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Discrepancies in the assessment of CO_2 storage capacity and methane recovery from coal with selected equations of state

Part II. Reservoir simulation

Marcin A. LUTYNSKI **, Elisa BATTISTUTTA **, Hans BRUINING **, Karl-Heinz A.A. WOLF **

[*] Silesian University of Technology , Gliwice, Poland. Marcin.Lutynski@polsl.pl

[**] Delft University of Technology (TU Delft), Department of Geotechnology, Delft, The Netherlands

Abstract. Enhanced Coalbed Methane is a technology that helps mitigate CO2 emissions and at the same time recover methane from coal seams. Usually CO2 in coalbeds is stored under supercritical conditions and adsorption, as a crucial parameter, is responsible for the capacity of coalbed to store CO2. In the first part of this study three equations of state with the same set of experimental data were tested. In this study Langmuir parameters serve as an input data for the reservoir simulator. A sensitivity study for the two sets of Langmuir parameters and two permeability values was performed. Although differences in the results of simulation with Langmuir parameters calculated with PR and SW seem to be insignificant, on a larger field scale these discrepancies can be noteworthy. Improper calculation of sorption data may lead into a significant mismatch with field production.

keywords: enhanced coalbed methane, carbon dioxide sequestration, equation of state, sorption in coal

1. Introduction

Enhanced Coalbed Methane is a technology that helps mitigate CO_2 emissions and at the same time recover methane from coal seams. One of the crucial parameters of ECBM is CO_2 adsorption capacity which is measured in laboratory during sorption tests. Calculated model parameters from experimental sorption isotherms are later key input data for reservoir simulators. There are many commercially available simulators which are specifically design to model the CBM/ECBM problems (Law et al. 2002; Hower 2003; Jessen et al. 2007; Wei et al. 2007).

In part I of this study (Lutyński et al. 2011) sorption isotherm calculation with three equations of state as well as Langmuir model fitting was presented. The calculated Langmuir parameters V_L and P_L for Span and Wagner EoS were 0.03648 sm^3/kg and 0.597 MPa, respectively and for Peng Robinson EoS 0.03071 sm^3/kg and

0.406 MPa, respectively. As defined by the ECLIPSE software, cubic meter of gas at standard conditions, that is at 16°C and 1013.25 hPa, per unit mass of coal under *in-situ* conditions is given as sm^3/kg. Soave-Redlich Kwong EoS did not give satisfactory fitting and was rejected for further considerations.

In this study, we investigate the influence of Langmuir parameters calculated in the previous study from raw laboratory data on the results of reservoir simulations.

In order to assess the impact of the calculated parameters on the results of reservoir simulation sensitivity, study with the use of ECLIPSE 300 simulator was performed. The software selected for the study is a three dimensional compositional simulator with a Coalbed Methane option. Basic features of this software are as follows: darcy flow of gas and water in the natural fracture system, adsorption/diffusion of two different gas components at the coal surface, diffusive flow between matrix and natural fracture system, and shrinkage/swelling of coal matrix due to desorption/adsorption of gases.

2. Simulation input data

Simulation grid (Fig. 1) and some of the parameters (e.g. relative permeability) were same as problem set 2 considered by Law et al. (2002). Other input data (depth, permeability, etc.) were typical for the coal basins in Europe. Swelling coefficient and methane sorption capacity were experimentally measured in a laboratory for the same Selar Cornish coal and compared with Durucan et al. 2009.

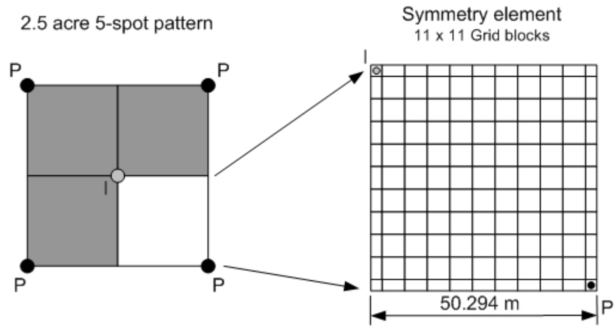

Fig. 1. Schematic diagram of grid system used in simulations

Major input parameters and coalbed characteristics are presented in table 1. The simulation were run for two values of permeability 1.5 md (milidarcy) and 20 md representing tight European coals and permeable US coalbasins respectively.

First case with fracture permeability of 1.5 md considers continuous CO_2 injection and CH_4 production for the period of 730 days whereas the second case (20 md) for the period of 365 days.

Injection rate (full well) was set as 36 000 sm^3/d for the first case (1.5 md) and 120 000 sm^3/d for the second case (20 md). Maximum bottomhole pressure of 15.0

MPa and maximum gas production rate of 20 000 sm^3/day (1.5 md case) and 100 000 sm^3/day (20 md case) were constraints.

In Figures 2 and 4 the results of gas production simulation are presented for both study cases (i.e. 1.5 md and 20 md). In case of low permeability case initial gas production rate calculated with PR is slightly higher than obtained with SW. The difference is insignificant (below 3%) although by the time when CO_2 concentration in the production well is higher than CH_4 the difference is increasing to 13%. These discrepancies are different in case of high permeability case. At the initial stage total gas production is higher in case of SW Langmuir parameters whereas after CO_2 breakthrough the total gas production rate is higher in case of parameters calculated with PR EoS. Figures 3 and 5 present mole fractions of gases in production wells. In either case CO_2 breakthrough time is shorter for the parameters calculated with SW EoS – for the high permeability case the difference is 6 days whereas for the low permeability case this difference is 46 days.

Table 1. Reservoir parameters and mechanical properties of coal used in the sensitivity study simulation

Parameter	Value	Unit
Reservoir properties and initial conditions		
Coal seam depth	1000	m
Coal seam thickness	9	m
Fracture porosity	0.01	-
Temperature	45 (318.15)	°C (K)
Pressure	9.0	MPa
Gas saturation/Water saturation	0.6/0.4	-
V_L (CH_4)	0.024457	sm^3/kg
P_L (CH_4)	0.72	MPa
Mechanical properties of coal		
Young's modulus (*E*)	2.165	GPa
CO_2 swelling coefficient	1.02	kg/m^3
CH_4 swelling coefficient	0.47	kg/m^3
Mechanical compliance	$40.10\cdot10^{-6}$	MPa^{-1}

Higher production rates obtained with SW EoS in the 20 md case at the initial stage can be explained by higher value of calculated V_L parameter. The influence of coal swelling during CO_2 is not that significant in case of high permeability. Therefore, CO_2 injection notably boosts methane production rates. For low permeability coal seams coal matrix swelling plays an important role and inhibits CO_2 migration within the coal. In such case the higher adsorption the bigger swelling and permeability decrease. This effect was observed for laboratory experiments with the same Selar Cornish coal (Mazumder and Wolf 2008). Accuracy of calculated Langmuir parameters has in this case a major impact on the coal matrix swelling as the Palmer-Mansoori compositional model accounts for this effect (Palmer and Mansoori 1998).

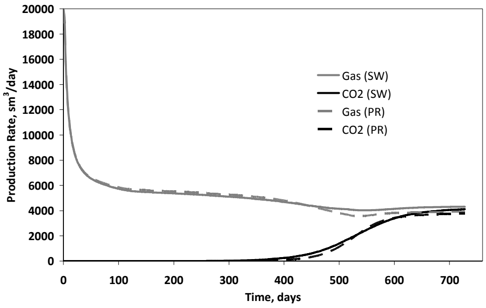

Fig. 2. CO_2 and total gas production rate for 1.5 md permeability case

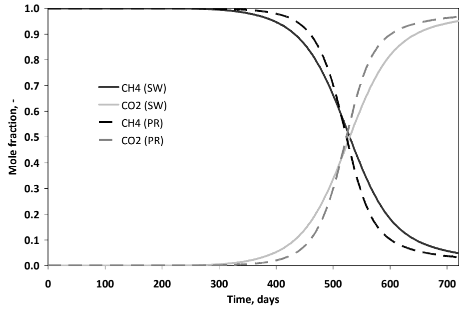

Fig. 3. Production gas composition for 1.5 md permeability case

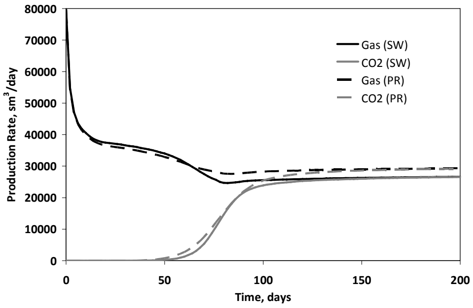

Fig. 4. CO_2 and total gas production rate for 20 md permeability case

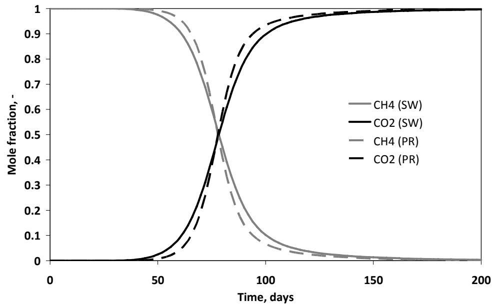

Fig. 5. Production gas composition for 20 md permeability case

3. Conclusions

From the above study it can be concluded that although differences in the results of simulation with Langmuir parameters calculated with Peng-Robinson and Span and Wagner seem to be negligible, on a larger field scale these discrepancies can be significant. More accurate calculation of gas sorption on coal can gives a better fit for history matching. The results of simulation show that selection of representative coal sample for the sorption experiments might be a crucial issue as slight differences in Langmuir parameters are reflected in production rates even for a small area.

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References

Durucan S., Ahsanb M. and Shia J.Q. (2009). Matrix shrinkage and swelling characteristics of European coals. Energy Procedia Vol. 1, Issue. 1. p. 3055-3062.

Hower T.L. (2003). Coalbed Methane Reservoir Simulation: An Evolving Science. SPE Annual Technical Conference and Exhibition. Denver, Colorado, Society of Petroleum Engineers.

Jessen K., Lin W. and Kovscek A.R. (2007). Multicomponent sorption modeling in ECBM displacement calculations. SPE-110258. Proceedings - SPE Annual Technical Conference and Exhibition, Anaheim, CA, November 11 - 14, 2007

Law D.H.-S., Meer L.G.H.v.d. and Gunter W.D. (2002). Numerical Simulator Comparison Study for Enhanced Coalbed Methane Recovery Processes, Part I: Pure Carbon Dioxide Injection. SPE Gas Technology Symposium. Calgary, Alberta, Canada, Copyright 2002, Society of Petroleum Engineers Inc.

Lutyński M., Battistutta E., Bruining H., Wolf K-H.A.A. (2011). Discrepancies in the assessment of CO2 storage capacity and methane recovery from coal with selected Equations of State. Part I - Experimental isotherm calculation. Physicochemical Problems of Mineral Processing 47, 159-168.

Mazumder S. and Wolf K.H. (2008). Differential swelling and permeability change of coal in response to CO_2 injection for ECBM. SPE Asia Pacific Oil and Gas Conference and Exhibition 2008 - "Gas Now: Delivering on Expectations".

Palmer I. and Mansoori J. (1998). How Permeability Depends on Stress and Pore Pressure in Coalbeds: A New Model. SPE Reservoir Engineering (Society of Petroleum Engineers) 1(6): 539-543.

Wei X.R., Wang G.X., Massarotto P., Golding S.D. and Rudolph V. (2007). A Review on Recent Advances in the Numerical Simulation for Coalbed-Methane-Recovery Process. SPE Reservoir Evaluation & Engineering 10(6): pp. 657-666.

Lutynski, M.A., Battistutta, E., Bruining, H., Wolf, K.A.A., Rozbieżności w ocenie ilości składowanego CO2 i odzysku metanu z pokładu węgla jako wynik zastosowania wybranych równań stanu gazu. Część II . Symulacje złożowe, Physicochem. Probl. Miner. Process., 47 (2011) 207-212, (w jęz. ang.)

Intensyfikacja wydobycia metanu z pokładu węgla za pomocą zatłaczania dwutlenku węgla jest technologią, która nie tylko przyczynia się do zwiększenia uzysku tego surowca energetycznego ale jednocześnie zmniejsza emisję CO_2. Pojemność pokładu węglowego jako zbiornika CO_2 wyznacza się na podstawie badań sorpcji w laboratorium. Zaadsorbowany w matrycy węglowej CO_2 znajduje się w stanie krytycznym i pomiar jego sorpcyjności jest istotnym czynnikiem, który determinuje wykorzystanie danego pokładu węgla jako zbiornika tego gazu. W pierwszej części studium dokonano analizy wpływu zastosowanego trzech równań stanu gazu tj. równania Penga-Robinsona (PR), równania Soave-Redlicha-Kwonga (SRK) oraz bardzo dokładnego równania stanu gazu dla CO_2 Spana i Wagnera (SW), jako równania referencyjnego na obliczenie pojemności sorpcyjnej tego gazu na węglu na podstawie tych samych danych eksperymentalnych. Wyznaczone parametry Langmuira posłużyły jako dane wejściowe do symulatora złożowego. W celu określenia wpływu obliczonych parametrów Langmuira na uzysk metanu wykorzystano symulator złożowy ECLIPSE 300 z opcją Coalbed Methane. Symulacje przeprowadzono dla dwóch wartości przepuszczalności pokładu węgla: 1.5 md reprezentującej niskoprzepuszczalne węgle europejskie oraz 20 md reprezentującej wysokoprzepuszczlane węgle północnoamerykańskie. Z przeprowadzonych analiz wynika, że wyznaczenie parametrów izotermy Langmuira dla danych obliczonych za pomocą równania stanu gazu PR zawyża dzienny uzysk gazu w początkowym okresie produkcji w przypadku pokładu o przepuszczalności 1.5 md, natomiast w przypadku pokładu o przepuszczalności 20 md produkcja w początkowym okresie jest zaniżona. Pomimo, że różnice w uzysku gazu dla parametrów Langmuira obliczonych z równania PR i SW wydają się być niewielkie w przypadku większej skali rozpatrywanego problemu różnica ta może być znacząca.

słowa kluczowe: intensyfikacja wydobycia metanu, sekwestracja dwutlenku węgla, równanie stanu gazu, sorpcja na węglu