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Evaluation of Variables' Hierarchization in Model-based Optimization of ICVs' Control for Producers, Injectors, and WAG-CO_2 Cycles Size in a Carbonate Reservoir under Uncertainty

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"In this work, we assess the impact of the use of ICVs in producers, injectors and WAG-CO_2 cycles size to improve a developed field's performance."

Introduction

This text summarizes the paper of Botechia and Schiozer (2023), which evaluates the optimization of control rules for ICVs in producers, injectors and also WAG-CO_2 cycles length, considering both nominal and probabilistic procedures. Botechia *et al*. (2021) and Botechia and Schiozer (2022) proposed and evaluated different model-based methodologies to optimize the operation rules of ICVs in producers and injectors, respectively, to improve the management and economic return of fields with characteristics of the Brazilian pre-salt, such as the high amount of gas (including CO_2) content. In these studies, the effects of the operation of ICVs in producers and injectors were evaluated separately. Botechia and Schiozer (2023) is the continuation of those studies. Thus, we assess the impact of the use of ICVs in producers, injectors and WAG-CO_2 cycles size to improve a developed field's performance. Moreover, we evaluate the impact of the hierarchization of the decision variables in the optimization process. To reach these objectives, we divided the work into two parts. The first part consists of a nominal procedure, performing (1) hierarchical optimization processes to analyze if the order that the optimization occurs influences the final results and (2) a joint optimization of all parameters for comparison purposes. The second part consists in a probabilistic approach, utilizing several simulation models representing uncertain scenarios (representative models).

Methodology

Part I: Nominal procedure

In this first part, we use a single simulation model, intending to verify if the order that the optimization process occurs impacts the results. We therefore perform three approaches (**Approaches A, B, and C**), which include three main steps each. The differences among each approach relate to initial parameter to be optimized (**Step 1**). In **Approach A**, the optimization process starts with the ICVs for producers, while **Approach B** starts with the ICVs for injectors, and, in **Approach C**, the procedure starts with WAG-CO_2 cycles size optimization.

These approaches are subdivided into two minor approaches each (**Approaches A1, A2, B1, B2, C1, and C2**), which are related to the optimization variable of the next steps of each process (**Steps 2 and 3**). **Table 1** summarizes the differences among the hierarchical approaches. After carrying out the first three steps, we recommend performing **Step 4**, in which Step 1 is carried out again to verify if the control rules obtained in Step 1 are still valid. In the case of significant changes in Step 4, we add **Step 5**, in which the same process of Step 2 is performed.

We also perform a process considering the optimization of all variables together, named in this work as **Approach NH** (non-hierarchical).

For the optimization of ICVs' operation of the producers, we use a reactive control rule with the GOR as a monitoring variable to shut-in the ICV as an "if…else" condition:

• If $GOR_{i,j} \geq GOR_{LIMITi,j}$, then close $ICV_{i,j}$, where i refers to well's number and j refers to the ICV's number.

***Table 1**: Hierarchical approaches carried out in this work.*

	Approach					
	A1	A2	B1	B2	C1	C2
Step 1	Producers' ICVs	Producers' ICVs	Injectors' ICVs	Injectors' ICVs	WAG cycles	WAG cycles
Step 2	Injectors' ICVs	WAG cycles	Producers' ICVS	WAG cycles	Producers' ICVS	Injectors' ICVs
Step 3	WAG cycles	Injectors' ICVs	WAG cycles	Producers' ICVs	Injectors' ICVs	Producers' ICVs
Step 4	Repeat Step 1					
Step 5	Repeat Step 2 (only if there are significant changes in Step 4)					

The optimization variable is the GOR_{LIMIT} of each zone of the producers, consisting of the value of the GOR of well i and ICV j that, when reached, offers the best objective-function's response. More information about this procedure can be found in Botechia *et al*. (2021).

For the ICVs in injectors, the goal here is to equalize the cumulative injected fluid volume between the zones of the injectors. More information about this procedure can be found in Botechia and Schiozer (2022).

For WAG-CO_2 cycles optimization, the optimization variable is the cycle size (in months), which in this work ranges from short cycles (3 months) to very long cycles (312 months). We considered the same cycle's size for all injectors.

Part II: Probabilistic procedure

To evaluate the impact of the aforementioned variables in uncertain scenarios, we apply the best hierarchical approach obtained in the first part in a set of 11 representative models (RMs). The reason of applying a hierarchical approach here is to evaluate the impact of individual steps of optimization also in different uncertain scenarios.

For comparison purposes, we perform the optimization under uncertainty in two different ways: (1) nominal optimization of the RMs: each RM is optimized exactly as in Part I of this work (but for only one approach), and, thus, we have the same number of strategies as the number of RMs (specialized strategies). Thus, the expected monetary value (EMV) is calculated (the average of NPVs). The strategy with the highest EMV is considered the best to be implemented.

The second way is to perform a robust optimization, in which all RMs are optimized simultaneously. In this case, only one production strategy is obtained.

Application

We used in this work a synthetic model analogous to a Brazilian offshore pre-salt carbonate field, the benchmark SEC1_2022 (Botechia *et al*., 2021).

Results

Part I: Nominal procedure

Figure 1 shows the best NPV of each step along the optimization process for all approaches. One must note that all hierarchical approaches converged to very similar solutions in terms of NPV values, regardless of the order of the variable chosen to be optimized. Approach NH presented a slightly higher NPV. The improvement in the objective-function in relation to the base case is 12.7% for the best hierarchical approach (Approach A1, although all approaches led to very similar results) and 13.2% for Approach NH. Each hierarchical approach took about 450 simulation runs, while the non-hierarchical took about 400 simulation runs.

One can also notice that the major improvements in the economic return are achieved for the ICVs in the producers (average improvement of 8%), followed by the ICVs in the injectors (average of 4%), and finally WAG cycles (average of 0.2%). The best WAG cycle size varied from 3 to 36 months for the hierarchical approaches and achieved 108 months for the non-hierarchical approach. Thus, in addition to the fact that this variable had minor impact in this study, the choice of the best WAG-CO_2 cycles size depends on other management variables and should be planned according to the control of those additional variables.

Part II: Probabilistic procedure

Figure 2 shows the percentage increase in NPV for the specialized strategies obtained for each RM (named S0 to S10), and also the increase in EMV for the robust strategy (named S_rob), considering each optimization variable.

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"A proper operation in ICVs and WAG cycles can significantly improve the economic return of the field. The most impacting variable is the ICV in producers, followed by ICV in injectors and WAG-CO_2 cycles size ."

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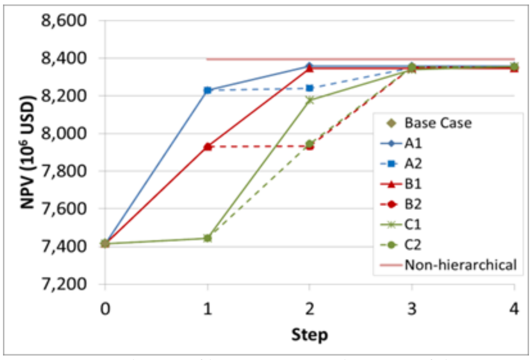

***Figure 1**: Evolution of best NPV over the steps of the optimization process for all approaches. Step 0 represents the base case (without ICVs operation and WAG cycles of 6 months). The horizontal pink line relates to the non-hierarchical procedure .*

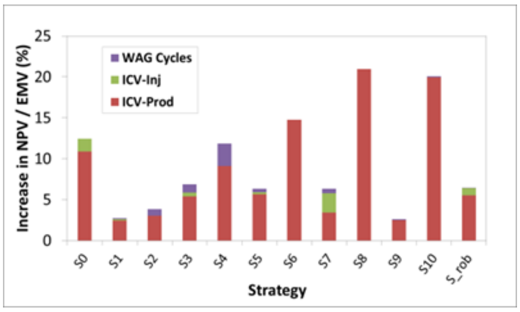

***Figure 2**: Percentage increase in NPV for the optimization of the strategies in each RM (S0 to S10) and increase in EMV for the robust strategy (S_rob).*

Similar to what was obtained in Part I of this work, the most impacting variable is the ICV for producers, reaching increases up to 20% in the NPV in some models, but with an average of 9% of improvement among the models. The highest increase for ICV in injectors and WAG cycles reached up to 2%, with an average among the models lower than 1%.

Table 2 presents the EMV for all the strategies (specialized and robust), highlighting that strategy S3 was the best in terms of economic return among the specialized strategies. However, the strategy obtained from the robust optimization achieved an EMV about 2% higher than S3.

The results showed that the proper operation ICVs (in producers and injectors) and WAG cycles can significantly improve the economic return of the field. Despite the platform being restricted by gas production capacity, the optimized cases presented a better balance in fluid flow through the reservoir and among the wells, increasing the oil production rate over time.

***Table 2**: EMV for each strategy in the probabilistic procedures.*

	STRATEGY											
	Nominal optimizations											Robust Opt.
	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S_rob
EMV (10^6 USD)	7768	7750	7677	7782	7660	7346	7617	7747	7630	7637	7521	7923

Conclusions

In this work, we evaluated the operation of ICVs in both production and injection wells, as well as the WAG-CO_2 cycles size in a benchmark case analogous to a developed carbonate field with light oil and high gas content. In the first part of the work, we used a single simulation model to assess seven different optimization approaches. In the second part, we performed a probabilistic procedure, applying one of the hierarchical approaches in eleven representative models.

The most impacting variable type is the ICV in producers, followed by ICV in injectors, while the WAG-CO_2 cycles size had practically no effect on the objective function.

Moreover, all hierarchical optimization procedures presented very similar results, suggesting that the order that the optimization is carried out does not greatly affect the final objective-function value. However, the non-hierarchical approach led to a slightly better result than the best hierarchical approach, with a slightly smaller number of simulation runs.

Thus, it is recommended to perform the non-hierarchical approach for the most impacting variables' type (in this work, ICVs in producers and injectors), but if necessary (due to some limitation), it is possible to divide the process hierarchically without significant loss in the accuracy of the results.

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