Feasibility Study of Time-Lapse Seismic: A Case Study

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Summary

A 4D feasibility study for the Balol Field in India shows that repeated seismic data can be used to observe changes in gas saturation. Two 4D analysis methods have been considered, first the conventional method by observing amplitude changes at selected interfaces, such as the top reservoir interface, and secondly to observe shifts in critical offsets for PP and PS reflections. Both methods show good potential for technical success. Typical near offset relative amplitude changes for PP-data are predicted to be up to 80-100%, and the PP critical offset change is expected to be 70m. Similar results are expected for the PS data.

Introduction

The area of study, Balol oil field lies in the heavy oil belt in the north-western part of the intra-cratonic rift graben of the Cambay Basin, Rajasthan, India. The major pay zone in the Balol sandstone reservoir is KS-I sand. The reservoir zone is 32 m in thickness and top of the reservoir is at depth 996 m and bottom of the reservoir lies at 1029 m. The porosity of KS-I lies in the range of 28-30% and its permeability varies from 8-15 darcy (Asit and Mohan, 2004). The oil in this reservoir is asphaltic in nature. The primary recovery of viscous and heavy oil from Balol is only 10-12%, hence the pay zone is under thermal EOR process. The in-situ combustion (ISC) process is being carried out in the Balol field to improve secondary recovery of oil from the sand stone reservoir. In-situ combustion is a thermal recovery technique in which a part of heavy oil in place is burned to generate heat. This heat brings reduction in viscosity of the crude oil to get improved mobility and hence oil production rate and recovery.

During in-situ combustion process, changes in pressure, temperature and fluid saturation cause changes in seismic response. Detecting and measuring these time-lapse changes lead to a better understanding of the movement of fire-front and fluid flow dynamics which inturn can help in optimizing the production and injection strategy for thermal EOR. The goal of time-lapse seismic monitoring (4-D surveys) is to use changes in seismic response to infer changes in reservoir conditions. Hence, the objective of this study is to improve the understanding of fluid flow within the reservoir so that petroleum engineers can optimize production decisions. So far, most of the time-lapse seismic studies have used normal offset data that is data with a maximum offset range less than 3000 m. Recent theoretical studies (Landrø et al, 2004) show that there might be a potential for extracting precise and complementary 4D information by exploiting long offset 4D seismic data.

Theory

Time-lapse seismic or 4D seismic is a repeated 2D/3D conventional seismic data or repeated 4C seismic at different time intervals. In 4D seismic, the difference between two seismic vintages acquired at different time intervals under same acquisition conditions gives information on the variation of geophysical properties due to the hydrocarbon production. However the subtraction process exhibits spurious residual energy, which is not related to the time-lapse signal such as random noise, acquisition related noise and signal bandwidth variation. This energy often limits the resolution of the 4D signal.

Most successful time-lapse seismic studies are obtained from high porosity, sand reservoirs (Landrø et al., 1999, Koster et al., 2000, Landrø et al., 2001). The main cause for this is that expected relative velocity and density changes due to production are very low for high velocity (carbonate) reservoirs. Therefore, there is a need for high precision estimates of velocity changes, and time-lapse refraction seismic might be a solution.

In conventional time-lapse seismic, changes in seismic response because of production or implementation of any secondary recovery methods are mapped using time-lapse amplitude anomalies in monitor surveys. Often pre-critical PP reflections and amplitude study is done in conventional analysis. In case of noise prone data it is found that long offset PS data gives much better time lapse response than the conventional. Hence in this study post critical PS reflections are also analyzed.

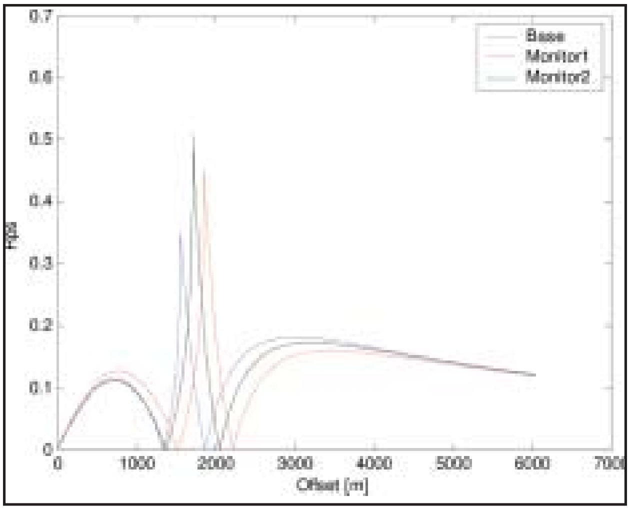

Fig 1: PS reflection coefficient (real part) with offset. Blue line shows the base plot and red and black lines correspond to 50% gas and 100% gas saturation in the monitor survey. Notice amplitude changes at near offsets (600-1000 m) as well as the strong shift in the "critical offset" peak around 1800 m.

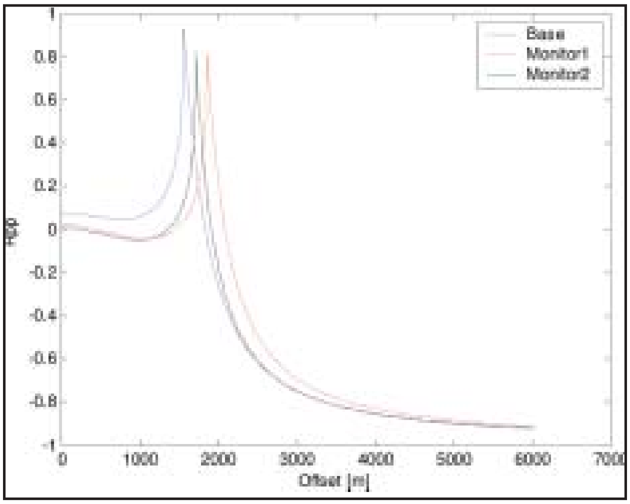

Fig 2: PP reflection with offset (real part). Blue line shows the base plot and red and black lines correspond to 50% gas and 100% gas saturation in monitor survey. Notice significant changes in near offset amplitude level and shift in critical offset around 1800-2000m.

Aim of this study was to observe changes in seismic parameters due to change in gas saturation; hence to carry out fluid replacement modeling we increased the gas saturation from 0 to 100% in steps of 10. In the pre-combustion case (base model) water saturation was 30% and oil saturation was 70%. It was assumed that as a result of fire flooding all the water is vaporized to steam, however oil saturation is decreased slowly to take into account the Feasibility study of time-lapse seismic increase of gas in the solution. Final monitor case is assumed to be 100% gas. The reservoir parameters used in computations are taken from Asit and Mohan (2004). The fluid replacement modeling was carried out by using Gassmann equations and different monitor models were generated for different values of gas saturation. In time lapse refraction analysis, there are several seismic modeling choices that can be done to test the feasibility of the method. In this work we used the Zoeppritz modeling first, and then compared it with FK-modeling scheme.

Conclusions

The results shown in figures 1-2 can be summarized as follows:

PS Reflections:

	50% Gas	100% Gas
Shift at critical offset	208.33 m	62.50 m
Shift at Post critical offset	375.00 m	208.33 m

PP Reflections:

	50% Gas	100% Gas
Shift at critical offset	291.66 m	166.66 m

It is noteworthy to mention that such a measurable change in peak shift of Rps and Rpp could be very useful for velocity change estimation within the reservoir layer. We also notice that there is a good 4D signal also for normal reflection seismic data in this case, since there are significant changes in reflectivity (both for PP and PS) at moderate offsets (for instance around 1000 m). This means that the Balol Field should be a good candidate for 4D seismic.

This synthetic study shows that 4D study of the Balol Field may be useful. The combustion of the reservoir will lead to changes in the fluid composition, which again will cause variations in amplitudes. These variations can be observed both for PP and PS reflections on the x- and z-components in varying magnitude and we also expect to observe time lapse amplitude changes with offsets.

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