Improving reservoir simulation with 4-D seismic surveys

John Zhang and Laurence R. Bentley

ABSTRACT

In order to manage a reservoir we need to be able to predict how fluids will flow in response to the production and injection of fluids. Reservoir simulation allows us to predict fluid flow. Before production, a reservoir is characterized using data from geology, seismic exploration, logging, well tests, core and laboratory work. During production, pressure, saturation and temperature change, and the change is predicted by reservoir simulation. Dynamic data collected during production and 4-D seismic surveys can be used to improve reservoir simulation. As a first step, reservoir simulation parameters are adjusted so that the model predictions approximate the bottom hole pressure (BHP), water cut, gas oil ratio (GOR) and other field observations. Reservoir parameters can be further adjusted so that the predicted changes in seismic response approximate the results from 4-D seismic surveys. We are currently searching for candidate 4-D research sites.

INTRODUCTION

Once reservoir fluids are produced or fluids are injected, it is important to understand the movement of fluids. Reservoir simulation as a conventional practice is widely used to predict fluid flow in a reservoir. The performance of the simulation model can be improved with production history matching. Recently, 4-D seismic surveys have been used to observe fluid changes (Sonneland et al., 1997). Four-D seismic survey results provide additional constraints that can be used to improve reservoir simulation models.

RESERVOIR CHARACTERIZATION

Many tools are used to characterize a reservoir. The geological model is the starting point. It defines a reservoir in the geological context. The model is used to delineate the geometry, unravel structure and trap mechanisms, and express stratigraphic architecture, lithofacies and lithology of the reservoir. The geological model forms the basis on which reservoir properties are interpreted. Sonic logs and core measurements give us porosity and permeability, electrical logs and laboratory work along with production data are used to derive saturation, DST and production tests measure pressure and are used to calculate permeability. These data points can be extrapolated using geostatistical models in combination with seismic velocity and other attributes.

FEASIBILITY STUDY

4-D seismic surveys are designed to investigate changes in pressure, saturation and temperature due to reservoir production and fluid injection. In some cases, however, these changes are not large enough to be differentiated seismically at a given seismic resolution. That means 4-D seismic surveys will not be a useful tool for delineating the changes in the reservoir's state. Therefore it is necessary to conduct a feasibility study. There are many factors that affect the change in seismic response due to changes in pressure, saturation and temperature. The elastic properties (bulk and shear moduli) of dry reservoir rock play an important role in determining whether an adequate change in seismic response will occur due to a change in reservoir conditions. The less stiff the dry reservoir rock, the more important the role of the pore fluids in determining bulk elastic properties of the reservoir rock. Thus the depth, overburden pressure and porosity in part control the feasibility of 4-D seismic surveys. Another factor is the contrast in fluid compressibility. If a fluid (e.g. gas) is displaced by another fluid (e.g. oil or water) which has a large contrast in compressibility, it increases the probability that seismic response change will be observable. In addition, fluids with a large density contrast can contribute to seismic response changes Recovery processes can also have significant impact on elastic properties. For example, steam injection increases temperature and may substantially decrease the seismic velocities. Previous experience has led to the development of feasibility ranking systems (Lumley et al. 1997, Wang, 1977). At the same time, we can use Gassman's model and a simple convolution to generate seismic attributes from the reservoir characterization model (Huang et al. 1997,1998). Then we can perturb fluid pressure and saturation to test sensitivity to the expected changes in the reservoir. If a reservoir has a good ranking and the seismic attributes are sensitive to fluid change, then the 4-D survey will have a good chance of achieving the monitoring objectives.

RESERVOIR SIMULATION

With the reservoir characterization model ready, the reservoir simulation model can be built to predict fluid changes. The general reservoir simulation model is based on the mass conservation law and Darcy's law,

$$-\nabla \bullet (\rho\vec{v}) = \frac{\partial}{\partial t}(\rho\phi) \tag{1}$$

where ρ is the fluid density, ϕ is the porosity and $\vec{v}$ is the Darcy velocity. This equation represents a system of partial differential equations. In specific situations, the general model can be reduced or simplified to specific models, i.e., miscible displacement models, compositional models, and black oil models. We can solve them numerically. There are several commercial simulators available to perform the calculations.

To run the simulation model we must populate the computational matrix with porosity and permeability values. However, these values are only known approximately because of the uncertainties associated with reservoir characterizations. In general, we must adjust our original parameter estimates in order to match the production history of the reservoir. Since there are only a few wells within the reservoir that are monitored, many different porosity-permeability distributions will give reasonable history matches. In other words, the problem has many non-unique solutions. Alternatively, 3-D seismic data is arealy extensive. Consequently, if we can observe changes in seismic response, we can use them as additional observations that must be considered during history matching. The model should not only match the changes in pressure, water cut and GOR, but it should, in conjunction with a rock physics model, match observed changes in seismic responses.

FUTURE WORK

We are presently studying the feasibility of using time-lapse seismic surveys to monitor changes in reservoir's state in the Blackfoot field. We are particularly interested in this field because of the 3-component (3-C) seismic data that has been collected over the field. With 3-C data, it is possible to investigate shear wave response as well as p-wave response. P-wave and S-wave respond differently to changes in the reservoir state, and using both has the potential of reducing equivalence problems in the interpretation of the change in seismic response (e.g. Wang et al., 1998). If the feasibility study is positive, it is hoped to use the site as a 4-D research site. In that case, we will construct a reservoir simulation model for the Blackfoot field. If the feasibility study is not favorable, we search for other candidate sites.

REFERENCES

Huang, X., Meister, L. and Workman, R., 1997, Reservoir characterization by integration of time-lapse seismic production data, SPE 38695.

Huang, X, Meister, L. and Workman, R, 1998, Improvement and sensitivity of reservoir characterization derived from time-lapse seismic data, SPE 49146.

Lumley, D.E., Behrens, R.A. and Wang, Z., 1997, Assessing the technical risk of a 4-D seismic project, The Leading Edge, 16(9), 1287-1291.

Sonneland, L., Veire, H.H., Raymond, B., Signer, C., Pedersen, L., Ryan, S. and Sayers, C., 1997, Seismic reservoir monitoring on Gullfaks, The Leading Edge, 16(9), 1247-1252.

Wang, Z., Cates, M.E. and Langan, R.T., 1998, Seismic monitoring of a CO_2 flood in a carbonate reservoir: A rock physics study, Geophysics, 63(5), 1604-1617.

Wang, Z., 1997, Feasibility of time-lapse seismic reservoir monitoring: The physical basis, The Leading Edge, 16(9), 1327-1329.