definition of Gradzone sample due to Norne’s different geological layers.

Figure 11 shows an auto-zonation SIMOPT suggested. The area divided in the respective layers reveals uncertainties in properties of flow across the faults C_10, C_21, C_26 and C_27. This confirms the visual inspection done in the previous section.
Results and case discussion

Several cases varying the amount of production data feed into the regression were conducted.

Change in the transmissibility of a near-sealing fault generally has much greater effect on reservoir flow, thus greater sensitivity, than a change in the transmissibility of a near invisible fault. The faults in the regression problem were initially considered to be pretty tight, with a MULTFLT of 0.001 – 0.1. The solution of the regression problem, displayed in table 4, suggests even tighter faults with MULTFLT values varying from 0.0005 – 0.04.

Tighter faults in the south-east part of the C-segment produce the results displayed by green line in figure 12-15. The initial model, blue line, and the matched model produce similar output from the beginning till the date when B-1BH was opened. However, after the 1/6-2006 till the end the difference is significant.

Table 4 - Transmissibility multiplier values for initial and matched model

<table>
<thead>
<tr>
<th></th>
<th>INITIAL MULTFLT</th>
<th>HMMULTFLT</th>
<th>NEW MULTFLT</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_10</td>
<td>0.0100</td>
<td>0.2869</td>
<td>0.0029</td>
</tr>
<tr>
<td>C_21</td>
<td>0.0010</td>
<td>0.4743</td>
<td>0.0005</td>
</tr>
<tr>
<td>C_26</td>
<td>0.1000</td>
<td>0.3679</td>
<td>0.0363</td>
</tr>
<tr>
<td>C_27</td>
<td>0.0500</td>
<td>0.4743</td>
<td>0.0237</td>
</tr>
</tbody>
</table>

Fig. 12 – WWCT in blue, WWCTH in pink, WWCT-MATCHED in green for B-1BH

Fig. 13 – GOR in blue, GORH in pink & GOR-MATCHED in green

Fig. 14 – OPT in blue, OPTH in pink & OPT-MATCHED in green

Fig. 15 – WCT in blue, WCTH in pink & WCT-MATCHED in green
4D history matching

Petro-elastic modeling is a key element of enhancing the knowledge of flow pattern. Seismic plays an important role to identify problem areas in Gradzone analysis.

Norne has 5 high quality surveys of 4D seismic, repeated seismic acquisition after field production, available. SIMOPT with seismic input get an enhanced method to calculate the objective function. 

\[ f = w_p \left( \frac{\alpha_p - c_p}{\sigma_p} \right)^2 + w_s \left( \frac{\alpha_s - c_s}{\sigma_s} \right)^2 \]

\( f_p \) is the contribution of production data in the total objective function \( f \) while \( f_s \) is the contribution of seismic data.

The potential of an enhanced understanding of Norne using 4D seismic is great.

Conclusion

Automatic history matching using only production data can provide great results. However, this requires great understanding and insight of the reservoir.

Norne has a great potential of matching the performance of segment C. A high degree of uncertainties are connected to the C-segment’s fault properties.

4D seismic can enhance the understanding of saturation patterns and general flow, thus being able to determine critical areas that need attention and correction to enhance the models performance.

A combination of production data and 4D seismic enhances the potential of a successful automatic history match. The reported production data provides accuracy for regression and 4D seismic provides field understanding in the Gradzone analysis.

References


Nomenclature

- \( f \) = objective function
- \( w_p \) = weight of production data
- \( w_s \) = weight of seismic data
- \( \alpha_p \) = observed production data
- \( \alpha_s \) = observed seismic data
- \( c_p \) = simulated production data
- \( c_s \) = simulated seismic data
- \( \sigma_p \) = standard deviation of production data
- \( \sigma_s \) = standard deviation of seismic data

\( f_p \) = contribution of production data in the objective function

\( f_s \) = contribution of seismic data in the objective function