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Fracture characterization, modeling and uncertainty analysis of a carbonate reservoir with integration of dynamic data (Middle East)

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Abstract. This field case study shows the benefits of fracture characterization and risk analysis. The uncertainty analysis was performed on production, plateau length and ultimate recovery factor. The field has been under production for more than 48 years, nevertheless it has produced less than 2% of the STOIIP. Historical data measurements on production rates (wopr, gor, wcut, etc) and pressures (static and flowing) have been used to constrain uncertain parameters during historical period and then propagate it into the prediction. Due to the low cumulative production, fracture characterization uncertainties have been incorporated (Discrete Fracture Network) together with reservoir uncertainties and geological uncertainties. Several surface/controllable parameters have been considered in the analysis evaluation on Plateau Length and Recovery Factor. The risk analysis accounts for two main recovery mechanisms: gas injection from the crest for Gas gravity drainage and periphery downdip water injection with natural imbibition. Several scenarios of DFN's and 43 uncertain reservoir parameters with their probability distribution were considered. Experimental Design and Response Surface Methodology was applied to minimize the number of Reservoir simulation runs of the study. Plackett and Burman Experimental Design was used for the Screening Phase. During the screening phase, it has been revealed that 7 uncertain parameters account for more than 80% of the total variation of Cumulative Oil Production. A detailed Latin Hypercube has been performed with 3 discrete fracture network, controllable uncertain parameters and the 7 most relevant parameters. This risk analysis identified the best cases of each phase of the development, P10 and P90, and the major uncertainties impacting the field development plan. Mitigation, acquisition, and monitoring plan have been defined accordingly to reduce the major impacting uncertainties.

Keywords: fracture, modelling, uncertainty analysis, carbonate reservoir

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Introduction

The decision-making process for field development plans is facing new challenges; managers are encouraged to take decisions under uncertainty rather than deterministic solutions. This practice has been fundamentally transformed in recent years, with many innovative workflows introduced into the literature. There is an increasing recognition of the need to preserve geologic realism during the historical period for more reliable forecasting, and an increasing acknowledgment of uncertainty, and the need to examine multiple history-matched models rather than a single best model for forecasting.

This study presents a practical approach to deal with the difficult problem of the risk analysis in the performance forecast applied to a Fractured Reservoir.

Methodology

Basically, the proposed methodology (Fig. 1) involves a three-step procedure using Experimental Design and Response Surface Methodology.

Fracture Reservoir Field Description

The considered Field (Fig. 2) is a fractured and faulted carbonate reservoir.

Oil accumulation is in three main zones. The producing intervals consist of layered chalky limestone with relatively high porosity (20%+) and poor matrix permeability (2-10 MD). These reservoir layers are interbedded with dense, more fractured layers. The overall structure of the field is a broad, NE-SW slightly elongated dome with gently dipping flanks. Production tests, core observations, and FMI/FMS image logs confirm high fracture permeability within open fractures oriented N30E across the crest of the structure. Interpretation of 3-D seismic shows numerous

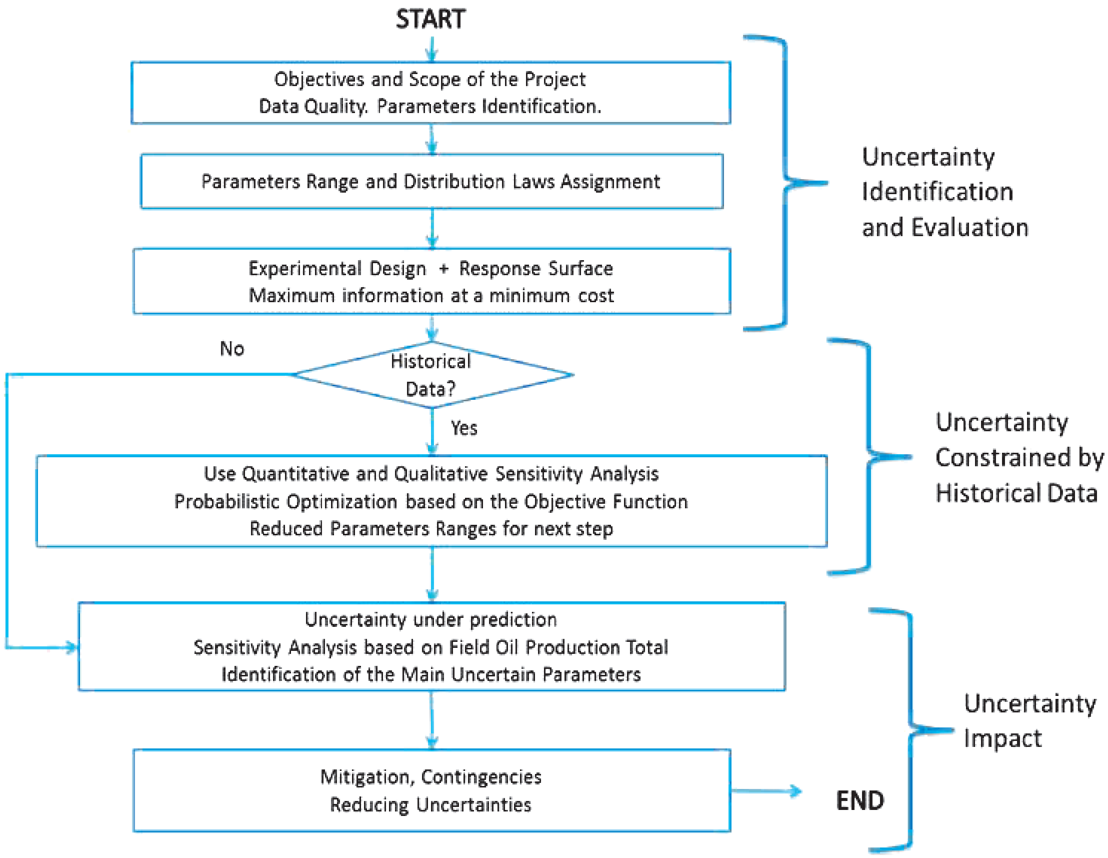

Figure 1. Methodology for Uncertainty Analysis

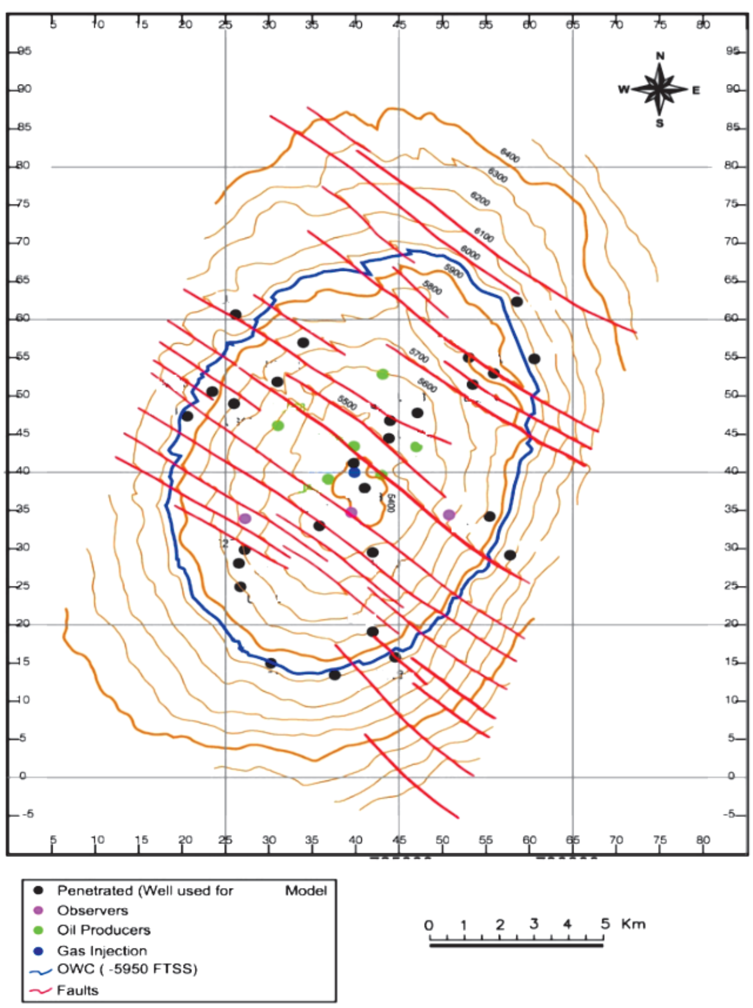

Figure 2. Fracture Reservoir Map

NW-SE striking normal faults with small throws cutting through the reservoirs. These faults are oriented perpendicular to the dominant trend of the open fracture system and are older than the latter NE fault system. The second set of fractures is sub-parallel to the fault trends, it is thought that these fractures are mineralized, they have little effect on fluid flow since they are crosscut by the younger open fractures. Oil viscosity is about 0.7 cp, with an initial GOR of 400 scf/STB. Oil is strongly undersaturated: the bubble point pressure is 1200 psi and the initial pressure of the reservoir was 2925 psi. Oil production started in August 1962 from one well at an average rate of 4468 stbpd of dry under-saturated oil. Available reservoir performance history and pressure data suggested limited water drive and lack of reservoir energy leading to an estimated very low primary recovery. It has been concluded that the best recovery mechanism is gas injection.

Considered Uncertainties

Forty-three Uncertain Parameters were identified for the following reservoir elements:

- Reservoir Connectivity;
- Fracture and Matrix Properties;
- Rock-Fluids Properties (GOR, Bo, Viscosity …);
- Controllable Parameters.

Some of the above parameters were applied at the field scale level and some of them applied to layer by layer basis. While the faults system was classified as three sub-set of faults, each set of fault has its own fault transmissibility.

First Experimental Design: Screening Phase – Plackett and Burman

Plackett and Burman experimental design is proposed with 44 simulations to evaluate the main effect of each uncertain parameter.

The analysis was focused on Cumulative Oil Production at the end of the Prediction for selecting the most influential variables for Risk Analysis.

Pareto Plot (Fig. 3), based on Global Sensitivity Analysis theory, shows the impact of each uncertain parameter in a percentage contribution of the total variation of Cumulative Oil Production at 01/01/2051. Out of the 43 parameters, there are 7 uncertain parameters contributing to 83% of the total variation of Cumulative Oil Production.

Second Experimental Design: Uncertainty Analysis Phase – Latin Hypercube

A Fracture Network Uncertain Parameter has been added at this stage. Each Discrete Fracture Network is an output (with a set of Properties, Fracture Porosity, Fracture Permeability, Block Height Size and Sigma Value) of an assumed continuous parameter named DFN-Case. This parameter represents the fracture extension and connectivity of the system.

On top of these sub-surface uncertain parameters, surface/controllable uncertain parameters have been considered for the Risk Analysis Evaluation.

Uncertainty on Gas Supply has been considered through a Multiplier of Gas Injection.

Wellhead pressure is an encouraging parameter to be considered, it may help recognize upside potential from minor adjustments on pressure.

Finally, restriction on high Gas Production has been considered through a GOR limitation parameter. This final uncertain parameter mainly works by being more restrictive in terms of GOR production.

Uncertain Parameters Constrained by Historical Data

In order to perform an uncertainty Analysis on brownfields, it is required to assign a threshold for acceptable solutions. It means that all combinations of uncertain parameters providing a global objective function higher than the threshold will be discarded. This methodology is usually called Uncertainty Analysis Constrained by Historical Data.

Probabilistic Distributions Analysis

The impact of all uncertain parameters; constrained and unconstrained by historical data plus surface uncertainties, will be assessed on Cumulative Oil Production at the end of prediction (01/01/2051) as well as Plateau Length. Response surfaces for these targets outputs have been built. Non-Parametric Response Surface has been used for these particular responses in order to have the best possible quality of the response surface, in terms of accuracy as well as Predictivity.

The highest impact on Cumulative Oil Production Variation is due to the DFN-Type. The Diffuse Case Scenario provides an intermediate value of Cumulative Oil Production, N30/130 SSF Case Scenario provides the highest value and finally, the minimum case Scenario provides the lowest value. DFN-type represents more than 45% of the total variation of Plateau Length.

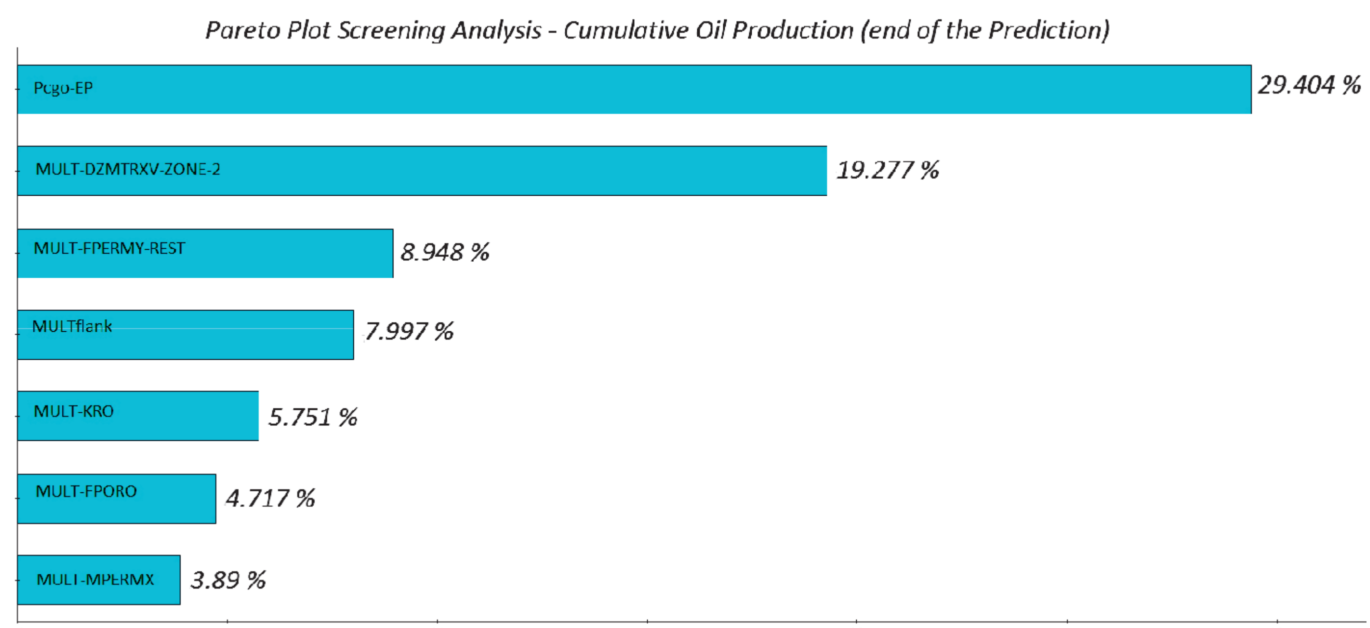

Figure 3. Pareto Plot – Screening Phase

Mitigation and Contingency Plan

When considering uncertainty reduction for some of the uncertain parameters, it has to be clearly defined the objective (Plateau Length, Cumulative Oil Production, etc.) and the quantification of the reduction in terms of the variation of the response. Parameters being considered for uncertainty reduction are in order of importance as follow:

- DFN Case Type;
- Communication through the dense;
- Communication through the flanks.

Knowledge improvement on those three uncertain parameters will lead to big reductions on the envelope P10-P90 for Plateau Length as well as for Cumulative Oil Production.

For three considered DFN Cases, the main risk on Plateau Length and on Cumulative Oil Production can be mitigated to a large extent with the management of Well Head Pressure.

Providing Flexibility on Well Head Pressure Management depending on the DFN Case Scenario is a key action to be considered for the FDP1 to respect production commitments (Fig. 4).

Summary and Conclusions

Some of the key conclusions and lessons learned from our experience are as follow:

- It is demonstrated how to mitigate risk of low production and plateau length by controlling key variables (e.g. THP);
- Controllable parameters must be included in any uncertainty analysis to gain flexibility and control in the results;

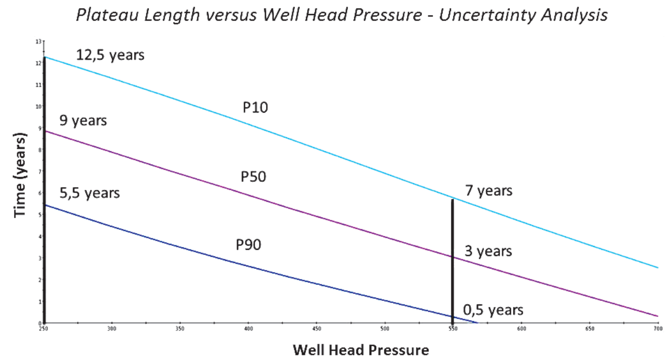

Figure 4. Probabilistic Plateau Length versus Well Head Pressure – Contingency Plan

- This risk analysis demonstrates how to identify the key uncertain parameters playing a role in the selected production targets (production and plateau length);
- Historical Data helps to constrain probabilistic distributions of the most influential parameters;
- Analysis of the most influential uncertain parameters impacting the history matching quality leads to better understanding of the model;
- Output probabilistic distributions help to place the base case in the uncertain domain as well as to define low and high cases for further economic analysis.

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