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Relative permeability hysteresis analysis in a reservoir with characteristics of the Brazilian pre-salt

Análise da histerese de permeabilidade relativa em reservatório com características do pré-sal brasileiro

Análisis de histéresis de permeabilidad relativa en un yacimiento con características del presal brasileño

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Abstract
The hysteresis of relative permeability and capillary pressure need to be more widespread in academic studies, in order to understand how they can influence reservoirs with light oil and high pressure. These phenomena become extremely important to have a good prediction of oil production, considering that in many cases, the use of hysteresis in calculations can lead to a better prediction of oil recovery, allowing the exploration of certain fields. Thus, this study had as main objective the analysis of two hysteresis models (Killough and Larsen and Skauge) widely used in commercial software, in order to investigate the behavior of a light oil reservoir using a miscible WAG-CO2 process. Thus, to achieve this goal, a semi-synthetic reservoir, with characteristics similar to those found in the Brazilian pre-salt, was considered and was modeled using commercial software from CMG. Hysteresis reduces fluid permeability, which can generate two effects: increased local sweep efficiency of the oil and loss of injectivity. The former effect contributes to increased oil recovery, while injectivity loss can decrease oil sweep, reducing oil recovery. Furthermore, this work found that hysteresis can cause loss of gas and water injectivity, however this did not prevent hysteresis from increasing oil recovery compared to the case without hysteresis.
Keywords: Pre-salt; Miscible WAG-CO_2; Hysteresis; Relative permeability.

Resumo
A histerese da permeabilidade relativa e da pressão capilar precisam ser mais difundidas nos estudos académicos, de modo a compreender como podem influenciar os reservatórios com óleo leve e alta pressão. Estes fenómenos tornam-se extremamente importantes para se ter uma boa previsão da produção de petróleo, considerando que em muitos casos, a utilização da histerese nos cálculos pode levar a uma melhor previsão da recuperação do petróleo, permitindo a exploração de certos campos. Assim, este estudo teve como principal objetivo a análise de dois modelos de histerese (Killough e Larsen e Skauge) amplamente utilizados em software comercial, a fim de investigar o comportamento de um reservatório de petróleo leve utilizando um processo WAG-CO2 miscível. Assim, para atingir este objetivo, foi considerado um reservatório semi-sintético, com características semelhantes às encontradas no pré-sal brasileiro, e foi modelado utilizando um software comercial da CMG. A histerese reduz a permeabilidade do fluido, o que pode gerar dois efeitos: aumento da eficiência de varrimento local do petróleo e perda de injetividade. O primeiro efeito contribui para o aumento da recuperação de óleo, enquanto que a perda de injetividade pode diminuir a varredura de óleo, reduzindo a recuperação de óleo. Além disso, este trabalho encontrou que a histerese pode causar perda de injetividade do gás e da água, no entanto isso não impediu de a histerese aumentar a recuperação de petróleo se comparado ao caso sem histerese.
Palavras-chave: Pré-sal; WAG-CO_2 miscível; Histerese; Permeabilidade relativa.

Resumen
La permeabilidad relativa y la histéresis de la presión capilar deben difundirse más en los estudios académicos, para comprender cómo pueden influir en los yacimientos con petróleo ligero y alta presión. Estos fenómenos se vuelven extremadamente importantes para tener una buena predicción de la producción de petróleo, considerando que en muchos casos, el uso de la histéresis en los cálculos puede llevar a una mejor predicción de la recuperación de petróleo, permitiendo la exploración de ciertos campos. Así, este estudio tuvo como objetivo principal el análisis de dos modelos de histéresis (Killough y Larsen y Skauge) ampliamente utilizados en software comercial, con el fin de investigar el comportamiento de un yacimiento de petróleo ligero utilizando un proceso miscible WAG-CO2. Así, para alcanzar este objetivo, se consideró un yacimiento semisintético, con características similares a las encontradas en el presal brasileño, y se modelizó utilizando un software comercial de CMG. La histéresis reduce la permeabilidad del fluido, lo que puede generar dos efectos: aumento de la eficacia de barrido local del petróleo y pérdida de inyectividad. El primer efecto contribuye a aumentar la recuperación de petróleo, mientras que la pérdida de inyectividad puede disminuir el barrido de petróleo, reduciendo la recuperación de petróleo. Además, este trabajo descubrió que la histéresis puede causar la pérdida de inyectividad de gas y agua, sin embargo, esto no impidió que la histéresis aumentara la recuperación de petróleo en comparación con el caso sin histéresis.
Palabras clave: Presal; WAG-CO2 miscible; Histéresis; Permeabilidad relativa.

1. Introduction

The Covid-19 crisis caused a historic decline in global oil demand in 2020, however, it did not last long. Due to policy changes by governments and variation in behavior, global oil demand is likely to increase in the coming years (IEA, 2021).

As reported by Pereira et al. (2022) pre-salt reservoirs are among the most important discoveries in recent decades due to the large quantities of oil in them. However, high levels of uncertainties related to its large gas/CO2 production prompt a more complex gas/CO2 management, including the use of alternating water and gas/CO2 injection (WAG) as a recovery mechanism to increase oil recovery from the field.

According to the ANP (2021), oil production in the country reached about 2.879 million barrels per day (MMbbl/d) and 132 million cubic meters per day (MMm³/d) of natural gas, totaling 3.707 million barrels of oil equivalent per day (MMboe/d). In the pre-salt region, the bulletin announced that production, in May, registered a volume of 2.835 MMboe/d, of which 2.239 MMbbl/d of oil and 94.7 MMm³/d of natural gas, which corresponded to 76.5% of the national production. The production came from 128 wells.

One of the great challenges of exploration in the Pre-salt involves the advanced recovery methods to be applied to improve the effective oil recovery from the reservoirs. The heterogeneity of carbonatic reservoirs, combined with high pressure and lithological complexity result in a low sweep efficiency, which decreases the productive efficiency of the reservoirs, leaving an undesired residual oil saturation (Salomão et al., 2015). Such concern increases with the application of the Water Alternating Gas - WAG injection pilot and the plans to extend the application of the method in the Pre-salt, as methods based on gas injection are objects of the poor sweep efficiency (Lima, 2021).

In Brazil, the Water Alternating Gas (WAG) technique was not used in offshore reservoirs, but it gained special importance with the discoveries of large volumes of oil in the Brazilian pre-salt. In this case, the reservoirs are at a depth from the sea surface that can reach 8,000m and are located in ultra-deep water (more than 2,000m); they are carbonatic reservoirs (more than 5. 000m); spread over a very large area; with high gas-oil ratios (greater than 200m³/m³ in the Tupi area); with high CO_2 content (8% to 12% in Tupi); subjected to high pressure and low temperature; developed immediately under a thick salt layer (more than 2.000m salt); and found around 300km offshore (Beltrão et al, 2009).

The classical macroscopic definition of multiphase flow in porous media is based on the Darcy equation. Within this equation there is the concept of relative permeability, which results in the reduction of the flow of each phase due to interaction with other phases. However, traditionally, the relative permeability is a function of fluid saturation only. Laboratory and theoretical studies show that relative permeability can depend on many other factors, such as rock wettability, fluid viscosity, and the mode of displacement in the porous medium, which can cause the hysteresis effect of relative permeability (Penninck, 2017).

In Brazil, in this area, some works have already been published. Santana in 2014 investigated the effects of relative permeability hysteresis in miscible WAG-CO_2. Two reservoirs with different degrees of heterogeneity were studied, water-wettable and with light oil. And found that hysteresis causes reduction of the relative permeability of the fluids, which can generate two effects: the increase of local oil sweep efficiency and the loss of injectivity.

Laboissiére (2014) also verified, on a laboratory scale, the influence of WAG on different rock/fluid properties (two-phase flow) and the effects of hysteresis of gas relative permeabilities (three-phase flow). Where he certified reductions of gas and water relative permeabilities during repeated cycles of gas and water injection.

Mello (2015) studied fluid characterization and compositional simulation of WAG-CO_2 for water-wettable carbonate reservoirs. In which he observed that the hysteresis of the three-phase relative permeability was the most influential phenomenon and the modeling of three simultaneous phenomena a priori and correct optimization, suggests the possibility of an increase in the recovery factor, while ignoring these phenomena has the potential for great loss in the recovery factor.

Tovar Muñoz (2020) used immiscible WAG-CO_2 injection into a water-wettable reservoir. Two hysteresis models of relative permeability were studied, the Killough (1976) model and the Larsen and Skauge (1998) model. They concluded that in some cases hysteresis can increase or decrease the FR.

The work of Tovar Muñoz (2020) presented an experimental study to obtain relative permeability curves for drainage and soaking, in a two-phase system using brine and CO_2 at reservoir conditions. The relative permeability curves were constructed by applying the modified Brooks and Corey model. Finally, the hysteresis effect was observed in the relative permeability curves of the carbonated brine as a result of the gas trapped during the drainage and soaking processes.

Considering the studies already done on the subject and aiming to deepen the knowledge on the subject, the present work proposes, to perform the analysis of two hysteresis models (Killough and Larsen and Skauge) widely used in industrial simulators. In order to investigate the behavior of the miscible WAG-CO_2 process in a semisynthetic reservoir, wettable with oil. In order to predict if the behavior will be similar to the water-wet reservoirs studied so far. To achieve this goal, the CMG commercial simulator was used.

2. Methodology

2.1 Materials and Methods

Four modules of the CMG, version 2020.10, were used to perform this study: WINPROP (Phase Behavior and Property Program), BUILDER (Pre-Processing Applications), GEM (Generalized Equation-of-state Compositional Reservoir Simulator) and RESULTS.

The reservoir fluid model was created from a PVT test proposed by Moortgat et al. (2010), which is light and has 8% molar CO_2, whose characteristics can be considered similar to those of the fluids extracted from the pre-salt layer.

The characteristic of the oil is: °API = 33. The differential release results that were published by Moortgat et al. (2010) were used in creating the fitted fluid model using WINPROP.

However, to maintain a reliable and representative fluid model with the original fluid, the differential release data provided by Moortgat et al. (2010), saturation pressure and viscosity, was used in WINPROP for fitting via the Peng-Robinson equation of state.

Figure 1 shows the regression plot of the gas-oil ratio (GOR), whose calculated and experimental values were approximated.

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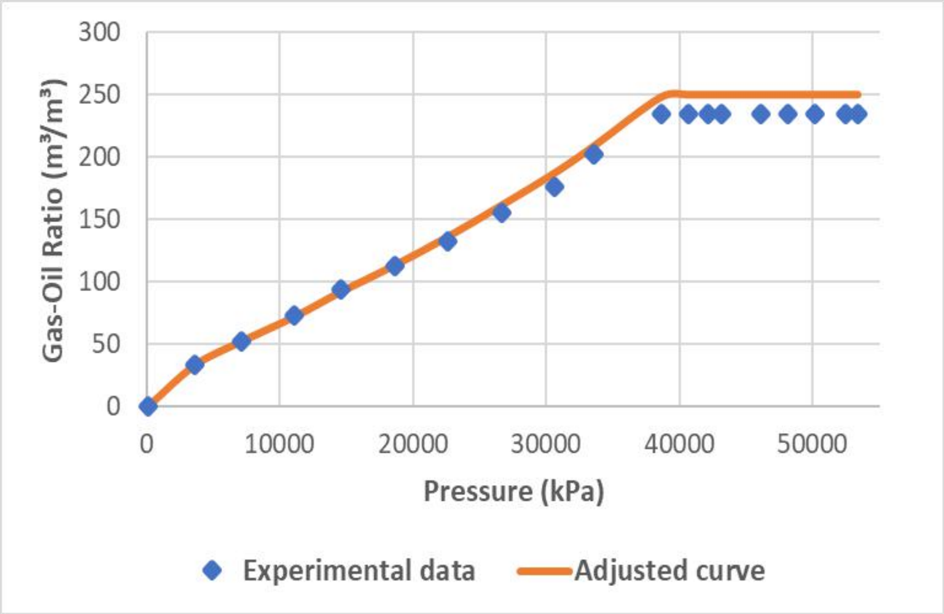
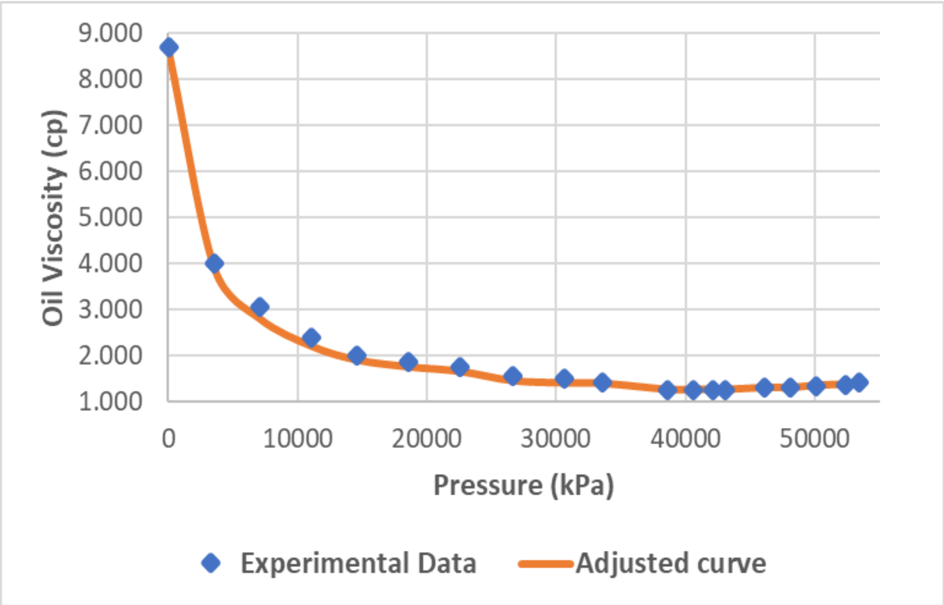
Figure 1 - Graph of calculated and experimental gas-oil ratio (GOR) vs pressure.



Source: Authors.

Figure 2 shows the plot of the oil viscosity whose calculated values are well matched to the experimental values.

Figure 2 -- Graph of calculated and experimental oil viscosity vs pressure.



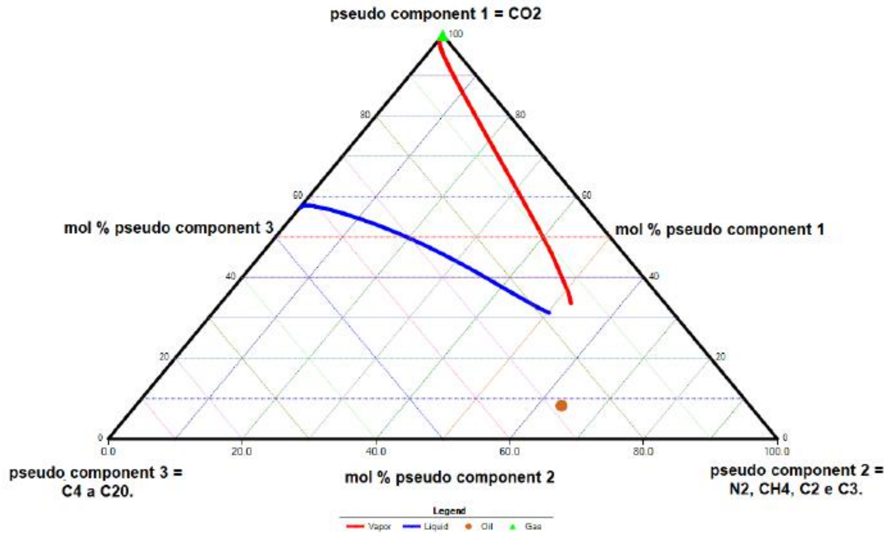
Source: Authors.

2.2 Calculation of the minimum miscibility pressure (MMP) of CO_2

In a project with gas injection usually involves a miscibility calculation for the study of vaporization or condensation processes. In this research, the WINPROP module from Computer Modelling Ltd. was used to calculate the minimum miscibility, first contact and multiple contact pressures.

To construct the pseudo ternary diagram, the components were grouped as follows: pseudo component 1 (CO2); pseudo component 2 (N2, CH4, C2 to C3) and pseudo component 3 (C4 to C20+), which can be seen in Figure 3.

Figure 3 - Pseudo ternary diagram of the reservoir and injected CO2 gas at initial reservoir conditions.



Source: Authors.

Using CO2, the calculation was performed using WINPROP:

- The minimum miscibility pressure was reached at 23,151.91 kPa;
- The first contact miscibility pressure was not found;
- The multiple contact miscibility pressure was reached at 44,298.82 kPa;
- The multiple contact miscibility mechanism was condensation.

The pseudo ternary diagram shown in Figure 3 is at a pressure of 62,742 kPa and temperature of 90 °C.

2.3 Reservoir model

The model studied was of a static reservoir in three dimensions (3D) in the Cartesian system, which according to Pires (2020) has thickness, length and width that can be found in sector models of real pre-salt reservoirs.

Table 1 shows the features used in the model.

Table 1 - Reservoir grid.

	3D SYSTEM
Total number of blocks	162,000
Dimension in x (m)	1,908.9
Dimension in y (m)	1,908.9
Dimension in z (m)	400
Number of blocks in i	45
Block size in i (m)	42.42
Number of blocks in j	45
Block size in j (m)	42.42
Number of blocks em z	80
Block size in z (m)	5
Distance between producer wells (m)	1,696.8
Distance between producer wells and the injector (m)	1,199.8
Injection scheme	Invert *five-spot*

Source: Authors.

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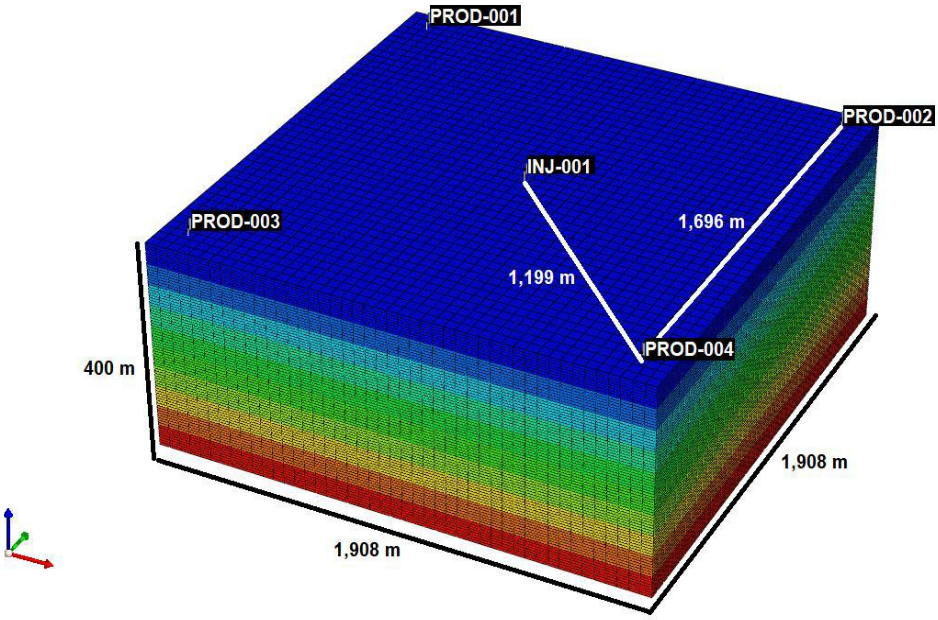
Figure 4 shows reservoir grid and well configuration.

Figure 4 - 3D reservoir model.



Source: Authors.

2.4 Reservoir properties

Table 2 shows the initial reservoir conditions for the base model, based on the work of Plata (2018).

Table 2 - Reservoir properties.

PROPERTIES	VALUES
Initial temperature of the reservoir (ºC)	90
Reference pressure (kPa) @depth	55,158.06
Reference depth (m)	4,936
Water-oil contact (m)	5,700

Source: Authors.

2.5 Rock Properties

The main rock properties are presented in Table 3. The data for each layer are actual values from a Brazilian pre-salt well.

Table 3 - Rock properties.

PROPERTIES	VALUES	AVERAGE
Horizontal permeability (mD)	0 – 2,230	232
Vertical permeability (mD)	0.1*kh	-
Porosity	0 – 0.209	0.15

Source: Authors.

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2.6 Relative Permeabilities

The water-oil relative permeability curves were plotted using the Corey correlation, Equation (1) and Equation (2). With *Sw* increase intervals of 0.075.

$$K_{ro} = (K_{ro})_{S_{wc}} \left[\frac{1 - S_w - S_{or}}{1 - S_{or} - S_{wc}}\right]^{n_o} \quad (1)$$

$$K_{ro} = (K_{ro})_{S_{wc}} \left[\frac{1 - S_w - S_{or}}{1 - S_{or} - S_{wc}}\right]^{n_o} \quad (2)$$

2.7 Operational characteristics of the base model

The main operating parameters used in the simulations are shown in Table 4 and was based on the paper published by Pires (2020).

Table 4 - Operational parameters of the wells.

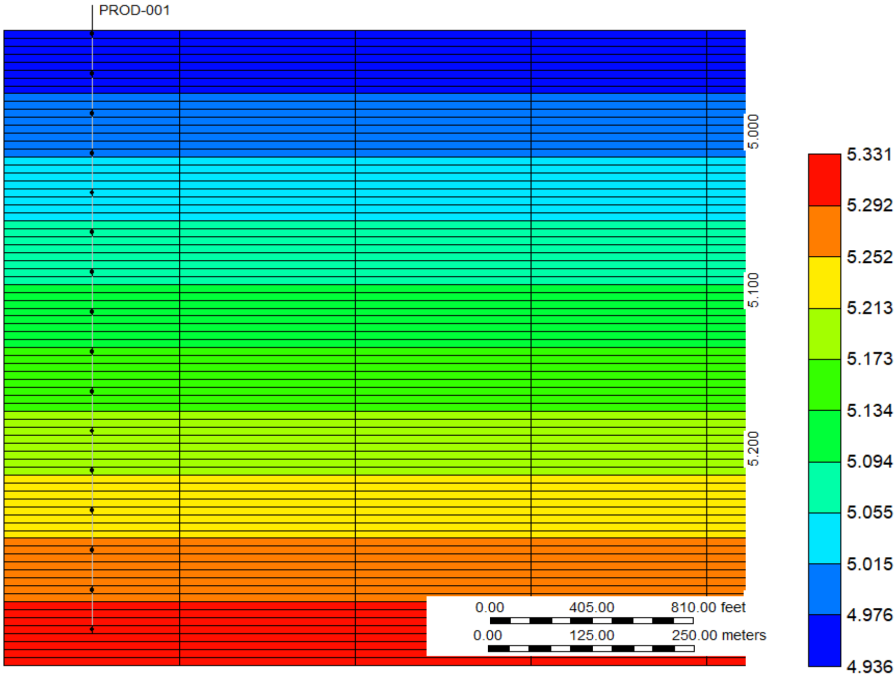
CONTRAINTS WELL	STL (m^3 SC/day)	BHP (kPa)
PRODUCER	12,000	50,000
	STG (m^3 SC/day)	**BHP (kPa)**
INJECTOR CO_2	12,000,000	75,000
	STW (m^3 SC/day)	**BHP (kPa)**
INJECTOR H_2O	25,000	75,000

Source: Authors.

The wells were cannoned every 25 meters (

Figure 5), as suggested in the study released by Correia (2015).

Figure 5 - Cannoning of one of the wells.



Source: Authors.

2.8 Analysis of the hysteresis model's

First, the hysteresis analysis of the killough model was performed; Table 5 shows the parameters chosen for factor analysis of Killough's (1976) model.

Table 5 - Parameters chosen for factor analysis of the Killough model (1976).

REFERENCES	PARAMETERS	MINIMO	MEDIUM	MAXIMO
Santana (2014)	S_{ormax}	0.2	0.4	0.6
Santana (2014)	S_{grmax}	0.2	0.4	0.6
Pires (2020)	Inj CO_2	2,000,000	7,000,000	12,000,000
Pires (2020)	Inj H_20	5,000	15,000	25,000

Source: Authors.

Next, the hysteresis analysis of the Larsen and Skauge model was performed; Table 6 shows the parameters chosen for factor analysis of Larsen e Skauge (1988) model.

Table 6 - Parameters chosen for factor analysis of the Larsen e Skauge model (1988).

REFERENCES	PARAMETERS	MINIMO	MEDIUM	MAXIMO
Santana (2014).	Sg_{rmax}	0.2	0.4	0.6
Larsen and Skauge (1998), Christensen et al. (2001), Rogers et al. (2001).	Krw3	1/10 Krw2	¼ Krw2	½ Krw2
Larsen and Skauge (1998).	α	0	2.5	5
Larsen and Skauge (1998).	a	0.25	0.625	1

Source: Authors.

- Finally, the Killought and Larsen and Skauge models were compared and some parameters considered important in them were analyzed, in order to verify their influence on the model's hysteresis.

3. Results

3.1 Sensitivity analysis of the hysteresis model of Killough's (1976)

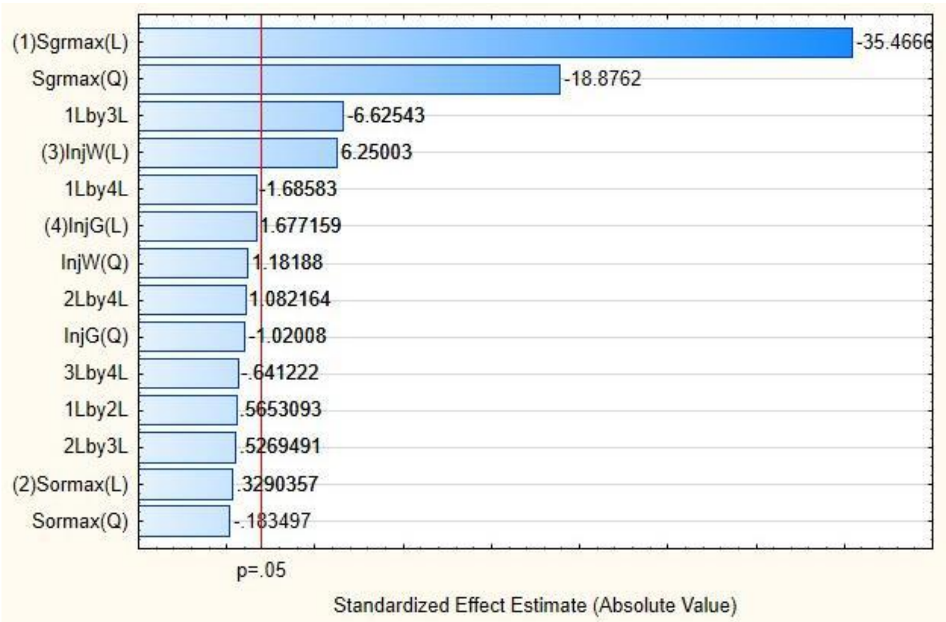
For the sensitivity analysis of Killough's (1976) hysteresis model the parameters Sgrmax - Maximum residual gas saturation; Sormax - Maximum residual oil saturation; InjG - CO2 injection flow rate and InjW - water injection flow rate were used, whose values can be seen in Table 5 of this work.

The linear significance (L) of the operational parameters and their interactions was evaluated using the Pareto diagram.

In the diagram, the value next to the bar results from the division of the mean of the responses at the analyzed levels by the standard error. When this value is positive it means that, with a change from the minimum to the maximum level of the analyzed variable there was an increase in the response, which in this case is the OR. The factors whose bars extrapolate the dividing line ($p = 0.05$) are considered statistically significant at the 95% confidence level.

The Pareto diagram for the 30-year period as a function of the percentage of oil recovered is shown in Figure 6.

Figure 6 - Pareto diagram for 30 years of oil recovery from Killough's (1976) two-phase hysteresis model.



Source: Authors.

In this 30-year period, the maximum residual gas saturation (Sgrmax) with linear significance was the parameter that presented the greatest influence, statistically significant, on the response variable. Followed by the water injection flow rate (InjW).

Through the pareto diagram it is possible to see that the parameter Sgrmax influences in a negative way when InjW influences in a positive way in the OR. That is, when Sgrmax increases its value from minimum to maximum there is a reduction in the OR, while InjW is the opposite, when the water injection flow increases from 5,000m³/day to 25,000m³/day there is an increase in the OR.

Both the gas injection flow and the maximum residual oil saturation were not significant in the 30 years of the project.

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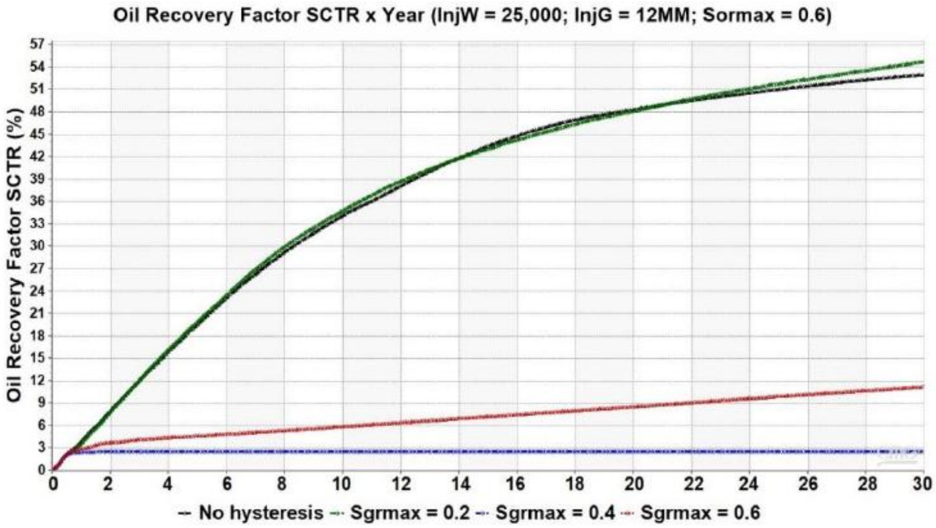
Furthermore, to prove that indeed the increase of Sgrmax =0.2 to 0.6 influences in a reduction of recovered oil, the graph of OR x year was plotted, Figure 7.

Figure 7 - Oil recovery factor x year for different Sgrmax values of the two-phase model.

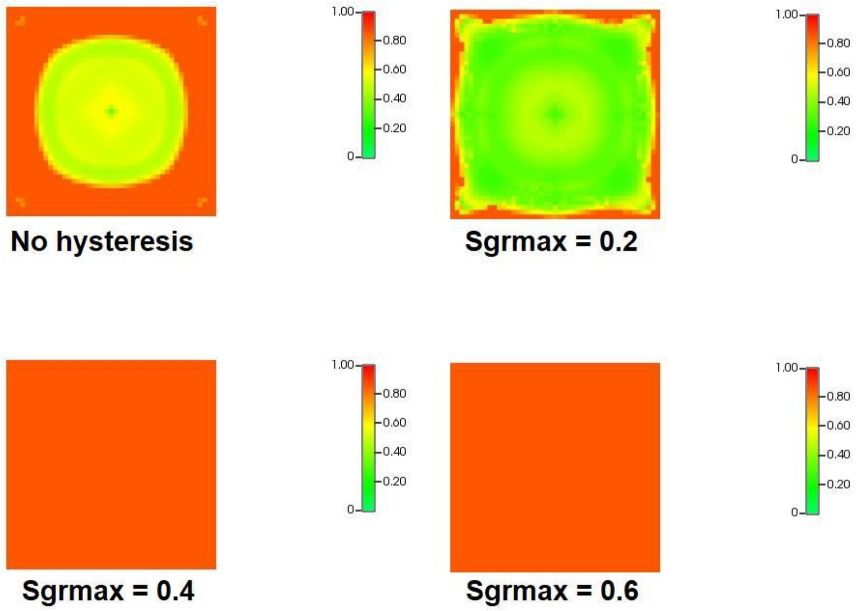


Source: Authors.

Analyzing Figure 7, it can be seen that the case without hysteresis and the case with hysteresis (Sgrmax= 0.2), which is the lowest value studied, practically overlap, separating approximately after 25 years of design. Being the case with hysteresis the one that obtained the highest OR at the end of the study.

Evaluating the influence of oil saturation (So) inside the reservoir in 27 years of design, it is notable that the case considering hysteresis (Sgrmax = 0.2), obtained a better sweep than the others, finding that So reduced more than other cases towards the producing wells, as shown in Figure 8.

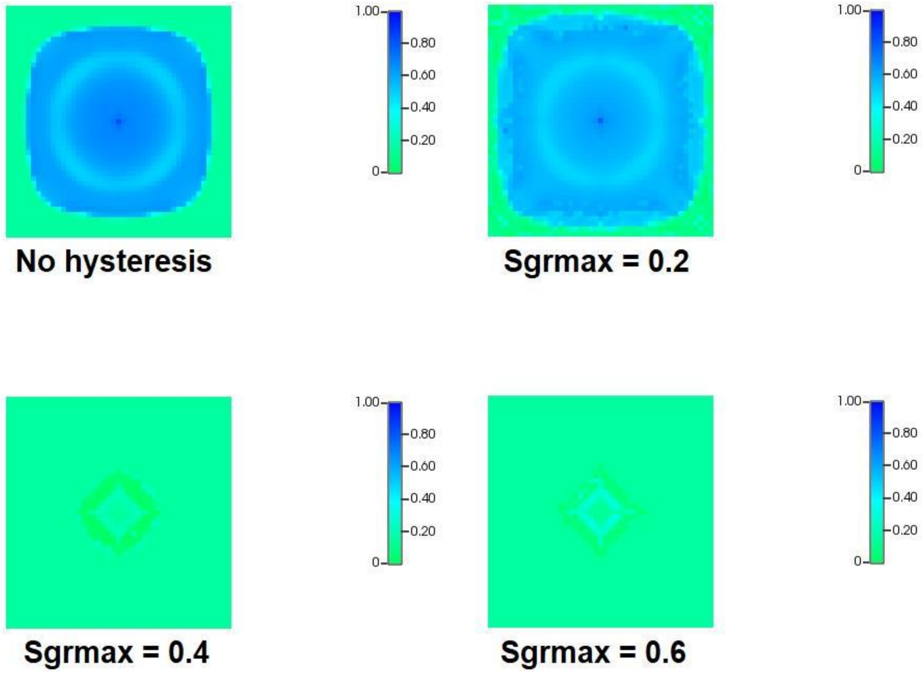
Figure 8 - Influence of oil saturation on 27 years of design for different Sgrmax and no hysteresis.



Source: Authors.

As well, the water saturation (Sw) increased in almost the same proportion, improving the sweep within the reservoir and consequently increasing the production, as shown in Figure 9.

Figure 9 - Influence of water saturation on 27 years of design for different Sgrmax and no hysteresis.



Source: Authors.

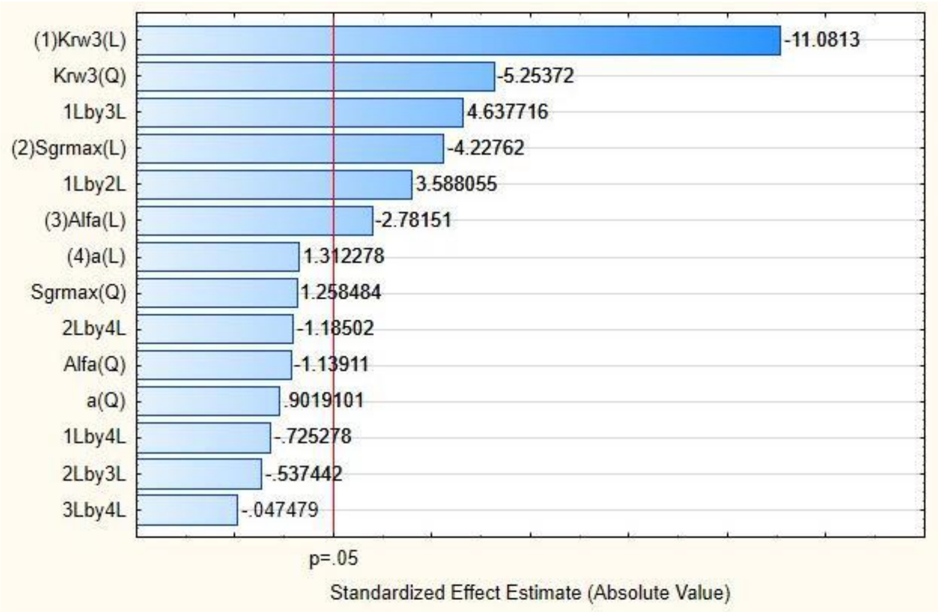
Hysteresis influences oil production when it is not taken into account, there can be different oil productions than the real ones.

3.2 Sensitivity analysis of the hysteresis model of Larsen and Skauge (1998)

For the hysteresis sensitivity analysis of the three-phase relative permeability of Larsen and Skauge (1998) the OR of the parameters Sgrmax, α (Alpha), Krw3 and the parameter "a" were analyzed, whose values can be seen in Table 6.

The Pareto diagram for the 30-year period as a function of the percentage of oil recovered is shown in Figure 10.

Figure 10 - Pareto diagram for 30 years of oil recovery from the three-phase hysteresis model of Larsen and Skauge (1998).



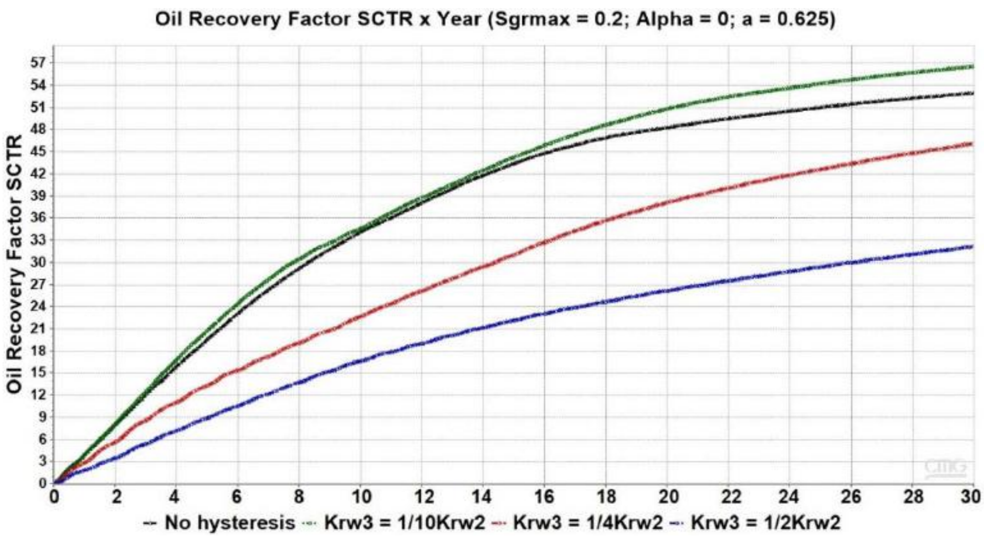
Source: Authors.

In this 30-year period, the three-phase relative water permeability (Krw3) with linear significance was the parameter that showed the greatest, statistically significant influence on the response variable. Followed by the maximum residual gas saturation (Sgrmax) and the gas mobility reduction exponent (Alpha). The parameter "a" was not statistically significant.

Through the pareto diagram it is possible to see that the three significant parameters: Krw3, Sgrmax and Alpha influence the OR in a negative way. That is, when we increase from the minimum to the maximum level there is a reduction in the OR.

To prove this information, we plotted the graph of OR versus year of the most significant parameter (Krw3), and observed that in fact the OR reduces with the increase in the value of Krw3, as shown in Figure 11.

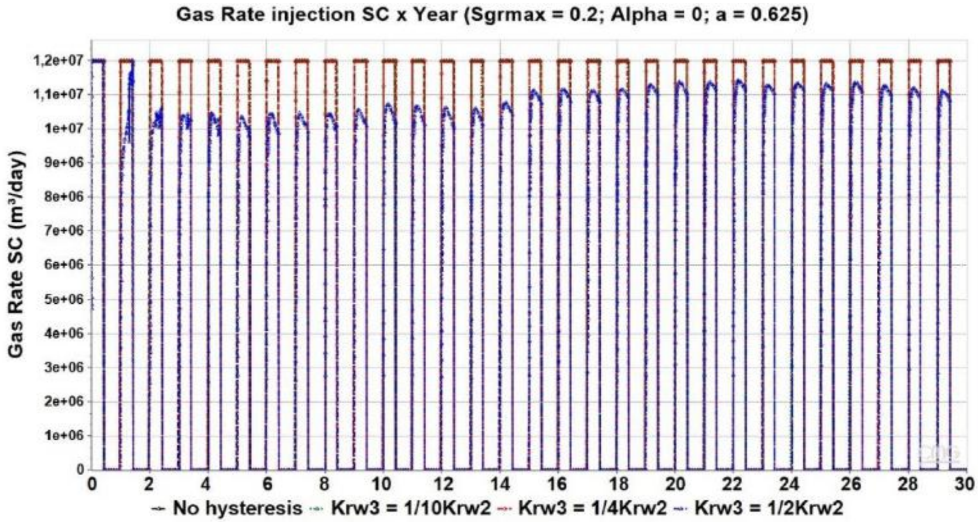
Figure 11 - Oil recovery factor versus year for different Krw3 values from Larsen and Skauge's three-phase model.



Source: Authors.

In order to investigate what was happening when we included hysteresis, we plotted the graph of gas injection flow versus year, Figure 12.

Figure 12 - Water injection flow versus year for different Krw3 values from Larsen and Skauge's three-phase model.

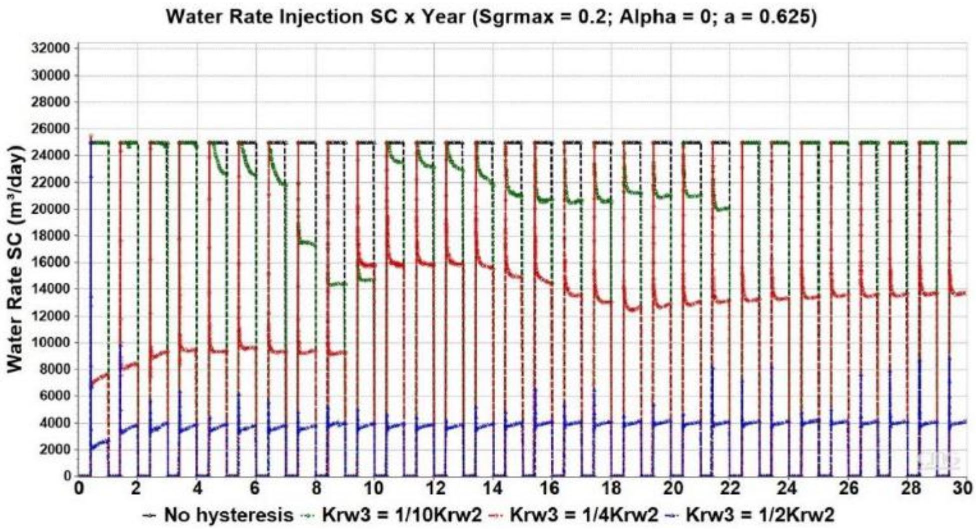


Source: Authors.

In Figure 12 it is possible to observe that the only case that presented a loss of gas injectivity was Krw3=1/2Krw2, the others are all overlapping, with no loss of gas injectivity.

Next we plot the graph of water injection flow versus year, Figure 13.

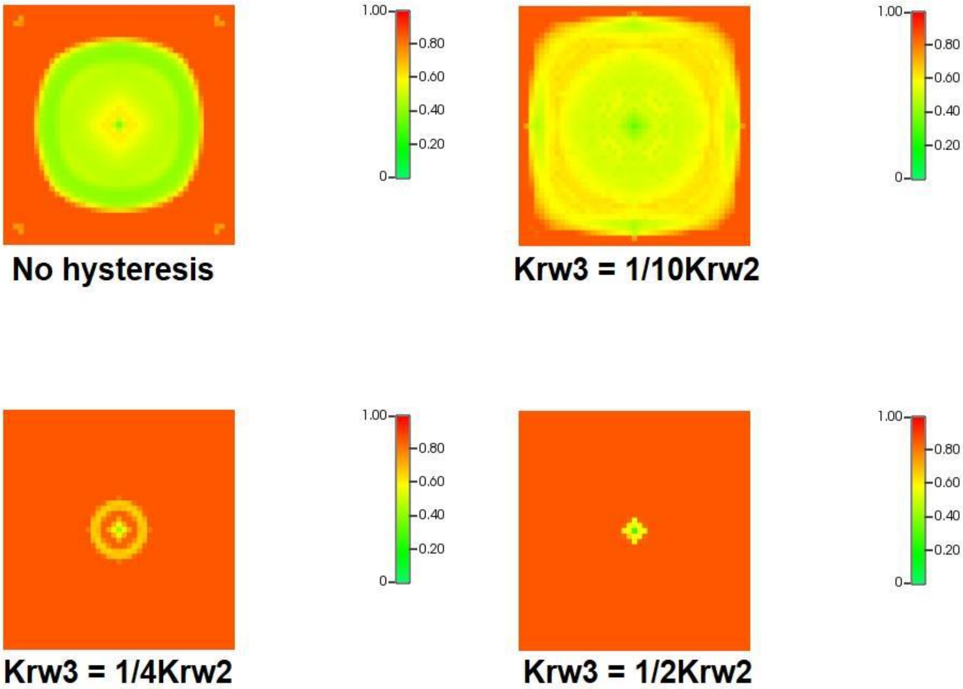
Figure 13 - Water injection flow versus year for different Krw3 values from Larsen and Skauge's three-phase model.



Source: Authors.

Also in Figure 13 all cases with hysteresis experienced a loss of water injectivity, except the case without hysteresis. However, the loss of injectivity was not greater than the sweep effect. For in the oil saturation map, Figure 14, it is possible to see the oil saturation decreasing towards the producing wells, especially the case with hysteresis (Krw3 = 1/10Krw2).

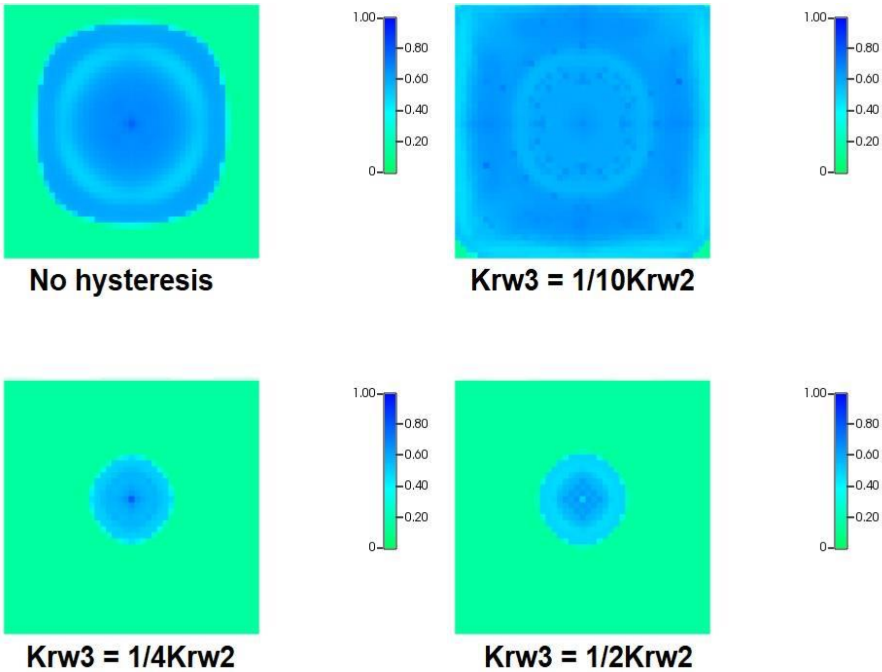
Figure 14 - Influence of oil saturation on 20 years of design for different Krw3 and no hysteresis.



Source: Authors.

The same occurs in the water saturation map, Figure 15, where we observed a greater increase in water saturation in the case with hysteresis (Krw3 = 1/10Krw2) than in the others. Proving that there was a greater drag of oil towards the producing wells, so it has the highest OR among the others.

Figure 15 - Influence of water saturation on 20 years of design for different Krw3 and no hysteresis.



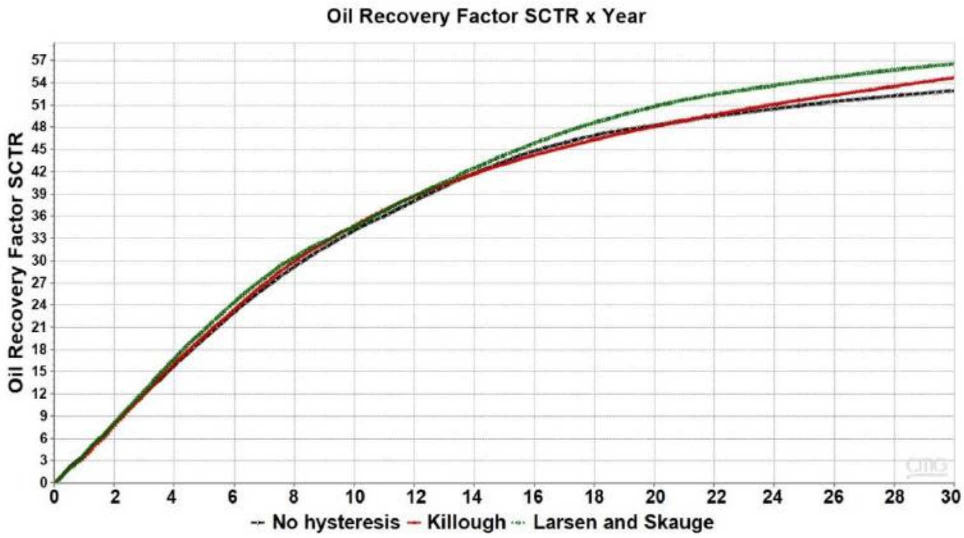
Source: Authors.

3.3 Comparative oil recovery of the hysteresis models studied

To compare the percent oil recovered from Killough's two-phase model, Larsen and Skauge's three-phase model, and the model without hysteresis, the cases that had the highest OR of all the models were used.

It can be seen in Figure 16 the oil recovery versus year for the two-phase, three-phase and hysteresis-free models.

Figure 16 - Oil recovery versus year of two-phase, three-phase and hysteresis-free models.



Source: Authors.

The three-phase Larsen and Skauge model also known as the WAG model is the model with the highest oil recovery prediction of them all, with the second model being the Killough two-phase hysteresis model followed very closely by the model without hysteresis. This shows that the choice of which hysteresis model and its parameters can affect its prediction of oil recovery by approximately 4% in this reservoir.

4. Discussions

The results had similar interpretations to previously published works, even though the specific study used an oil-wet reservoir, while others in the literature worked with water-wet reservoirs. As was the case of Penninck (2017) and Santana (2014). Proving that hysteresis does affect the injection of fluids, both in water and oil wetted reservoirs.

5. Conclusions

Killough's (1976) model presents two parameters necessary for its use: Sormax and Sgrmax. The sensitivity analysis for 30 years of design showed that Sgrmax was the parameter that most significantly influenced the reduction of oil recovery and injectivity loss.

The model of Larsen and Skauge (1998) has four parameters necessary for the employment of the model, which are Sgrmax, α, "a" and krw3. The sensitivity analysis showed that Krw3 was the parameter that most significantly influenced the FR, followed by Sgrmax and α, while the parameter "a" was not significant in the 30 years of design.

Hysteresis in oil recovery mainly influences two parameters: injectivity and sweep efficiency. The effect of these two parameters on production is opposite, and it is therefore important to study each case in detail to identify which is the predominant effect. In the case of our specific study, although both effects occur, what predominated was the sweep of oil towards the producing wells, when we worked with the minimum levels of the parameters (Sgrmax = 0.2; α = 0, a = 0.625 and Krw3 = 1/10Krw2).

Among the models studied, the Larsen and Skauge model was the one that presented the highest recovery factor in the reservoir studied.

And that depending on the hysteresis model considered and the value of the parameters imposed, the behavior of the reservoir may be different.

Finally, the reason we analyzed hysteresis was because it influences the production results of the field, which depending on the operational conditions, can increase or decrease the recovered oil.

It is recommended that field scale tests be carried out to validate the results obtained in this work and that the effects of relative permeability hysteresis be studied in a real field with neutral or intermediate wettability rock.

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Nomenclatures

α	Residual oil saturation correction factor
a	Reduction coefficient of residual oil saturation
BHP	Bottom hole pressure
k	Layer
kh	Horizontal permeability
Kro	Relative oil permeability
(Kro)swc	Relative oil permeability at connate water saturation
krw	Relative water permeability
(krw)Sor	Relative water permeability at residual oil saturation
krw3	Three-phase relative permeability to water
no	Corey exponent for oil
nw	Corey exponent for water
OR	Oil Recovery
Sgrmax	Maximum residual gas saturation
So	Oil saturation
Sor	Residual oil saturation
Sormax	Maximum residual oil saturation
STL	Surface liquid rate
STG	Surface gas rate

STW	Surface water rate
Sw	Water saturation
Swc	Connate water saturation

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