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Evaluation of gas production from multiple coal seams: A simulation study and economics

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A B S T R A C T

Gas production from multiple coal seams has become common practice in many coal basins around the world. Although gas production rates are typically enhanced, the economic viability of such practice is not well studied. In order to investigate the technical and economic feasibility of multiple coal seams production, reservoir simulation integrated with economics modelling was performed to study the effect of important reservoir properties of the secondary coal seam on production and economic performance using both vertical and horizontal wells. The results demonstrated that multiple seam gas production of using both vertical and horizontal wells have competitive advantage over single layer production under most scenarios. Gas content and permeability of the secondary coal seam are the most important reservoir properties that have impact on the economic feasibility of multiple seam gas production. The comparison of vertical well and horizontal well performance showed that horizontal well is more economically attractive for both single well and gas field. Moreover, wellhead price is the most sensitive to the economic performance, followed by operating costs and government subsidy. Although the results of reservoir simulation combined with economic analysis are subject to assumptions, multiple seam gas production is more likely to maintain profitability compared with single layer production.

1. Introduction

Coalbed methane (CBM), or coal seam gas (CSG), along with shale gas and tight gas, are important unconventional natural gas. The global recoverable CBM resource is estimated to be 49 trillion m^3, accounting for 21.7% of world unconventional gas resources [1]. Gas production from coal seams is also important for coal mining safety as CBM is a hazardous gas in mining [2,3]. Much of the early CBM development has been primarily focused on single coal seams (or groups). Thin seams (i.e., less than 6 m) in the United States were usually bypassed in favor of developing the gas resource in much thicker coals [4], because thick and continuous coalbeds were considered to have greater gas resources. However, with the depletion of more attractive thicker coal seams, development has moved towards thinner coal seams. In many CBM plays, coal seams are generally thin while the total thickness of multiple coal seams through a certain interval can be large [5–9].

Gas production from multiple thin coal seams has become a common practice in many basins. The first commercial production of CBM in Alberta, Canada, was established in 2002 from the Horseshoe Canyon Formation [6] where number of coal seams vary from 5 to 30 per well [7]. In 2012, nearly all coalbed methane wells drilled in Alberta have targeted the thin coal seams in the Horseshoe Canyon Formation (ultimate gas in place 5.07 trillion cubic meters) and Belly River coal zones along the Calgary-Red Deer corridor [8]. In Appalachian basin of southwestern Virginia, the United States, the thickness of a single coal seam is usually 1.5–1.8 m, while total thickness of multiple coal seams can be above 4.6 m [9]. CBM wells are typically completed in 3–5 coal seams and gas production of 250–500 MCFD (6875–13,750 m^3/day) is quite common for a single well [9,10]. In the Black Warrior Basin, the United States, CBM is produced from multiple thin coal seams ranging from 0.3 m to 2.0 m thick distributed through more than 300 m section [11]. Multi-seam completion technology was developed in the Black Warrior Basin to recover gas from numerous coal seams with varied reservoir properties [12]. Multi-seam well completion methods have also been developed at Rock Creek, Alabama project; gas is produced from at least ten thin coal seams over a 122 m interval in the Mary Lee and Black Creek coal groups [13].

Outside of North America, CBM wells completed in multiple coal seams have also been exercised. For instance, wells drilled in

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Hedong coal basin, located along the eastern flank of the Ordos Basin in China, generally targeted up to 10 coal seams with the cumulative coal thickness ranging from approximately 7.6 m to 19.8 m, with individual seams ranging up to 5.8 m in thickness [14]. In Australia, the Bowen and Surat Basins have long been recognized as potential CBM giant with annual CSG production of 337 PJ (9.58 billion cubic meters) [15]. The gas is primarily produced from thin high permeability coals in the Jurassic-age Walloon Coal Measures in the Surat Basin and from several relatively thick Permian-age coal seams in the Bowen Basin [16]. Production from the large number of individual coal seams are co-mingled in a single vertical well in the Surat Basin [16]. The Walloon Coal Measures contain up to 24 seams in the Surat Basin [17]. In 2011, the Surat Basin had overtaken the Bowen Basin as the chief supplier of natural gas in general, but of CSG in particular [16].

Despite common practice of multiple seam production, little has been done to understand the economic viability of such practice, as multi-seam completion costs more than single seam completion. Decreasing profits might occur for multiple seam production despite higher production rate when additional investment cannot be paid back by increased production. This may become unfavorable for maximizing the economic return of the CBM project. Thus the practicality of multi-seam well versus single-seam well should be evaluated based on both the technical and the economic factors.

Efforts have been made to systematically study commingled CBM reservoir production performance from the technical point of view. Clarkson et al. applied pressure transient analysis to Horseshoe Canyon CBM wells production data to study the contribution of each seam on total gas production [18]. Burgoyne and Clements proposed a probabilistic approach to predict CBM well performance using multi-seam well test data [19]. Zhang et al. studied favorable regions for multi-seam coalbed methane joint exploitation based on a fuzzy matter-element model [20]. The impacts of a number of geological factors such as coal thickness, burial depth, gas content, reservoir pressure gradient, and reduced water level on the gas production were analyzed and estimated [20]. In the work of Jiang et al., multiple seam gas production process of a fractured vertical CBM well was simulated using COMET3 numerical simulation software and the interlayer interference mechanism of multi-seam drainage was illustrated [21]. Some effort has been paid to the economic assessment of CBM projects. Dhir et al. presented a technique for determining the economic feasibility of proposed coalbed methane investments [22]. Luo et al. have evaluated CBM development in China by Net Present Value [23]. Nasar et al. compared the economical practicality of different drilling patterns in deep, thick CBM reservoirs under diverse reservoir properties with Net Present Value (NPV) analysis [24]. Sander and Connell conducted the economic assessment of enhanced coal mine methane drainage as a fugitive emissions reduction strategy [25]. However, no work has been done to study multi-layer CBM production from the economic perspective. Moreover, there are no work to study the impact of reservoir properties, such as permeability, reservoir pressure, and gas content, on the economics of the commingled production performance.

The objective of this study is to investigate the technical and economic feasibility of gas production from multiple coal seams under various scenarios with different reservoir properties. Both vertical well and horizontal well were studied to compare the economics. In this work, an approach integrating reservoir simulation and economics modelling was applied. A coalbed methane reservoir simulator, SIMED II was first verified using the field gas production data of a Horseshoe Canyon CBM well to test the applicability of SIMED II in commingled production. Then a series of simulation studies were performed to investigate key properties that affect gas production from multiple coal seam and the economic returns were compared between gas production from multiple-seam and single-seam completions to assist decisions on whether multiple seam production is more profitable.

2. Methodology

2.1. Multiple seam CBM production simulation

Production forecasts are essential for computing anticipated returns from proposed investments. In this work, the coalbed methane simulator, SIMED II, was used to perform the production prediction. SIMED II is a two-phase, three dimensional, multi-component simulator designed to model coalbed methane reservoirs and detailed description of this simulator is documented elsewhere [26]. However, the simulator has not been verified for gas production from multiple coal seams using field data. Therefore, the first step in this work was to use field production data from Horseshoe Canyon CBM well presented in [18] for history match. The detailed reservoir parameters used in the simulation can be found in Clarkson [18], in which a four-layer dry CBM reservoir was analytically modelled. The objective of this validation is to match the commingled production data while simultaneously matching gas rates from each coal layer. The bottom hole pressure (BHP) in Fig. 1 was used to control the well production and the gas production rate was calculated to perform history match. Fig. 2 shows the simulation results of commingled production while single layer rates at 365th day is shown in Fig. 3. It shows that SIMED II simulation of the gas production rate (red color) is in reasonable agreement with the measured production data (blue color) despite derivations after 570 days which may due to adjustment of operation treatment such as re-stimulation [18] and the BHP used in this work is constant after about 300 days.

2.2. Economic evaluation method

Discounted Cash Flow (DCF) method was used to evaluate the economic viability of multiple seam CBM production under different scenarios. This approach is generally adopted in the oil and gas industry [27]. Commonly used indicators include the net present value (NPV), the internal rate of return (IRR), and the payback period [28]. All three indicators were used in this study to provide different and complementary attributes of economic feasibility.

NPV is the present value of cash flows discounted at an average rate i_o. It is a fundamental parameter to express value of a project assuming success [29]. IRR is the interest rate for which the NPV equals to zero. It measures the investment efficiency [22]. Rather than focusing on the return from cash flows, the payback period is the length of time required to recover the cost of an investment [30]. Unlike NPV and IRR, It ignores the time value of money [31]. This indicator is relatively more important to smaller investors,

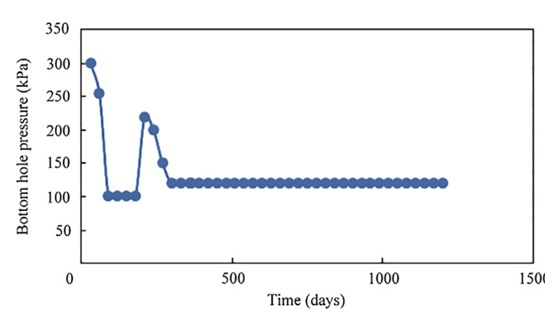

Fig. 1. Bottom hole pressure used in simulation validation.