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Practical procedure to select well opening schedules in pre-salt reservoirs using WAG-CO_2

Anthony Andrey Ramalho Diniz

Introduction

After proving a new hydrocarbon discovery, the proposal of a field development plan is one of the most important steps to develop and manage the new oilfield.

The exploitation strategy should specify important characteristics of the production strategy (infrastructure) which can significantly impact the expected profit of the entire field. This infrastructure project requires the specification of components that can include: size, location, and arrangement of surface facilities; number, position, and completion of wells; platform processing capacities, well opening schedules, use of intelligent wells, among others.

In a project involving many wells, due to limitations of rigs, drilling, completion and opening order of wells may be important for the project investment.

Motivation

The main motivations for this work are: (1) lack of studies in this topic applied to the pre-salt; (2) there are many possible combinations for the opening order, which would require many simulations to test all alternatives; (3) the relative importance of the drilling order compared to other parameters such as number and position of the wells.

Objective

Based on the motivations cited above, the objectives of this work were: (1) evaluate the influence of well opening schedules in NPV of a project inspired in pre-salt fields, using WAG-CO_2; and (2) verification of the possibility of proposing a simple procedure to specify the well opening schedules without the need to perform a complex optimization study.

Methodology

At first, we identified four main aspects, summarized in Fig. 1, inspired by proposals presented by other authors, which could be combined to define the well opening schedules to be investigated, as follows:

1. The way of operating the first injector well – to make possible reinjecting all the produced gas, we knew that we had to open the first well to reinject gas, but it could participate on WAG (be also switched to reinject water) or be completed to inject only gas during the whole time;
2. The criterion to open producer wells – based on their ascendant or descendant well economic indicator order;
3. The criterion to open injector wells – based on their descendant economic indicator or proximity to the sequentially opened producer wells;
4. The relationship between producer and injector wells – how many producer wells we could open before opening a new injector well, guaranteeing the reinjection of all the produced gas.

After the investigation of the impact of these four aspects and verification of their best results, we performed an optimization process, to define a reference for comparison with the direct application of our investigated approach. The optimization was a process that demanded more time and computational resources, using an optimization algorithm, which produced scenarios swapping the wells, in a permutation scheme that does not repeat the opening of the same well in each individual scenario.

An important aspect that we took into consideration was an environmental premise of the mandatory reinjection of all the produced gas. All the scenarios that did not satisfy this premise were disregarded from the evaluations for the proposed approach and optimization results.

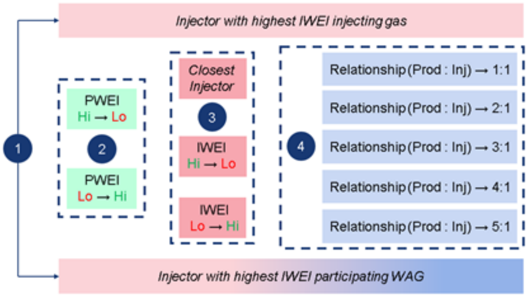

***Figure 1**: Variables considered for the well opening schedule.*

Case Study

This study was performed using the UNISIM-II-D-BO benchmark case, an open-access case with pre-salt characteristics, obtained from the set of simulation models that were created based on the initial stage of field development, under uncertainties based on the well log information of three wells collected from the UNISIM-II-R model, using the well configuration that can be seen in Fig. 2. One of those three wells was a wildcat and the other two were exploration wells.

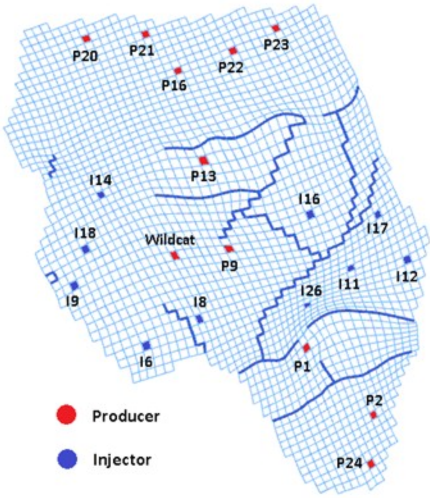

***Figure 2**: UNISIM-II-D benchmark with the well configuration adopted for this research.*

Results

The combination of the four aspects shown in Fig. 1 resulted in just 60 simulations, from where we verified that:

1. The way of operating the first injector well – comparing NPVs of scenarios with the first injector well only injecting gas during the whole project time and participating on WAG, we verified that the highest NPVs were reach in scenarios with the well participating on WAG;
2. The criterion to open producer wells – for similar scenarios, the highest NPVs were reached where producer wells were opened from the highest to the lowest well economic indicator, while the opposite approach were useful to estimate the consequence of bad choices (lower NPVs);
3. The criterion to open injector wells – highest NPVs were reached when injector wells were opened based on their distance to the closest producer. In similar scenarios, NPVs from the opening based on their eco-

nomic indicators were among the lowest results;

4. The relationship between producer and injector wells – if we ignore the environmental premise, as higher this relationship, higher the NPV. However, for the 4:1 and 5:1 relationship, none of the simulated scenarios satisfied this premise, and there were some specific situations that not even the 3:1 relationship satisfied the environmental premise. However, in general, the 3:1 relationship presented the best results, but we recommend evaluating this aspect for each specific case.

Table 1 shows the best and worst results for the simulated cases, separated according to the way of operating the first injector well. From those results, it is possible to verify that a bad choice in the well opening schedule can result in an impact of about 9% in NPV which is very significative.

Table 1*: Differences between the best and worst results (NPV) for the first well only injecting gas or participating on WAG.*

	GAS		WAG	
	NPV (Bi US$)	Differ. (%)	NPV (Bi US$)	Differ. (%)
Best NPV	2.249	9.18	2.290	5.40
Worst NPV	2.060		2.173	

After the evaluation of the cases produced from the combination of the four main aspects, we ran the optimization process, considering the first well beginning with the gas injection, but contributing on WAG, what we had already identified as the best choice, in the previous simulations (14 iterations, with 190 simulations each; total of 2,660 simulations). Despite the large number of simulations, the process was simplified by defining the first injector as the one with the highest IWEI, which reduced the number of variables and simulation runs.

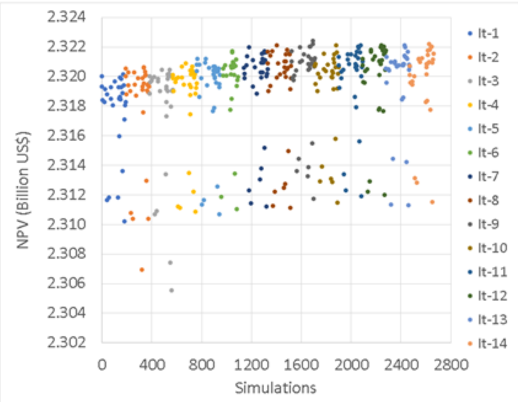

Figure 3*: Evolution of the optimization process for the first well collaborating with WAG.*

Table 2 provides a comparison between the best result from the optimization process and the best NPV evaluated for the cases defined from the combination of the four aspects, considering the first injector well collaborating with the WAG, which was the condition with highest NPV.

Table 2*: Comparison between the best result from the 2-OPT optimization and from the best cases defined from the combination of the four parameters.*

	WAG	
	NPV (Bi US$)	Differ. (%)
Best NPV - optimization	2.322	1.40
Best NPV - defined cases	2.290	

For the optimization process, the best NPV obtained was US$ 2.322 billion (Fig.3), which is 1.40% better than the result reached for our proposed evaluation.

After all tests, our suggestion for a fast decision is:

1. The operation of the first injector well to be opened (the one with the highest well economic indicator) – we recommend it collaborates with the WAG cycle;
2. Producer wells – choose based on the highest to the lowest well economic indicator;
3. Injector wells – choose based on the closest distance to the producer wells;
4. Relationship between producers and injector wells – perform simulations considering 1:1; 2:1; 3:1, and 4:1. After these simulations, remove those that do not satisfy the premise of reinjecting all the gas and choose the one with the highest NPV.

Concluding Remarks

In conclusion, the difference between the results from the optimization and the best proposed configurations was 1.4%. Comparing the time consumption (~30 compared in the simplified approach against 2,660 simulations in the optimization process), we can suggest to use these additional simulations in other parts of the optimization process (for instance number and position of wells). We could also search for more efficient optimization process but, in general with a decrease in the expected result).

This example was a deterministic case; considering uncertainties, these differences would increase making the simplified approach even more attractive.

Therefore, we recommend to perform the optimization process to choose the best option if there is available time and resources; but we suggest the indicated simplified approach as an option to make a fast decision with fewer simulations.

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