Fuel 148 (2015) 87–97

Contents lists available at ScienceDirect

Fuel

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

Stochastic reservoir simulation for the modeling of uncertainty in coal seam degasification

C. Özgen Karacan [a,*], Ricardo A. Olea [b]

[a] NIOSH, Office of Mine Safety and Health Research, Pittsburgh, PA, United States
[b] USGS, Eastern Energy Resources, Reston, VA, United States

HIGHLIGHTS

- Coal property realization was used.
- CBM reservoir simulations were conducted.
- History match errors were quantified.
- Uncertainty in results was evaluated.
- Most likely representations of coal properties were determined.

ARTICLE INFO

Article history:
Received 26 July 2014
Received in revised form 13 January 2015
Accepted 14 January 2015
Available online 7 February 2015

Keywords:
Coal seam gas
History matching
Geostatistics
Sequential simulation
Realization
Mean square error

ABSTRACT

Coal seam degasification improves coal mine safety by reducing the gas content of coal seams and also by generating added value as an energy source. Coal seam reservoir simulation is one of the most effective ways to help with these two main objectives. As in all modeling and simulation studies, how the reservoir is defined and whether observed productions can be predicted are important considerations.

Using geostatistical realizations as spatial maps of different coal reservoir properties is a more realistic approach than assuming uniform properties across the field. In fact, this approach can help with simultaneous history matching of multiple wellbores to enhance the confidence in spatial models of different coal properties that are pertinent to degasification. The problem that still remains is the uncertainty in geostatistical simulations originating from the partial sampling of the seam that does not properly reflect the stochastic nature of coal property realizations. Stochastic simulations and using individual realizations, rather than E-type, make evaluation of uncertainty possible.

This work is an advancement over Karacan et al. (2014) in the sense of assessing uncertainty that stems from geostatistical maps. In this work, we batched 100 individual realizations of 10 coal properties that were randomly generated to create 100 bundles and used them in 100 separate coal seam reservoir simulations for simultaneous history matching. We then evaluated the history matching errors for each bundle and defined the single set of realizations that would minimize the error for all wells. We further compared the errors with those of E-type and the average realization of the best matches. Unlike in Karacan et al. (2014), which used E-type maps and average of quantile maps, using these 100 bundles created 100 different history match results from separate simulations, and distributions of results for in-place gas quantity, for example, from which uncertainty in coal property realizations could be evaluated.

The study helped to determine the realization bundle that consisted of the spatial maps of coal properties, which resulted in minimum error. In addition, it was shown that both E-type and the average of realizations that gave the best match for invidual approximated the same properties resonably. Moreover, the determined realization bundle showed that the study field initially had 151.5 million m^3 (cubic meter) of gas and 1.04 million m^3 water in the coal, corresponding to Q90 of the entire range of probability for gas and close to Q75 for water. In 2013, in-place fluid amounts decreased to 138.9 million m^3 and 0.997 million m^3 for gas and water, respectively.

* Corresponding author. Tel.: +1 412 3864008.
E-mail address: cok6@cdc.gov (C.Ö. Karacan).

http://dx.doi.org/10.1016/j.fuel.2015.01.046
0016-2361/Published by Elsevier Ltd.

1. Introduction

Coal seam degasification is an important practice for minable coal seams for two reasons; the first is its proven effectiveness in improving the safety of underground coal mines by reducing the risk of methane explosions through a reduction in coal gas content, and the second is the potential of utilizing produced methane as an unconventional energy source either as pipeline gas or to generate electricity at the mine site [15,23].

It is widely recognized that ventilation of underground coal mines with an adequate amount of dilution air is important to prevent formation of explosive methane–air mixtures. However, when gas contents of coal seams are high, or their structural and reservoir properties favor high methane emissions, ventilation alone may not be enough to keep methane levels within statutory limits, thus increasing the potential for methane ignitions. Coal gas extraction developed in the 70s in the Oak Grove field of the Black Warrior Basin in Jefferson County, Alabama, and initially was intended to reduce high gas content of the Mary Lee coal seam and thus reduce methane emissions into active mine workings. The results of these past efforts showed that methane production using vertical boreholes and combined with hydraulic fracturing significantly decreased frictional ignitions and methane explosion dangers in coal mining [8].

Coal seam gas drainage that started with mining safety in mind has drastically improved since the 70s: for optimum reservoir management, for effective gas injection and production in minable and unminable coal seams, gas capture from abandoned mines, and for gas production and geo-sequestration (e.g. [21,27,18,19,16,20,10,3,26]. Due to the socio-economic importance of these objectives, production analyses (e.g. [1] and coal bed reservoir simulation techniques have been developed and improved over the years, and have remained as one of the most dependable and effective methods of reservoir analysis and management [11]. This is especially true for coal seam reservoir models that are benchmarked using simultaneous multi-well history matching of well production.

The purpose of history matching, especially multi-well, is to gain confidence in the values of assigned coal properties and their distribution within the modeling domain of interest. However, coal seams are more heterogeneous compared to conventional oil or gas reservoirs, and properties that control fluid storage and flow may show significant variations even over small distances [17]. Establishing multiple coal properties and assigning uniform values to match observed productions are deterministic, time consuming, and ultimately may not be effective for multi-well history matching. In order to address this problem and to be able to simultaneously history match multiple wells, Karacan et al. [12] modeled a coal seam degasification area in Indiana using geostatistics to produce average interpolated values for parameters and predictions from E-type realizations of coal properties. The approach included six years of production data from nine wells, allowing for effective simultaneous multi-well history matching. However, in Karacan et al. [12], full advantage of stochastic simulations

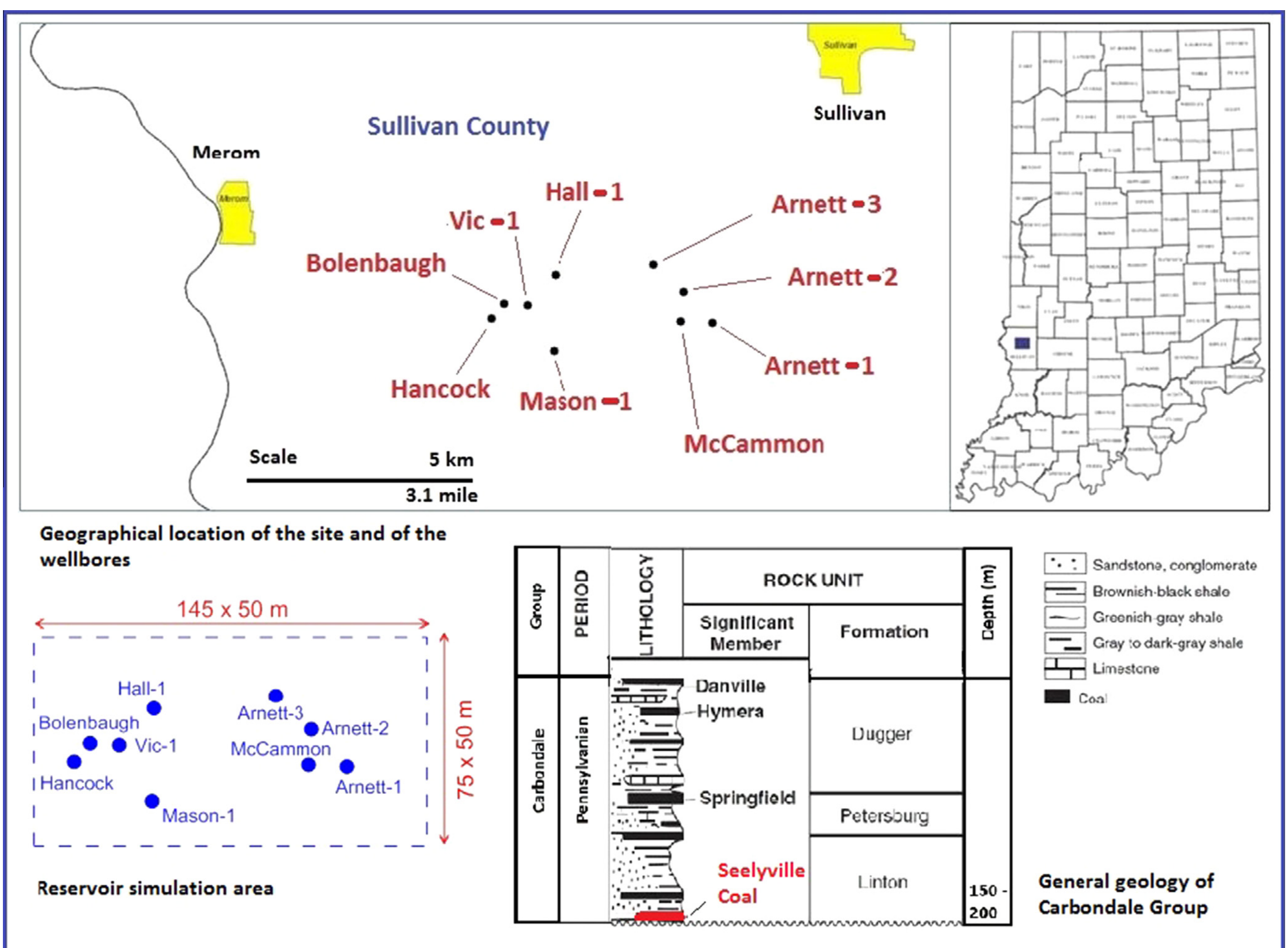

Fig. 1. Location of study area with the coalbed methane wells. General geology of the Carbondale group where Seelyville coal is located and the boundaries and size of the modeled area are also shown.