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A Probability Approach to Development of a Large Carbonate Reservoir with Natural Fractures and Stratiform Super-Permeabilities

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Abstract

This paper describes a development strategy with peripheral water flood for Haradh Arab-D reservoir, a large oil bearing carbonate part of the greater Ghawar field. In a heterogeneous matrix permeability background, geological discontinuities such as faults, fractures, and stratiform high permeability streaks lead to a decisional divergence between development options. In this regard, optimizing the field development plan aims to find a proper balance among several conflicting requirements.

The paper focuses on the sensitivity analysis and risk assessment running concurrently with reservoir simulation to develop a Pareto chart for different reservoir parameters such as Fracture density and connectivity, Super-permeability layers, Skin damage, Aquifer size, and Kv/Kh ratio. The most sensitive parameters with respect to oil recovery are identified for re-assessment and further improvement and optimization of the development plan. Data acquisition program, reservoir performance evaluation and production injection strategies are conducted with these sensitivities in mind. They are executed with the highest priorities given to the most sensitive parameters.

In order to ensure that the target objective is achievable, wells drilled during the initial development phase are tested to validate the development strategy. Monte Carlo simulations again are run on periodic basis with actual field data input to further optimize the development.

Introduction: Geological and Simulation Setting

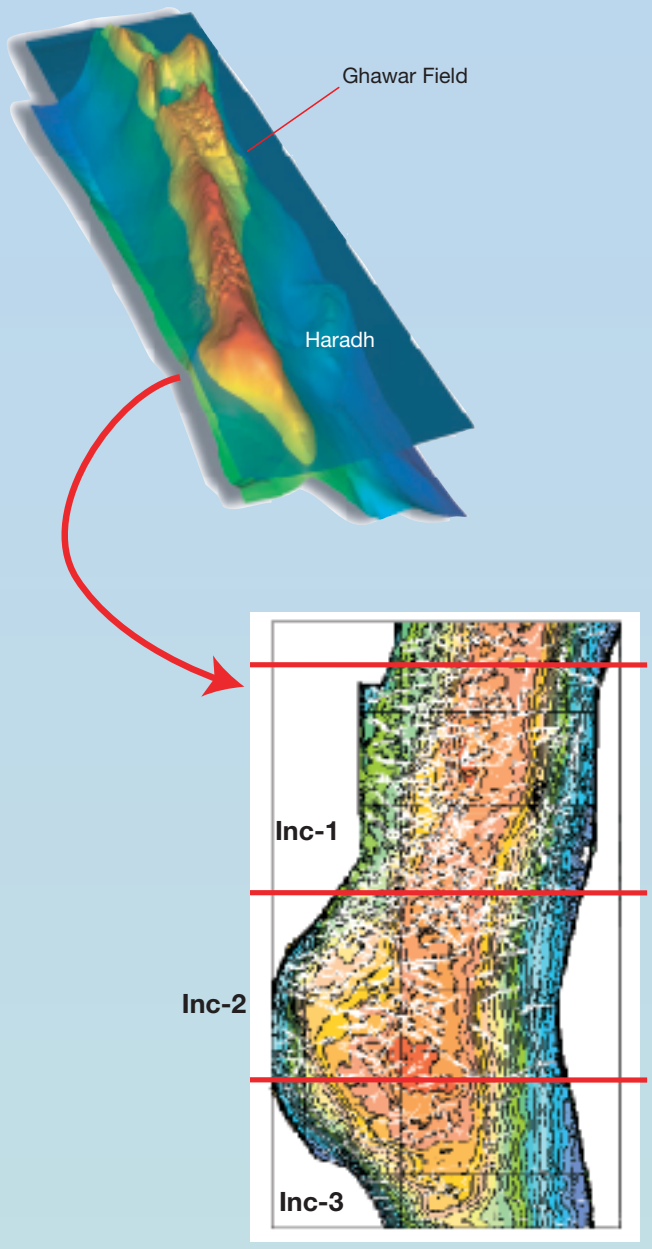

Figure 1: Map of Haradh

Haradh, part of the greater Ghawar field, is divided into three increments (fig.: 1). Increment-1 was recently put on production, Increment-2 is being developed and is the subject of discussion in this paper, and Increment-3 is yet to be developed.

Geologically, the Arab-D carbonate reservoir is divided into several Zones (fig.: 2): Zone-1, at the top, is non-porous and has very low permeability. Zone-2A, immediately below Zone-1, is mostly skeletal oolitic limestone with scattered vugs and local super-permeability zones. Below Zone-2A is Zone-2B which commonly includes dolomite and Cladocoropsis based super-K phenomenon. Below Zone-2B are Zone-3A and 3B which have much poorer reservoir quality and permeabilities. Major and minor faults identified from 3-D seismic data and fracture swarms have been observed at various degrees throughout the reservoir (fig.: 3).
To accurately simulate this complex reservoir, the simulation models have been built following a specific methodology recently developed by IFP and Saudi Aramco[4]. The main characteristic of those models is the use of a dual media approach where the fracture corridors and the super-K bodies are represented together in the fracture medium.

To perform as many simulation runs as possible, the increment (approximately 30 Km. in the East-West direction and 20 Km in the North-South direction) is divided into 4 segments, each represented by a dual Φ/K model (fig.: 4).

Each sector has a grid size of 250x250 meters with a total number of cells in the order of 50000.

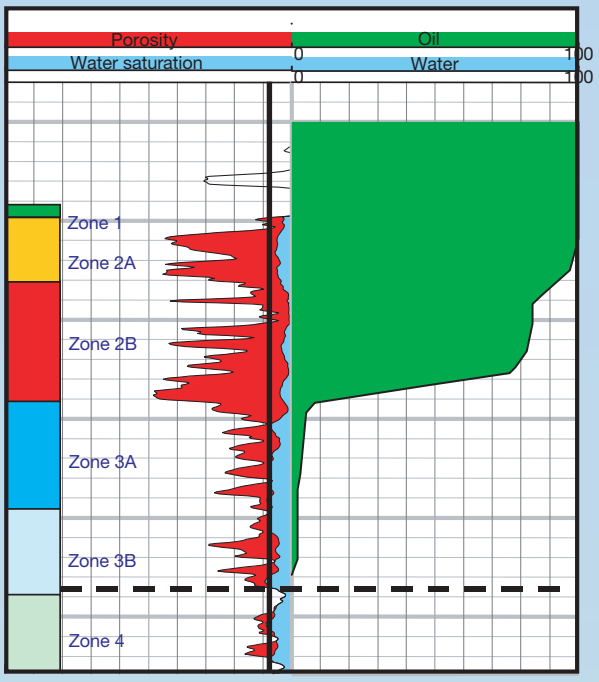

Figure 2: Arab-D Zonation

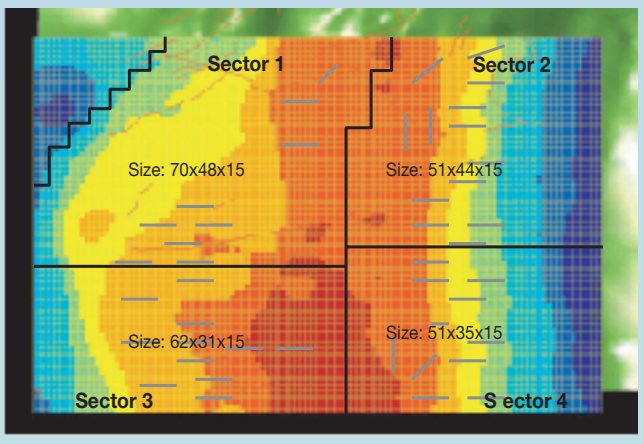

Figure 4: Simulation grids of the 4 sector models

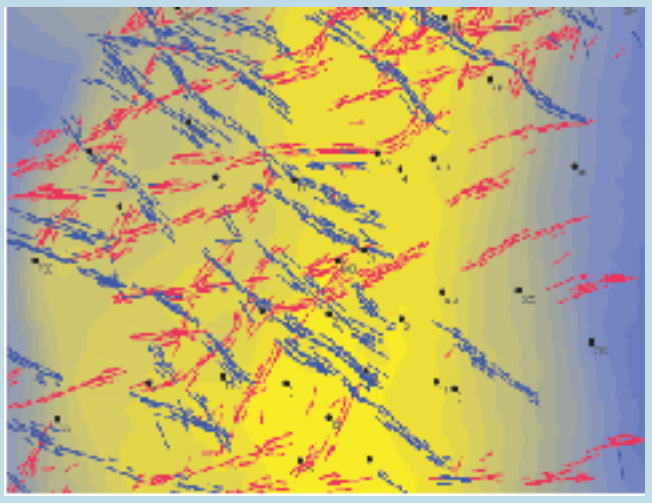

Figure 3 - Fracture Map of Haradh Inc. 2

Optimization of the Development Plan through Sensitivity Study and Risk Analysis

The Workflow Approach of Sensitivity Study

The essential ideas of the sensitivity study are to identify the key reservoir parameters that are likely to affect the recovery and the production plateau. Once the most sensitive parameters are identified, they become the business decision drivers that affect the field development plan.
In order to effectively run the sector models with numerous possibilities of the reservoir parameters uncertainties, experimental design methodology is used. The experimental design methodology is an efficient statistical technique, which provides the maximum information at the lowest simulation cost by varying all the uncertain parameters simultaneously. In this study, the experimental design approach has been applied using the tools recently developed by IFP.

The Sensitivity Parameters Studied

From previous studies as well as preliminary simulation results, it was suspected that the fracture swarms and the super-K bodies were the most influential features regarding the dynamic behavior of the field. Hence, fracture conductivities of the 2 separate fracture sets, fracture connectivity (fig.: 5) and super-K permeability have been considered as first order parameters in the sensitivity studies we performed. In addition to those, 4 other influential parameters have been studied: residual oil saturation, aquifer volume, skin and vertical/horizontal permeability ratio.

The sensitivity study has been performed in 2 steps. First, the influence of the 8 parameters together is quantified. In the second step, so-called the risk analysis, 5 parameters are more precisely studied and the oil production (or the plateau duration) is modeled as a function of these parameters in order to provide a probability distribution of the response.

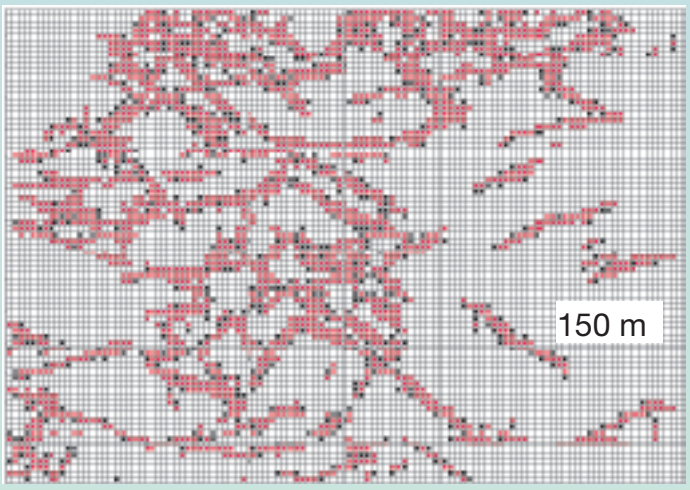

Figure 5: Fracture Length Threshold (150m): Impact on Fracture Cells