

Ranking of Candidates for Underground Gas Storage Structures under Uncertainties Using Flow Simulation: West of Iran as a Case study

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Abstract

Underground gas storage is the primary means of managing fluctuations in supply and demand, and it is an essential component of an efficient and reliable interstate natural gas transmission and distribution network. Therefore, identifying gas storage capacity, injectivity, and containment is very important in every underground gas storage (UGS) project. Already, a giant scheme in Iran for identifying, ranking, and certifying UGS reservoirs has been carried out through the country. In this study, a methodology for a fast screening and risk ranking of candidate reservoirs, which in principle does not discard the green and slightly small reservoirs with few wells, is demonstrated. First, four structures out of more than twenty given structures were selected according to the client's comments. Then, the performance of these candidate structures as the main focus of this study was determined. For performance analysis, the flow simulation method that can be characterized by the uncertainty conditions influencing deliverability behavior was applied. Based on the available data, the main uncertainty parameters (static, dynamic, and economic) affecting capacity, injectivity, and containment were determined. Then, based on designing many wells as a producer and as injectors, the distribution probability of deliverability of structure under different uncertainty was identified. Finally, the performance and the risk of each candidate structure were analyzed and compared, and then they could be ranked and proposed for further detailed implementation.

Key words: Underground Gas Storage, Ranking, Flow Simulation, Uncertainty

Introduction

Geological storage acts as a buffer to balance out temporal differences between the production and consumption of gas. Slightly depleted or green gas fields that are the most important storage types were filled with hydrocarbons in the past and a certain number of these hydrocarbons have been produced (withdrawn). The advantages of these fields are well known trapped structures from the time of reservoir exploration and testing and later hydrocarbon production. Usually, when the gas fields are not entirely depleted, the remaining gas can be utilized as cushion gas, without any gas injection. The simplest way for the construction of underground gas storage is the conversion of a green gas field to a gas storage utility using early gas production then the gas injection. However, not all gas fields are suitable for conversion to underground storage.

The prerequisites and suitable properties of gas fields include a proven reservoir structure that can hold the

hydrocarbons, a depth that can be translated into a pressure range, connected porosities to provide the gas capacities, and sufficient permeability for good injection and production rates of the wells.

Each of the parameters must be checked out, and their performance based on uncertainty analysis due to a lack of data must be investigated.

For using a green gas field as underground storage, a certain technical criterion must be met. Preferably, proper reservoir thicknesses, as well as good petrophysical properties, are required. Moreover, the applicable and approved minimum and maximum injection and withdrawal pressures are needed to achieve proper withdrawal and injection rates. Therefore, an extensive reservoir characterization, reservoir modeling, and simulation need to be performed under uncertainties. To be able to evaluate the complete range of uncertainties, it is necessary to quantify different models (for static and dynamic) to be integrated into a consistent framework.

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Typically, model uncertainty is seen as multiple realizations of a geostatistical-based process using stochastic simulations. In most cases, there is uncertainty in all of the estimates used in screening and concept selection. As a result, operators are faced with the complex problem of developing a design that is robust to various revelations of the uncertain variables. Systematic uncertainty analysis can help operators solve this problem by describing and quantifying the sensitivity of project value to the design decisions and the uncertainties. An uncertainty analysis should be comprehensive and include all uncertain variables, and it should simultaneously account for reservoir and production behavior objectives.

Determining and selecting the optimal candidate UGS are complicated. A detailed protocol for the screening and selection of gas storage reservoirs was provided by Bennion and Thomas (2000). According to the protocol, several methods for selecting gas storage as criteria based algorithms were proposed and demonstrated. Also, the other work for predicting a partially depleted gas reservoir was carried out by Azin and et al. (2008) as UGS was simulated. There appears to be a gap in the research literature for selection and screening of both as flow simulation methods and multiple reservoirs to compare.

This paper investigates the feasibility of a techno-economical green gas field in the west of Iran that will be ranked based on the results of flow simulations. These green gas fields are initially known as structures that have been explored as traps of large volumes of natural gas. There is a lack of data for these structures; just one well and a few samples

and production tests accompanying well logging have been available. Therefore, characterizations of these structures have been done using reservoir simulation under spatial uncertainties for selecting the best candidate for gas storage site implementation. Finally, as a comparison, these structures have been analyzed and proposed based on economic aspects. Figure 1 shows the location of four green gas structures (A, B, C, and D) in the west of Iran. Each one has shown signs of gas existence during the production tests.

Materials And Methods

Structure Selection Methodology

In this paper, four green gas reservoirs that have a minimum potential for being underground gas storage will be studied. For this work, it is necessary to examine the main geological criteria (i.e. depth of reservoir rocks, the volume of pore space, permeability and thickness of reservoir rocks, the existence of an impermeable layer above the gas storage etc.) and economic criteria (i.e. distance from the main pipeline systems and gas consumers, gas price etc.). Reservoir flow simulation is the best quantitative method for studying and ranking these candidates. In addition, the result of the work is a 3D model of the distribution of properties of the reservoir. This model describes in detail the geological structures of the hydrocarbon-bearing horizon with its reservoir characteristics, which can also be determined by the maximum gas injection volume and injection rate.

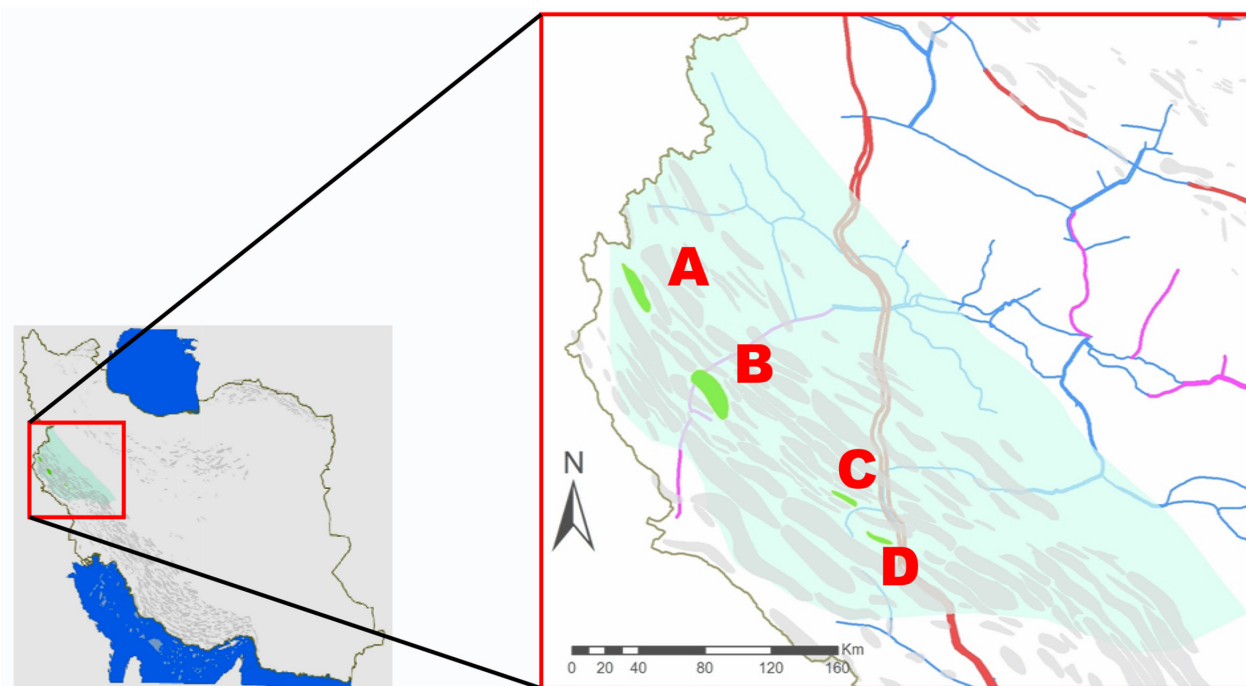


Fig. 1: Location of four understudy structures (green gas field) in the west of Iran.

The following steps were done for investigation of the techno-economical feasibility study in these four structures:

- Reservoir characterization based on the integration of all available data (geological, petrophysical, seismic, and reservoir engineering).
- Static modeling for constructing 3D distribution of rock properties, i.e. porosity.
- Dynamic modeling based on matching and verifying with production tests, i.e. DST.
- Building a gas cycling base case for each structure due to available constraint parameters.
- Uncertainty analysis based on the integration of static and dynamic data (technical data) and economic data as multiple realizations.
- Comparison based on an objective function (NPV) for three optimistic, most likely, and pessimistic scenarios and then selection of the best structure.

Results And Discussion

Application

These four gas structures are located in the west of Iran (Lurestan area). They have formed all asymmetric anticlines sticking from the northwest to the southeast.

The Ilam, Sarvak and Garau formations (fractured carbonate) of the “Bangestan” group covers the entire area of fields as

gas reservoirs practically. Unfortunately, all formations do not have a common gas-water contact due to being in a gas down to the section. For example, Figure 2 shows the sketch of one well due to completion, production test, and petrophysical logs.

Also, based on seismic and geological data, the underground contour (UGC) of each structure has been generated for each formation. In Figure 3, the top of the UGC map and a cross-section of fluid contact in each formation are shown. For all structures, the reservoir data, rock, fluid properties, and production data are the first steps to be examined. Most of the structures are dry gas reservoirs except one that is a gas condensate reservoir. For example, Figure 4 shows the results of relative permeability and phase diagram in a structure.

Also, using the geostatistics methods, the 3D distribution of each reservoir parameter has been generated stochastically. In Figure 5, the 3D distribution of porosity for one structure is shown.

Then, the initialization was made using the compositional simulation due to dual porosity. After that, a history match case was created depending on near-wellbore simulation using well test data. The fracture parameters were the most important tuning parameters in these cases. Finally, a base case for each of four structures as scenario prediction was conducted. Before that, the constraints of production and injection have been identified. Table 1 shows the constraints for the implementation of gas storage.

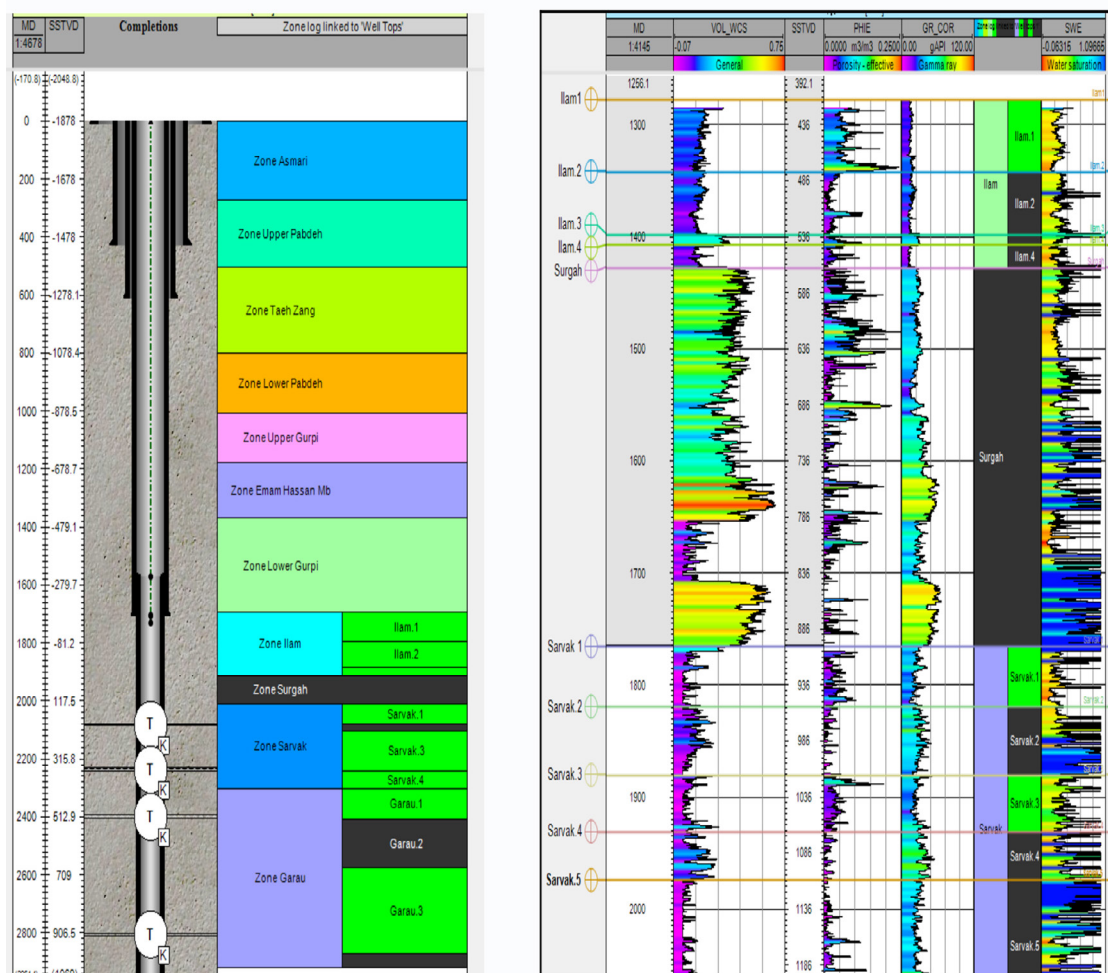


Fig 2 Example of well sketch and well logs for one structure under study.

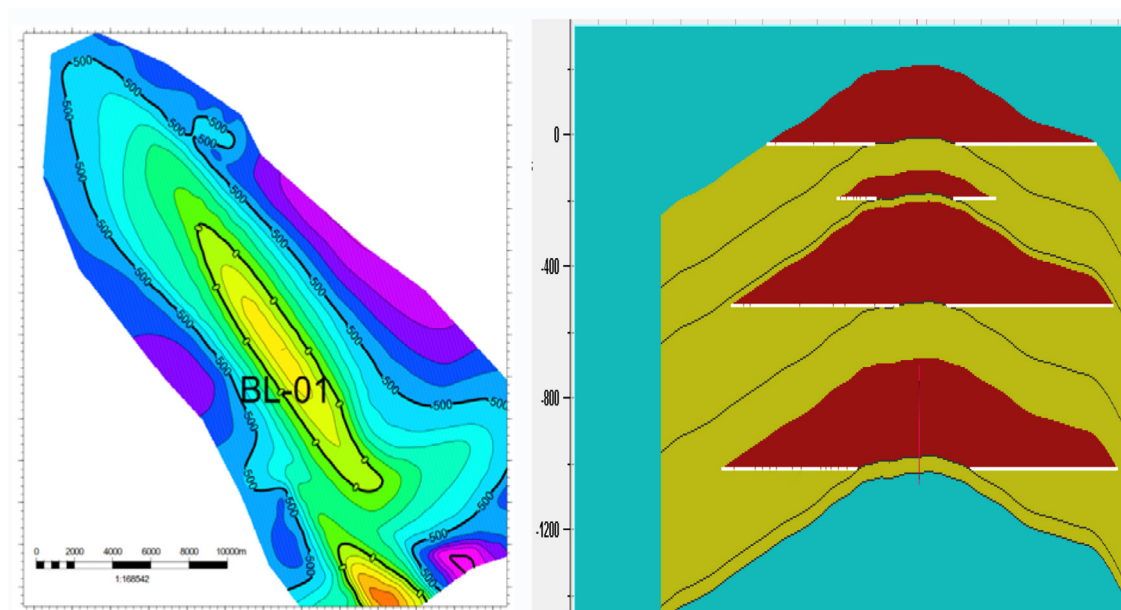


Fig 3 UGC map and cross-section of water gas contact for one structure under study.

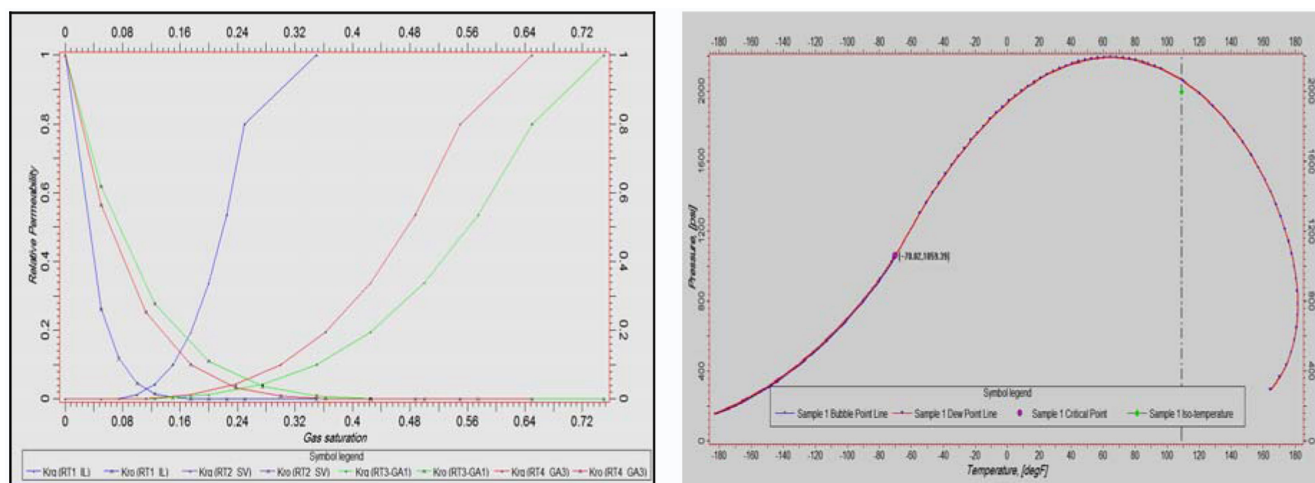


Fig 4 Relative permeability and fluid model for one structure under study.

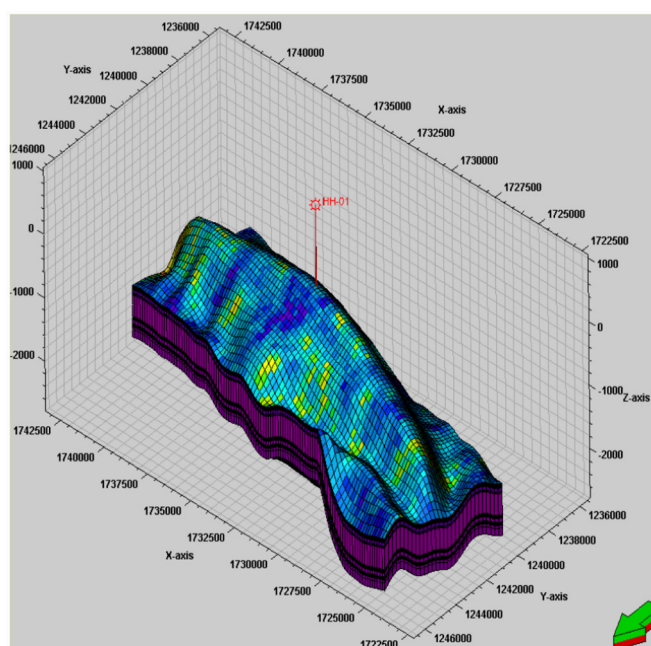


Fig 5 3D of porosity distribution for one structure under study.

Table 1 List of constraint parameters for the implementation of the base case scenario.

---	Constraint	Value
Well	Min BHP	90 Bar
	Max Water to Gas production	10 bbl per MMscf
	Min Gas production	1 MMscf per day
	Max well length	700 m
	Tubing size	7 in
	Min BHP with Compressor	35 Bar
	Max Gas injection	Equal to initial reservoir pressure
Field	Injection cycle	8 months
	Production cycle	4 Months

In these structures, horizontal well was selected as the best wells due to high their performance; therefore, the best configuration has been determined based on gas zone coverage, sweep area, and radius investigation of wells for new production and injection wells. Figure 6 shows the well placement of horizontal wells for one of these structures in the crest of the anticline.

For developing these structures, in the early phase, gas production is necessary as natural depletion due to a decrease in reservoir pressure for preparing the gas injection phase. The time of natural depletion can be obtained based on simulations; for example, in one of the structures, the suitable value of 10.8 MMscf/d was obtained for a decline of 3000 psi of reservoir pressure to 2575 psi. Then the second phase, the gas cycling, can be simulated in six-year periods, as shown in Figure 7 for one of these structures. The gas injection will commence at a rate of 4.7 MMscf/day and will continue for eight months.

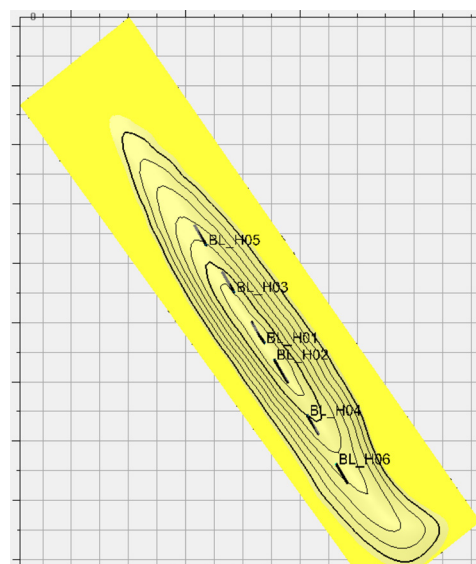
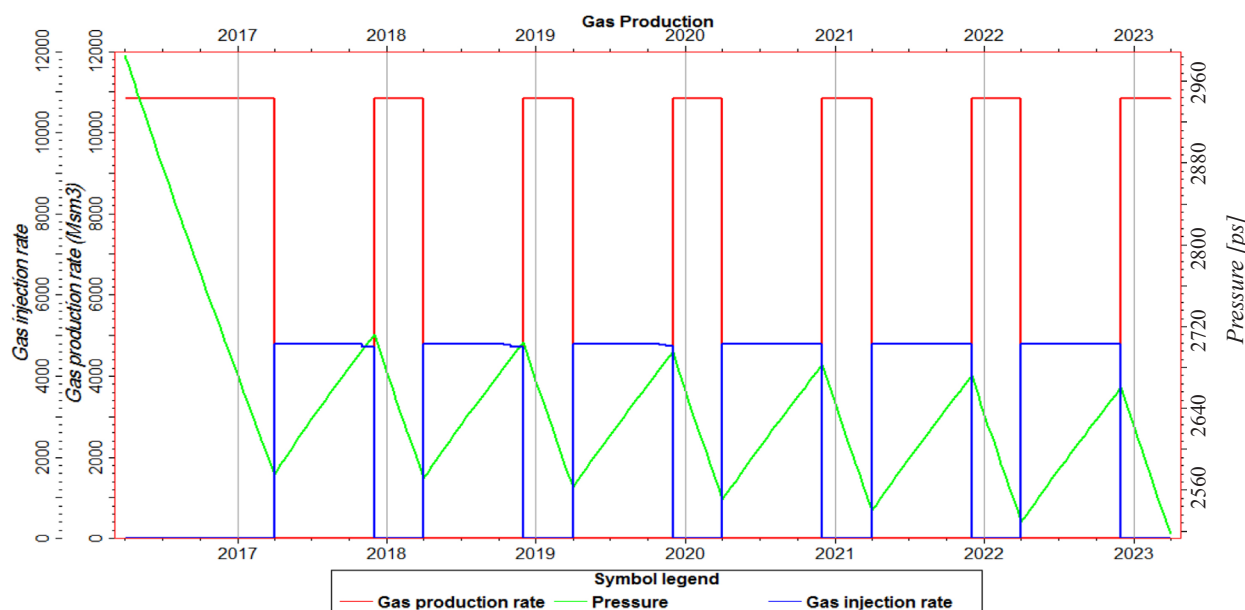
Figure 8 also shows the cumulative of gas production and injection in six-year periods. The working gas in this figure was estimated equal to 1.3 Bscm. Moreover, gas in place (GIP) of this structure was calculated to be 24.3 Bscm.

These steps were repeated for other structures; also, during the withdrawal phase of the simulation studies, no water production has been observed.

Due to the lack of data, the influence of each uncertainty parameter on the objective function (working gas) must be shown.

Thus, firstly, a sensitivity analysis was done for identification of most influence parameters; afterwards, uncertainty analysis has shown the variation of these uncertainty parameters on the objective function.

Table 2 shows a list of uncertainty parameters for both static and dynamic data. The range of each uncertainties parameter for each structure must be identified. Therefore, in Figure 9, the range of variation of each static and dynamic uncertainty parameter has been distinguished.

**Fig. 6** Well placement of horizontal wells for one structure under study.**Fig. 7** Gas injection and production accompanying pressure profile for one structure under study.

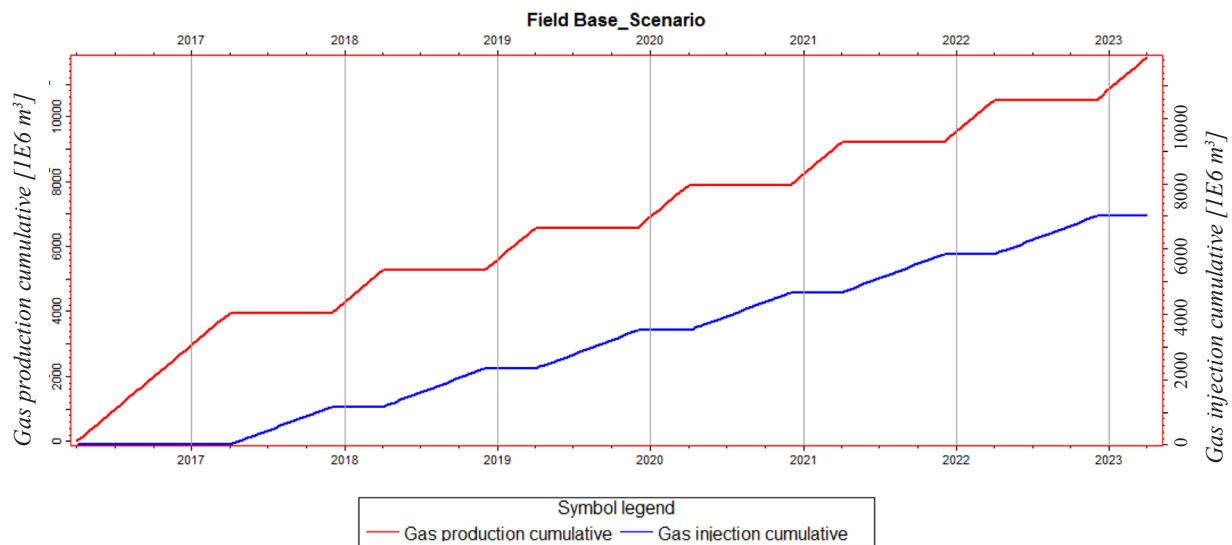


Fig 8 Cumulative gas production for one structure under study in six years.

Table 2 The list of static and dynamic uncertainty parameters.

Static parameters	Dynamic parameters
UGC map, \$Seed	Rock compressibility matrix, \$Comp_M
Matrix porosity, \$PORO_M	Rock compressibility fracture, \$Comp_F
Seed number, \$SeedPORO	Swir, \$Swir
Correlation length (Horizontal variogram), \$Var_Major, \$Var_Minor	Krw, \$Krw
Kh/Kv, \$RatioMKvKh, \$RatioF_KvKh	Krg, \$Krg
Fracture porosity, \$Mult_POROF	Shape of Pc, \$aw, \$ao
Fracture permeability, \$Mult_PermF	Corey water, \$CoreyW, \$CoeryOW
Sigma factor, \$Sigma	Corey gas, \$CoreyG, \$CoeryOG
GWC, \$GDT_G3	

	Type	Pr	Int	Name	Base value	Distribution	Arguments		
1	Uncertain			\$GDT_G3	-1028	Uniform	Min	-1040	Max -1016
2	Uncertain			\$Var_Major	3000	Uniform	Min	1000	Max 5000
3	Uncertain			\$Var_Minor	3000	Uniform	Min	1000	Max 5000
4	Uncertain			\$PORO_M	1	Uniform	Min	0.8	Max 1.2
5	Uncertain			\$Mult_PermF	1	Uniform	Min	0.2	Max 1.5
6	Uncertain			\$Mult_POROF	1	Uniform	Min	0.2	Max 1
7	Uncertain			\$Sigma	1	Uniform	Min	0.01	Max 1000
8	Uncertain			\$Comp_M	2.03E-06	Uniform	Min	1E-06	Max 8E-06
9	Uncertain			\$Comp_F	2.068E-05	Uniform	Min	1E-05	Max 8E-05
10	Uncertain			\$Corey_G	3	Uniform	Min	2	Max 4
11	Uncertain			\$Corey_OG	6	Uniform	Min	5	Max 7
12	Uncertain			\$Corey_OW	3	Uniform	Min	2	Max 4
13	Uncertain			\$Corey_W	4	Uniform	Min	3	Max 5
14	Uncertain			\$Krg	0.8	Uniform	Min	0.6	Max 0.9
15	Uncertain			\$Krw	0.8	Uniform	Min	0.6	Max 0.9
16	Uncertain			\$Sor	0.05	Uniform	Min	0	Max 0.1
17	Uncertain			\$Swir	0.75	Uniform	Min	0.7	Max 0.8
18	Uncertain			\$aw	1	Uniform	Min	0.5	Max 3
19	Uncertain			\$ao	5	Uniform	Min	1	Max 6
20	Uncertain			\$RatioF_KvKh	1	Uniform	Min	0.2	Max 1
21	Uncertain			\$RatioMKvKh	1	Uniform	Min	0.5	Max 1
22	Expression			\$GDT_G3_INIT	1			\$GDT_G3*3.28	
23	SEED variable			\$SeedPORO	65				

Fig 9 The list of static and dynamic uncertainty parameters accompanying their range.

Figure 10 shows the sensitivity analysis results as tornado charts, as shown, the fracture parameters (porosity, permeability), UGC map, matrix porosity, GWC, Kv/Kh of fracture and sigma factor are the most influencing parameters. Therefore, an uncertainty analysis was done based on these parameters.

Also, Figure 11 shows the results of uncertainty analysis, i.e. for one structure as the distribution of objective function (working gas) based on multiple simulations. According

to this figure, the variation of working gas is between 140 MMscm (pessimistic) to 1480 MMscm (optimistic).

Also, economic studies based on Table 3 were considered. Then, Net Present Value (NPV) was calculated according to Table 4 for each structure in three scenarios (i.e. pessimistic, most likely, and optimistic scenarios).

Finally, based on the integration of techno-economical studies, a ranking was done for four structures, as seen in Table 5. These structures were compared to their NPV.

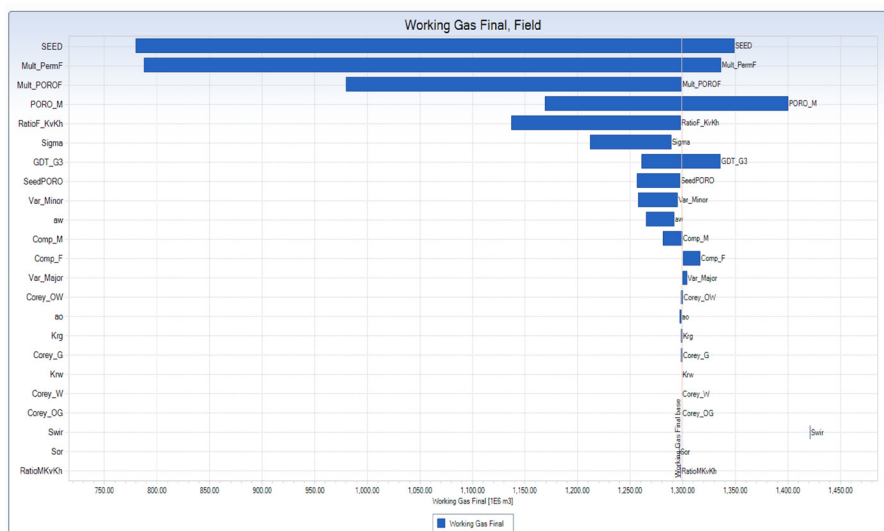


Fig 10 Tornado chart based on sensitivity analysis for one structure under study.

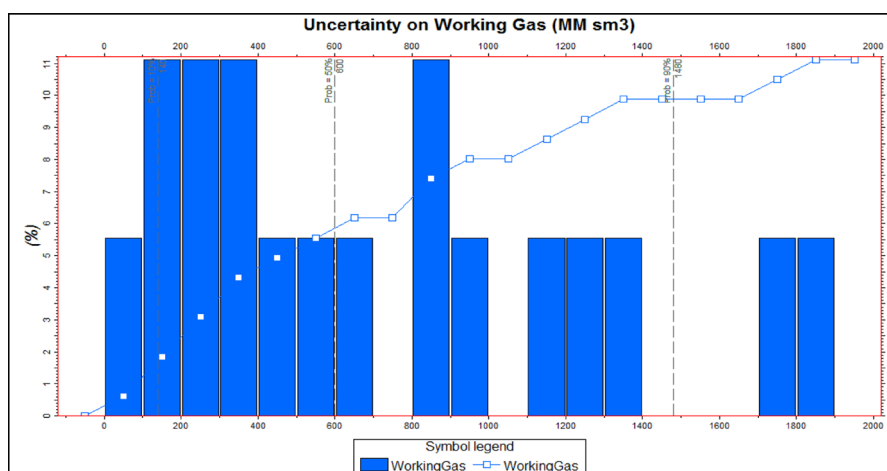


Fig 11 Distribution function for working gas-based uncertainty analysis for one structure under study.

Table 3 The list of economic parameters considered in the study.

Injection gas price dollar per Mscf	Production gas price dollar per Mscf	Surface facilities for 10MMscm /day (MM\$)		Pipeline per km (M\$)	Well drilling and completion (M\$)	Compressor station installation (MM\$)			
		With generator	Without generator			1300Mscm/d	500Mscm/d	300Mscm/d	100Mscm/d
8	10	56.3	50.6	625	33.9	24.8	16.9	13.5	9

Table 4 The calculated NPV for 4 structures in three cases of P10, P50, and P90.

NPV (MM\$)			Structure
Pessimistic (P10)	Most likely (P50)	Optimistic (P90)	
-222	600	1611	B
-288	85	825	D
-264	-99	299	C
-315	-269	-69	A

Discussion

After using the reservoir simulation for different structures (green gas field), the gas cycling of the base case scenarios was studied for six years. The final results are as follows:

- All the structures are fractured carbonate except structure A.
- The structures A and B are dry gas reservoirs, and others are gas condensate reservoirs.
- The result of the study shows that horizontal drilling of seven new producers for structure A, six new producers for structure B, seven new producers for structure C, and eight new producers for structure D are considerable.
- The initial gas in place (P50) for each of the structures, i.e. A, B, C, and D, are 13.1, 28.4, 14.8, and 33.4 Bscm, receptively.
- A dynamic reservoir simulation for a complete injection-withdrawal cycle has been completed.
- Development strategy was defined as one-year gas production and then gas injection-withdrawal periods for the next years.
- Based on uncertainty analysis, the working gas for structure A is between 10 and 152 MMscm, for structure B is between 140-1480 MMscm, for structure C is between 20 and 355 MMscm, and for structure D is between 27 and 612 MMscm.
- For all structures, there is a wide range of estimated working gas, which shows high-risk projects.
- Based on techno-economic studies, structure B was proposed as the best ideal candidate for gas storage implementation.
- For the best candidate, gas production was estimated between 0.24 and 5.2 MMscm/day through 8 months. In an optimistic case, this gas production can be supporting the consumption of one of the border states.
- In the best case of gas injection, it was estimated between 0.06 and 1.35 MMscm/day through four months.
- The total produced gas in the case of the best candidate is between 2 and 16 Bscm for the next 6 years.

Conclusions

- Uncertainty is the concern of an integrated asset team. Their integrated 3D model is the source of all their knowledge, but also the lack of it is the uncertainties.
- Geological modeling must be tightly integrated with dynamic flow simulations to allow a more reliable ranking of the multiple realizations of the reservoir. It is also an ideal way to investigate and optimize alternative field development

Table 5 The list of final rankings for 4 structures.

Gas production (Bscm), P50	CAPEX (MM\$)	C.v. of NPV (%)	NPV (MM\$), P50	Rank	Structure
6	252.6	32.7	600	1	B
2.7	307.1	7.6	85	2	D
1.26	257.8	-17.6	-99	3	C
0.542	300	-109.3	-269	4	A

strategies.

- In carbonate fractured uncertainty on fracture, parameters may be a major issue when evaluating working gas.
- Experimental design techniques should be employed as part of the standard workflow in the uncertainty analysis.
- For high subsurface risk projects (e.g. in UGS), uncertainty analysis and probabilistic estimation of reservoirs play key roles in making a sound development decision.
- The proposed workflow explicitly assesses the value of available data to reduce the prior uncertainty. Therefore, it will be a great use for planning the future well drilling to reduce appraisal uncertainty.
- For the proposed gas storage implementation, a careful and detail investigation should be considered, and all the necessary data should be gathered to decide a scenario for satisfaction.

Nomenclatures

BHP: Bottom Hole Pressure
 Bscm: 109 Standard Cubic Meter
 CAPEX: CAPillary EXpenditure
 CV: Coefficient of Variation
 DST: Drill Stem test
 GDT: Gas Down To
 GIP: Gas In Place
 GWC: Gas Water Contact
 Kh: Horizontal Permeability
 Krg: Gas Relative Permeability
 Krw: Water Relative Permeability
 Kv: Vertical Permeability
 MM\$: 106 Dollars
 MMscf/d: 106 Standard Cubic Feet per Day
 NPV: Net Present Value
 Swir: Connate Water Saturation
 UGC: UnderGround Contour
 UGS: Underground Gas Storage

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