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OPTIMISATION AND RISK ASSESSMENT OF A WATER SHUT-OFF TREATMENT IN A WYTCH FARM HORIZONTAL WELL

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Summary

Limitations on water handling capacity at Wytch Farm mean high water-cuts from horizontal wells could lead to loss of oil production. To avoid this, a pilot study has been undertaken on a single horizontal well, to investigate the potential for a water shut-off treatment and estimate the associated risk. The study has shown that a water shut-off treatment early in 1997 should be economically beneficial to the performance of the field as a whole. Conditions that would reduce the return on the treatment have been identified and can be avoided by optimising the strategy, increasing the robustness of the project.

Description of work

The study comprised three parts:

- 1) Geological modelling of many realisations of the region around the horizontal well F18.
- 2) Incorporating the geostatistical realisations in a full field model and assessing them by comparing simulation predictions with the historical well performance
- 3) Predicting future performance with and without a water shut-off treatment for realisations which gave a satisfactory history match and evaluating the risk from the range of predicted outcomes.

Geological modelling

The Sherwood Sandstone reservoir comprises a thick (\cong 160m) succession of fluvial, lacustrine and aeolian sandstones and associated sediments. Sedimentologically, the reservoir is described as an association of five principal lithotypes, defined as; floodplain mudrocks, floodplain heterolithics, perilacustrine sandflat, lacustrine heterolithics and fluvial sandstones. The reservoir model comprises eight layers (zones), four of which are treated as being homogeneous, and four heterogeneous, in character. Fine scale geological models were built in the region of the well using geostatistical techniques for each of the heterogeneous zones (zones 10, 30, 50 and 70). The voxel size was 5m x 5m x 0.25m.

The geostatistical package STORM¹, in conjunction with the SIS (Sequential Indicator Simulation) routine from GSLib², was used to perform the geostatistical modelling and upscaling to locally refined ECLIPSE grids in the region of the well. The grid cells in the locally refined region had dimensions of 20m x 20m x 2m (approx). (For the rest of the field, the coarse gridded deterministic full-field ECLIPSE model was used). Each zone was modelled and upscaled separately.

SIS was used as the method for modelling both lithotypes and lithotype associations, with the exception that STORM's channel modelling routine was used for the braided fluvial channels in zones 50 and 70. Each realisation was conditioned to honour the observed lithotype in the horizontal well under consideration, plus another horizontal well nearby, that crossed the modelled volume (Figure 1). Each stochastic realisation was populated by petrophysical data using constant porosity and permeability for each lithotype. The petrophysical realisation was then upscaled to the simulation grid (porosity averaged arithmetically, permeability solved from a single phase pressure equation).

For each zone, a range of realisations were generated by varying the geological parameters. These sensitivities were chosen so as to cover all reasonable geological possibilities. For zone 10, 6 realisations were produced, whilst 18 realisations were produced for each of the other zones, giving a total of 60 geostatistical realisations. Potentially these could have been combined to give $6 \times 18 \times 18 \times 18 = 34992$ models of the whole reservoir.

Earlier studies had indicated that uncertainty in the reservoir description had the major impact on water cut development whilst the uncertainty in relative permeability was of secondary importance. Consequently, the relative permeabilities were not varied in the study.

History matching

Local grid refinement was applied to the full-field ECLIPSE simulation model of the Sherwood reservoir in the region of the well (see Figure 1). 75 cases were chosen, in which the fine-grid cells were populated by data from the geostatistical models rather than from the original deterministic model. The cases were chosen as the results from earlier cases became known, in order to ensure that the full range of uncertainty was covered.

Production was simulated from field start-up to the year 2000 for these cases, to assess the impact of combinations of geostatistical models for each of the heterogeneous units and parameter values in deterministic zones. It was quickly found that changing geostatistical realisations for zones 10 and 30 had no or very little effect on the end results, whilst variations in zone 70 had the greatest impact.

Each case was assessed on the quality of its watercut history match. Due to limited numerical data, this was based upon a judgement of each case, marking it to be Good, Fair or Bad. 20 cases were selected from the history matching exercise, to investigate possible water shut-off treatments. The criteria by which these twenty cases were selected were:

- a) Choose cases which have at least a Fair history match to the F18 production data, giving preference to those that have a Fair/Good or Good history match.
- b) Include only one of a group of cases having identical behaviour if this is attributable to similar reservoir properties.
- c) Add the completely deterministic case.
- d) Add cases with extreme watercut behaviour, provided they have at least a Fair history match.

Discussion of typical cases

Examination of the results showed that, in general, cases with zero porosity and permeability in the heterolithic (non-net) regions have lower watercuts at early times than those with finite porosity and permeability in these regions. The application of low value cut-offs which are traditionally applied to porosity and permeability in deterministic modelling is analogous to setting the porosity and permeability of the heterolithic regions to zero. This work demonstrates that the procedure may have a significant impact on the modelled sweep efficiency. This is illustrated in Figure 2, which shows the water saturation in a cross section of the reservoir for two such cases. The saturations are more heterogeneous in the case with zero porosity and permeability in the heterolithic regions, whereas it is swept more efficiently if these regions have some permeability. This is because the permeability contrast between the channels and heterolithics is reduced and the heterolithics provide some communication between the channels when their permeability is non-zero.

Evaluation of Water Shut-Off Strategies

Three water shut-off strategies were assessed, by comparing them on the base case model (Figure 1b):

- a) Shutting off the lowest zone (80)
- b) Shutting in all of zone 80 and approximately half of zone 70
- c) Shutting in the whole of zones 70 and 80

The first strategy reduced field water production by approximately 5 MMSTB, without loss of oil production. The second strategy reduced water production by around 9 MMSTB, with little or no oil loss. The third strategy gave a similar 10 MMSTB reduction in water production, but with up to 0.5 MMSTB loss of oil. The second strategy was therefore applied to each of the 20 cases. The results of these cases were compared with those of the corresponding waterfloods, and were used in the economic analysis described below.

NPV's for Water Shut-Off Treatments

The net present value (NPV) of the treatment was calculated for each case and was also re-evaluated, incorporating the possibility of technical and operational failure. The method used was as follows: The reductions in well water and oil production were calculated annually for each sensitivity case. The reduction in water production from the well releases some of the topsides water handling capacity. This allows other wells to be produced at increased rates, which may improve overall recovery. In this study, the loss of water production was equated to a gain in oil recovery by the expression

Equivalent gain in oil recovery = Drop in water production/10

The loss in oil production seen in the sensitivity cases was subtracted from the gain in oil calculated from the above expression to give a net oil gain. This net oil gain was calculated annually and converted into a discounted monetary value. From this a NPV was calculated for each sensitivity case. A second set of NPVs was also calculated to include the risk of operational/technical failure.

The distribution of NPVs for the various cases (excluding operational uncertainty) are shown in Figure 3. Even when taking into account the risk of operational failure, a significant positive expected net present value was predicted for the treatment.

The NPV histogram is bi-modal, with higher NPVs for the cases having non-zero permeability heterolithics in zone 70 than for those with zero permeability heterolithics in this zone. The watercut rises more slowly in the cases with zero permeability heterolithics, therefore the lower half of zone 70 is not completely swept at the time of treatment. The water shut-off strategy could therefore be optimised either by delaying the treatment or shutting off zone 80 only if the watercut develops slowly, indicating that this is the more realistic reservoir model.

The impact on the NPV of the grid resolution was also investigated. Running the full-field model without local grid refinement gave a much poorer NPV for the water shut-off treatment, than if the same model was run, but with local grid refinement applied. This indicates that a decision not to treat a well based upon a coarse grid model could potentially be incorrect.

Key Technical Points

The key technical points to note are:

- 1. The need for fine scale modelling in the region of the wellbore to accurately model performance.
- 2. The significance of not applying cut-offs to petrophysical data, and so allowing "non-net" rock to . contribute to flow. The evidence in this case currently supports the theory that in this reservoir "non-net" rock can contribute to flow.

- 3. The value in selecting simulation cases in the light of previous results, in order to consider the whole range of possible outcomes with the minimum of wasted effort.
- 4. The need to assess the economic value of a water shut-off treatment in the light of its impact on the performance of the whole field, and not just the single well.
- 5. The study was carried out over a period of 4 months (including developing the methodology and techniques). Subsequent studies would take approximately 2.5 months. Such resource expenditure may be justified for high angle wells, where water shut-off treatments are more expensive and involve newer technology, and where there is potential to optimise the treatment method. To extend the use of such techniques to a broader range of applications would require software enhancements to speed up the assessment of multiple realisations.

Current status of field

This work was carried out in the period Sept 1995 - Jan 1996, and predicted water cuts into the future. Figure 4 shows the range of predicted well performances, and the actual data. The observed data falls within the predicted range, even 2 years after the history-matching exercise. The immediate needs for a treatment have reduced, as water handling has been de-bottlenecked, and so no treatment has as yet taken place.

Conclusions

A methodology has been developed which quantifies the uncertainty in outcome (NPV) of a water shutoff treatment due to the risk of inappropriate treatment design, caused by uncertainties in the reservoir description, facilitating assessment of potential risk and reward before committing to costly interventions. The technique has been applied to the horizontal producer F18 in Wytch Farm and the risk of operational failure has also been included in the evaluation of NPV. The study shows that a water shut-off treatment has a significant positive NPV and identifies key criteria for success. Strategies for optimising the treatment for different watercut developments have been suggested. This methodology can reduce the requirement for a PLT before treatment, with potentially large associated cost savings.

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in Well F18