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"Method to optimize the development and management of waterflooding and intelligent wells (ICVs) for a heavy oil reservoir."

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Model-based production strategy optimization for a heavy oil reservoir considering waterflooding and intelligent wells

Andrés Fernando Peralta Sánchez

Introduction

Heavy oil reservoirs are complex due to low oil recovery factors, and under waterflooding, they present high and quick production of water caused by poor sweep efficiency. Decision-making procedures for developing and managing a production strategy are also hard because all variables, uncertainties, and physical phenomena must be studied to avoid potential wrong decisions.

Intelligent wells (IW) equipped with inflow control valves (ICVs) can control multiple production/injection zones, improving the water management observed for waterflooding. However, extra work is necessary since more design and operational parameters are studied.

This document is a summary of the work by Peralta et al. (2025) where nominal production optimization is the focus for the development and management of a heavy oil reservoir considering waterflooding without ICVs (WF) and with ICVs (WF+ICV) as production strategies.

This work concentrated on step 6 from a general methodology that is based on a 12-step (SCHIOZER et al., 2019), by performing the model-based field development and management with life cycle optimization for the selection of production strategies. Accordingly, a complete procedure is applied to select and compare the studied strategies (WF and WF+ICV) by optimizing their design and control variables through model-based reservoir simulation, using the Net Present Value (NPV) as the objective function (OF).

Objective

The objective is to apply a complete methodology to nominally (only one scenario/model) optimize the development and management for WF and WF+ICV as production strategies through model-based decision analysis, allowing a decision-maker to make comparisons and select the best strategy for a similar case.

Methodology

We use manual and assisted processes to maximize the OF based on reservoir engineering knowledge and applying the Iterative Discrete Latin Hypercube sampling algorithm (IDLHC).

The strategies are optimized in hierarchical procedures, where G1 (design/project variables) is assessed first, followed by G2L (control/operation variables).

The optimization process is similar to both strategies, however, there are four more variables for WF+ICV: (1) number and (2) position of ICVs in G1, and operation of ICVs for (3) producers and (4) injectors in G2L, respectively. Then, to avoid repeating some phases, we take the best G1 result from WF as our starting point to complete the G1 for WF+ICV with a special focus on the number and position of ICVs. See Fig. 1 where the hierarchical process to optimize the strategies is shown.

We use the simulator ECLIPSE (E100) (Schlumberger, 2021) to perform the simulation jobs. To visualize the outputs of the simulation we applied the ResInsight (EQUINOR et al., 2021) software, also, in-house software named MERO (UNISIM, 2022) from our group UNISIM was coupled with E100 to run the simulations with economic analysis for both, manual and/or automatic approaches.

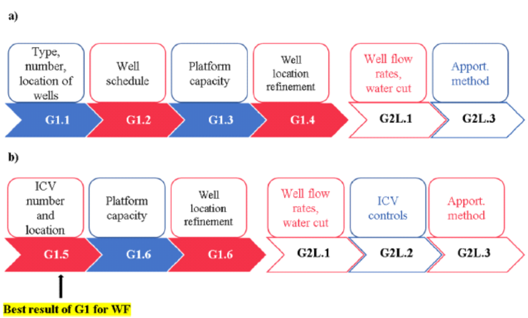

***Figure 1**: Workflow of the assisted hierarchical optimization process for WF (a) and WF+ICV (b). G1 variables in filled background arrows, G2L variables in no filled background arrows.*

Application

A base case named EPIC001 was applied to this work, see Fig. 2. The model was built based on data from a real case, which represents part of an offshore Brazilian field with a heavy oil reservoir (13º API).

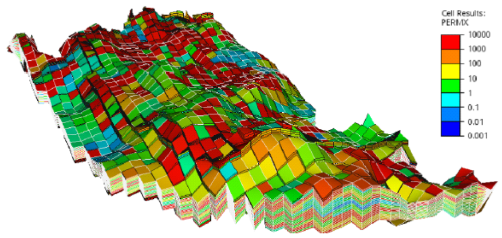

***Figure 2**: Permeability X (mD), 3-D view for the base case.*

The simulation model has a 30x53x59 grid with a cell size of 100×100m length and variable thickness (avg 1.94 m) where the type of the grid is a corner point with 30,694 active blocks. One characteristic of this reservoir is the absence of any aquifer or fractures. This field is highly heterogeneous and has "packages" of high permeability rocks (over 1000 mD) among others with very low permeabilities and good porosity.

Results

WF - G1

Fig. 3 shows the evolution of the NPV during the G1 optimization variables (well candidates, well opening schedule, platform capacity, and well location refinement). At the end of this phase, we obtained an ORF of 0.2689 with $ 311.86 M USD in NPV after 198 total simulations in about 40 hours.

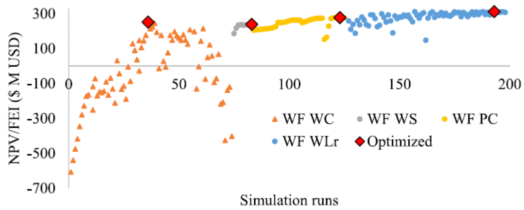

***Figure 3**: Evolution of NPV for G1 optimization variables in WF. Well candidate in orange, well opening schedule in gray, platform capacity in yellow, well location refinement in blue. The best result for each variable in red rhombus.*

WF - G2L

Fig. 4 illustrates the evolution of the NPV for the G2L optimization variables (well production and injection flow rate, well water cut limit, and apportionment method). We obtained a final ORF of 0.2693 with an NPV of $ 315.05 M USD (1.02% higher than G1) by performing 299 total simulations in almost 39 h.

WF+ICV - G1

The whole G1 optimization process ran 347 total simulation runs with a duration of about 61 hours, see Fig. 5. The ICVs installation and the platform capacity re-optimization plus the well refinement position had a 17% rise in the NPV when compared to the best G1 result for WF (starting point). More oil production with less production and injection of water were the contributors to this improvement.

WF+ICV - G2L

Fig. 6 shows a 973 total simulation runs performed in about 175 hours, obtaining a final ORF of 0.2779 with an

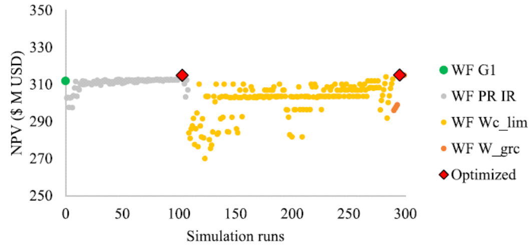

Figure 4*: Evolution of NPV for G2L optimization variables in WF. The Best result of G1 in green, well production and injection rate in gray, well water cut limit in yellow, apportionment method in orange. The best result for each variable in red rhombus.*

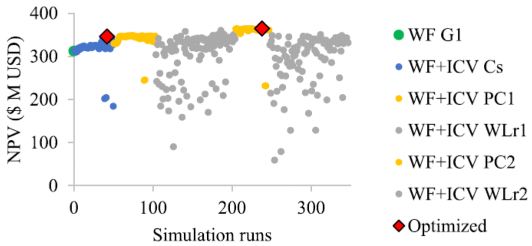

Figure 5*: Evolution of NPV for G1 optimization variables in WF + ICV. Cs_ICV (number and position of ICVs) in blue, PC (platform capacity) in yellow, WLr (well location refinement) in gray; the best G1 result for WF in green. The best result for each variable in red rhombus.*

increase of 2.54 % in NPV ($ 373.69 M USD). More oil production, better water management (lower production and injection of water), and pressure maintenance were found by combining ICV controls when closing ICV zones with high water cuts and injecting water in a controlled manner into the reservoir.

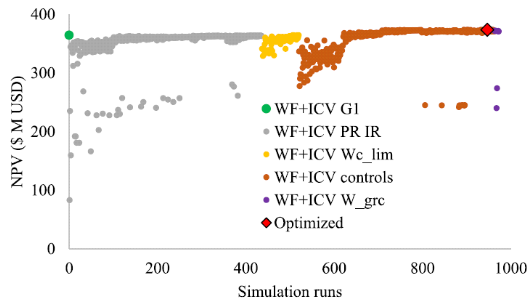

Figure 6*: Evolution of NPV for G2L optimization variables in WF + ICV. The best result of G1 in green, well production and injection rate in gray, well water cut limit in yellow, ICV controls in brown, apportionment method in purple. The best result for each variable in red rhombus.*

Summary and selection of the best strategy

WF+ICV obtained a bigger value in OF than WF, with $ 373.69 and $ 315.05 M USD (a difference of 18.61%), respectively. This higher NPV value from WF+ICV is supported by efficiently achieving a superior oil recovery factor with considerably better management of the production and injection of water when compared to WF. Fig. 7 illustrates the gain in oil recovery due to a better water sweep efficiency by the WF+ICV strategy since it had a more distributed injection than WF as some water injection channels denoted by the black arrows are observed in the map.

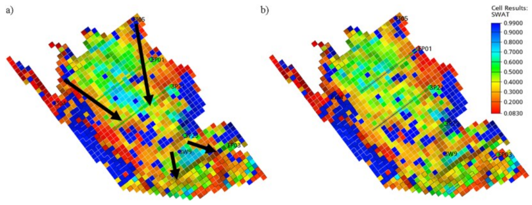

Figure 7*: Water saturation map (layer 20) of WF (a) and WF+ICV (b) strategies at the end of the simulation period.*

Conclusions

Our methodology worked adequately to optimize the waterflooding (WF) and waterflooding with ICVs (WF+ICV) strategies for a heavy oil reservoir considering a nominal case. Consequently, a decision-maker or a researcher could use this procedure for similar cases to optimize, compare, and select production strategies.

The results showed that WF+ICV is more feasible for our case and obtained a larger NPV. The WF+ICV strategy had a better sweep efficiency than WF due to intelligent management in the completed well intervals provided by the ICV controls. More oil with less production and injection of water, while maintaining the reservoir pressure overcame the lower field performance under WF without the ICVs.

Acknowledgments

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"Intelligent wells obtained a larger Net Present Value (NPV) (18,61% higher) overcoming waterflooding."

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