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UNISIM-IV: BENCHMARK PROPOSAL FOR LIGHT OIL CARBONATE RESERVOIR WITH HIGH CO_2 CONTENT

[a] Botechia, V. E. [1]; [a] Correia, M. G.; [a] Rios, V. S.; [a] Davolio, A.; [a] Santos, S. M. G.; [a] Hohendorff Filho, J. C. V.; [a] Schiozer, D. J.

[a] University of Campinas, Campinas, São Paulo, Brazil

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ABSTRACT

The Brazilian pre-salt fields are carbonate reservoirs with good quality oils, but they can present high amount of CO_2 in dissolution, which leads to a high amount of produced gas and can limit oil production. Therefore, the development and management of fields with those characteristics are complex tasks that involve many decisions, with a large number of variables to be considered. Thus, numerical simulation plays an important role in overcoming the challenges that arise from the management of these fields, integrating different subjects such as geosciences and reservoir characterization, data assimilation, production facilities, production optimization processes, economic evaluation, and decision analyses under uncertainty. Open source benchmarks are often used in numerical simulation studies to evaluate and compare techniques and methods, using the same comparison basis. The objective of this paper is to present UNISIM-IV, a set of carbonate benchmarks analogous to a pre-salt field, adding new possibilities to the scientific community and organizations that can improve workflows in the context of reservoirs with the characteristics mentioned above. The benchmark is divided into four different cases: UNISIM-IV-2019, UNISIM-IV-2022, UNISIM-IV-2024, and UNISIM-IV-2026, where the date refers to the date of the analysis. The main differences among these cases involve the stage of field's life cycle, ranging from early development phase (2019) to a developed reservoir with eight years of production (2026). Thus, the available history data and the mapped uncertainties differ between the cases. The users can choose the case that best suits their needs, depending on specific research objectives. Each of these cases comprise: (1) an ensemble of prior uncertainties, (2) production, injection, and pressure history data, and (3) a history-matched simulation model suggested as a base case. There is also a reference case, named UNISIM-IV-R, which consists of a model with a very refined grid and known information used as the "true response" to generate all data that could be measured in a real field, such as production history and well logs.

KEYWORDS

numerical simulation; benchmark; field development; field management; carbonates

[1] To whom all correspondence should be addressed.
Address: University of Campinas, mailbox 6052, Campinas, Sao Paulo, Brazil
ZIP Code: 13.083-970 | e-mail: botechia@unicamp.br
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1. INTRODUCTION

Some fields from the Brazilian pre-salt are associated with carbonate-depositional environment **(Cazarin et al., 2016)**, which present light oil and high content of CO_2 **(Pasqualette et al., 2017)**. Due to environmental issues, there is a necessity for reinjecting the gas in such cases. Given this condition and high GOR in this type of field, the production of gas can be a bottleneck for oil production, with a challenging management, which may, in turn, require several decisions with a large number of variables. Moreover, these fields pose new challenges for research, demanding the development of methodologies that can overcome these challenges, improve the production and economic return, and reduce the risks involved in the process.

The development of open source benchmarks is important for the scientific community and energy companies for validation and comparison of different methodologies and techniques, regarding numerical simulation subjects, such as data assimilation, optimization processes, integration with 4D seismic studies, and probabilistic decision analysis approaches.

Most of the open source benchmarks available currently are based on clastic reservoirs: SPE10 **(Christie & Blunt, 2001)**, Brugge **(Peters et al., 2009)**, Norne **(Adlam, 1995)**, and UNISIM-I **(Avansi & Schiozer, 2015)** are some examples. Regarding carbonate reservoirs, UNISIM-II is a benchmark that represents a naturally fractured carbonate reservoir **(Correia et al., 2015)**, UNISIM-III is based on Brazilian pre-salt giant fields **(Correia et al., 2020)** and Costa Model is based on information of the Rub Al Khali basin, a sub-basin of the wider Arabian Basin **(Gomes et al., 2022)**.

The objective of this work is to present UNISIM-IV, a new benchmark based on carbonate pre-salt fields with high gas-oil ratio (GOR) and associated CO_2 content. UNISIM-IV is based on the Sector 1 of UNISIM-III **(Correia et al., 2020)**, which was chosen because it represents the main challenges and geological features of a pre-salt field, while reducing the computational efforts when compared to UNISIM-III. The benchmark is built for studies regarding data assimilation for uncertainty reduction, optimization processes, probabilistic management and decision analyses methodologies, modeling of WAG-CO_2 flooding as EOR mechanism, inflow control valves (ICVs) studies, integration with production facilities, and use of machine learning techniques for data-driven forecasts, among others.

The static and dynamic data are a combination of information from two wells of a karstic reservoir and synthetic data. The benchmark is divided into four separated cases: UNISIM-IV-2019, UNISIM-IV-2022, UNISIM-IV-2024, and UNISIM-IV-2026. The main difference among them is the stage of the field development. Thus, the amount of available information (i.e. number of wells, history period size, and some of the uncertainties considered) changes from one case to another, and each one can be used for different purposes. Moreover, as a new feature compared to previous open-source benchmarks, we considered well and platform stops during the history period (ranging from a few hours to days), an important aspect to contemplate for data assimilation. We also considered short-term decisions and the use of machine learning for data-driven forecasts to make this benchmark a more realistic case.

To generate the synthetic data, a reference case (UNISIM-IV-R) was built, consisting of a refined-grid model with detailed information that represents the ground truth. This model represents the actual reservoir and, therefore, it provides all possible measured data in a field, such as production history and well logs.

In addition, we considered some “unknown unknowns” in the coarser simulation models, which are unmapped uncertainties present only in the reference case to represent the challenges faced by practitioners in real cases.

2. DATA USED

The geologic and rock/fluid data combine pre-salt data and synthetic data. The benchmark is constructed considering compositional and single-porosity/single-permeability approaches. The information considered to develop UNISIM-IV is:

- Map images of the depth of formation surfaces
- Images of interpreted seismic profiles

- Porosity and permeability logs from two wells
- Facies distribution from two wells
- Rock-fluid data based on public information from Brazilian pre-salt reservoirs
- Fluid data from public reports

Most of the information used for the construction of the static model is public access data, combined with some information supplied by the Brazilian National Oil, Gas and Biofuels Agency - ANP.

3. WORKFLOW FOR THE BENCHMARK CONSTRUCTION

The steps comprising UNISIM-IV development are:

1. Construction of the reference case (UNISIM-IV-R) with the available information
2. Generation of a prior ensemble of uncertainties (geostatistical realizations and scalar uncertainties of rock, fluid, and rock-fluid properties) based on data gathered from pseudo-wells drilled in the reference case (UNISIM-IV-R). Upscaling is performed to obtain coarser simulation models
3. Generation of a realistic production history data (using pseudo-well drilled in the reference case) with the addition of random noise as well as production stops

The procedure applied in Steps 2 and 3 are similar for each case of the Benchmark, differing only on the number of pseudo-wells and available information, considering each stage of field development (UNISIM-IV-2019, UNISIM-IV-2022, UNISIM-IV-2024, and UNISIM-IV-2026).

Thus, the number of well logs (Step 2) and the history period size (Step 3) varies among the cases. Figure 1 illustrates the steps for generation of the benchmark cases proposal.

3.1 Reference case (UNISIM-IV-R)

The reference model is based on Sector 1 of UNISIM-III (Correia et al., 2020), which was developed partially by Chaves (2018), but additional trends were included later in the geological model (Correia et al., 2020). This model has a grid resolution of 50 x 50 x 2 meters, with 170 x 157 x 595 blocks in 'I', 'J', and 'K' directions, respectively, totaling 15,880,550 blocks, from which 2,717,997 are active blocks, with about 4.7 billion std m^3 of oil in place. The structural model consists of four surfaces and three faults.

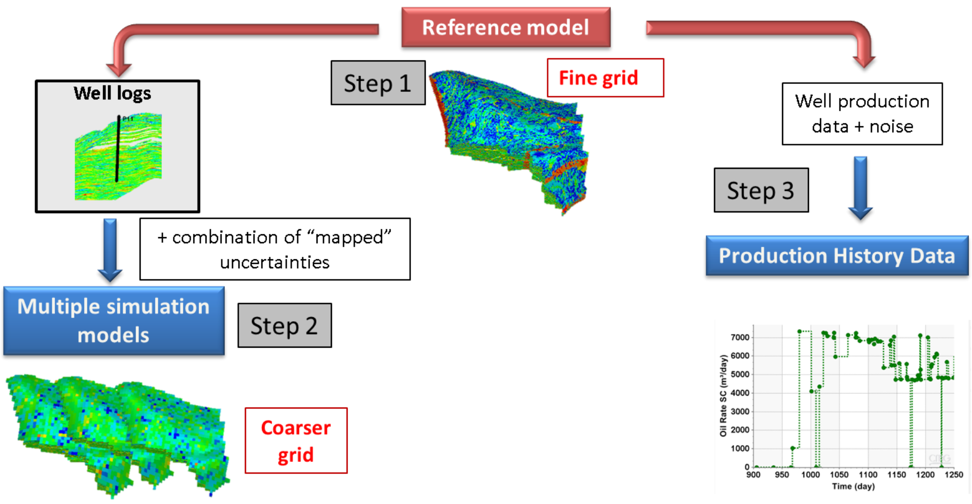

Figure 1. Steps for generation of the benchmark cases.

Table 1. Main data for compositional fluid modeling (adapted from **Petrobras, 2015**).

Property	Value	Unit
CO_2 - Gas	44	(% molar)
CO_2 – Res. Fluid	37	(% molar)
Reservoir Temperature	90	(°C)
Psat	500	(kgf/cm²)
Initial Oil Visc.	0.39	(cP)
RGO flash	442	(std m³/m³)
RGO dif. Lib.	604	(std m³/m³)
RGO separator	415	(std m³/m³)
Bo separator	2	(std m³/m³)

The facies modeling considers three zones: in Zones 1 and 2, the facies vary from microbial laminar and stromatolitic carbonates to wackestone, mudstone, and shale. For Zone 3, the transition varies from grainstone (coquinas) to wackestone, mudstone, and shale. Regarding the petro-physical modeling, porosity and horizontal permeability were populated using Gaussian simulation biasing by facies. The vertical permeability was defined by applying an average multiplier on horizontal permeability for each zone. The net-to-gross (NTG) is calculated based on a cut-off approach. If porosity is equal to zero or the permeability is smaller than 0.1 mD, than NTG is equal to 0; otherwise, NTG is 1. More details about the geological and petro-physical modeling can be found in **Chaves (2018)** and **Correia et al. (2020)**.

The fluid model considers a compositional approach for reservoir simulation, since this benchmark corresponds to light oil with high CO_2 content and the recovery mechanism is WAG-CO_2 injection. The representation of the fluid model considers five pseudo-components. Table 1 shows the main data used for the compositional fluid modeling, obtained from a public report **(Petrobras, 2015)**.

Figure 2 shows a 3D view of the permeability map of UNISIM-IV-R (Figure 2a) and a 2D vertical slice of the permeability of the same model (Figure 2b).

3.2 Generation of prior ensemble of uncertainties

3.2.1 Geologic model and static uncertain variables

The geologic model has the same grid cell size of UNISIM-III-R but the geostatistical modeling is constrained to log information from three pseudo-wells (for UNISIM-IV-2019) and 13 pseudo-wells (for UNISIM-IV-2022, UNISIM-IV-2024, and UNISIM-IV-2026). Regarding the static uncertain variables, one of them is the random seed used in the geostatistical modeling process for facies and petrophysical properties. Facies are used for generating the petrophysical properties (porosity, permeability, and net-to-gross) and for defining the different rock types in the simulation model. The base value used as input for the facies fraction, porosity, and permeability attributes is the average value from well logs. However, as the base value is uncertain, especially in the inter-well sections, the

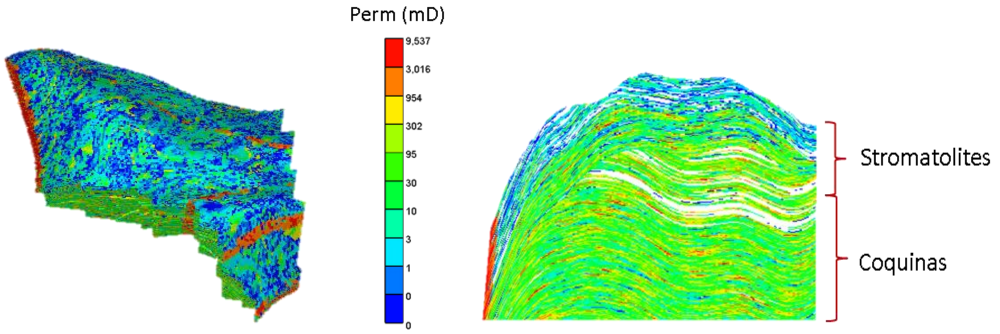

Figure 2. (a) Permeability 3D view and (b) 2D vertical slice of the reference model.

Table 2. Description of static uncertain variables **(Correia et al., 2020)**.

Property	Attribute	Probability Distribution	Geostatistical Technique
Structural Horizons	Height	Normal	Minimum Curvature
Facies	Stochastic Seed Spatial Variability Well-log fraction	SEED Variable Normal Normal	Truncated Gaussian Simulation
Porosity	Stochastic Seed Well-Log Average Spatial Variability*	SEED Variable Normal Normal	Sequential Gaussian Simulation
Permeability	Stochastic Seed Correlation factor with porosity Well-Log Average	SEED Variable LogNormal LogNormal	

* correlated with facies

average values on well logs are considered as uncertain. A normal distribution function is applied for the average value for facies and porosity and a lognormal distribution is applied for permeability. Other uncertain attributes are described in Table 2. The uncertainties and the respective values used as input to generate the geostatistical properties are subjective and can be changed by the participants of the benchmark proposal for comparative approaches.

To increase the realism of the benchmark proposal, some geological trends are not mapped in the geostatistical realizations, depending on the stage of the field, as the information from well logs at each stage of field development is insufficient to identify these geologic attributes. For UNISIM-IV-2019, unmapped trends include fractures clusters near faults, volcanic rocks, and karsts. For all other cases (UNISIM-IV-2022, UNISIM-IV-2024, and UNISIM-IV-2026), only the fractures clusters remain as unmapped uncertainty.

3.2.2 Upscaling of geologic model

Since geological and reference models have high resolution, resulting in large runtime to simulate (from 2 to 8 days), it is necessary to make an upscaling procedure to decrease computational efforts. Thus, in the coarser simulation models, the cells have dimensions of 200 x 200 x 5 meters, with 47 x 39 x 291 blocks in 'I', 'J', and 'K' directions, respectively, totalizing 533,403 blocks, from which 77,004 are active blocks. Porosity is upscaled by the arithmetic average weighted by NTG. Permeability is upscaled using a directional averaging technique based on the harmonic-arithmetic mean. NTG is upscaled using the arithmetic average. In the end, the porosity is multiplied by NTG. Therefore, NTG is not exported to the flow simulation model.

For UNISIM-IV-2022, two rock types (stromatolites and coquinas) are exported to the flow simulator in coarser models. For the other cases, since the karsts became mapped uncertainties, four rock types are exported: stromatolites, coquinas, karsts in stromatolites region, and karsts in coquinas region. As this data is uncertain, the relative-permeability curves for stromatolites and coquinas range from mixed-wet to strongly oil-wet.

3.3 Generation of well history data

To generate the history data, we run numerical simulation of the reference model until the end of the history period for each case, obtaining production, injection, and pressure data for each well. The reference case is simulated integrated with production systems (consideration of tables for pressure loss for producers). Then, white noise is added to emulate measurement errors. The period of history production varies for each UNISIM-IV case, as illustrated in Figure 3. There is first an Extended Well Test (EWT) for one year in all cases, with one producer and one gas recycling injector. In Figure 3, the blue part of the timeline refers to the history period, which should not be changed by the users of the benchmark, since this comprises "past" time. The red part refers to "future," and changes in the production strategy

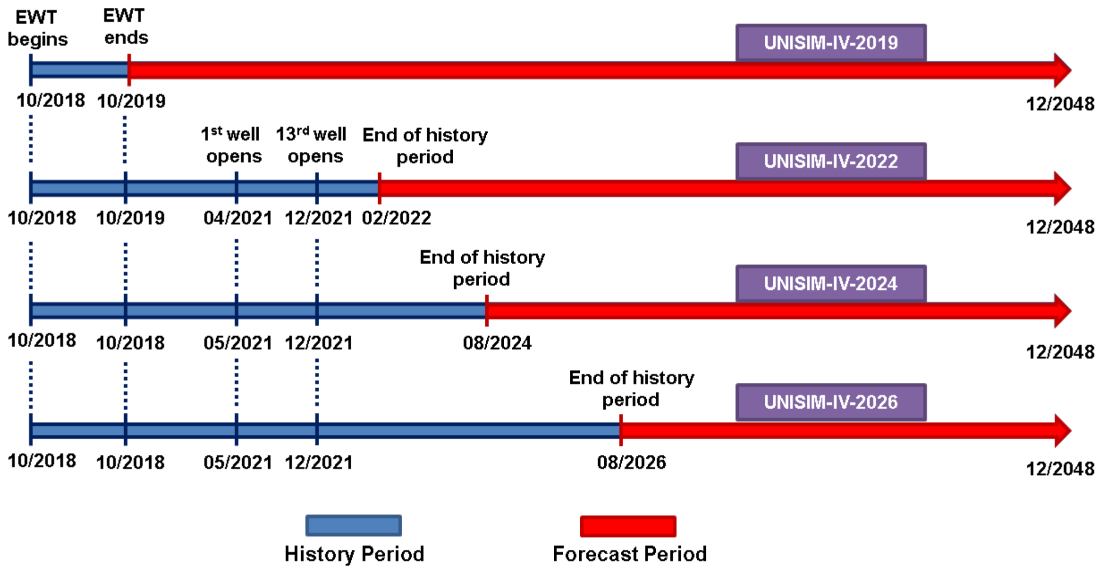

Figure 3. Timeline of the four cases of UNISIM-IV.

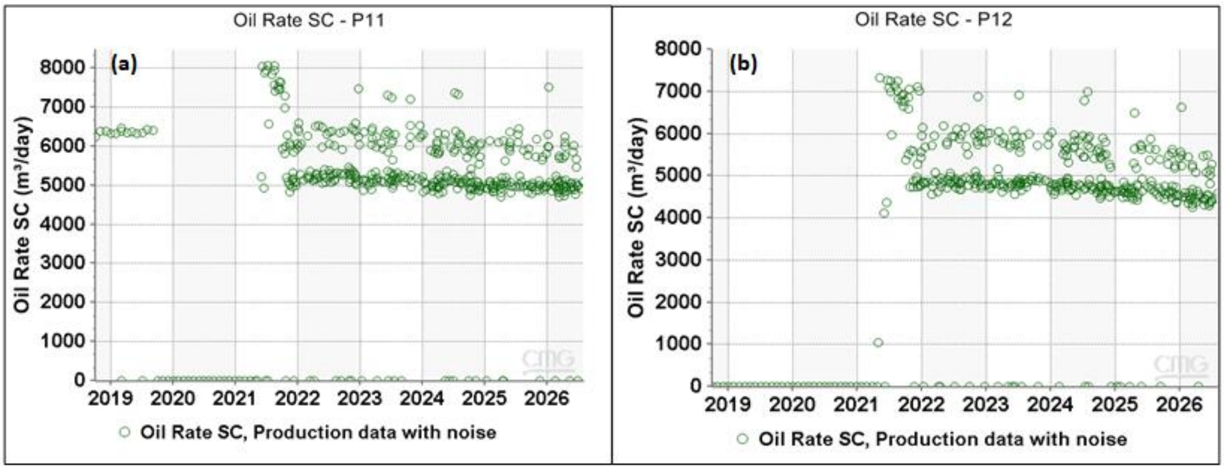

Figure 4. Oil production history with noise for wells (a) P11 and (b) P12 in UNISIM-IV-2026.

can be made (attention for cases that already have perforated wells, since their position cannot be altered). Figure 4 exemplifies the oil production data with noise of two wells in UNISIM-IV-2026, where one can also notice the well stops.

Moreover, the data is generated considering integration with production facilities. Reservoir-to-surface pressure drops are calculated in the steady-state multiphase flow simulator for the producers considering well total length (sea depth to riser length, distance between platform and x-tree to flowline length, and wellbore depth to production tubing length), using several parameters to obtain a hydraulic pressure-loss table. The pressure loss calculation between reservoir and surface is performed using the multiphase flow correlation from **Aziz et al. (1972)**. The table is generated using a commercial software, and some of the required data are: diameter of pipes, length and roughness of the pipes, water salinity, surface and reservoir temperature, fluid correlations **(Vazquez & Beggs, 1980; Standing, 1947)**, and fluids densities. Furthermore, the following independent variables are correlated in the table: ranges of watercut, liquid rate, gas-liquid ratio, and well-head pressure. Table 3 shows the parameters for pressure loss calculation.

Table 3. Parameters for pressure-loss tables generation.

Parameter	Value	Unit
Riser length	2100	meters
Production tubing internal diameter	6.625	inches
Flowline internal diameter	8	inches
Riser internal diameter	8	inches
Reservoir temperature	90	Celsius degrees
Temperature on well-head	40	Celsius degrees
Relative roughness	0.0006	-
Water salinity	240,000	ppm
Oil density	922.4	Kg/m³
Water density	1030	Kg/m³
Gas density	1.2768	Kg/m³

Table 4. Important dates in UNISIM-IV benchmark.

Date	Days	Nomenclature	Description
02/09/2018	0	t_0	Simulation Initial Time
02/10/2018	30	t_{EWT}	Beginning of EWT
02/10/2019	395	t_{2019}	End of EWT / End of UNISIM-IV-2019 history period
27/04/2021	968	-	Production of the development plan begins (not applicable to UNISIM-IV-2019)
26/12/2021	1211	-	13^{th} well of the development plan (first phase) opens (not applicable to UNISIM-IV-2019)
02/02/2022	1249	t_{2022}	End of UNISIM-IV-2022 history period
02/08/2024	2161	t_{2024}	End of UNISIM-IV-2024 history period
02/08/2026	2891	t_{2026}	End of UNISIM-IV-2026 history period
02/12/2048	11049	t_f	Simulation final time / maximum date of field abandonment

4. BENCHMARK CASES PROPOSAL

As previously mentioned, UNISIM-IV benchmark has four proposed cases. Although the geological model is the same for all, the differences are related to the stage of the field's life cycle. UNISIM-IV-2019 has three wells drilled, two consisting of the Extended Well Test (one producer and one gas recycling injector) and one more producer used for geostatistical modeling purposes (exploration well), hence this case can be used for development studies. UNISIM-IV-2022, UNISIM-IV-2024, and UNISIM-IV-2026 have the first phase of the production strategy already developed, consisting of six producers and seven WAG-CO_2 injectors (all vertical wells). The wells of the EWT are also used in the development plan. The focus of these three cases concerns the management/production stage of the field's life cycle. Moreover, there are additional slots in the production unit to connect four new wells (two producers and two injectors), which can be added later based on the decision risk analysis for the forecast period (second phase of well drilling campaign), and can also be used for the field's revitalization studies. Control variables (regarding the daily management of equipment installed in the field, after the development phase, i. e. well rates, WAG cycles or ICV control) can be changed in the forecast period based on optimization and management studies. The amount of available data is the main difference among these cases. A premise for all the cases is that the gas must be fully reinjected. Table 4 shows the important dates for the UNISIM-IV cases.

4.1 Decision variables, approaches, and scenarios

4.1.1 Decision variables

The decision variables considered in the decision analysis process regarding the

Table 5. Well data and operational conditions.

Type	Vertical Producer	Vertical Injector (gas)	Vertical Injector (water)	Unit
Maximum water rate	-	-	10,000	(m^3/day)
Maximum liquid rate	8,000	-	-	(m^3/day)
Maximum gas rate	-	4,000,000	-	(m^3/day)
	Min 50,000	Max 75,000	Max 75,000	BHP (kPa)

Table 6. Maximum available capacities for the production unit.

Type	Definitive Production system	
	m^3/d	bbd
Maximum oil rate (m^3/day)	28,617	180,000
Maximum liquid rate (m^3/day)	28,617	180,000
Maximum water production rate (m^3/day)	23,848	150,000
Maximum gas production rate (m^3/day)	12,000,000	-
Maximum water injection rate (m^3/day)	35,771	225,000

Table 7. Parameters of the base case simulation model for each benchmark case.

Benchmark Case	Aver. Perm. (mD)	Aver. Poros.	Av. Depth (m)	Initial Av. Press (kPa)	Number of wells with history	History period size (days)
UNISIM-IV-2019	200	0.08	5,543	63,000	2	395
UNISIM-IV-2022	192	0.10			13	1249
UNISIM-IV-2024	299	0.09			13	2161
UNISIM-IV-2026	228	0.10			13	2891

development strategy selection are: number, position, and opening sequence of wells (except for the wells already drilled and with production history, which varies for each UNISIM-IV case), well control variables (i. e. economic limit for well shutdown or well rates), ICV control, and WAG cycles control.

Since this field presents large thickness and good vertical communication, it is recommended the use of vertical wells. Table 5 presents the operational constraints of the wells for standalone simulation studies (without integration with production facilities), while Table 6 presents the platform constraints related to the forecast period. The constraints for wells are considered due to technical and operational reasons, and to avoid working below the saturation pressure (minimum BHP of producers) and fracturing (for maximum BHP of the injectors). Moreover, the rate constraints are related to topside issues.

4.1.2 Nominal approach

The nominal approach consists of the selection of a base case from a set of history-matched simulation models. Each UNISIM-IV case has its own ensemble of models and, hence, its own base case. For UNISIM-IV-2019, the base case was selected considering the model closest to 50% of cumulative probability (P50) for the volume of oil in place (VOIP). For UNISIM-IV-2022, UNISIM-IV-2024, and UNISIM-IV-2026, the base case was selected considering the P50 for several indicators: net present value (NPV), cumulative oil, water, and gas production (Np, Wp, and Gp, respectively), oil recovery factor (RF), injected water (Wi), and well economic indicator for producers (WEI – **Botechia et al, 2013)**. Table 7 shows several parameters of

Table 8. Deterministic economic scenario.

Variable/Parameter	Value	Unit
Revenues		
Oil price	314.5	USD/m³
Costs (OPEX)		
Oil production	35.73	USD/m³
Water production	3.58	
Water injection	3.58	
Gas production	0.0096	
Gas injection	0.0103	
Abandonment (% of investments - CAPEX)	20.0	%
Investments (CAPEX)		
Drilling and completion of vertical well	125.0	10^6 USD
Well to platform connection	100.0	
Interval Control Valve (ICV)	1	
Platform	2	10^9 USD
Fiscal Assumptions		
Corporate tax rate	34.0	%
Social tax rates charged over gross revenue	9.25	
Royalties rate	15.0	
Other Parameters		
Annual discount rate	9.0	%

Table 9. Reservoir uncertainties.

Attribute	Level [value] (probability)				
	0	**1**	**2**	**3**	**4**
GEO	100 geostatistical realizations (0.01)				
KR_est	KR0 [strongly oil-wet] (34%)	KR1 [oil-wet] (33%)	KR2 [mixed-wet] (33%)	-	-
KR_coq	KR0 [strongly oil-wet] (34%)	KR1 [oil-wet] (33%)	KR2 [mixed-wet] (33%)		
TRANSF	TRANSF0 [0.0] (20%)	TRANSF1 [0.003] (20%)	TRANSF2 [0.008] (20%)	TRASNF3 [0.100] (20%)	TRANSF4 [1.000] (20%)
PVT	PVT0 [0.06 cp] (50%)	PVT1 [0.035 cp] (25%)	PVT2 [0.085 cp] (25%)	-	-

Table 10. Operational uncertainties.

Attribute	Level [value] (probability)		
	0	**1**	**2**
SA - Platform	SA0 [1.00] (33%)	SA1 [0.98] (34%)	SA2 [0.96] (33%)
SA - Group	SA0 [1.00] (33%)	SA1 [0.98] (34%)	SA2 [0.96] (33%)
SA - Producers	SA0 [1.00] (33%)	SA1 [0.96] (34%)	SA2 [0.92] (33%)
SA - Injectors	SA0 [1.00] (33%)	SA1 [0.96] (34%)	SA2 [0.92] (33%)
WI	WI0 [1.00] (34%)	WI1 [1.40] (33%)	WI2 [0.70] (33%)

the benchmark base cases while Table 8 shows the deterministic economic scenario used for NPV calculation.

4.1.3 Probabilistic l approach

The probabilistic approach consists of a set of reservoir (Table 9) and operational (Table 10) uncertainties. A prior ensemble of uncertainties is provided, so modifications and new parametrizations can be made for data assimilation and history matching purposes, including the addition of new uncertainties or the removal of others. Though the previously mentioned base case is a history-matched model, the probabilistic

Table 11. Optimistic and pessimistic economic scenarios.

Variable/Parameter	Optimistic	Pessimistic	Unit
Revenues			
Oil price	440.3	188.7	USD/m³
Costs			
Oil production	46.4	28.6	USD/m³
Water production	4.65	2.86	
Water injection	4.65	2.86	
Gas production	0.0124	0.00768	
Gas injection	0.0134	0.00824	
Abandonment (% of investments - CAPEX)	20.0	20.0	%
Investments			
Drilling and completion of vertical well	156.0	100.0	10^6 USD
Connection (vertical well-platform)	125.0	80.0	
Interval Control Valve (ICV)	1.3	0.7	
Platform	2.25	1.6	10^9 USD
Fiscal Assumptions			
Corporate tax rate	34.0		%
Social tax rates charged over gross revenue	9.25		
Royalties rate	15.0		
Other Parameters			
Annual discount rate	9.0		%

approach does not provide ensembles of history-matched models. The benchmark users need to perform data assimilation processes to obtain an ensemble of history-matched models.

Reservoir uncertainties

- **GEO:** geostatistical realizations that include: variations in the distribution of horizontal and vertical permeability and porosity, rock types, and uncertainty in the transition from stromatolites to coquinas. In the case of UNISIM-IV-2022, UNISIM-IV-2024, and UNISIM-IV-2026, it also considers the karstic features (the karsts were considered unmapped uncertainty in UNISIM-IV-2019 and discovered after field development)
- **KR_est:** Relative permeability for the stromatolites region (curves)
- **KR_coq:** Relative permeability for the coquinas region (curves)
- **TRANSF:** Faults transmissibility (scalar)
- **PVT:** Gas viscosity (scalar)

Operational uncertainties

- **SA:** System availability for platform, groups of wells, producers, and injectors (multiplier)
- **WI:** Well productivity/injectivity (well index multiplier) (multiplier)

Economic scenarios

The economic uncertainties include oil price, operational costs, and investments. Table 11 presents the optimistic and pessimistic economic scenarios.

4.2 Expected results

We recommend publishing the methodologies developed and the results achieved using this benchmark with output data containing the assumptions made, the selected production strategy configuration, and indicators of the process, such as: methods, number of simulation runs, execution time, and evolution of the objective-function.

4.3 Benchmark Availability

The UNISIM-IV benchmark is available in UNISIM's website: https://www.unisim.cepetro.unicamp.br/benchmarks/en/

5. CONCLUSIONS

This work presented UNISIM-IV, a new benchmark with geological and operational characteristics of Brazilian pre-salt fields, consisting of a light-oil carbonate reservoir with high CO_2 content. This open source dataset can be of great relevance to the scientific community, as well as the industry, for the development of methods that deal with the aforementioned challenges.

The benchmark is divided into four different cases (UNISIM-IV-2019, UNISIM-IV-2022, UNISIM-IV-2024, and UNISIM-IV-2026). The differences between cases relate to the stage of the field's life cycle and, hence, the following aspects change from one case to another: period and duration of production history (amount of production data available) and some of the uncertainties considered. Therefore, users can choose the most appropriate case depending on their research objectives, which can comprise: data assimilation to uncertainty reduction, optimization processes and decision analysis under uncertainty for field development and management.

The data provided include: (1) a set of prior uncertainties for probabilistic studies (these uncertainties can be modified during data assimilation studies), (2) production, injection, and history data, and (3) a simulation model suggested as a base case or in nominal approaches.

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NOMENCLATURE

Bo	Oil formation volume factor
EOR	Enhanced oil recovery
EWT	Extended well test
GOR	Gas-oil ratio
Gp	Cumulative gas produced
ICV	Interval control valve
Np	Cumulative oil produced
NPV	Net present value
RF	Oil recovery factor
VOIP	Volume of oil in place
WAG	Water-alternate-gas
WEI	Well economic indicator
Wi	Cumulative water injected
Wp	Cumulative water produced

6. REFERENCES

Adlam, J. The norne field development overview. In: **Offshore Technology Conference**, Houston, USA. OTC-7925-MS, 1995. https://doi.org/10.4043/7925-MS

Avansi, G. D.; Schiozer, D. J. UNISIM-I: Synthetic model for reservoir development and management application. **International Journal of Modeling and Simulation for the Petroleum Industry**, v.9, p. 21-30. 2015.

Aziz, K.; Govier, G. W.; Fogarasi, M. Pressure drop in wells producing oil and gas. **Journal of Canadian Petroleum Technology**, vol. 11, p. 38-48, 1972. https://doi.org/10.2118/72-03-04

Botechia, V. E.; Gaspar, A. T.; Schiozer, D. J. Use of well indicators in the production strategy optimization process. SPE 164874-MS. In: **SPE Europec**, London, United Kingdom, 2013. https://doi.org/10.3997/2214-4609.20130541

Cazarin, C. L.; Bezerra, F. H.; Ennes-Silva, R. D.; Balsamo, F.; Auler, A. S. Using analogue hypogene karst systems to understand the Pre-Sal carbonate reservoirs offshore Brazil. Oral presentation given at the **AAPG/SEG International Conference and Exhibition**, Cancun, Mexico, 2016.

Chaves, J. M. P. Multiscale Approach to Construct a Carbonate Reservoir Model with Karstic Features and Brazilian Pre-Salt Trends Using Numerical Simulation. Master's thesis, University of Campinas, Campinas, Brazil, 2018.

Correia, M. G.; Hohendorff Filho, J. C. V.; Gaspar, A. T. F. S.; Schiozer, D. J. UNISIM-II-D: Benchmark case proposal based on a carbonate reservoir. SPE 177140-MS. In: **SPE Latin America and Caribbean Petroleum Engineering Conference**, Quito, Ecuador, 2015. https://doi.org/10.2118/177140-MS

Correia, M. G.; Botechia, V. E.; Pires, L. C. O.; Rios, V. S.; Santos, S. M. G.; Rios, V. S.; Hohendorff Filho, J. C. V.; Plata Chaves, J. M.; Schiozer, D. J. UNISIM-III: Benchmark case proposal based on a fractured karst reservoir, In: **ECMOR XVII**, On-line event, 2010. https://doi.org/10.3997/2214-4609.202035018

Christie, M. A.; Blunt, M. J. Tenth SPE comparative solution project: A Comparison of upscaling techniques. SPE-72469-PA. **SPE Reservoir Evaluation and Engineering**, v. 4 (04), p. 308-317, 2001. https://doi.org/10.2118/72469-PA

Gomes, J, C.; Geiger, S.; Arnold, D. The design of an open-source carbonate reservoir model. **Petroleum Geoscience**, v. 28, 2022. https://doi.org/10.1144/petgeo2021-067

Pasqualette, M. A.; Rempto, M. J.; Carneiro, J. N. E. Parametric study of the influence of GOR and CO_2 content on the simulation of a Pre-Salt field configuration. OTC-28093-MS. In: **Offshore Technology Conference Brasil**, Rio de Janeiro, Brazil, 2017. https://doi.org/10.4043/28093-MS

Peters, E.; Arts, R. J.; Brouwer, G. K.; Geel, C. R. Results of the Brugge benchmark study for flooding optimization and history matching. SPE-119094-MS. In: **SPE Reservoir Simulation Symposium**, USA, 2009. https://doi.org/10.2118/119094-MS

Petrobras, 2015. Teste de longa duração e sistemas de produção antecipada de Libra – Bacia de Santos – II. Caracterização da atividade. In Portuguese. Available in: http://licenciamento.ibama.gov.br/Petroleo/Producao/Producao%20-%20Bacia%20de%20Santos%20-%20TLD%20e%20SPAs%20de%20Libra%20-%20Petrobras/EIA/II_2_CaracAtividade/II_2-CaracAtividade.pdf (last accessed on: December 9, 2019)

Standing, M. B. A Pressure-Volume-Temperature Correlation for Mixtures of California Oil and Gases. **Drilling and Production Practice**, API, 1947.

Vazquez, M. E.; Beggs, H. D. Correlations for Fluid Physical Property Prediction. **Journal of Petroleum Technology**, v. 32(6), p. 968 – 70, 1980. https://doi.org/10.2118/6719-PA