Journal of Natural Gas Science and Engineering 42 (2017) 69–84

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

Seismic assisted history matching using binary maps

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ARTICLE INFO

Article history:
Received 11 October 2016
Received in revised form
26 January 2017
Accepted 7 March 2017
Available online 10 March 2017

Keywords:
4D seismic interpretation
History matching
Binary maps
Gas exsolution
Gas dissolution
Water evolution

ABSTRACT

This paper addresses the challenge of integrating 4D seismic data with production data in a quantitative manner in order to improve the forecasting ability of a reservoir model and reduce the associated uncertainty. It presents a history matching workflow that has been applied to production data and time lapse seismic data. In this procedure, the production data objective function is calculated by the conventional least squares misfit between the historical data and simulation predictions, while the seismic objective function uses the *Current* measurement metric between a binary image of saturation change. This approach is implemented on a real field data from the United Kingdom Continental Shelf (UKCS), where uncertain reservoir parameters which consist of global and local parameters are initially assessed. These parameters include flow based multipliers (permeability, transmissibility), volume based multipliers (net-to-gross, pore volume), as well as the end points of the relative permeability curves (critical saturation points). After the initial screening, sensitive parameters are selected based on the sensitivity analysis. An initial ensemble of fluid flow simulation models is created where the full range of uncertain parameters are acknowledged using experimental design methods, and an evolutionary algorithm is used for optimization in the history matching process. It is found that the primary control parameters for the binary seismic gas match are the permeability and critical gas saturation, while the volumetric parameters are important for the binary seismic water match in this particular reservoir. This approach is compared to seismic history matching using full seismic modelling, preserving all amplitudes. The results demonstrate that the binary approach gives a good match to gas saturation distribution and water saturation distribution, and the reservoir parameters converge towards a solution. The conventional approach does not capture some signals of hardening and softening in the seismic data, and hence in summary, the binary approach seems more suitable as a quick-look reservoir management tool. A unique feature of this study is the application of the binary approach using *Current* measurement metric for seismic data history matching analysis, as this circumvents the use of the uncertain petroelastic model. This approach is easy to implement, and also helps achieve an effective global history match.

1. Introduction

Reservoir engineers desire the ability to predict the performance of an oil field in an efficient and timely manner; this is coveted as it expedites efficient reservoir monitoring, management, planning and economic evaluation (Obidegwu et al., 2014). In order to accomplish this objective, different procedures and mechanisms are employed to acquire, coordinate and interpret data obtained from the reservoir as input to the reservoir simulation model. This model has to confidently replicate the historical data for it to be considered worthy of realistic predictions, and this process of updating the reservoir model to satisfy the historical data is known as history matching. Over the past years, production data (oil rates, water rates, gas rates, pressure) have been the main historical data available, however, time-lapse (4D) seismic data is now considered a major dynamic input for history matching. That a model is matched to production data is not a sufficient condition for it to make improved predictions (Sahni and Horne, 2006), the model needs to integrate all available data as well as the geologists interpretation of the reservoir in order to provide the most representative reservoir model or models (Landa, 1997; Wang and Kovscek, 2002). The need to monitor fluid displacement is a great challenge that has been successfully overcome with the use of 4D seismic technology (Hatchell et al., 2002; Vasco et al., 2004; Portella and Emerick, 2005; Huang and Lin, 2006; Kazemi et al., 2011), which is the process of repeating 3D seismic surveys over

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http://dx.doi.org/10.1016/j.jngse.2017.03.001
1875-5100/

a producing reservoir in time-lapse mode (Avansi and Schiozer, 2011). Quantitative use of 4D seismic data in history matching is an active research topic that has been explored extensively (Arenas et al., 2001; Aanonsen et al., 2003; Gosselin et al., 2003; MacBeth et al., 2004; Staples et al., 2005; Stephen and MacBeth, 2006; Kazemi et al., 2011; Jin et al., 2012), the main challenge being quantitatively incorporating the 4D seismic into the reservoir model (Landa, 1997; Walker et al., 2006).

Fig. 1 shows the different domains in which seismic data could be incorporated into the reservoir model as has been described previously (Stephen and MacBeth, 2006; Landa and Kumar, 2011, Alerini et al., 2014). The three main domains are: (1) The simulation model domain, where the observed seismic data is inverted to changes in pressure and saturation, and are then compared with the simulation output (Landrø, 2001); (2) The impedance domain, where the observed seismic data is inverted to changes in impedance, and the simulation model is forward modelled to derive impedances, and both impedances are then compared (Ayzenberg et al., 2013), or (3) The seismic domain, where the impedances derived from the simulation model are convolved with a wavelet to generate a synthetic seismic, and this is then compared with the observed seismic (Landa and Kumar, 2011). The aforementioned domains use seismic modelling, rock physics modelling or petro-elastic modelling to address this challenge, however these modelling processes are complex, time consuming, use laboratory stress sensitivity coefficients, as well as Gassmann's equation assumptions (Landrø, 2001; Gosselin et al., 2003; Stephen et al., 2005; Floricich, 2006; Amini, 2014). There have been other methods that circumvent the complex seismic modelling process (Landa and Horne, 1997; Kretz et al., 2004; Wen et al., 2006; Jin et al., 2012; Rukavishnikov and Kurelenkov, 2012; Le Ravalec et al., 2012; Tillier et al., 2013) which employed the use of image analysis tools, binary processing, or dynamic clusters to integrate the seismic data into the reservoir model. In this paper, a method is proposed where seismic data and simulation data are converted to binary seismic gas maps and binary simulation gas maps respectively, such that a comparison of the observed seismic data directly with the simulation output in the binary inversion domain is possible (Fig. 1). The objective function for calculating the misfit of the production data will be the popular least squares misfit, while the seismic objective function will be the *Current* measurement metric (Glaunès et al., 2008; Chassagne et al., 2016). This approach is contrasted with the conventional seismic modelling approximation scheme, and the context of the study is set by a UKCS field dataset.

2. Field data set

The binary seismic assisted history matching concepts in this paper will be applied to a real field data located at the United Kingdom Continental Shelf (Martin and Macdonald, 2010), with the aim of history matching the observed data, as well as forecasting the future production profiles and saturation distributions as a means of validating the new improved models. The main features of the data are that the reservoir pressure is close to its bubble point pressure, such that the commencement of production activities will lead to depressurization and gas exsolution; and that there is a subsequent pressure maintenance scheme in place by the use of water injector wells, so there will be water sweep distributions expected in the reservoir. The reservoir permeability is in the range of 200 mD to 2000 mD, with a reservoir porosity ranging from 25% to 30%. The pore compressibility is 7×10^{-6} psi^{-1}, oil viscosity is 3.5 cp at reservoir temperature, water viscosity is 0.5 cp at reservoir temperature, and the oil formation volume factor is 1.16 rb/stb. Fig. 2 shows an outline of the reservoir, the position of the water injectors and oil producers, and the timeline of activity of the wells relative to the multiple seismic data surveys. There are 10 years of production activity from 1998 to 2008, and it should be noted that the history match will be implemented for the first 7 years, while the remaining 3 years will be used to validate the history matching process and forecasting ability. It should be also noted that the 3 years used for the forecasting analysis is not really forecast per se, but observed historical data which is held back to validate the history matching exercise. The simulation model was provided by the field operator, and its dynamic properties will be discussed in the next section.

3. Methodology

3.1. Simulation model conditioning

The simulation model used in this study has dimensions of approximately 9600 m by 4900 m by 700 m, and has 128 cells by 53 cells by 35 cells in the X, Y and Z direction respectively. The

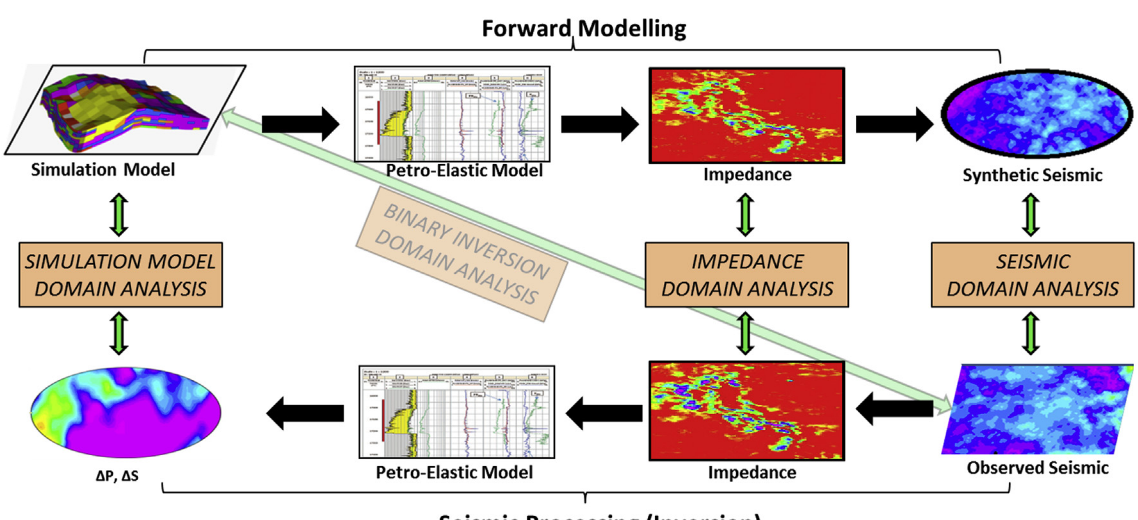

Fig. 1. The different domains at which seismic history matching can be explored – the simulation model domain, the impedance domain, and the seismic domain. The binary inversion domain is proposed as a quick-look reservoir management tool.