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History matching and production prediction of a horizontal coalbed methane well

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ABSTRACT

This paper presents a numerical simulation study that demonstrates history matching and production prediction for an actual horizontal coalbed methane (CBM) well located in Australia. A brief analysis of limited core analysis and well log data is presented. Numerical reservoir simulation is used to carry out a manual history matching to the field data of gas and water production rates and well bottomhole pressure. The matching parameters are porosity, relative permeability and skin factor. The reported field data show that there are sharp changes in the well bottomhole pressure and water and gas rates. This response of the reservoir is matched with a numerical model that has a varying skin factor along the horizontal well. This is deemed reasonable given that the drilling fluid has longer contact with the formation at the heel of the well, causing more formation damage. But the field data indicates that the formation damage is mitigated quickly with production. This is explained by the fact that the invaded mud is forced back during water and gas production and coal shrinkage. The production predictions show that skin factor and coal shrinkage have important effects on the CBM production of a horizontal well. However, the coal formation damage controls the gas rate more than the shrinkage for the examined case study with the assumed coal shrinkage parameters.

1. Introduction

Coal is sourced from peat which was buried and converted to coal at appropriate pressure and temperature conditions (Gayer and Harris, 1996). Coal has a dual-porosity system which includes micro-, meso- and macro-porosity and a fracture system composed of butt and face cleats (Laubach et al., 1998). These two systems are also known as the primary and secondary porosity systems (Stevenson and Pinczewski, 1995). Gas is stored primarily in coal by adsorption, which accounts for approximately 95–98% by mole fraction of the gas in place. The rest is stored in pores and fractures (Shi et al., 2008). The butt and face cleats represent the conduit for gas and water flow and the adsorption/desorption is the process that controls gas transport from matrix to cleats (Laubach et al., 1998). For the production of coalbed methane (CBM), the seam is first dewatered which reduces the pore pressure in the face cleats for CBM to desorb from matrix.

Most coal seams are tight with low permeability, hence drilling horizontal or multilateral wells can improve CBM production rate and recovery compared to traditional vertical wells (Keim et al., 2011). Horizontal wells have been successfully drilled in many different coalbed reservoirs (Mutalik and Magness, 2006). As reported in literature, the skin factor is important for gas production (Ding et al., 2006). However, drilling a horizontal well may also cause more damage to coal seams because it requires longer time for the contact between the seam and drilling fluid (Gentzis et al., 2009).

Due to the complicated nature of coal, several critical formation properties such as porosity, permeability and skin factor are difficult to be determined and they change during the primary CBM production. History matching is an efficient method to predict these parameters indirectly by integrating the laboratory and log data (Elrafie et al., 2006; Maschio et al., 2009; Shi and Durucan, 2004a; Shi et al., 2008). However, history matching is a non-unique process, giving similar matches for different combinations of input data. So it is important to validate the outcome after the history matching.

History matching can be performed manually or automatically. Both have been reported in the literature to determine uncertain parameters of coal seams (Bennett and Graf, 2002;

Abbreviations: CBM, coalbed methane; DAF, dry ash free; AMC, ash-moisture content; CH_4, methane; P_L, Langmuir pressure, kPa; V_L, Langmuir volume, m^3/t; Sm^3, volume at surface condition; BHP, bottomhole pressure, kPa; TVD, true vertical depth, m; L_w, well length, m; H, thickness, m; Φ, porosity, %; K, permeability, md; SI, sensitivity index, %

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Oudinot et al., 2005; Shi and Durucan, 2004a; Shi et al., 2008; Stevenson and Pinczewski, 1995). The automatic history matching process seems to be rather difficult for the horizontal wells especially because of the varied skin factor along the well trajectory.

Two wells, a horizontal well (AN_1) and a vertical well (CN_1), have been drilled in an Australian CBM field (Fig. 1). The horizontal well has been produced so far with some key parameters (porosity, relative permeability, coal seam thickness and skin factor), which are crucial for predicting the future CBM production, being still uncertain.

This paper presents a numerical analysis of historical production data of well AN_1 through history-matching and sensitivity analysis. We examine the effects of porosity, coal seam thickness, realtive permeability and skin factor on coal seam production performance. We finally attempt to predict the production performance of well AN_1 using a shrinkage model (Shi and Durucan, 2004b, 2005).

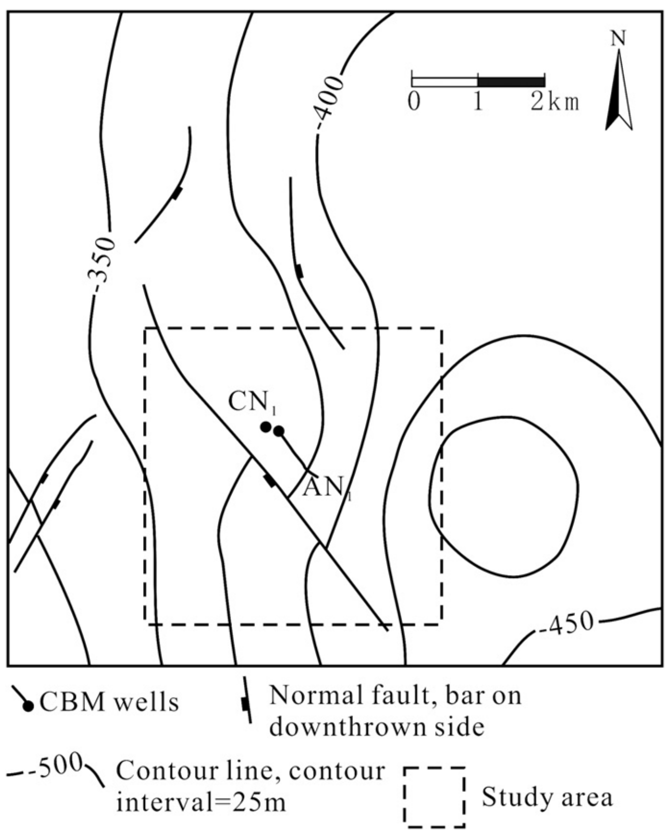

Fig. 1. Contour map of the top depth of the study area.

2. Data analysis

2.1. Gas content measurements and log interpretation

Desorbable gas (Q_1), lost gas (Q_2) and remaining gas (Q_3) volumes were measured in the laboratory using coal samples taken from the field. The raw gas content is the sum of Q_1, Q_2 and Q_3. Table 1 lists the results for 8 samples. The average total gas content is 5.47 Sm^3/ton and the total gas content, based on dry ash-free (DAF), is 15.85 Sm^3/ton.

Coal density was measured using the wire-line logs. The ash-moisture content (AMC) has a strong relationship with the coal density. Fig. 2 shows the relationship between the coal density and AMC. The equation is as follows:

$$C_{AM} = 52.632D_C - 36.097 \quad (1)$$

where C_{AM} is the content of ash-moisture in % and D_C is the coal density in g/cm^3.

The raw gas content can be predicted based on the relationship between the measured AMC and the measured raw gas content. Fig. 3 shows the relationship between the AMC and raw gas content in the study area. The equation is the following:

$$C_{RG} = -0.1356C_{AM} + 14.049 \quad (2)$$

where C_{RG} is the raw gas content in Sm^3/ton.

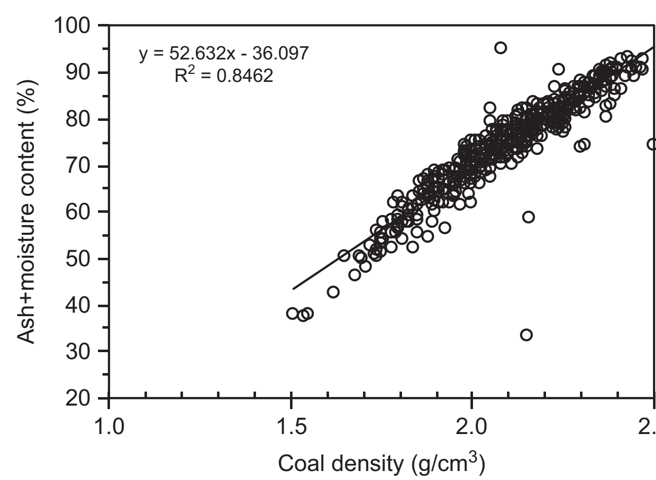

Fig. 2. Laboratory data for the coal density versus ash+moisture content.

Table 1
Gas desorption test results, core samples from the closed well CN1.

Sample number	Depth (m)	Q_1 (Sm^3/ton)	Q_2 (Sm^3/ton)	Q_3 (Sm^3/ton)	Total raw gas (m^3/ton)	Total DAF gas (m^3/ton)	Sorption time (Days)
1	392.39	1.38	2.31	0.22	3.91	13.71	0.14
2	393.27	0.83	1.33	0.25	2.41	11.50	0.21
3	394.28	1.36	2.39	0.61	4.36	14.54	0.21
4	395.25	1.69	3.35	0.50	5.54	12.95	0.17
5	396.22	2.52	4.71	0.08	7.31	21.58	0.13
6	396.70	1.19	2.10	0.32	3.61	15.41	0.13
7	397.21	2.72	4.45	0.49	7.66	17.70	0.11
8	398.24	2.88	5.51	0.56	8.95	19.43	0.14
Average		1.82	3.27	0.38	5.47	15.85	0.16

Note: Q_1 = raw desorbable gas, Q_2 = raw lost gas and Q_3 = raw remaining gas, DAF = dry ash free.