

# Efficient workflow for optimizing intelligent well completion using production parameters in real-time

Bruno da Cruz Schaefer\* and Marcio Augusto Sampaio

Departamento de Engenharia de Minas e de Petróleo, Escola Politécnica, Universidade de São Paulo, USP, Praça Narciso de Andrade S/N, Vila Mathias, CEP 11.013-560, Santos, 05508-010 São Paulo, Brasil

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**Abstract.** Intelligent Well Completion (IWC) has been successfully deployed over the years to improve reservoir management, with better results in heterogeneous reservoirs. This work proposes an efficient workflow to identify well candidates for Inflow Control Valves (ICV) application and production optimization using parameters in real time. The methodology searches for potential reservoir layer grouping in the producer well, in order to control zonal flow, without expending too much computational time in valve positioning. ICV control strategy uses real-time production guide rates generated by the simulator, reducing optimization parameters. The proposed workflow is applied to a synthetic reservoir model, with properties similar to the Brazilian pre-salt area. This novelty strategy for ICV modelling and control presented a significant reduction in optimization parameters. Results show that Net Present Value (NPV) – and IWC economic gain – are highly dependent on the economic scenario. Nevertheless, the methodology has potential for application in more complex simulations, with greater number of wells or optimization parameters, like multi-position or continuously variable position ICV.

## Abbreviations

BHF	BottomHole Flowrate
BHP	BottomHole Pressure
EOR	Enhanced Oil Recovery
GOR	Gas–Oil Ratio
$G_p$	Cumulative gas production
ICV	Inflow Control Valve
IOR	Improved Oil Recovery
IWC	Intelligent Well Completion
MPFM	MultiPhase FlowMeters
$N_p$	Cumulative oil production
NPV	Net Present Value
PSO	Particle Swarm Optimization
STG	Gas Production Stream
STL	Liquid Production Stream
STO	Oil Production Stream
STS	Solvent Production Stream
STW	Water Production Stream
WCUT	Water CUT
$W_{inj}$	Cumulative water injection
$W_p$	Cumulative water production

\* Corresponding author: [bruno.s@usp.br](mailto:bruno.s@usp.br)

## 1 Introduction

IWC technology has already proven itself as a powerful tool to improve oil recovery in different scenarios. It can prevent early water/gas breakthrough, optimize production and control water cuts/pressures by zone. An intelligent well allows for downhole parameter monitoring and remote operation. The ability to handle downhole well flow separately makes IWC useful in reservoir management.

When working with thick heterogeneous reservoirs, the permo-porous properties can vary significantly in the extension of the well. The necessity to control zonal flow for better reservoir management makes IWC useful when trying to obtain a higher recovery factor. Reservoir simulation in these scenarios can help identify and understand how this variation could affect oil flow and reservoir sweep. Along with IWC, reservoir simulation can aid in the development of EOR/IOR strategies.

The majority of reservoir simulators focus on modelling the flow through porous media and the software often do not have flexibility when representing wellbore completion equipment. This difficulty in representing completion equipment leads the reservoir engineer in the search for adaptations when modelling the well. Great part of the research in reservoir simulation is made by placing one ICV on each layer, generating a higher number of valves

per well, as showed in the work of Almeida *et al.* (2007), Ranjith *et al.* (2017) and Sampaio *et al.* (2015a). While this approach can be effective for individual layer flow analysis, not always this simulation scenario can be replicated on the field. Research has also been made on optimization of ICV positioning as one can see in Barreto and Schiozer (2015), Goh *et al.* (2016) and Sampaio *et al.* (2015b).

Grebenkin *et al.* (2015) studied active ICV control and different types of valves. The research focused on simpler on/off valves, in order to reduce the number of optimization parameters. The simulation aimed at maximizing the oil production rate after the peak production period, in order to minimize the drop in overall field production. They concluded that on/off valves showed results slightly under the optimal solution, but the extra computational effort, for a small gain, could not be attractive in every scenario. Being able to control ICV flow makes the relation of “ICV ratio-well production” similar to “well ratio-field production”, giving opportunity to apply well control methodologies (de Brito and Durlofsky, 2020) to individual layer control. Vasper *et al.* (2016) proposed a proactive control for ICV and an alternative closed loop optimization, based on the produced stream. The closed loop optimization had a smaller increase of optimization parameters as the initial scenario got more complex. The proactive control showed a much higher computational cost. There is also the issue of preemptively acting the ICV and the associated uncertainties of defining ICV cycling frequency. Abellan and Noetinger (2010) proposed a methodology for optimizing data acquisition based on information theory that could be used to define ICV cycling strategy, preventing an exaggerated number of cycles that would not aggregate new information in simulation results.

The use of a real time completion design was experimented by Goh *et al.* (2016) to reduce the dependency of static initial data. The authors based the completion design from single well dynamic modelling and real time decision making during well construction, with more realistic results especially when working with marginal reservoirs. However, the authors alert to the high computational cost of this approach and recommend it to be used in simpler, single-well modelling.

Water cut can be measured by surface sensors as Coriolis flowmeters or MultiPhase FlowMeters (MPFM). For subsea wells, there are also subsea MPFM that can be deployed right next to the subsea well, eliminating time delay from wellhead through flowline until the production platform. Arsalan *et al.* (2015) present developments on downhole water cut measurement but its application depends on completion project design.

The present study focuses on a workflow to identify potential well candidates for IWC. A simplified methodology is proposed to group layers for ICV application, in order to achieve a completion design that could easily be applied in the field. One common strategy of WCUT monitoring is suggested for ICV (reactive control) and two new strategies (proactive controls) – usually applied to group of wells (Sampaio *et al.*, 2019) – are suggested to be applied to a group of layers, to model and control zonal flow, using production parameters in real-time, decreasing the number of variables in the optimization process.

## 2 Methodology

Starting from a conventional completion scenario, this work proposes an efficient workflow for layer grouping and ICV positioning, considering field restrictions for IWC installation. Three ICV control strategies are proposed: one reactive approach based on Water CUT (WCUT) limitation and two proactive control strategies based on production rates from each zone. Figure 1 shows the proposed workflow in this methodology.

### 2.1 Optimization of conventional completion

The base case is a producer well without intelligent completion in a five-spot configuration with water injection. The first step is to run the simulation with all layers open (*i.e.*, perforated) for the producer. This first run with conventional completion must have its NPV optimized before moving to IWC, as observed by Barreto *et al.* (2016) and Morais *et al.* (2017). The optimization of conventional completion is necessary to ensure that the IWC simulation will not generate over-optimistic results when compared to the base case.

### 2.2 Quality map generation

Quality maps can be used as an indicator of parameter quality to help in decision making processes (Fornel and Le Ravalec, 2020) or as visual aid for results analysis. After the optimization of conventional completion, NPV is analyzed by layer, generating a quality map for the well. NPV must be calculated for each layer and normalized by the maximum NPV in the optimized conventional completion to generate the map. The deterministic economic scenario used to calculate the NPV is the one suggested in UNISIM-II-D benchmark case study by Santos and Schiozer (2018).

The main objective of the quality map is to allow for faster decision making when positioning the ICV, as ICV placement can usually turn into an optimization problem of its own. Optionally, quality maps can be generated as an auxiliary analysis with parameters like cumulative oil production ( $N_p$ ), cumulative water production ( $W_p$ ), cumulative gas production ( $G_p$ ), Gas-Oil Ratio (GOR) or WCUT.

### 2.3 Layer grouping and ICV positioning

The layers are grouped together by analyzing more profitable zones (higher NPV). Due to technical restrictions for field applications, the maximum number of grouped zones for this work was three, considering a direct-hydraulic control system for the ICV in a vertical producer well. The ICV configuration is similar to the one presented by Schnitzler *et al.* (2015) in Figure 2, with one ICV for each grouped zone.

Besides making the scenario more feasible for field applications, these restrictions also help to reduce the number of parameters for the optimization stage. The number of

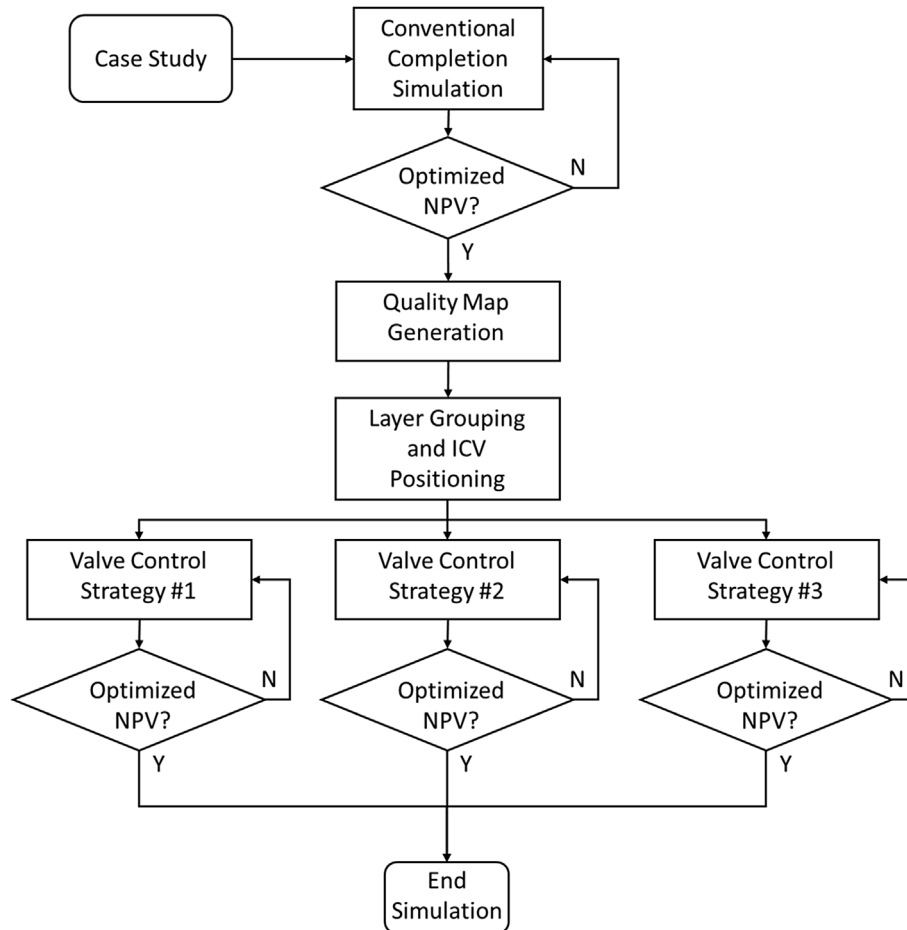


Fig. 1. Proposed workflow.

ICV will depend on the existence of low permeability layers – barrier zones – between grouped producer zones.

### 2.3.1 ICV representation

After defining the number and position of the ICV, the simulation is rerun with the defined grouped zones. As previously stated, ICV representation in the simulator is made by grouping layers together. This is done by creating overlapped “virtual wells” for each zone. Figure 3 shows an example of layer grouping, resulting in 2 ICV, with virtual wells “P1” and “P2”.

To emulate zonal flow control, virtual “single zone” producer wells are positioned in the same location, tying each well to a different depth. These virtual wells are tied together to a production group, to emulate the real producer well. Usually, this is a workaround for the lack of adequate tools in simulators to represent completion equipment and wellbore effects.

Another effective way to model ICV is using “control lumps”, available in the simulator. The lumping feature can be used to group layers and control them as a whole block. This can be very useful to simulate zonal flow control. Nevertheless, in this article the modelling of ICV with “virtual wells” allows the use of “production guide rate”

control strategies available in the commercial simulator, that is only applicable to wells and not to lumps.

### 2.4 Valve control strategies

The proposed control strategy for the ICV is as follows:

- Strategy 1: On/off ICV operation based on the same WCUT limit for all zones. This type of reactive control uses a fixed threshold for the WCUT, above which the ICV is closed.
- Strategy 2: Proactive ICV operation, based on production guide rates (continuously variable ICV). The guide rates are provided by the user for each time step, acting preemptively before water breakthrough.
- Strategy 3: Proactive ICV operation, based on production guide rates (continuously variable ICV). The guide rates are provided internally by the simulator and vary in real-time according to production parameters of the field.

Control types can be modified from on/off ICV to multi-position ICV for strategy 1 if desired, with the associated extra computational time. Multi-position and

continuous variable opening ICV should allow for a finer flow control, but the addition of intermediate positions in the valve would increase computational effort during optimization processes. In a more complex scenario, the use of a reduced-order model could be considered (Jansen and Durlofsky, 2017), especially if using a full-scale reservoir model.

The commercial simulator can use internal guide rates for apportioning production rate among wells in a group (Computer Modelling Group, 2018). The novelty of this work is using this feature in strategy 3 with “virtual wells”, to control zonal flow, instead of total well flow rate. The guide rates are generated internally by the software, according to parameters supplied by the user for the priority formula in (1):

$$\text{Priority}(iw) = \frac{A_0(ig) + \sum_{i=1}^{nph} A_i(ig) \times Q_i(iw)}{B_0(ig) + \sum_{i=1}^{nph} B_i(ig) \times Q_i(iw)}, \quad (1)$$

where *iw* is the priority index for an ICV contributing to a targeted group (*ig*), entire well in this work, *A<sub>i</sub>* and *B<sub>i</sub>* (*i* = 0, *nph*) are the weighting coefficients for the numerator and denominator, respectively. All the weighting coefficients are non-negative real numbers and at least one *A<sub>i</sub>* and one *B<sub>i</sub>* must be non-zero. The weighting coefficients (for production, *nph* is equal to 6) are showed in Table 1.

### 3 Case study

The case study was made with the application of the previous methodology in a reservoir model based on a Brazilian offshore field, described as follows. As mentioned before about ICV positioning, optimal well placement also frequently develops into an optimization problem of its own, making it impossible to test all possible well positions, as stated by Fornel and Le Ravalec (2020). This paper uses a benchmark for initial condition definition and focus on the expedite proposed workflow.

#### 3.1 Reservoir model

The methodology was applied to the UNISIM-II-D benchmark case study (Santos and Schiozer, 2018), which is a synthetic dual-permeability model with properties similar to the Brazilian pre-salt reservoirs, with thick vertical net pay and highly heterogeneous. A grid section of 11 × 11 × 30 blocks was extracted from the full model. The wells were positioned in a five-spot configuration, with water injection as secondary recovery method. Figure 4 shows the reservoir section and the effective permeability – “*z*” direction.

The injector wells were positioned on the corners of the section and all the layers were completed for water injection. The producer well was positioned in the center of the section with all the layers completed, for the conventional completion simulation run. Figure 5 shows the

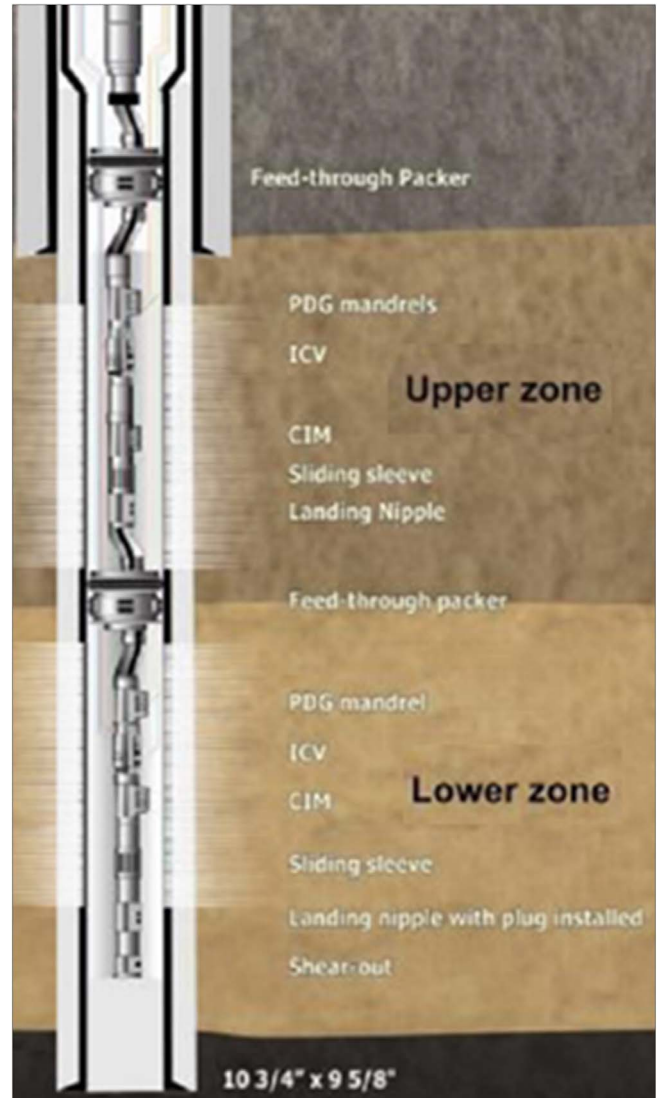


Fig. 2. Typical Brazilian pre-salt completion design (Schnitzler et al., 2015).

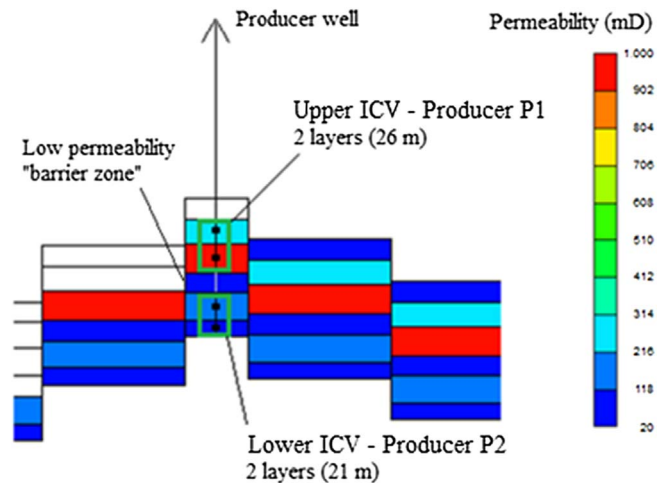


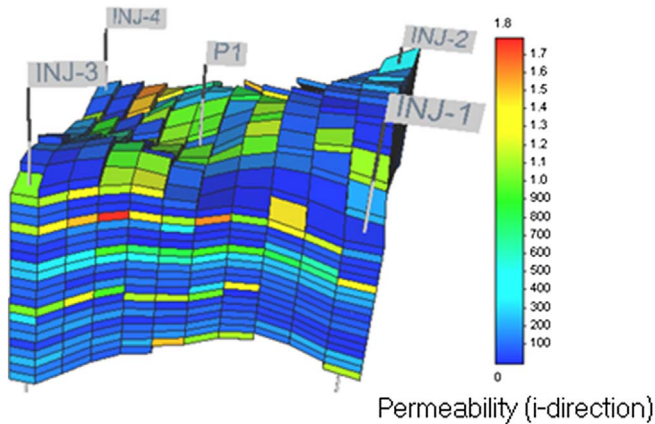
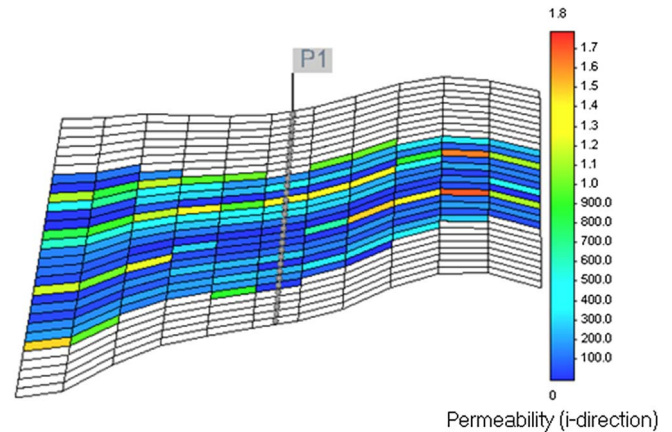
Fig. 3. Example of layer grouping.



**Table 1.** Priority formula coefficients.

$i$	CONST	*STO	*STG	*STW	*STS	*STL	*BHF
NUMER	$A_0$	$A_1$	$A_2$	$A_3$	$A_4$	$A_5$	$A_6$
DENOM	$B_0$	$B_1$	$B_2$	$B_3$	$B_4$	$B_5$	$B_6$

STO, STG, STW, STS, STL and BHF are oil, gas, water, solvent, liquid streams and bottom-hole fluid rates, respectively. In order to generate the internal guide rates prioritizing wells with lower WCUTs, the coefficients  $A_1$ ,  $A_3$  and  $B_3$  must be supplied.

**Fig. 4.** Reservoir section –  $11 \times 11 \times 30$  blocks.**Fig. 5.** Cross-section of the producer well showing permeability variation.

cross-section of the producer well, where one can observe that only the layers from 10 to 25 are inside active blocks in this region.

### 3.2 Operational constraints

The operational constraints for the simulation were based on the UNISIM-II-D benchmark case study (Santos and Schiozer, 2018) and are listed in Table 2.

A trigger was set in place to start the water injection through the injector wells when the BHP of the producer reaches  $275 \text{ kgf/cm}^2$  (min BHP for producers). With multiple producer wells, injection can start when the first producer drops below a specified pressure or a time window can be used (for example, after “ $n$ ” years of production, which can be optimized). Initially, WCUT monitoring in the producer was set to 0.95 and GOR monitoring limited to  $750 \text{ m}^3/\text{m}^3$  for the first simulation run.

### 3.3 Economic scenario

The deterministic economic scenario used was the one proposed by UNISIM-II-D benchmark. Platform investment in the benchmark considers 32 wells connected to the platform. In this work, platform investment was reduced proportionally to the number of wells in the five-spot configuration, to a value of 175 MM USD. Economic parameters, from UNISIM-II-D, are presented in Table 3.

### 3.4 Optimization constraints

The conventional completion configuration was optimized with CMOST<sup>®</sup> software, from the CMG suite, using Particle Swarm Optimization (PSO) in order to maximize the NPV. The parameters used in PSO are presented in Table 4. The default values provided by CMOST were used, except for the population size that was increased to 50, due to the high number of simulations (4000) used in the base case.

The optimization constraints are presented in Table 5.

The optimization for each proposed strategy with IWC is also made using PSO with CMOST. The number of simulations for the optimization stage in each strategy was dependent on the number of parameters to be optimized. Consequently, computational cost for each control strategy is highly dependent on the number of parameters.

## 4 Results and discussion

This section presents the main results of the proposed methodology applied to the UNISIM-II-D benchmark.

### 4.1 Conventional completion (base case)

The simulation was run with the conventional completion scenario and the parameters were optimized within the ranges presented in Table 5. Figure 6 shows the production

**Table 2.** Well operational constraints.

	Producer	Injector	Unit
Water rate	–	Max 5000	m <sup>3</sup> /d
Liquid rate	Max 3000	–	m <sup>3</sup> /d
BHP	Min 275	Max 480	kgf/cm <sup>2</sup>

**Table 3.** Economic parameters.

Parameter	Value	Unit
Oil price	257.9	USD/m <sup>3</sup>
Gas price	0.026	USD/m <sup>3</sup>
Oil production cost	48.57	USD/m <sup>3</sup>
Gas production cost	0.013	USD/m <sup>3</sup>
Water production cost	4.86	USD/m <sup>3</sup>
Water injection cost	4.86	USD/m <sup>3</sup>
Drilling and completion of vertical well	50.34	MM USD
Connection well-platform	13.30	MM USD
1st ICV (each well)	1.00	MM USD
Additional ICV (each well)	0.30	MM USD/ICV
Abandonment cost	4.13	MM USD
Annual discount rate	9%	–
Corporate tax rate	34%	–
Social tax rate – over gross revenue	9.25%	–
Royalties rate – over gross revenue	10%	–

**Table 4.** PSO parameters.

Parameter	Value
Inertia weight	0.7298
Cognition component ( $C1$ )	1.49618
Social component ( $C2$ )	1.49618
Population size	50

rates before and after the conventional completion optimization.

Initially, the producer well was closing after almost 20 years of production for breaking the WCUT limit of 95%. The objective function in the optimization process was set to maximize NPV, which increased the WCUT limit to 99%. As can be observed in [Figure 7](#),  $N_p$  slightly increased and  $W_p$  greatly increased, due to the extension of production time. Extra income from oil production compensated greater water production costs.

The NPV obtained for the base case was 65.41 MM USD.

## 4.2 ICV positioning

With the results from the conventional completion, NPV was analyzed for the producer well. The NPV analysis was broken down by layers to generate the quality map

of the well, in order to identify potential candidates for layer grouping. [Figure 8](#) presents the NPV by layer, normalized by the highest NPV value from layer 13.

Considering only the active blocks from layers 10 to 25 and the NPV results from [Figure 8](#), the layers were grouped in two zones:

- Upper zone – upper ICV: from layer 11 to 15.
- Lower zone – lower ICV: from layer 21 to 23.

Field restrictions were taken into account considering 5 m (layers 16–20) for setting a production packer between the two zones. The section to be considered a barrier zone must have low vertical permeability values, to prevent crossflow between zones. [Figure 9](#) shows the final diagram for setting completion equipment.

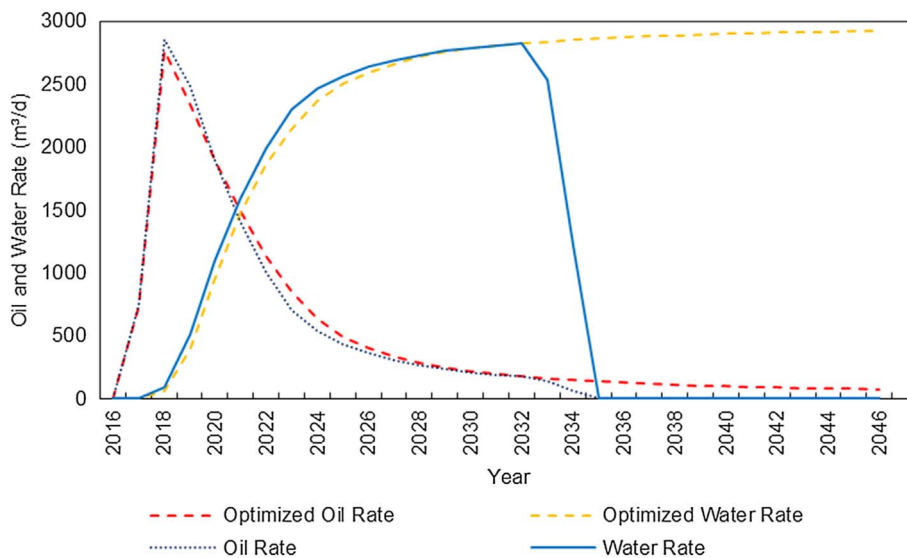
## 4.3 Control strategies

After defining the grouped zones for ICV modelling, this section presents the results for the control strategies proposed in the methodology.

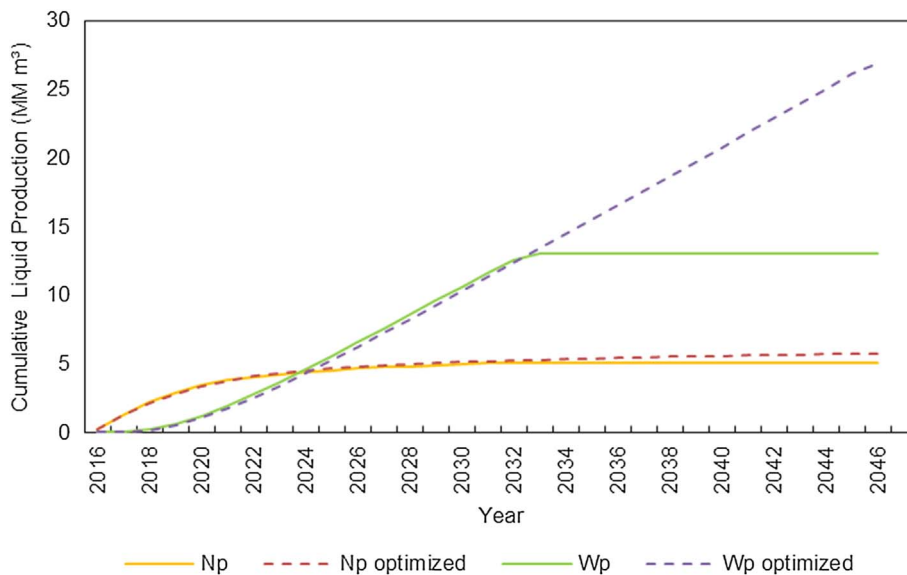
Control strategies use two “virtual” single zone producer wells to simulate the ICV. Producer  $P1$  was set in layers 11–15 to control the upper zone, while producer  $P2$  was overlapped with  $P1$  but was set in layers 21–23 to control the lower zone. Both wells were tied to a production group, in order to simulate the real producer well.

**Table 5.** Optimization parameters.

Parameter	Initial value	Min. value	Max. value	Unit
BHP injector	480	0	480	kgf/cm <sup>2</sup>
BHP producer	275	275	450	kgf/cm <sup>2</sup>
BHP producer – inj trigger	275	275	450	kgf/cm <sup>2</sup>
Oil prod. rate	3000	10	3000	m <sup>3</sup> /d
Water inj. rate	1250	0	1250	m <sup>3</sup> /d
WCUT	0.95	0.90	0.99	–



**Fig. 6.** Liquid rates for conventional completion.



**Fig. 7.** Cumulative liquid production for conventional completion.

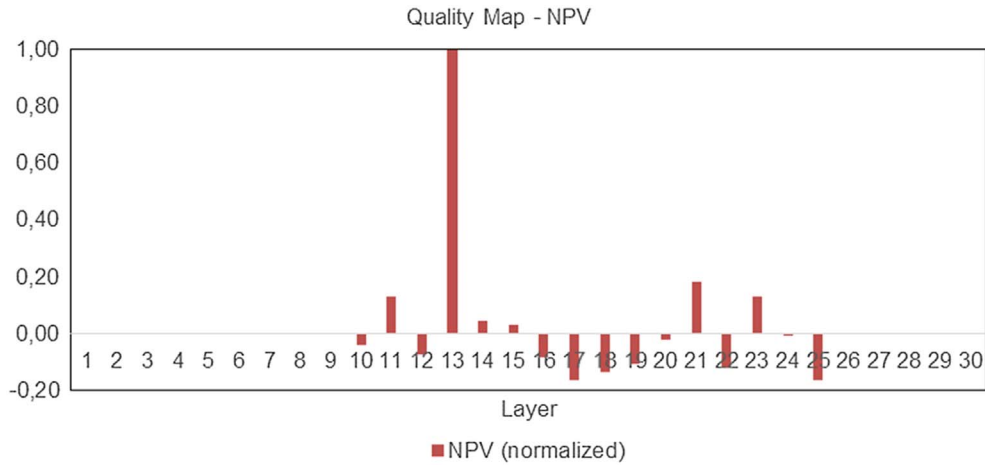


Fig. 8. NPV – normalized by maximum value.

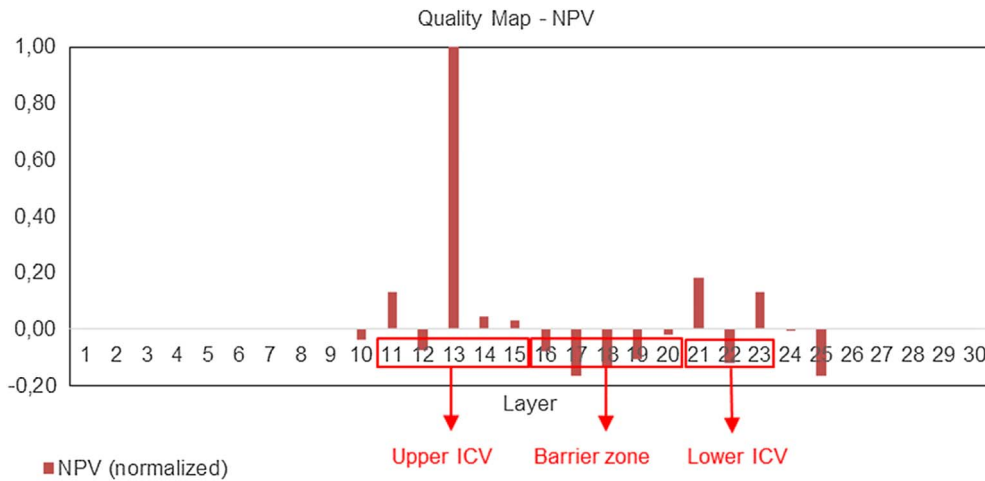


Fig. 9. Position of completion equipment based on quality map.

During the development of control strategies, it was observed that the BHP of both wells *P1* and *P2* were unlinked to each other, as can be seen in Figure 10.

The simulator did not understand both virtual wells as being the same – real – well. It was necessary to find a way to couple both wells together. Two trigger variables were used in the simulator, to tie both BHPs together. Considering the BHP from *P1* as the most restrictive condition in this case, BHP from *P2* was targeted to follow BHP values from *P1*.

Figure 11 presents BHP of both zones (*P1* and *P2*), linked to each other.

### 4.3.1 Strategy 1

ICV modelling for strategy 1 was based on a reactive approach. This strategy proposed the same WCUT limit for both ICV (the same value for well). A trigger setting was designed for WCUT monitoring. The trigger was initially set to shut the virtual well if the WCUT went over 90% across the ICV. In this case, six variables were used in the optimization process with a total of 10 000 simulations run.

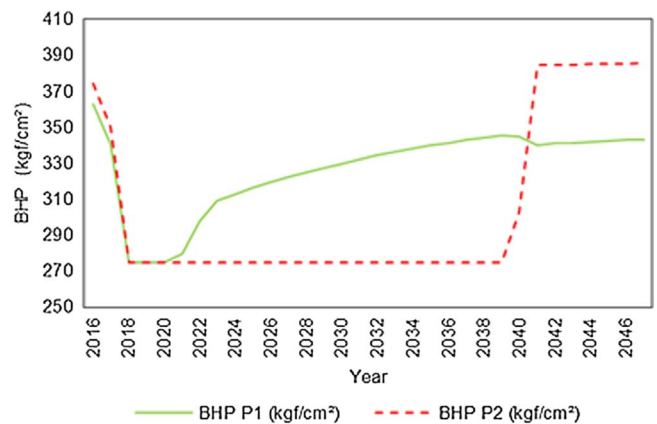
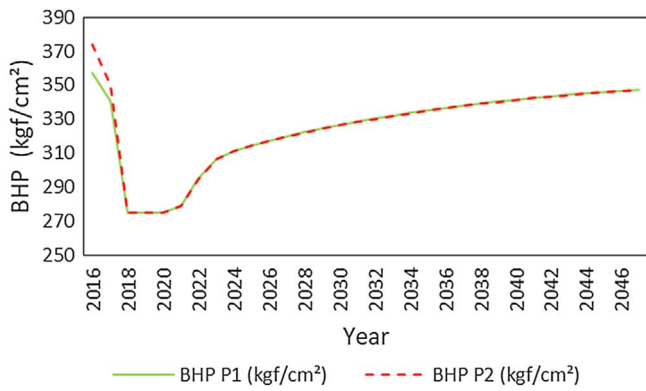


Fig. 10. BHP of *P1* (upper ICV) and *P2* (lower ICV).

Table 6 presents the parameters after the optimization of strategy 1.

Figure 12 shows the results for this strategy, compared with the base case of conventional completion (after optimization). The reactive approach closes the upper





**Fig. 11.** BHP of *P1* (upper ICV) and *P2* (lower ICV) after coupling.

**Table 6.** Optimized parameters for strategy 1.

Parameter	Value	Unit
BHP injector	480	kgf/cm <sup>2</sup>
BHP <i>P1</i>	275.73	kgf/cm <sup>2</sup>
BHP <i>P2</i>	301.15	kgf/cm <sup>2</sup>
BHP producer – inj trigger	450	kgf/cm <sup>2</sup>
Oil prod. rate	3000	m <sup>3</sup> /d
Water inj. rate	797.77	m <sup>3</sup> /d
WCUT – ICVs	0.9339	–

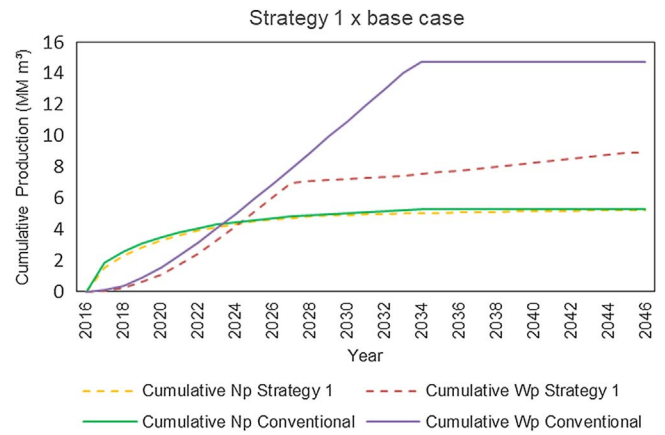
ICV (virtual well *P1*) after the water breakthrough, and the lower ICV (virtual well *P2*) stays open. There is a major reduction in the cumulative water production compared to the conventional completion, with a minor loss in oil production. In this case, with a 30-year horizon, the lower ICV did not closed, as the WCUT limit was not reached. When looking at field application, this result could lead to a simplification in the completion project, eliminating the lower ICV and reducing equipment cost. However, the lower ICV was not removed in this study, for a more general approach and to perform a fair comparison with other strategies.

The calculated NPV in this scenario is 62.46 MM USD, 4.51% lower than the base case, influenced mainly by the additional investment in IWC.

### 4.3.2 Strategy 2

Strategy 2 uses guide rates provided by the user to control the oil rate of each zone, by controlling each virtual well. These guide rates may change every time step. While this allows for proactive control, acting the ICV before water breakthrough, it also increases significantly the number of optimization parameters. Considering two virtual wells and a thirty years production period (operating the ICV each year), there are sixty guide rates to optimize adding up to the optimized parameters of Table 7, for a total of 67 variables in the optimization and 15 000 simulations run.

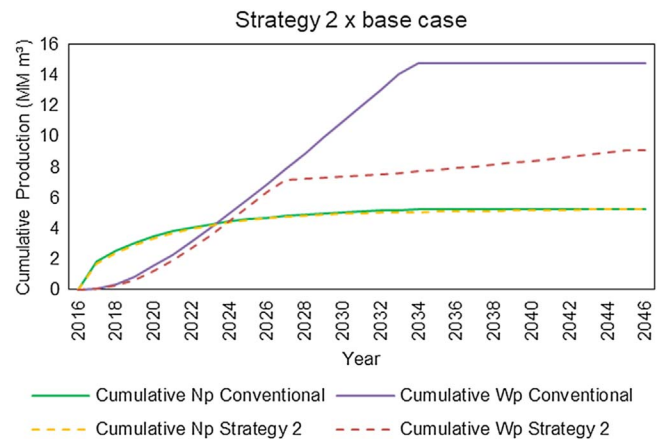
Figure 13 shows the cumulative oil and water production for strategy 2. There is a small gain in  $N_p$  with a  $W_p$



**Fig. 12.** Oil and water production for strategy 1, compared to the base case.

**Table 7.** Optimized parameters for strategy 2.

Parameter	Value	Unit
BHP injector	479.99	kgf/cm <sup>2</sup>
BHP <i>P1</i>	275	kgf/cm <sup>2</sup>
BHP <i>P2</i>	479.14	kgf/cm <sup>2</sup>
BHP producer – inj trigger	439.48	kgf/cm <sup>2</sup>
Water inj. rate	829.38	m <sup>3</sup> /d
WCUT – upper ICV	0.9379	–
WCUT – lower ICV	0.9835	–



**Fig. 13.** Oil and water production for strategy 2, compared to the base case.

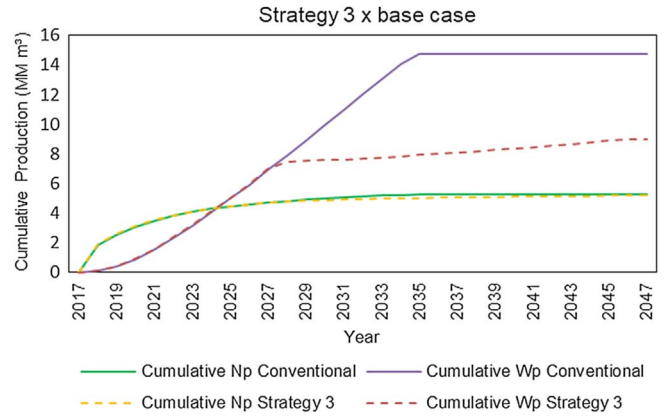
similar to strategy 1, resulting in the NPV of 68.91 MM USD, 5.35% higher than the base case.

### 4.3.3 Strategy 3

In strategy 3, by using the internal guide rates generated by the simulator in real time, production rates were controlled

**Table 8.** Optimized parameters for strategy 3.

Parameter	Value	Unit
BHP injector	446.81	kgf/cm <sup>2</sup>
BHP P1	275	kgf/cm <sup>2</sup>
BHP P2	443.20	kgf/cm <sup>2</sup>
BHP producer – inj trigger	402.37	kgf/cm <sup>2</sup>
Water inj. rate	957.53	m <sup>3</sup> /d
Coefficient A <sub>1</sub> (*STO NUM)	41 536.20	–
Coefficient A <sub>3</sub> (*STW NUM)	99 738.94	–
Coefficient B <sub>3</sub> (*STW DEN)	482.18	–
WCUT – upper ICV	0.9412	–
WCUT – lower ICV	0.8976	–



**Fig. 14.** Oil and water production for strategy 3, compared to the base case.

**Table 9.** Comparative analysis of the strategies.

	Conventional completion	Strategy 1	Strategy 1 (lumped)	Strategy 2	Strategy 3
$N_p$ (MM m <sup>3</sup> )	5.253	5.223 (−0.57%)	5.141 (−2.13%)	5.255 (+0.03%)	5.180 (−1.33%)
$W_p$ (MM m <sup>3</sup> )	14.752	8.916 (−39.56%)	8.220 (−44.28%)	9.090 (−38.58%)	8.991 (−39.26%)
$W_{inj}$ (MM m <sup>3</sup> )	22.608	16.796 (−25.71%)	16.885 (−25.31%)	16.987 (−24.86%)	16.737 (−25.97%)
NPV (MM USD)	65.41	62.46 (−4.51%)	64.56 (−1.30%)	68.83 (+5.35%)	69.63 (+6.45%)

**Table 10.** Comparative analysis of the optimization stage.

	Conventional completion	Strategy 1	Strategy 2	Strategy 3
Number of parameters	6	7	67	10
Simulations run	4000	10 000	15 000	10 000
Simulations needed for optimal solution	824	9312	10 584	3679

with the priority formula in (1), relying on optimization of only three weighting coefficients for the guide rates, prioritizing wells with lower WCUT. Compared to a classic proactive control of opening and closing ICV through the productive life of the well (as seen in strategy 2), this strategy reduced significantly the optimization parameters. Liquid production rate was set at a fixed target on the maximum rate of 3000 m<sup>3</sup>/d for the real well (group of both virtual wells). Table 8 presents the optimized parameters for strategy 3. In this case, only ten variables were used in the optimization process for a proactive approach and a total of 10 000 simulations run.

Figure 14 shows the cumulative oil and water productions for strategy 3, compared to the base case. NPV with this strategy is 69.63 MM USD, 6.45% higher than the base case and the best result among the proposed strategies.

#### 4.3.4 Strategies comparison

The results from the previous strategies were compared to the conventional completion simulation (base

case). Strategy 1 was also run with lumped layers for ICV representation as an extra scenario, to compare different types of modelling in the same strategy. Strategies 2 and 3 demanded “virtual wells” modelling due to commercial simulator limitations so they were not run with lumped layers in the comparison.

Table 9 presents the results of  $N_p$ ,  $W_p$ , Water Injection ( $W_{inj}$ ) and NPV of each scenario, with all percentages related to the base case.

As can be seen in Table 9, there is a small fluctuation in  $N_p$  values for all strategies and higher  $N_p$  does not necessarily mean higher NPV. In this case study, as the  $N_p$  values are not so different among strategies, a small anticipation of oil production had more influence over NPV, resulting in higher NPV for strategies 2 and 3. Strategy 1 with lumped layer control also benefited from anticipation of oil production, despite of having the lowest  $N_p$ .

As expected, the use of IWC improved water management as a whole, considerably reducing  $W_p$  and  $W_{inj}$  in all strategies. Nevertheless, IWC would not be recommended with reactive control in this study, as the NPV obtained was smaller than the base case.

The results with a proactive approach were considerably better (strategies 2 and 3) with higher NPV than the base case. Strategy 2 would be highly discouraged due to the number of parameters in the optimization stage, needing too much computational effort, even though NPV was higher than the base case. This strategy could benefit of optimization in cycling frequency (Abellan and Noetinger, 2010), reducing the necessity to cycle all ICV every time-step. Strategy 3 presented the best solution, with a good balance between computational cost and optimal result.

Table 10 shows a comparison for the optimization stage in order to analyze the computational cost in each case. The use of the INGUIDE feature allowed for proactive control without adding too much computational cost (*i.e.* number of parameters) and also showed faster convergence to the optimal solution.

## 5 Conclusion

This work presented a methodology for expedite ICV positioning focused on field replicability and the analysis of NPV through a quality map proved to be a valid tool for faster ICV placement. Optimization gains in conventional completion were higher than in IWC, corroborating the results of Barreto *et al.* (2016) and Morais *et al.* (2017).

The main objective of this work was the use of an efficient methodology with quality maps and ICV proactive control using production parameters in real time. Strategy 3 was able to deliver an expedite simulation of IWC, aiming at field replicability and compatibility with well construction timespan. There was an 85% reduction in optimization parameters with real-time control from strategy 2 to strategy 3, presenting itself as an interesting alternative for scenarios with higher number of optimization parameters, such as multi-position/continuous variable position ICV or a field study with more than one well equipped with IWC. Proactive control is usually associated with difficulties when translating it to field application, but the proposed methodology allowed for real-time proactive control and not much more computational effort than a commonly used reactive approach. However, BHP coupling among virtual wells should be a concern when using this kind of approach to emulate zonal flow control. If BHP constraints are well represented, virtual wells can perform similar to lumped layer modelling. A comparison between the two types of modelling is advised for validation purposes. It is also important to observe which zone would be the most restrictive for the group.

For this specific case study, IWC presented a small gain with proactive control (strategies 2 and 3) in NPV. Proactive control using production parameters in real time in strategy 3 presented itself as the best solution. For the real-time strategy proposed, to control WCUT values with production curves, they must be properly fitted to the model.

One should notice that NPV is highly dependent on the proposed economic scenario. When analyzing NPV values, it is important to notice that all proposed strategies have an extra cost associated with the ICV. If  $N_p$  gain for IWC

were clearly higher, the decision could be made only based on the  $N_p$  and the process could be even faster.

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