

Real Time Exploration and Development Well Decisions Using PC Based Reservoir Simulators

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Abstract

Reservoir simulation has typically been applied to only the larger and more complicated reservoirs. The cost of performing such studies in a Unix/Workstation environment is high and most fields are not analyzed using reservoir simulation. High-power inexpensive PCs, and software with a powerful, user-friendly interface that does not require a simulation expert has changed the economics of performing such studies to such an extent that engineers and geologists are now using PC-based reservoir simulation to evaluate exploration plays on a real-time basis. This paper documents the process and results of a study that involved mapping, gridding, geostatistics and reservoir simulation of an exploration prospect while the drilling rig was on-site. The paper demonstrates the feasibility of using PC-based reservoir simulation as a routine part of reservoir management, beginning with the exploration well.

Introduction

In the past, only the larger, more profitable reservoirs were analyzed with reservoir simulation due to the high cost of performing such studies. The costs are high due to three main reasons. First, Unix workstations and the geological and reservoir simulation software that run in the Unix environment are expensive to purchase. Second, Unix based hardware and software typically require a significant amount of support to keep the systems up and running. Third, since the interfaces between the user and the calculation modules do not allow one to rapidly build the initial model, run the cases and analyze the results, companies incur the significant expense of training and maintaining simulation experts. The first two reasons can be disposed of by shifting to the PC world now that the high-end PCs have the power to run large models in a reasonable time period. Both the PC itself and the geological and reservoir simulation software that run on the PC are far less expensive to purchase and support than the Unix workstation-based alternatives. The third reason for expensive simulation studies, the lack of first-rate interfaces that will significantly lower the man-hours and experience required to complete a study, is an issue that has only recently been addressed satisfactorily.

This paper provides a case study of an exploration prospect that was evaluated using both geological and simulation modeling tools. The operator had drilled and logged an offshore exploration well and needed to decide whether or not to abandon the well or sidetrack to another location. Gemini Solutions, Inc. (GSI) was asked to simulate the prospect and

provide possible flow streams for the economic model. This request in itself is not particularly unique as GSI routinely analyzes exploration prospects. However, what does make it unique was the time limit for the study. Based on rig cost driven decision times, we completed the study in just over 5 hours, including inputting maps, running geostatistics, building single well and full field models, and running sensitivity cases. The rest of this paper documents the procedures and time for completing the study.

Goals of the Study

The exploration play was an offshore, 12000-foot deep, faulted sand deposit. Production from an offsetting fault block was used to establish the most likely fluid and rock properties. Uncertainties in the reservoir included the original gas, oil and water volumes, compartmentalization, aquifer influx strength, gas-oil ratio, permeability, thickness, porosity, and oil/water contact. The initial development well, W1, penetrated 29 feet of net pay which corresponded to only about half of the anticipated pay for the well. The well was logged successfully, providing additional data for the analysis. A financial analysis showed that the prospect was borderline based on the recovery factor used to calculate the original economics. One possible alternative to abandoning the well and, therefore, the prospect, was to sidetrack the well into an expected thicker section. The operator was in the difficult position of not clearly understanding whether the prospect should be developed or abandoned.

GSI was consulted at 4 p.m. on a Thursday afternoon and asked whether we had the time to study this prospect. GSI replied that the data could be picked up tomorrow (Friday) and we could work on the model Monday. GSI was informed, however, that the rig would be on standby (US\$125k/day) by noon Friday if a decision hadn't been made. An overnight answer was a must because the daily rig cost prevented delays exceeding this time limit. They needed a completed study including digitizing, geostatistical mapping, full field simulation, and numerous sensitivities before 8 a.m. the next morning. GSI agreed to tackle this challenging study.

Discussion

In the past, preparing and inputting geological and other data for this type of study would have typically taken weeks to complete. The main impediment to performing studies rapidly was the lack of user-friendly geologic and simulation tools with an interface to the user that allowed rapid data entry and analysis and contained correlations to generate properties that were unavailable. Due to user-friendly PC based mapping, gridding, and simulation software now being available in the petroleum industry, companies are able to provide simulation results in a "real time" environment. The software used to complete this study were Merlin and Apprentice. Apprentice is a digitizing/ geostatistic characterization/mapping package that can be used to generate maps, calculate volumetrics, and export grid data to various simulators. Merlin is a full-featured black-oil simulator with pre and post processors, and a transparent interface to Apprentice. Both packages run on the PC, and can effectively build models of 100000 cells or more on a high end Pentium PC.

GSI received the data at about 6:30 p.m. in its office and organized a staff of 3 engineers to complete the project. One engineer reviewed data from the operator and corresponded with the client over discrepancies and questions. A second engineer digitized the known maps, calculated volumetric hydrocarbons-in-place, and exported the data to the simulator. A third engineer built a single well model and ran several cases to examine the sensitivity to different rock and fluid properties. Finally, the single well model and the Apprentice grids, including faults, well locations and all rock properties were combined to complete a full-field model. This workflow was completed by 10:30 p.m., a four-hour process.

The top of structure map was digitized using the current seismic map. The net thickness map was developed using a geostatistics kriging routine and the best estimate available at the time for area thickness variation. Fig. 1 is the structure map after it was digitized into Apprentice. A grid was placed over the structure map and the kriging algorithm was used to populate the grid cells. Fig. 2 and 3 show the results of the kriging step. Note that the grid in both figures is rotated 90 degrees counterclockwise from the digitized data shown in Fig. 1. The oil portion of the reservoir is shown in darker gray.

The area of interest lies in the fault block furthest south in the picture. The contact with and productivity of the fault block to the north is uncertain. Later sensitivity cases included placing water in the northern-most fault block.

One of the greatest concerns was the effect faulting would have on water influx. The east to west fault, separating the northern and southern fault blocks, was modeled as both open, as it is shown, and completely sealing by extending the fault to the east. In this worse case, a sealing fault would significantly reduce the effective influx of water. This second map interpretation represented a more depletion drive dependent production mechanism for the producing fault block and established a lower limit for oil recovery.

While the mapping and gridding was being completed, a single well model was created in Merlin to establish the recovery for a typical pattern model, and to run sensitivities to rock and reservoir variables to understand which parameters had the greatest effect on recovery. The effects of permeability and variable rock compressibility were determined to be important parameters during this phase of the study. Merlin allows single well models to be created in minutes through an automatic setup, and just as quickly, converted to full field models with Apprentice grids transparently imported. Without these features available in PC-based models, neither GSI nor anyone else could build these types of sophisticated simulation models in the timeframe required by the operator.

Once the Apprentice grids were merged into the single-well model to construct the full-field model, a plan was established for the field using the base case variables. Production profiles and ultimate recoveries were calculated for this case. As this was a new prospect, much of the prospect data was uncertain, and it was of greater importance to the operator to establish whether likely minimum recovery cases for the most conservative variable combinations would still yield an economic prospect. Five cases for likely ranges of variables were run before 11 p.m., Thursday night. The resulting plots and maps were then cut and pasted into PowerPoint for the presentation. The use of PC-based simulation allows one to make use of readily available presentation software and word processors and avoids the time-consuming task of preparing presentations in the workstation environment.

In the past, presentations of simulation results to companies were limited to completed simulation runs. Invariably, the meeting participants questioned the effect of values used for certain variables and the operating conditions built into the model. This questioning occurred even when these same individuals were responsible for setting these parameters and cases. One advantage of PC based simulation is the portability of the hardware and software. Laptop computers can now be taken to an office and simulation results shown through a projector. For this project, the five completed cases were presented at 8 a.m. Friday morning to the engineering/geoscience/management team that commissioned the study. Other management personnel also attended and an additional six cases were requested and run during the meeting. By 10 a.m., the operator's questions had been answered. In total, eight cases were seen as the likely spread for the anticipated production profiles in the reservoir, and remarkably seven of the eight cases were well above the minimum return required to sidetrack the well and develop the reservoir. A summary of results for the eight cases is shown in **Table 1**. Of the eight cases, only the case with the limited aquifer and constant rock compressibility was marginally economic, and the other seven cases had good to excellent net present values.

A view of the change in oil saturation with respect to time for the case with full aquifer support and variable compressibility (Case 4) is shown in contour maps (**Fig. 4 and 5**) and in cross-sections (**Fig. 6 and 7**). Note that the water sweeps the reservoir quite efficiently for this case and the majority of the remaining oil is at close to the residual oil saturation to water. Both the original well, W1, and the proposed sidetrack, WST1, are shown on the contour maps. The results of the quick simulation studies provided the operator with the ability to quantitatively evaluate the risks for a new prospect that needed to be sidetracked, and as a result, increased the operator's confidence in drilling the sidetrack well. The resulting well WST1 was successful, and the operator now has an economic reservoir.

Although reservoir simulation provides the best tool the industry has for evaluating hydrocarbon reservoirs, historically, it has only been used for a small percentage of potential applications. This lack of use is because, first, it took too long to complete the studies, second, only a few experts in large companies had the knowledge necessary to manipulate these complicated tools, and third, there are large costs associated with maintaining the hardware, software and expert simulation personnel. Mastering this type of complexity is no longer required. PC-based simulation with the appropriate user interfaces

can become an everyday engineering tool and can be used in applications as diverse as production logging and evaluating exploration prospects even before the first well is drilled.

Conclusions

Traditionally, reservoir simulation has been a long and involved process involving the difficult integration of people and tools from several disciplines, including geology, geophysics, and reservoir engineering. Based on the results of this study, we conclude:

1. Currently, a PC-based characterization and simulation system exists that allowed an operator, over night, to model and evaluate the potential for sidetracking and completing an exploration well while the rig was on site.
2. PC-based characterization and simulation in conjunction with the appropriate user interface allows engineers and geoscientists to model reservoirs on a routine, real-time basis.
3. Simulation can become an everyday engineering tool that can be used in applications as diverse as production logging to evaluation of exploration prospects even while the first well is being drilled.
4. The cost of PC based simulation is low due to the lower cost of hardware, software and support. In addition, the manpower costs are significantly lowered due to the powerful interface that reduces both the time needed to complete a study and the need for simulation experts.

Table 1 - Case Summaries

Case	Aquifer?	Rock Compressibility	Permeability (millidarcies)	"Flat Line" Oil Rate (BOPD/years)	Oil Recovery (% OOIP)
1	Full	Constant	350	2500 for 6 years	46
2	None	Constant	350	2500 for 2 years	14
3	None	Variable	350	2500 for 2 years	21
4	Full	Variable	350	2500 for 6 years	48
5	20 %	Variable	350	2500 for 5 years	39
6	Full	Variable	200	2500 for 5.5 years	46
7	Full	Variable	200	5000 for 3 years	49
8	Full	Variable	100	5000 for 2 years	44

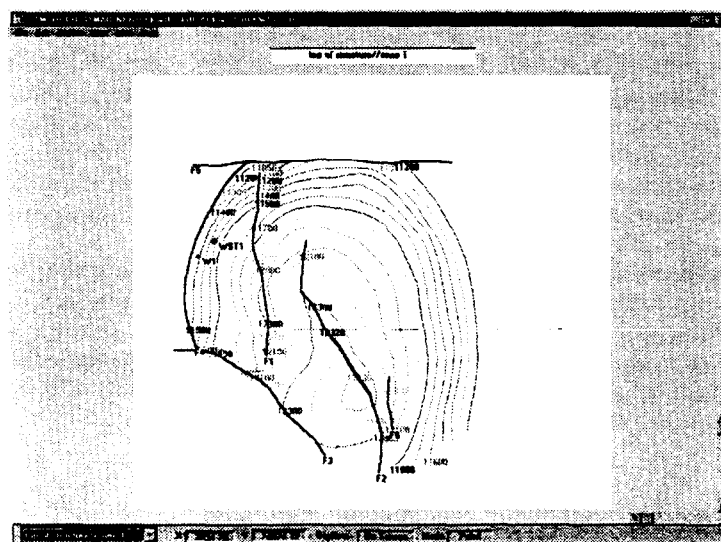


Figure 1 - Digitized Structure Map

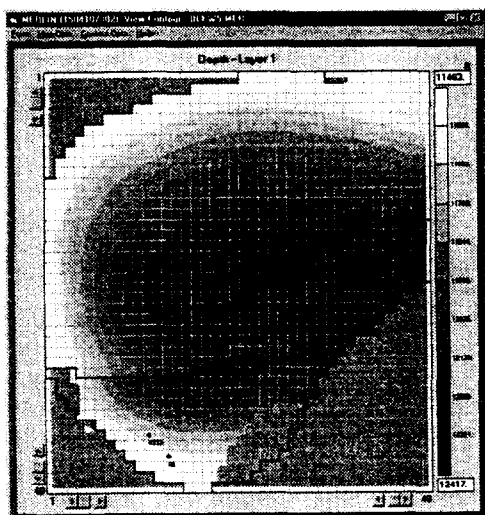


Figure 2 - Gridded Top-of-Structure Map

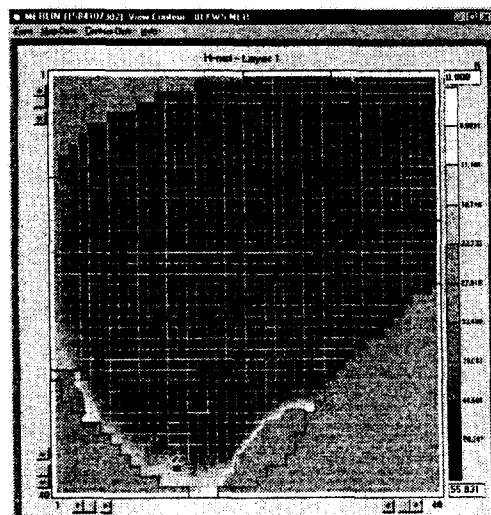


Figure 3 - Gridded Net Pay Map

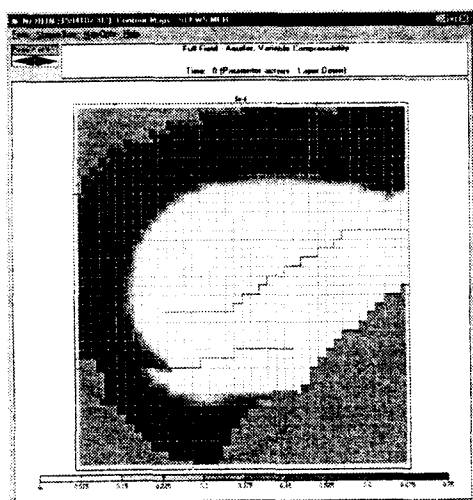


Figure 4 - Case 5 Oil Saturation Contour Map at Initial Reservoir Conditions

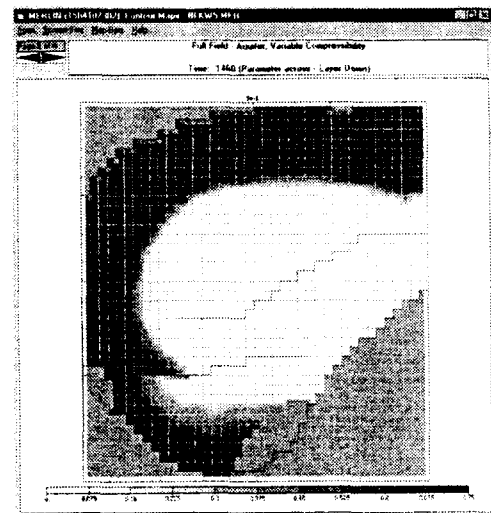


Figure 5 - Case 5 Oil Saturation Map After Four Years of Production

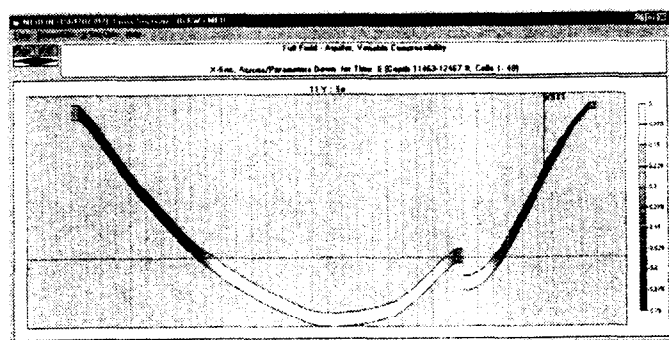


Figure 6 - Case 5 Oil Saturation Cross-Section at Initial Reservoir Conditions

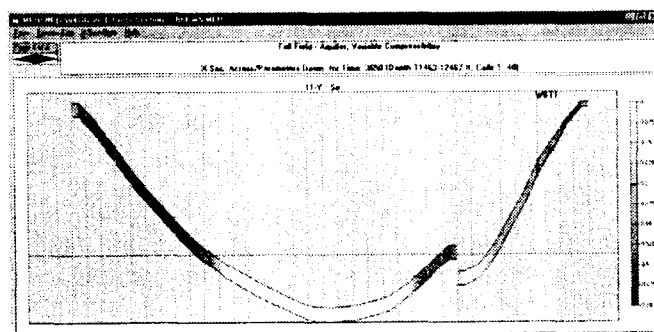


Figure 7 - Case 5 Oil Saturation Cross-Section After Four Years of Production