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Application of Compositional Simulation in Seismic Modeling and Numerical Well Testing for Gas Condensate Reservoirs

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SUMMARY

Recognition of condensate blockage is important in reservoir monitoring and management since the secondary operations such as gas cycling might need to be triggered to re-pressurize the reservoir. This study addresses the monitoring of a realistic gas condensate reservoir by time-lapse seismic data and transient well test analysis. A compositional reservoir modelling is employed to perform the numerical well test simulation. However, implementing a compositional fluid flow simulation highlights the limitations of the current petro-elastic model (PEM). Therefore we have developed an approach to consider the compositional changes of the fluid in the petro-elastic modelling. The equivalent black-oil model results are cross-validated against the compositional PEM as well. Our results show that the original widely used Batzle & Wang approach should be modified for a gas/condensate system. We show that the response strength of the well testing and the 4D seismic are complementary in each particular flow period (drawdown and build-up) which can be coupled to give useful information for reservoir monitoring purposes.

Introduction

Condensate blockage is a phenomenon in gas condensate reservoirs in which the liquid saturation which is rich in heavy components builds up near the well bore areas during production (retrograde condensation). Increasing the condensate dropout saturation reduces the gas mobility and finally reduces the productivity index possibly as high as 65% (Fan et al., 2005). Recognition of this situation is important in reservoir monitoring and management decision since the secondary operations such as gas cycling would need to be triggered to pressurize the reservoir. This study addresses the monitoring of a realistic gas condensate reservoir by time-lapse seismic data interpretation and transient well test analysis.

We show that the response strength of well testing and the 4D seismic are complementary in each particular flow period (drawdown and build-up). Drawdown well testing is not usually able to show the effect of condensate saturation changes within the test while build-up response can illuminate the near wellbore saturation accumulation (Hamdi et al., 2011). Unlike the well testing behaviour, the condensate effect can be monitored during the drawdown period by the 4D seismic signature. However, during the build-up response the saturation change is small and this prevents a strong 4D seismic signature. Because the liquid phase is not mobile or has a very small mobility, a vast portion of the heavier components will not be produced. Therefore, the composition of the fluid remaining in the reservoir changes with production. This has been modelled through a compositional modelling of the reservoir fluid. However, implementing a compositional fluid flow simulation highlights the limitations of the current petro-elastic modelling in conjunction with fluid composition change. Therefore an effort has also been made in order to take into account the compositional changes of the fluid with time in our seismic modelling. This has also been compared with the typical seismic black-oil modelling approach resulting in some practical guidelines for using the equivalent black-oil models for such compositional systems.

Data analysis

A lumped ten-component, medium-rich condensate fluid system has been inserted into a single-well compositional simulation of a heterogeneous commingled braided-fluvial reservoir. A conventional well-test design including a single drawdown of 20 MMscf/day for 15 days, which is followed by a shut-in period of the 15 days has been simulated. Since the gas compressibility and the gas viscosity are strongly pressure dependent, the associated diffusivity equation is highly nonlinear. However, the diffusivity equation will be linearized by introducing the pseudo pressure function m(p). For gas well test analysis, the pressure terms are replaced by m(p) and the drawdown and the build-up responses are analyzed based on the pseudo-pressure derivative responses on log-log plots. The inertia and the positive coupling effects (Jamiolahmady et al., 2010) have not been considered in this study.

The petro-elastic modelling (PEM) is based on the estimation of the fluid bulk moduli. Batzle and Wang (1992) have proposed a black-oil based correlation for calculating the compressional wave velocity in the oil and the gas. The application of this formulation to gas condensate reservoirs needs specific modification, which mainly affects the gas phase calculation. Different approaches can be implemented for the required modification.

The first approach is applicable when black-oil modelling is desired. In this approach the gas/condensate fluid system is simplified into a binary system composed of “wet-gas” and “live-oil” components. The liquid content of the gas condenses at the surface facilities particularly within multi-stage separators and within the wellbore whenever the pressure falls below “first” dew-point pressure. We have noted that in our system using the specific gravity of the produced “dry gas”, γ_{DG}, will consequently underestimate the gas density by 40%. This eventually reduces the estimated gas and oil bulk modulus by almost 50% as well. The so-called “recombination method” (Gold et al., 1989) is applied in order to calculate the correct well-stream gas gravity. The recombination method has originally been derived for a “wet gas” or a “gas condensate” fluid initially above “first” dew point pressure. In this method the specific gravity of the dry gas and oil, at different separators are recombined with their associated gas-oil-ratios to reproduce the wet gas specific gravity. The calculated gas gravity should also be corrected for effect of “non-hydrocarbon” contents (Sutton, 2005). The pseudo-critical properties of the gas condensate are therefore obtained using Sutton’s method (2005)

$T_{pc}=164.3+357.7\,\gamma_{WG}-67.7\,\gamma_{WG}^2$, in Rankine

$P_{pc}= 744- 125.4\,\gamma_{WG}+5.9\gamma_{WG}^2$, in psi

These pseudo-critical properties are ultimately used in calculations of gas deviation factor (Dranchuk and Abou-Kassem, 1975) and bulk modulus (Batzle and Wang, 1992). In our case, the original dry gas pseudo-critical properties using the original Batzle and Wang method underestimate the reduced pressure and temperature by 10% and leads to an extra 1% error in gas deviation factor calculation. The live oil component, on the other hand contains a considerable amount of gas in solution. The original Batzle and Wang model accounts for the amount of solution gas and then the calculated velocity and bulk modulus of oil are reliable.

The second approach is based on the prediction of fluid properties when the fluid composition is known. Unlike the first approach in which the gas gravity was used to reproduce the pseudo-critical properties here they are directly calculated from the changing gas phase compositions according to the so-called “SBV” method (Stewart et al., 1959). The pseudo-critical properties are then used to calculate gas density and gas deviation factor. For the oil phase, the pseudo-liquid density at standard condition, ρ_{osc}, requires a multi-stage approach following the modified Standing-Katz’s method (Pedersen et al., 1984). In this approach ρ_{osc} has been correlated with the density of the H_2S and propane-plus fraction, $\rho(H_2S+C_{3+})$, the weight percent of methane and N_2 in the entire system, $(m_{C1+N2})_{C1+}$, the density and weight percent of ethane in the (H_2S+C_{2+}) and the density of $(H_2S+CO_2+C_{2+})$. This pseudo-liquid density is then used in calculation of the velocity and predicting the oil bulk modulus (Batzle and Wang, 1992).

Having selected the compositional fluid modelling approach and dry PEM rock parameters calibrated to a real field we implement the Gassmann’s fluid substitution. Dry frame stress sensitivity for sands is calculated using MacBeth (2004) model. A 30 HZ Ricker wavelet was then used to generate synthetic seismic volumes at different drawdown and shut-in times.

Results and discussion

Figure 1 shows a cross-section of saturation changes and associated 4D seismic signatures during drawdown and build-up periods. The drawdown response (Figure 1(A), Figure 1(B)) indicates a stronger amplitude change due to higher rate of the saturation change ($\Delta So=0.16$) while the build-up response (Figure 1(C), Figure 1(D)) has a smaller saturation change (e.g. $\Delta So=0.08$) and subsequently a weaker amplitude change. This is due to the fact that the rate of condensate vaporization during build-up is less than the condensate dropout during drawdown. A detailed comparison of the 4D seismic cross-sections also shows that the 4D signature of the build-up response is associated with a polarity reversal in near wellbore areas. This is explained by the opposite trends of pressure (and saturation) changes during build-up and drawdown. In addition, the lateral change of condensate saturation during build-up and drawdown has also been shown in the RMS amplitude map of the 4D seismic responses (Figure 2). Figure 2 illustrates the fact that a higher saturation change during the15 days of the drawdown period (Fig.2(A)) produces a stronger spatial 4D seismic signature than the 15 days of build-up (Figure 2(B)). The geological well-test response of the model shows a “ramp effect” phenomenon in which the pressure (or pseudo-pressure) derivative response increases over at least one log-cycle on the well test log-log plot (Corbett et al., 2011).This pseudo-pressure derivative rise is affected by the multi-phase flow in near well bore area which in turn causes the derivative response to deviate from that of the ramp effect (Hamdi et al., 2011). Figure 3 shows that the deviation is magnified in the build-up response when the compressible zone is passing over the already accumulated condensate dropout region.

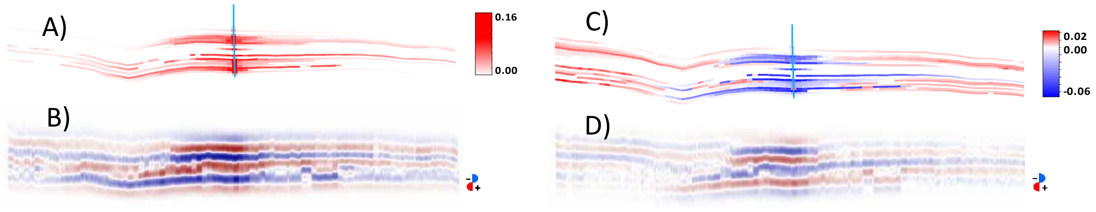

Figure 1 (A, B) vertical cross-section of condensate saturation change during 15 days of drawdown and its corresponding time lapse seismic section. **(C, D)** Saturation change after 15 days of build-up, and its corresponding time lapse seismic section.

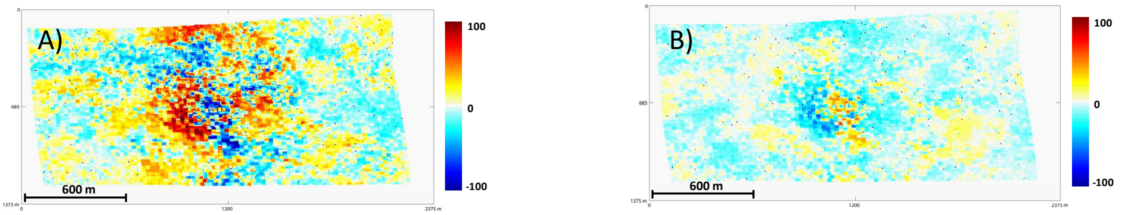

Figure 2 (A) The 4D seismic response for 15 days of drawdown (S15-S0). **(B)** The 4D seismic response for 15 days of build-up (S30-S15). The results are based on compositional fluid modelling.

The early-time hump of the build-up derivative response is an indication of the mobility reduction and associated skin factor. A "long" production time prior to shut-in can dramatically affect the build-up pseudo-pressure derivative response, however due to a short "transient" state (<20 hr in this case), the high saturation change occurred within a "long" shut-in time is not completely captured by the "transient" response considered. This is due to the fact that when the pressure wave hits the external boundaries of the reservoir the pseudo-steady state prevails, which in the case of a multi-layer commingled reservoir, results in flattening and eventually rollover trend of the build-up derivative response at late times.

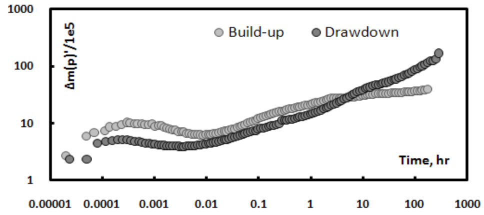

Figure 3 Gas pseudo-pressure derivative responses. Build-up (light colour), drawdown (dark colour).

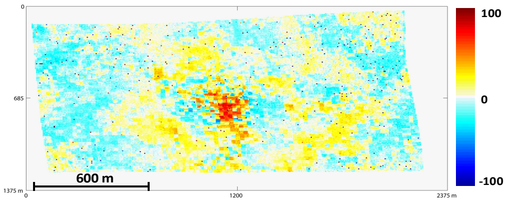

Figure 4 The 4D seismic response during 15 days of build-up (dry gas fluid modelling).

The acoustic properties of fluids from different approaches are summarised in Table 1. These results are for 30 days of gas production. The results show that the compositional and modified black-oil models are in a good agreement, however using dry gas model as it is documented in Batzle and Wang (1992) will result in erroneous values. Specifically gas density and bulk modulus are under-predicted by 40%, and oil bulk modulus by 50%. This will be reflected in the elastic properties of saturated rock, which for our PEM setting can make a difference in impedances of 1%. Depending on the PEM settings and the reservoir production mechanism with a higher rate of fluid composition changes, these differences can be more pronounced. Figure 4 shows the 4D response map of build-up computed from the dry-gas method. This map is remarkably different from the compositional 4D signature. It shows a particular stronger positive amplitude changes near the wellbore area.

	Fluid						Saturated Rock		
	ρ_{gas} (kg/cu.m)	ρ_{oil} (kg/cu.m)	ρ_f (kg/cu.m)	Kg (MPa)	Ko (MPa)	Kf (MPa)	ρ (kg/cu.m)	Vp (m/s)	Vs (m/s)
Dry gas	259.6	520.4	279.2	97.7	269.7	102.6	2204.9	2665.6	1398.9
Modified BO	404.6	529.9	413.7	141.7	495.5	149.7	2230.5	2659.3	1390.9
Compositional	401.9	538.6	412.7	129.5	509.4	137.6	2230.3	2658.1	1391.7

Table 1 The acoustic properties of fluids and saturated rock from different approaches.

Conclusions

The application of compositional numerical well-testing and seismic modelling in a complex gas/condensate reservoir is studied. In such reservoirs the fluid composition is continuously changing. Therefore the original widely used Batzle & Wang approach should be modified for a gas/condensate system. This is achieved with a compositional or a modified black-oil technique. The complementary information extracted from interpretation of well-testing and 4D seismic is coupled to give useful information for reservoir monitoring purposes. This work also highlights the application of compositional simulation in reservoir geophysics. The permanent sensors or seismic nodes might somewhat fulfil the practical requirements of short time-lapse seismic surveys for this study, however quick turnaround in processing and interpretation remains as a challenge to conquer.

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