Use of Water Cut to Optimize Conventional and Smart Wells
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Abstract
Water-cut prediction by reservoir simulation can be used as the main parameter to determine well shutdown time. In general, analytical formulations are used to determine the maximum water cut that a well can reach and this value is used as a monitoring parameter in reservoir simulation. Moreover, water-cut value can be a good indicator to evaluate field performance and it can be used as a variable in optimization process. This paper presents a methodology to optimize production strategy using water cut as a parameter to shut down wells and smart completions as a variable of the optimization process and as an economic indicator to evaluate strategy efficiency. A discussion on the use of water cut in a reservoir simulation is made, regarding the benefits and limitations of the use. The results show that using only analytical formulation to determine the water cut to shut down wells and completions is not a good approach to maximize production strategy Net Present Value (NPV). On the other hand, the optimization of well and valve operation using water cut significantly improves the NPV. Water cut is successfully used to indicate strategy efficiency and to suggest strategy modification. The results also show that it is necessary to be careful in the use of water cut in an optimization process, because it can present several limitations. This study may help engineers to decide if it is necessary to run an optimization process to determine the parameter used to shut down wells. Furthermore, the results show the importance of a good estimation of the time to shut down wells and completions to reach the optimum potential of a production strategy.

Introduction
Water cut is a production parameter that is calculated by the ratio between the water production rate and the fluid production rate. In fields in which the gains and costs with gas production is negligible or proportional to the oil production, the water cut is an important economic indicator to determine how profitable a well or completion is. Hence, water cut is widely used to indicate the time limitation to shut down wells and completions, mainly using reservoir simulation, because the usual simulators do not have direct keywords to deal with economic evaluation (Gharbi 2005; Yang et al. 2003; Maschio et al. 2008). Moreover, in cases in which it may be interesting to shut down wells and completions before they reach the economic limit, water cut is also used as a variable to optimize the time of shutting down (Silva and Schiozer 2009). Therefore, water cut is an important indicator in the evaluation of the time limit of operation and as a variable in an optimization process. The focus of this work is the use of water cut in a reservoir simulation in the process of production strategy selection.

A strategy-selection process is used to select the exploitation strategy of an oil reserve, including platform, type of wells, well position, surface facilities, well completions, etc. In general, this process is divided into steps to reduce the number of variables (Coopersmith et al. 2003; Schiozer and Mezzomo 2003). An important step to evaluate production strategies is the optimization of operational control of the field, wells and inflow-control devices (ICV), the latter when smart wells are used (Mezzomo 2006). The problem consists of finding an optimum control over a time interval, which maximizes a specific performance indicator of a reservoir, in general, the NPV. Several controls are important in a field optimization. In reservoir simulation, controls can be an operational parameter, controlling flow and pressure, or a monitoring parameter, which monitors a certain parameter and acts when a specified value is reached, water cut, for example.

Silva and Schiozer (2009) propose a methodology to optimize production strategy. The methodology includes an optimization of a conventional and smart-well operation using water cut as a variable. The optimization consists of maximizing the NPV by manually changing a single value of water cut to operate all wells and completions. However, no considerations about the efficiency of the use of water cut to optimize well operation are made.

Asadollahi et al. (2012) propose an optimization workflow that uses shut-in water cut as a variable of an optimization problem, calculation of the water-cut limit by economic formulation and also use of the water-cut parameter to perform
engineering evaluation, improving initial guesses of the optimization process. It is concluded that water cut can be successfully used as an optimization variable and to improve initial and optimal strategies NPV.

Dehdari and Oliver (2011) present a method to solve a constrained production optimization using the bottom-hole pressure (BHP) and well-fluid rate as variable; thus, water cut is not an optimization variable. The results show that the use of a water-cut limit to avoid inadequate operation of wells and completions is essential to improve the NPV. Notwithstanding, the method to calculate the water-cut limit is not presented.

It is important to highlight that water cut is frequently used only to shut down wells and completions and this type of control could not be suitable in cases in which a smooth control optimization is more appropriate, although this kind of optimization may consume many more simulations. Zandvliet et al. (2007) show that a bang-bang control, also named on-off control, could sometimes be used without reservoir-performance losses. This means that it is possible to apply an on-off control to represent a smooth control without a significant reduction of NPV. Brouwer and Jansen (2004) also prove that sometimes a bang-bang control is enough to improve NPV by well operation. However, they explain that this depends on the operating constraints and/or the type of control variable.

Concluding, water cut is a reservoir parameter used in reservoir simulation to monitor and operate wells and completions. Moreover, water cut can be used to indicate profitability and to guide production-strategy optimization. However, strategy evaluation can be underestimated if water cut is used incorrectly. Therefore, it is important to have suitable methods to deal with water cut as a simulation parameter, avoiding wrong evaluations and obtaining the best results.

Objective
The objective of this work is to show a methodology to improve production strategy using water cut as an economic indicator and as a variable of the optimization process. The methodology uses the water-cut parameter to make evaluations and to help decide whether the strategy could be improved or not and to choose what could be changed, showing details about how to use water cut in a way to obtain the best results in a production-strategy selection process, before the perforation of wells. The operation of wells and ICV are the focus of this objective.

Background Theory
In a simple analysis, the option for shutting down a well could be made based on its own cash flow and on the general costs, for instance, facility operation costs, injection costs, etc. If the cash flow is positive, the well would keep operating; if it is negative, the well should be closed. Using reservoir simulation, it is a common practice to calculate a well cash flow using only the fluid production. If all of the costs and gains could be associated with oil and water production, it would be possible to find a relation between water cut and well cash flow. Thus, a water-cut limit could be used as a monitoring parameter in reservoir simulation. A simple way to formulate an equation to deal with the problem is presented as follows.

The economic limit of a well or completion operation occurs when the cash flow goes to zero, meaning that the revenue is equal to the production costs, plus taxes and other inherent costs. Thus, considering the economic limit of operation, the cash flow can be formulated by the follow equation (Eq. 1).

\[ OPI_{lim} \rightarrow CF^i(Q_{o}^i, Q_{w}^i, \theta) = 0 \]  

(Eq. 1)

where:
- \( OPI_{lim} \) economic limit of well operation “i”.
- \( CF^i \) isolated cash flow of well “i” ($).
- \( Q_{o}^i \) well “i” oil production rate (L$^3$/T).
- \( Q_{w}^i \) well “i” water-production rate (L$^3$/T).
- \( \theta \) function used to share general costs among all wells ($).

Regarding a cash flow for a single producer well, it can be calculated by the oil price, its fluid production rates, production costs associated with its own production and general costs shared among all wells. The equation may be as complex as the fiscal regime and assumptions considered. Sharing costs can be done equally by all wells or using a specific function to determine the exact value to include in a specific well’s cash flow. The following equation (Eq. 2) can represent a simplified cash flow.

\[ CF^i = (P_o - C_o) \times Q_{o}^i - C_w \times Q_{w}^i - \theta \]  

(Eq. 2)

where:
- \( P_o \) oil price ($/L$^3$).
- \( C_o \) oil production cost ($/L$^3$).
- \( C_w \) water production cost ($/L$^3$).
Another important cost that impacts on a producer well is the required injection to enhance the well’s production. Considering only water injection in field recovery and the possibility to associate water injection with fluid production, the following equation can be formulated (Eq. 3).

\[ Q_{inj}^f = n \times (Q_o^f + Q_w^f) \]  

(Eq. 3)

where:
- \( Q_{inj}^f \)  field water-injection rate (L³/T).
- \( Q_o^f \)  field oil-production rate (L³/T).
- \( Q_w^f \)  field water-production rate (L³/T).
- \( n \)  ratio between water injection and fluid production rates.

Sharing the costs of injection proportionally for all wells, the shared costs can then be written as Eq. 4.

\[ \theta = C_{inj} \times Q_{inj}^f \times \frac{(Q_o^i + Q_w^i)}{(Q_o^f + Q_w^f)} \]  

(Eq. 4)

where:
- \( C_{inj} \)  water injection cost ($/L³).

Replacing Eq. 3 with Eq. 4, yields (Eq. 5)

\[ \theta = C_{inj} \times n \times (Q_o^f + Q_w^f). \]  

(Eq. 5)

A cash-flow equation can be calculated using Eq. 6.

\[ CF^i = (P_o - C_o) \times Q_o^i - C_w \times Q_w^i - C_{inj} \times n \times (Q_o^f + Q_w^f) \]  

(Eq. 6)

Therefore, at the limit of operation, the following equation can be written as Eq. 7.

\[ OP_{lim}^i \rightarrow (P_o - C_o) \times Q_o^i - C_w \times Q_w^i - C_{inj} \times n \times (Q_o^f + Q_w^f) = 0 \]  

(Eq. 7)

Water cut can be stated in the following way (Eq. 8):

\[ WCUT^i = \frac{Q_w^i}{Q_o^i + Q_w^i} \]  

(Eq. 8)

where:
- \( WCUT^i \)  water cut of well \( i \).

Isolating \( Q_o^i \) in Eq. 7, replacing it in Eq. 8 and making simplifications, the equation yields a formulation which expresses the water cut at the economic limit of operation (Eq. 9).

\[ WCUT_{lim}^i = \frac{(P_o - C_o - C_{inj} \times n)}{(P_o - C_o - C_w)} \]  

(Eq. 9)

A more complex equation can be written to incorporate financial details of more sophisticated cash flows. Eq. 10 shows a simplified equation to calculate the water-cut limit of a Brazilian Royalty/Tax regime.

\[ WCUT_{lim}^i = \frac{P_o - \Psi(P_o, T, C_o, Roy, C_{inj} \times n)}{P_o - \Psi(P_o, T, C_o, Roy, C_{inj} \times n) + \Omega(C_w)} \]  

(Eq. 10)

where:
- \( \Psi \)  function to describe the cash-flow discount relative to production, tax, costs, etc.
- \( \Omega \)  function to describe the relative costs of water production.
- \( T \)  taxes and government take.
- \( Roy \)  royalties.
Therefore, the limit of operation of a well or completion based on cash flow is directly correlated with a water-cut value and its value can be calculated using a developed formulation based on the economic model. Notwithstanding, in certain cases, in which a well interferes negatively on the whole field’s performance, it would be best to shut down the well before it reaches the economic limit (Barreto et al. 2010).

Considering reservoir simulation, a water-cut parameter can be used in the strategy-optimization process. Basically, a water-cut parameter can be used as a variable to optimize the best time to shut down wells and completions and as an indicator to identify if wells and regions are shutting down sooner than expected and indicating why this is happening.

A large number of variables can be used in a mathematical optimization process to find the best shutdown time of wells and well regions. The variable can be a simulation keyword of well monitoring, well operation, well structure or a reservoir parameter, for example, water cut, completion maximum rate, layer completed and grid block productivity index. Monitoring a water-cut parameter to shut down a well or a completion is a simple method of representing an operation. In order to change the shutdown time of a well or region, it is only necessary to change the value of monitored water cut. Therefore, in an optimization process, a large number of variables are not needed to optimize the operation and, in the simplest case, only one variable is required in the process of optimizing all of the wells and well regions. However, using water cut brings some disadvantages and limitations to the problem. Therefore, water cut must be used in a reasonable way.

Eq. 10 shows a generic representation of an optimization process using an economic indicator as an objective function and a water-cut parameter as a variable. Considering that all wells or regions must be shut down in the \( W\text{CUT}_{\text{lim}} \), the number of variables “\( q \)” reduces to a single variable because it is only necessary to optimize one water-cut value. For cases in which it is better to shut down each well or completion at different times, with different water-cut values, it is necessary to optimize a water cut for each well or completion.

\[
F(\text{ECO}) = \max f(W\text{CUT}_1, W\text{CUT}_2, \ldots, W\text{CUT}_q) \\
\text{s.t.} \quad a_i \leq W\text{CUT}_i \leq b_i; \text{to } i = 1,2,\ldots,q
\]

where
- \( E\text{CO} \): economic parameter (such as NPV ($S) or CF($)).
- \( W\text{CUT}_i \): water cut which monitors an \( i^{th} \) well or completion.
- \( q \): quantity of wells or completions.
- \( a_i \): lower limit of \( i^{th} \) water cut.
- \( b_i \): upper limit of the \( i^{th} \) water cut.

This procedure can consume various simulations. For instance, if the desirable precision of water cut is two decimal places, the solution set has one hundred possibilities but, using the correct methods, it is possible to find a good solution with a couple of simulations, even with manual optimization.

There are some cons and limitations in the use of water cut to optimize a well or completion operation. Figure 1 shows three different examples of curves that can represent water-cut behavior. Each curve has particular problems that will be presented.

- **Curve A**
  - **Main problem:** curve floats over time. More than one very same value of water cut over production life;
  - **Negative impact:** the optimization process may stop at the wrong point, earlier than the best; a range of the solution set cannot be explored.
  - **Observing Figure 1**, if the best time to shut down the well or region is between A1 and A2, this time will not be found because the simulation will stop at a point before A1.
  - **Conclusion:** in cases in which the water cut is not monotonically increased along time, water cut will not be a good variable to optimize well or completion shutdown time.

- **Curve B** (between points B1 and B2)
  - **Main problem:** curve with a very high inclination. A high-inclination region can dominate the greater part of a solution set.
  - **Negative impact:** the optimization process may concentrate the search in this region.
  - **Observing Figure 1**, most of the water-cut values is in the region between B1 and B2, approximately 60% of the water-cut range. In this region, only five years can be explored, around 17% of its production life.
  - **Conclusion:** it is necessary to observe if the optimization method was capable of searching in all regions of the solution set.

- **Curve B** (between points B3 and B4)
  - **Main problem:** curve with a very low inclination.
  - **Negative impact:** low precision when discrete representation is used. Greater precision of the water-cut parameter might be necessary to obtain the same precision as shutdown time.
Observing Figure 1, in order to get a precision of one year or less between B3 and B4, it is necessary to consider three or more decimal places in the water-cut value. This precision may be not suitable because the higher the precision of the variable, the higher the solution set of the problem will be.

- Curve C
  - Main problem: curve inclination is equal to zero. It is more common before the breakthrough (C1).
  - Negative impact: if the best time to shut down is before the breakthrough, it will be impossible to find the best solution; this problem will occur in all regions in which the curve inclination is zero.
  - Observing Figure 1, the value of water cut is zero until the 5th year.
  - Conclusion: it is necessary to observe if the water cut increases monotonically during the simulation time instead of maintaining the very same value during production life. In cases in which the optimization process searches for a solution before the breakthrough, it is necessary to verify if the well could be completely removed from the case.

Finally, water cut can be used as an economic indicator to evaluate whether a well or well region is correctly exploited or not. The expectation is that it could be exploited up to its economic limit or as near this limit as possible and that it should not be shut down while it is profitable. Although in some cases it is better to shut down a well before it reaches the economic limit, when a study points out that a well should be shut down too early, with very low water-cut value, this can indicate that there is something wrong and that the well or region is not being exploited correctly. It may suggest that the strategy is not efficiently optimized and a change can be made to extend its production life or that the well is located in a worthless region or even that it needs to be removed from the strategy. Therefore, in a production-strategy selection process, it must be decided if it is profitable to shut a well sooner than expected, or it will be worthwhile to apply small changes in the well or completion by, for instance, moving the well, closing the worst completions, applying different technologies, such as inflow-control devices (ICV).

Concluding, water cut can be used in reservoir simulation to determine the economic limit of production, to aid in the optimization process and to indicate strategy efficiency. Therefore, water cut is an important parameter to make strategy evaluation using reservoir simulation. Water cut is a simulation parameter that is easily handled, providing information regarding production and economics, which can help engineers and decision makers, particularly in a production-strategy selection process. However, it must be carefully used, in order to avoid erroneous evaluations and waste of simulation time.

Methodology
The methodology consists of the improvement of a production strategy based on the water-cut limit calculated by analytical formulation, a water-cut parameter as a variable of the optimization process and three indicators based on forecasted water-cut value. The indicators are:

- $W_{\text{Cut}}_{\text{lim}}$ – indicates the limit of economic operation of a well and ICVs. It is calculated by analytical formulation.
- $W_{\text{Cut}}_{\text{opt}}$ – indicates the efficiency of production of all of the wells or well regions. It is estimated by Eq. 10, where $q = 1$ and it uses only a single water-cut value to shut down all of the wells and ICVs.
- $W_{\text{Cut}}_{\text{ind}}$ – indicates the worst well or well region in the production strategy. It is estimated by Eq. 10, where $q$ is equal to the total number of producers or ICVs and one water cut is optimized differently for each well or well region.
Below, **Figure 2** shows the methodology scheme.

![Flowchart of proposed methodology.](image)

The methodology consists of the following steps:

1. Calculation of water-cut limit \((WCUT_{lim})\) based on the economic model and evaluation of water-cut curves in order to verify if using water cut is suitable to run the optimization process;
2. NPV optimization is run to determine the best water cut to shut down all of the wells or ICVs. Therefore, the NPV is optimized by changing a single value of water cut as a monitoring parameter. In this work this water cut is called an optimum water cut \((WCUT_{opt})\).
3. Subtraction of \(WCUT_{lim}\) from \(WCUT_{opt}\) is evaluated and compared with a pre-established tolerance value (Tol). If the difference is smaller than the desirable Tol, it indicates that the influence among the wells’ production is weak and the process is ended. If the difference is higher than Tol, it indicates that the production strategy needs to be changed and the methodology follows to the next step;
4. The NPV optimization process is run to identify the worst well, which has most negative influence on other wells. The optimization is made using one water-cut value as a variable \((WCUT_{ind})\) for each well or ICV, instead of having a single value for all wells. Manual optimization is also made to refine the solution and to verify if the use of water cut was able to find the best solution.
5. Manual optimization is made to improve the production strategy by changing well placement and closing the most-offending completions or even the entire well. The wells or ICV with the worst \(WCUT_{ind}\) are selected in order to change the production strategy. If the NPV strategy has improved, the methodology is restarted; if it has not improved, the methodology is finished.

**Reservoir model**

To evaluate the use of water cut as a simulation parameter in production-strategy selection, two synthetic reservoir models are used. The first is developed to evaluate the methodology of conventional-well analysis (Case 1) and the other to evaluate smart-well analysis (Case 2).

Case 1 is a Black-oil model, with no aquifer, no gas cap and water injection. The maximum thickness is around 90m. The simulation grid is an orthogonal corner-point grid with 43x55x6 blocks (14190 blocks). The model has a heterogeneous distribution of porosity and permeability. Sandstone and low permeability zones are also distributed in the reservoir. These characteristics provide a non-uniform distribution of water injection. The model can be divided into 3 main layers, top layer, middle layer and bottom layer. The top layer has an intermediate characteristic, with a zone with a good distribution of porosity and permeability and zones with low porosity and permeability. The bottom layer is the worst zone to flux, with low porosity and permeability. The middle layer is the best layer, with high porosity and permeability. The initial strategy has 12 horizontal wells, 7 being producers, namely PROD03, PROD04, PROD05, PROD06, PROD08, PROD10 and PROD12. The maximum operational rate is 6000 m³/day, for producers and injectors.
Case 2 is a region of a generic reservoir with horizontal wells and one channel as geological heterogeneity. The simulation grid-block dimension has 26x57x6 blocks with a constant grid block size of 20x20x10m. The reservoir includes one producer well and two injector wells, separated uniformly to represent a portion of a major reservoir. Eight monitoring regions (MR) are defined to operate the producer as smart wells, MR-1 to MR-8. The well is tested using ICV, a kind of valve which is able to control the flow by closing a valve aperture. The valve can operate completely opened and completely closed (on/off mode).

**Economic Model**

A deterministic economic model is used. The main economic parameters used are described in Table 1. The NPV calculation is based on the Brazilian fiscal regime of concession. For smart-well evaluation, the investment in a single ICV is USD 200,000 and each additional is USD 85,000.

<table>
<thead>
<tr>
<th>Economic parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil price</td>
<td>50.00 USD/bbl</td>
</tr>
<tr>
<td>Oil-production cost</td>
<td>10.00 USD/bbl</td>
</tr>
<tr>
<td>Water-production cost</td>
<td>1.00 USD/bbl</td>
</tr>
<tr>
<td>Effective interest rate</td>
<td>0.09</td>
</tr>
<tr>
<td>Water-injection cost</td>
<td>1.00 USD/bbl</td>
</tr>
<tr>
<td>Income tax</td>
<td>25%</td>
</tr>
<tr>
<td>Royalties</td>
<td>10%</td>
</tr>
<tr>
<td>Social contribution</td>
<td>9%</td>
</tr>
</tbody>
</table>

**Optimization models**

An evolutionary algorithm and a manual optimization are used to improve the production strategy and the ICV operation. The evolutionary algorithm is used to optimize the value of \( WCUT_{\text{ope}} \) and \( WCUT_{\text{ind}} \). The manual optimization is used to improve the production strategy, changing well completion perforation in grid blocks and well location. The objective function of both processes is the field’s NPV.

The evolutionary algorithm is based on the optimization presented in Eq. 10 in which \( WCUT_{\text{ope}} \) and \( WCUT_{\text{ind}} \) are the variables. The evolutionary algorithm operates with decimal notation. Although the method uses the three basic operators of a genetic algorithm, elitism, crossover and mutation, the operations are made by mathematical formulations and not by genetic representation (Barreto et al. 2010).

**Results**

Considering the economic model, \( WCUT_{\text{lim}} \) is equal to 0.94. The NPV for the initial strategy using \( WCUT_{\text{lim}} \) as a condition to shut down wells is USD 801 million. The adopted tolerance (Tol) is \( \pm 0.02 \).

Figure 3 shows the curve of water cut over time of all wells using the initial strategy. It can be observed that the water production starts after the first year of production, meaning that an optimization process could not find a better solution between the beginning of simulation and the first or second year of production. However, if the best time to shut down a well occurs earlier than expected, it is an indication that some modification in the strategy related to this well must be done; when it is better to shut down a well before breakthrough, it is the same change that will be made in a well that shuts down with a low water cut. Therefore, it is not a problem for the methodology.

The water-cut curves of PROD03, PROD04 and PROD05 have the same characteristic; the water cut increases quickly from the beginning. Therefore, different values of water cut cannot significantly affect the time of shutdown. In this case, it is difficult to find the best value for shutdown and these values need to be verified with a manual correction in order to know if the best value was found.

The water-cut curves of PROD08, PROD10 and PROD12 have a low inclination at the end of time-production life of wells. In the worst case, a variation of 0.01 in water cut can only change the time of shutdown in 1.60 year. This precision is suitable enough to run the optimization process. However, it is necessary to verify the time of shutting down these wells using manual correction.

The water-cut curve of PROD06 has a particular problem. The water cut does not increase monotonically. An optimization process could not find a solution between the 7th and the 9th year. Therefore, in any simulation process, it is necessary to verify if the best time to shut down PROD06 is really found and if higher values can improve the field’s NPV.

The same analysis is made for every simulation run and the possible problems are verified and fixed by manual correction.
Table 2 shows the results obtained for Case 1. It can be observed that following the proposed methodology, the NPV has improved. In general, the $W_{ CUT\text{opt}}$ trend is to increase as the NPV strategy is improved; except from strategies C to D. Therefore, the low value of $W_{ CUT\text{ind}}$ indicates a non-optimized strategy. The use of $W_{ CUT\text{ind}}$ to chose the next change in production strategy is valid. Changing the well with the worst helps the strategy to be improved. It can be observed that the higher the NPV is, the higher and closer to $W_{ CUT\text{lim}}$ are the $W_{ CUT\text{opt}}$ and $W_{ CUT\text{ind}}$ of the worst well.

Table 3 shows the optimization of the well production using ICV for Case 2. The results show that following the suggested methodology, the well’s NPV is improved and a single valve is selected to control two reservoir regions. $W_{ CUT\text{opt}}$ and $W_{ CUT\text{ind}}$ also end to increase as the strategy is improved. It can be observed that selecting the region with lowest $W_{ CUT\text{lim}}$ helps to improve the strategy, although the efficiency of the optimization process may be improved by selecting more than one region to control with ICV. In this case, MR-7 and MR-8 could both be selected at the first step of optimization if other indicators were used to select regions.

Table 3: Well-production optimization using ICV - Case 2

<table>
<thead>
<tr>
<th>Strategy</th>
<th>NPV (USD million)</th>
<th>$W_{ CUT\text{lim}}$</th>
<th>$W_{ CUT\text{opt}}$</th>
<th>$W_{ CUT\text{lim}} / W_{ CUT\text{opt}}$</th>
<th>Worst $W_{ CUT\text{ind}}$</th>
<th>Worst region</th>
<th>Changes in strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>302</td>
<td>0.94</td>
<td>0.72</td>
<td>0.22</td>
<td>0.10</td>
<td>MR-7</td>
<td>A ICV to control MR-7</td>
</tr>
<tr>
<td>B</td>
<td>307</td>
<td>0.94</td>
<td>0.85</td>
<td>0.09</td>
<td>-</td>
<td>MR-8</td>
<td>A single ICV to control MR-7 and MR-8</td>
</tr>
<tr>
<td>C</td>
<td>328</td>
<td>0.94</td>
<td>0.93</td>
<td>0.01</td>
<td>-</td>
<td>-</td>
<td>No changes</td>
</tr>
</tbody>
</table>

Conclusions

Applying the proposed methodology improve significantly the NPV strategy for Case 1 and 2. Water cut is used to shut down wells and ICV in the economic limit time, as variable an optimization process to indicate strategy modifications. It is shown that the economic production limit can be associated with water cut analytical equation, considering a specific economic model, although wells and ICV can be shut down before reach the economic limit. Using water cut to optimize time of shutting down, due to the irregular and variety types of water-cut curves, optimizations process needs to be carefully run, and it is necessary to observe if water cut curve is suitable to find a good solution. Three indicators are suggested in this work to evaluate strategy efficiency. $W_{ CUT\text{lim}}$ indicates the maximum limit to shut down a well, $W_{ CUT\text{opt}}$ indicates the influence of one well production in other wells, and $W_{ CUT\text{ind}}$ indicates the worst well which is the first candidate to be modified. It is shown that how different $W_{ CUT\text{opt}}$ is from $W_{ CUT\text{lim}}$, there is more influence among wells/well regions production and it is possible to improve the production strategy. $W_{ CUT\text{ind}}$ is successfully used to indicate the worst well and completion and to indicate strategy changes. However, other indicator may help the efficiency of optimization process. To conclude, water cut
can be used in optimization of wells, completions and whole production strategy, helping the optimization of production strategy, although it should be carefully used, because the limitations of the use.

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