Petroleum Res. J. Vol. 18 (2005); P. 137–148, 10 Figs.

Evaluation and Ranking of Scenarios for Redeveloping Mature Fields: A Need for Improved Methodologies

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تقييم وتصنيف سيناريوهات لإعادة تطوير الحقول المعمرة: الحاجة إلى تحسين المنهجيات

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تتعلق هذه الورقة بمنهجيات ووسائل جديدة تبدو ضرورية لتحسين إنتاجية الحقول المعمرة، وذلك بتصميم طرق كفاءة لإعادة هندسة تلك الحقول، ومن ثم يمكن زيادة إنتاجيتها والوصول إلى الحد الأقصى لتلك الإنتاجية.

لقد تم تأسيس تلك المنهجيات على تقنية COUGR التي تم تطويرها بمعهد النفط الفرنسي، للتعامل مع الغموض المصاحب لوضع استراتيجية لتطوير الحقل. كما توفر هذه التقنية زيادة التعرف على المكمن بأقل تكلفة وتقترح طرقا للكشف عن نقاط الغموض متعددة المصادر، ومن ثم وضع استراتيجية متطورة لبلوغ الحد الأقصى اقتصاديا في بيئة محفوفة بالمخاطر.

وتقدم هذه المنهجيات، جنبا مع جنب المعرفة المعمقة لهندسة عمليات الاسترداد الإضافي ومنهجيات معالجة البئر، طريقة كفؤة لتحسين الاسترداد الإضافي لمكامن النفط والغاز في الحقول المعمرة.

Abstract: *This paper deals with new methodologies and tools which appear necessary to improve the evaluation of the potentials of mature fields. By designing efficient ways for reengineering, it becomes possible to increase their recovery factor and thus maximize their value.*

Those methodologies are based on the COUGAR™ technology developed at the IFP for dealing with uncertainties associated with field development strategy. This technology allows enhancing the knowledge of a given reservoir at the lowest cost, propose ways to minimize the uncertainties of various origins, and thus improve the sweeping strategy in order to maximize the economics in a risk-prone environment. Principles and applications of this technology to actual field cases are presented in this paper.

These methodologies, along with a deep understanding of the design of recovery processes and well treatment strategies, offer new and efficient ways of improving the oil and gas recoveries from mature fields.

INTRODUCTION

According to the reference scenario retained by the WETO European Commission (World Energy, Technology and Climate Policy, Outlook 2030), the world demand for energy should reach 17 Gtep in 2030 and possibly 30 Gtep in 2050 whereas today it is only equal to 10 Gtep. In 2030, approximately two-thirds of the energy demand will be provided by the hydrocarbons. Still in 2050 and beyond, hydrocarbons will constitute the main and easiest access to energy for humanity.

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To sustain this rapid growth in demand (approximately 1.8% per year), the hydrocarbon reserves renewal through exploration alone will not be sufficient. Another key source has to be "the improvement in recovery factor" from mature fields.

In a recent paper[1], the concept of Integrated Reservoir Management (IRM) as a key issue to enhance the production of existing reservoirs was addressed. IRM consists not only of EOR techniques such as chemical or gas flooding as was the case in the seventies and early eighties. It includes, as well, strategies of field redevelopment using field surveillance and monitoring to locate by-passed oil zones, complex well architectures to target those zones, well productivity and injectivity enhancement.

Combination of all those methodologies and techniques allows to optimize the development of the fields, lower the cost of that development, extend the life of the existing fields, and, hence, increase the recovery factor and the value of those fields.

Discriminating among the different possible scenarios, performing sensitivity analysis by accounting for various technical and economic constraints is, as quoted in reference 2 (Zekri and Jerbi, 2002), "the ultimate goal of reservoir engineering management".

To reach that goal, compare and rank different development strategies, the reservoir engineer has to be provided with specific methodologies and tools.

This paper is addressing those issues in two sections.

- The first section will present the COUGAR™ methodology, fully detailed in reference 3 (Zabalza-Mezghani and *et al.*) which allows quantifying uncertainties and provides a way to optimize the economics in a risk prone environment. A field application is presented.
- In the second section of this paper, the question of ranking between several development strategies is addressed. A field application is presented.

THE COUGAR METHODOLOGY

The Problematic

Information acquired while evaluating and exploiting hydrocarbon reservoirs has increased and improved during the last decade. Thanks to high technology data acquisition programs, it is nowadays possible to calibrate complex numerical models that integrate all this information for generating detailed geological and fluid flow modeling and optimizing these models for maximizing oil recovery and economics. Unfortunately, all these data are generally associated with significant errors and uncertainties. The main consequence is that the output of the modeling workflow, such as the production profiles, final oil recovery and economic evaluation, will be uncertain as well.

Uncertainties may be present at any stage of a reservoir modeling workflow. They include:

- ***The Static Modeling***: based on the main structural and sedimentary geological features. A lot of data are generally combined to build this static model, starting from surface geology, outcrops, regional studies, core and fluid properties, to well log analysis and seismic acquisition. This means acquiring and combining data from very different scales.
- ***The Scale-up***: To limit the computation time, up-scaling consists in converting a static model fine grid to a coarser one. This can cause very significant uncertainties, especially for highly heterogeneous media.
- ***The Fluid Flow Modeling***: uncertainties concern physical parameters, such as up-scaled Kr-Pc curves, well architecture and productivity, as well as other uncertainties such as the PVT modeling itself or the numerical solver chosen for the simulations.
- ***The Integration of Production data***: which can be efficiently used to better inform the reservoir model, though presenting uncertainties due to acquisition errors or surface reallocation problems. On top of that the history matching process itself presents uncertainties because of the non uniqueness of the solution, or the mathematically ill-posed problem to be solved.
- ***The Production Scheme Development and the Economic Evaluation***: The maximization of the net present value requires making choices regarding the field production scheme based on technical and economic criteria. This may include a decision on the number of production wells, their location and architecture, injection schemes, as well as surface facilities.

The Experimental Design Methodology

Due to the variety of uncertainties occurring all along the modeling workflow, an exhaustive sensitivity analysis is excluded as it would require a too large number of numerical simulations. Moreover, if the sensitivity analysis is conducted without any support it will be hardly possible to evaluate the coupling effects of various parameters as each parameter will be varied successively. The COUGAR methodology was developed at IFP to perform a comprehensive sensitivity analysis at the lowest cost, both in terms of CPU simulation time and result interpretation.

It consists in using an experimental design technique[4,5] to compute an approximation - or a "proxy" model - of each output of the modeling workflow. The experimental design technique enables one to select, for a given cost, the minimum set of numerical simulations required to accurately calibrate these "proxy" models.

Any output of the modeling workflow (including for instance volumes of fluid in place, production profiles, additional recovery factor or field net present value) can hence be linked to the influential uncertainties through a specific "proxy" model. These models running quasi instantaneously can then be used for further analytical purposes, such as the computation of probabilistic reserves or the optimization of a redevelopment scheme scenario.

Engineers specify any output of the modeling workflow, called response (cumulative oil production, net present value, ...) and some input uncertain parameters X_1, X_2, ..., X_n called factors, that may influence the response (petrophysics, field structural map, well locations, redevelopment scenarios, ...). The COUGAR™ methodology provides tools for identifying the factors that are influential on the response, and for building a proxy model linking the response to the influential factors, such as illustrated below:

$$\begin{aligned}\text{Response} = {} & a_0 + a_1X_1 + a_2X_2 + \dots + a_nX_n \\ & + a_{12}X_1X_2 + \dots + a_{n-1,n}X_{n-1}X_n \\ & + a_{11}X_1^2 + a_{22}X_2^2 + \dots + a_{nn}X_n^2\end{aligned} \qquad (1)$$

where a_0, a_1, ..., a_{nn} are constant coefficients obtained by fitting a set of numerical simulations.

The main advantage of this proxy model is its negligible cost to estimate new values of the response compared to full reservoir simulations. This regression model can then be used to make safe predictions of the process over the uncertain domain, to generate probabilistic distribution of the response using Monte-Carlo sampling technique and to optimize controllable factors (such as development scenario parameters on well location, well horizontal length and orientation,...) to maximize the response.

The standard method described above applies for deterministic uncertainties which are assumed to vary continuously between a minimum and a maximum value. Porosity and permeability mean facies values, PVT data and well locations, are examples of such parameters. The method has to be extended to tackle the following uncertainties:

- *"Discrete" Uncertainties* which correspond to a parameter that can take only a finite number of discrete values, such as the depositional scenario, the boolean behaviour of a fault which is conductive or not, or the optimal number of new production infill wells to be implemented. To take these parameters into account, the COUGAR methodology proposes to combine specific discrete experimental designs[6] with decision tree capability.
- *"Stochastic" Uncertainties* which do not present a smooth behavior on production responses (for instance a small increment of the parameter value may lead to drastically different results in terms of production profiles) or uncertainty that can take an infinity of equi-probable discrete values (for instance infinity of equi-probable structural maps, fracture maps, geostatistical realizations, history-matched models). To take into account these kind of uncertainties, the COUGAR™ methodology suggests to use the Joint Modeling method[7,8,9] which consists in computing two statistical proxy models:
  - One for the production response as a function of deterministic uncertainty
  - One for the variance of the production response to represent the effect of the stochastic uncertainty.

RISK ASSESSMENT OBJECTIVES

Once the uncertainties relative to a specific field case have been identified, risk assessment may consist of various objectives:

- Assessing the relative impact of each uncertainty on the production and determining the influential ones.
- Quantifying the risk on field production associated with those influential uncertainties.
- Optimizing all "controllable" uncertainties (such as well locations).
- Reducing risk by integrating any dynamic data when available.

These risk assessment objectives can be tackled using the experimental design methodology[10-14] and further detailed below.

Assessing the Uncertainty Impact

For such an objective, a linear model (equation 1 is a first order polynomial function) is generally sufficient. It involves a limited number of reservoir simulations for a large number of uncertain parameters.

The relative contribution of each uncertain parameter on the response is then calculated and illustrated using the so-called Pareto plot. Uncertainties are ranked and a threshold below which uncertainties are reputed negligible is defined.

Quantifying the Risk on Field Value

Having identified the influential uncertain parameters, reservoir engineers would like to know the resulting risk on the reservoir modeling workflow outputs, for instance on incremental oil productions, oil recovery factor or field net present value.

This resulting risk on field value is obtained using a sampling method, such as Monte-Carlo technique, using the fast proxy-model. The final result is a probabilistic distribution and corresponding percentiles of any reservoir modeling workflow outputs are derived from probabilistic input parameters.

APPLICATION TO MATURE FIELDS

Due to their long history, mature fields have a large amount of dynamic data. Reservoir engineers systematically integrate these data to better calibrate the reservoir model and, therefore, to reduce the uncertainty range on each modeling workflow input, hence on field production forecasts. This history match process is, however, recognized as a challenging issue, and in practice it is difficult to derive a reservoir model that perfectly fits all the dynamic data.

Many reservoir simulation models, which properly match the dynamic data, can hence be obtained by using either manual history-matching techniques or assisted history matching with optimization methods. All these reservoir models are equi-probable. The main concern is to select the "right" matched model for performing further production forecasts and further production scheme optimization. To achieve that purpose, the Joint-Modeling method, as stated above, is used assuming that all the matched models are considered as a unique stochastic uncertainty. Using this method, it is then possible to quantify the risk associated with the history-matching process uncertainty itself (which actually can be very high) and/or to optimize the future production scheme while taking into account the dynamic data available. This methodology has been fully validated on a synthetic case[15] as well as on the PBR case[16] as summarized here below.

Risk Assessment on a Mature Field Case - The PBR field

We present here the JM method applied to a real field located offshore Brazil (PBR field)[16]. The objective was to maximize the incremental production of the reservoir through a redevelopment plan while taking into account the uncertainty in history-matching induced by the existence of infinite number of equi-probable matched models. The study employed the following two steps:

- ***History-matching***: The geostatistical and flow models were constrained to the production data. Several equi-probable matches were obtained.
- ***Redevelopment Production Scheme Optimization***: The goal was to quantify the added value of history-matching in terms of uncertainty reduction on production forecast and the optimization of new well location and rates taking into account the remaining uncertainty after matching.

PBR Field Modeling Workflow

The PBR reservoir is developed with 34 oil production wells and 13 water injection wells, such as illustrated in Figure 1. The production started June 1979. During the first five years, the field was produced by primary depletion. Water injection started April 1984 for pressure maintenance.

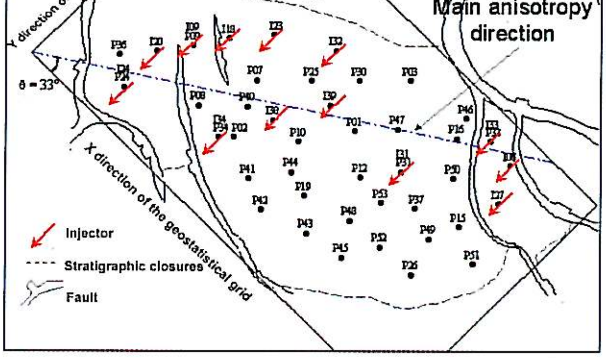

Fig. 1. Well location map of the PBR field.

Four facies were identified in the reservoir: sandstone LT-1 and LT-2 facies have good reservoir properties, whereas LT-3 and LT-4 (actually non-reservoir zones) include clays and marls. The workflow of the PBR reservoir model has been fully integrated in the same simulation process, from the construction of the geostatistical lithofacies model to the fluid flow simulation.

History-matching Process

A main objective was the definition for the entire simulation workflow to measure the mismatch between the observed data (d_i^{obs}) and the simulated data (d_i^{sim}) using the weighted least square

$$OF = \frac{1}{2}\sum_{i=1}^{n} w_i (d_i^{obs} - d_i^{sim})^2$$

formulation: where w_i are the weighting factors.

The production data available for the PBR field were the oil flow rates at surface conditions, the water cuts and the static pressures for all producers.

A preliminary sensitivity study was performed, using the experimental design technique to select the most influential inversion parameters among the deterministic uncertain parameters of the simulation workflow. In addition to these 8 deterministic inversion parameters, the geostatistical realization itself was considered unknown in the inversion process. The spatial distribution of the facies model was parameterized using the Gradual Deformation Method[17,18].

The history-matching process was performed 5 times with different sets of initial deterministic parameters and with different initial geostatistical realizations. The initial sets were chosen within the predefined uncertainty domain. These five matched models led to the same quality of match (same order of magnitude for the resulting objective function), which was considered as satisfactory except in the south-east region where some major geological assumptions may have to be reviewed.

Re-development Scheme Optimisation

The objective was to maximize the reservoir cumulative oil production after an additional period of production of 10 years (COS-10y) by including two new producers. A technical issue concerned the choice of the matched model which was to be used for this optimization process. In fact, the 5 history-matched models were used through a unique stochastic uncertainty on the matching process. The production parameters to optimize were the locations and production rates of the two infill production wells (NW1, NW2). A preliminary sensitivity study has shown that the Y locations of the wells were not significantly influential on the production forecasts. Finally, the JM method was used to model the COS_10y response with respect to the following production parameters: the X locations (X1, X2) and the oil production rates (Q1, Q2) of the two infill production wells (NW1, NW2). Dispersion induced by the history match uncertainty was considered through the variance model.

The joint models obtained were used to optimize the production scheme by maximizing the mean model. This gave the optimal values for X1, X2, Q1 and Q2 parameters and the corresponding mean and variance values of COS_10y response forecast, summarized in Table 1. A 95% prediction interval due to the uncertainty on the history match process was deduced: from 53.68 MMm³ to 56.97 MMm³ in terms of final cumulative oil production.

Table 1. Optimisation of the production parameters using the JM method.

	Optimal	Unit
X1	38	cell #
X2	47	cell #
Q1	852	m3/d
Q2	1500	m3/d
Mean COS_10y	55.32	MMm3
Variance	0.71	(MMm3)²
Standard deviation	0.84	MMm3
Min of 95% conf. Interval	53.68	MMm3
Max of 95% conf. Interval	56.97	MMm3

In Figure 2, the cumulative oil production profile intervals since the beginning of field production without history match and after history match are displayed. As expected, the history matching

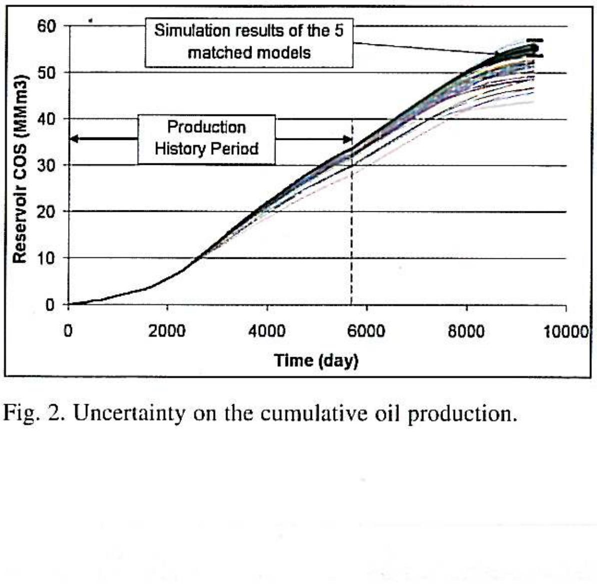

Fig. 2. Uncertainty on the cumulative oil production.

significantly reduces the uncertainty on prediction, by 75%.

However, even when using very high technology history match process such as constraining both the geostatistical realizations and the dynamic parameters as matching parameters, 25% of uncertainty remains acceptable due to the history match process. The Joint Modeling method has enabled a successful quantification of the impact of the history match process on further production forecast, and consequently, redevelopment plan has been optimized taking into account the associated risk.

CONCLUSIONS ON THE COUGAR™ METHODOLOGY

The COUGAR™ methodology was developed within a Joint Industry Project (JIP) named COUGAR, which was launched by IFP in March 2001 for two years and which is currently open to new oil industry partners for a 3-year extension work program. The main objective of this JIP is to develop a prototype software based on statistical approaches, such as experimental design methodology validated through real field case studies provided by the partners. All kind of uncertainties may be simultaneously or separately investigated, from the static model including the main geological assumptions (structural, stratigraphic, ...), the geostatistical parameters (seed, correlation length, variograms, petrophysical properties, ...), the scale-up model assumptions, the fluid flow simulation model parameters (relative permeabilities, fluid properties, well location and productivity, ...), up to the surface facilities scenarios and economic uncertain parameters (oil price, OPEX, CAPEX, ...). Any outputs of the modeling workflow, including, for instance, volume of fluids in place, production profiles per well, field net present value, etc., can be computed as a specific "proxy" model which represents the impact of the main uncertainties on this output. These proxy models can then be used to optimize for instance a redevelopment plan (infill well location and architecture, injection rates, plateau duration,...) while taking into account all the inherent risk in the reservoir.

Using COUGAR™, petroleum engineers will be able to propagate an uncertainty within their own modeling workflow and to compare the uncertainty impact on any output of the field evaluation, whether technical or economic. Decisions at each phase of the field life, from exploration, appraisal, development, to final recovery, can hence be taken while quantifying the risk associated with all the technical and economic uncertainties that may affect this decision.

Ranking of Development Strategies

The advent of new techniques for better evaluating reserves and developing continuously improving field surveillance and monitoring strategies, leads the oil industry to build evermore detailed static and dynamic reservoir models.

As seen in the previous section, the COUGAR™ technology is designed to help in the decision making process in all phases of field life starting from exploration to late IOR development strategies.

To simplify even more the duty of the reservoir engineers and assess a limited number of pre-select development scenarios it can be worth considering additional ingredients such as the combination of "light" calculations and analysis techniques for screening and optimization with computationally intensive full physics simulation.

Figure 3 illustrates this workflow. The rectangular boxes on the top indicate the elements of a conventional reservoir modeling study. The rounded boxes on the bottom represent new tools that would need to be developed in order to assist the engineer to (1) take coherent modeling decisions and (2) pre-select potential redevelopment scenarios which will be analyzed and ranked using our COUGAR™ technology.

This workflow consists of three different themes: Data Analysis, IOR Screening and Drainage Pattern Optimization. These themes are detailed in the next sections.

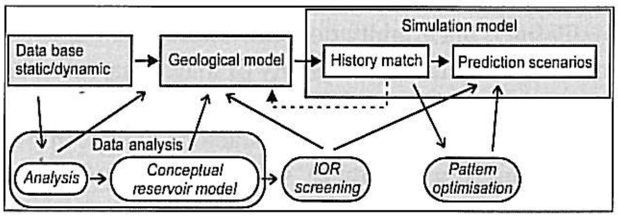

Fig. 3. Work flow combining "light" analysis techniques with detailed geological modelling and full physics simulation.

Data Analysis

Analysis

Besides elaborate static or dynamic reservoir modeling, it is important to obtain the best possible understanding of the reservoir architecture and the performance of the present recovery processes. This understanding can be obtained from review of previous reservoir studies (with risk of prejudice), as well as from direct analysis of the field data. Analysis of the production history serves to identify potential alternative strategies to target remaining oil, as well as possible inefficiencies in the current recovery strategy (cross flow behind casing, scale formation, gas cusping, thief zones). Analysis of the production history can also help detail the appropriate reservoir modeling approach: point out the key geological features and flow processes that need to be captured in the models.

Analysis of the production history of mature reservoirs generally involves handling of large volumes of data of varying quality. There may be hundreds of wells, a long production history, a large number of workovers, a multitude of SCAL data as well as several subsequent recovery strategies (natural depletion, water injection, gas injection, infill drilling). Construction of a well-organized data base (as complete and accurate as possible) is an essential first step for efficient analysis of the recovery history.

Data analysis can include material balance, statistical analysis routines for production data and assessment of main displacement characteristics (gravity dominated, viscous dominated, thief zones). A key element of the analysis is also the visualization of the data; bubble plots of production, composite plots showing production, static pressure, PLT and RFT data, as well as perforation history. To this end, the reservoir data base should be linked to a flexible user interface allowing composite visualization of all data, as well as the execution of (user defined) analysis scripts and software (material balance). Development of this type of flexible software is currently being contemplated by the IFP.

The Conceptual Reservoir Model

Based on above analysis, a conceptual reservoir model can be elaborated. This conceptual reservoir model is a simplified description of the reservoir which is representative of a volume fraction of the total reservoir.

Depending on the process of interest (for example well inflow performance modeling or sweep efficiency analysis) a conceptual model can be a 2D cross section, a single well in a radial geometry, a symmetry element of a pattern (quarter five spot) or a pattern with a limited number of wells. The conceptual model should contain the key reservoir heterogeneities. Although an exact history match is not required, the model should capture the global dynamic reservoir behavior. The model can have a geostatistical basis, being constructed of rock types with certain correlation lengths. The conceptual model should be simple enough so that it can be changed easily, and the turnaround time should be low (< 1 hour per run) so that many sensitivities can be evaluated in a relatively short timeframe. If required, several conceptual models can be constructed, each of which being representative for a specific part of the total reservoir volume.

In the analysis phase of the study, COUGAR™ type studies as presented in part-1 can be run on the conceptual model to assess, in more detail, the effects of different reservoir characteristics (heterogeneity, vertical permeability, fluid properties, *etc*) on reservoir performance under the current recovery mechanisms. This work provides additional insight into the reservoir performance, helps in defining an appropriate modeling approach, helps to identify an history matching strategy, and can also serve to identify and evaluate IOR strategies.

IOR Screening

Screening for IOR redevelopment scenarios is performed on different levels. A first step consists of the use of basic screening parameters. For example, many chemical processes can not be applied at high reservoir temperature and salinity due to their rapid degradation. In a second step, the additional recovery of the pre-selected processes can be assessed using either analytical models, or by running the pre-selected processes on the conceptual reservoir model. Again, the COUGAR™ approach can be applied to quantify the uncertainties associated with the proposed IOR processes (*e.g.* water shutoff, EOR, productivity/ injectivity enhancement).

IOR screening should take proper account of the facilities aspects, and the present state of the wells and completions. The IOR project should be considered as an integrated project in which geologists, production engineers and reservoir engineers make their contribution.

Field example of Analysis and IOR Screening

A field example of the above IOR screening process is an offshore carbonate reservoir located in the Gulf of Oman. The reservoir is a multi layer formation which has been on commingled injection and production for about 25 years. Characteristic of the displacement process is the rapid water breakthrough in thief zones. As a result of high water cycling, pressure maintenance has not been fully achieved, and the reservoir is below the bubble point pressure. Analysis of the water flooding data indicated four "types" of remaining oil (Fig. 4): (1) Oil remaining in low permeability layers, (2) bypassed oil in layers with a thief zone, (3) traditional residual oil, and (4) remaining oil associated with areal sweep (due to well pattern and sub-seismic faults).

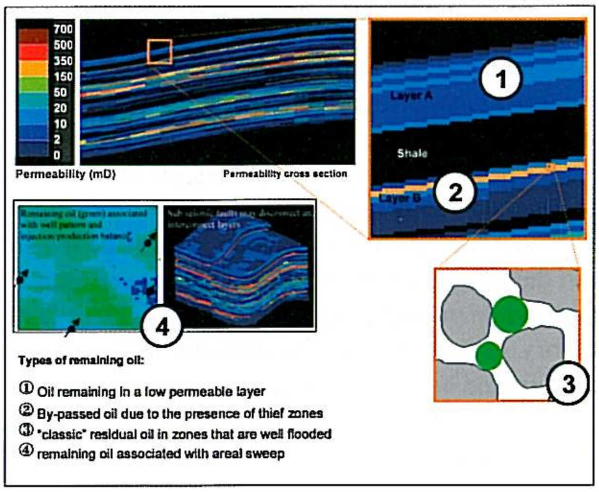

Fig. 4. Drainage pattern optimisation, workflow.

Preliminary screening revealed that specific reservoir conditions (P, T, water chemistry, heterogeneity) make it difficult to apply most conventional EOR processes like chemical floods, miscible or immiscible gas flooding gas flooding.

After reviewing the options, water alternating gas injection (WAG) was identified to potentially target "type" (2) and (3) remaining oil, while intelligent completions were proposed for better distribution of the injection water over the reservoir layers, targeting type (1) remaining oil.

Conceptual reservoir models were constructed in the form of high resolution cross section models to quantify the EOR potential of WAG. Special emphasis was put on the three-phase relative permeability and capillary pressure description. COUGAR^{TM} based sensitivity analysis, focusing on the reservoir heterogeneity and uncertainty in three-phase petrophysical data, indicated a disappointing incremental oil recovery of WAG of the order of 3%. This incremental recovery was insufficient to justify the required surface facilities modifications for WAG injection in this mature offshore field. However, review of existing surface facilities, showed that there was a possibility to apply the existing gas lift system for a SWAG (simultaneous water and gas injection) scheme. Further simulation studies indicated that the expected additional recovery of SWAG was of the same order of magnitude as WAG. Economic analysis of the SWAG process showed that this process, due to its low cost, would be of significant economic value as a breakeven additional recovery of less than 0.3% was required.

Drainage Pattern Optimization

The third theme of the workflow presented at the beginning of this section consists of drainage pattern optimization (Fig. 5). Evaluation and optimization of drainage pattern is a problem that can involve a large number of variables: well positions, well architecture, balance of injectors and producers, intelligent completion technology, stimulation. Optimization of all these options on the full field model would require a two-stage approach starting with a simplified model.

The approach proposed would be to run the development optimization studies on a simplified model, which runs very rapidly. The optimization is not performed on the actual parameter of interest (recovery, Net Present Value), but on a parameter which is equivalent to this parameter of interest. The result of the optimization is validated in the full physics reservoir simulator.

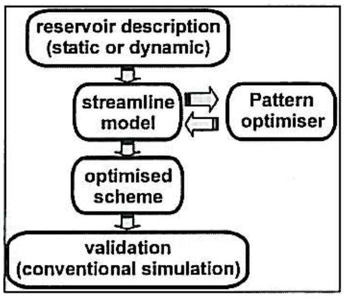

Fig. 5. Drainage pattern optimization, workflow.

For the optimization, a streamline code would be used. These optimization runs are performed in incompressible mode. Therefore, there are no pressure transients (which can present some limits for certain cases), only one pressure calculation is required to obtain the "steady state" plateau rate for a given scenario. This allows very efficient comparison of different competing strategies to maximize production rate, like horizontal well length, reduction of well spacing, stimulation, gas lift, ESP.

For the optimization of the volumetric sweep efficiency, the Time of Flight (TOF) data (weighted by the mobile oil) and the drainage area data from the simulator are used. The basic idea is illustrated in Figure 6. The TOF approach allows rapid optimization of the well locations to equilibrate the TOF of the mobile oil from its present location to the production well. Note that the optimizations of well type, number of wells (injectors and producers) and well location are performed simultaneously for all the wells in the model.

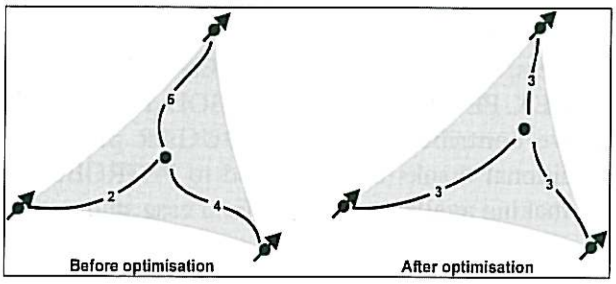

Fig. 6. Illustration of the optimization of well location using Time of Flight (TOF) information.

Field Example, Pattern Optimization Studies

The development studies on a giant field located in Middle East form an illustration of the use of streamline simulation to optimize drain length, drain orientation and well architecture of the horizontal development wells.

This field is divided into three increments (Fig. 7). Increment 2 was recently put on production, and is the subject of this field example.

The increments are characterized by three main features: the matrix, which has a good permeability of up to 200 mD, thin super-K layers, with a typical permeability of 2+ D, and high permeable fracture swarms. Data analysis and simulation studies indicated that fracture swarm is a main cause of early water production.

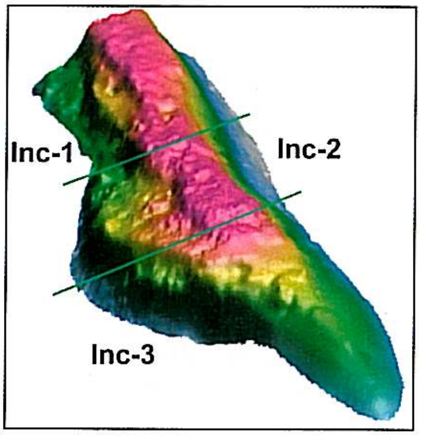

Fig. 7. Structure map.

Figure 8 shows a map of the fracture distribution in increment 2, as well as a contour pressure map generated by high resolution streamline simulation. TOF calculations corresponding to Figure 7 are shown in Figure 9.

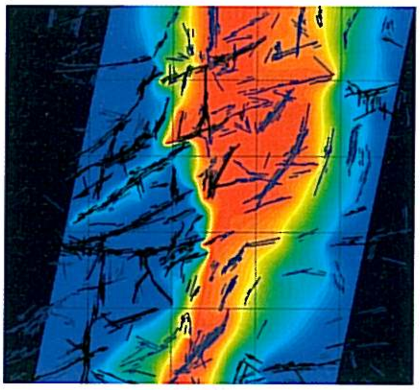

Fig. 8. Drainage pattern optimisation, workflow.

Based on the TOF plot in Figure 9, a Monte Carlo approach was applied to determine the performance of different well types (horizontal wells, multilateral wells), well lengths and well orientations.

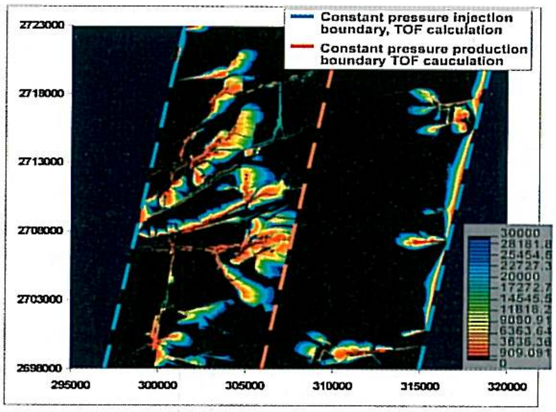

Fig. 9. TOF data for increment 2.

Figure 10 shows results, in terms of achieved PI per invested dollar, for the single drain horizontal wells, as a function of the well length and well orientation. The optimum configuration was subsequently validated in the finite difference simulation model. A statistical survey of existing horizontal wells in the area also confirmed the results of Figure 10.

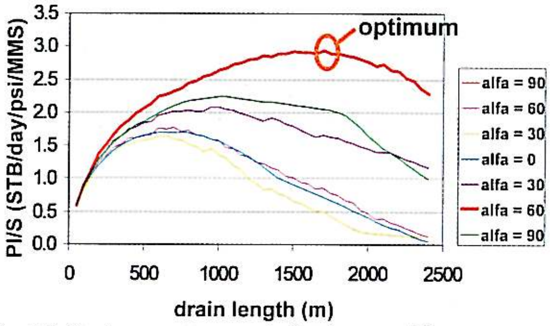

Fig. 10. Drainage pattern optimisation, workflow.

Combining Those Approaches: Towards Integrated Reservoir Studies for Optimal Development Scheme

We have clearly seen in the two previous sections concerning the COUGAR™ methodology developed for quantifying uncertainties and ranking development strategies that a fast but rigorous diagnosis of each possible development scheme has to be properly accounted for, and would require, sometimes, to be studied in a detailed way.

One concern is related to the fact that generally the outcome of a development strategy can still be uncertain. This demands the development of the experimental design technique so as to deal with specific decision tree where scenarios are of probabilistic nature.

This is the goal of the follow-up of the development of the IFP led COUGAR II joint industry funded project. Such an issue is vital to be able to optimize any petroleum production in the future.

CONCLUSIONS

Nowadays, due to the advent of the field surveillance and field monitoring strategies, a large amount of data is acquired and should allow the improvement of the understanding of the reservoirs and, hence, optimize their exploitation. This applies, as first priority, to mature field production which needs to be optimized to face the fast growing world energy demand for the next 30 to 50 years.

Taking advantage of this huge amount of data, and quantifying and reducing the uncertainties they create in the field development process, is a main objective of the comprehensive methodology based on the COUGAR™ technology presented in this paper. This methodology is employed to define a simplified model (the proxy model) which will behave as the true reservoir model but running much more rapidly. This proxy model, which can be coupled to some economic spread sheets can then be used to make production forecasts and optimize the recovery factor as well as the net present value.

In order to perform a preliminary screening analysis which can help to rapidly point out best candidates among possible (re)development strategies, the methodology can comprise specific items including use of simplified simulations.

Those methodologies and tools are already available as illustrated by the field cases presented in this paper and are subject to continued development and improvement at IFP. Those developments are conducted under the form of joint industry-funded projects and should contribute to constitute in the coming years important components of the new toolbox of the reservoir engineers.

ACKNOWLEDGMENT

The authors wish to thank the current COUGAR partners, namely BHP Billiton, ENI-AGIP, GDF, PEMEX, PETROBRAS and REPSOL-YPF for their active contribution to the COUGAR program. Additional thanks are addressed to PETROBRAS for making available the PBR field case study.

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