Applied Energy 131 (2014) 67–78

Contents lists available at ScienceDirect

Applied Energy

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

A sequential approach to control gas for the extraction of multi-gassy coal seams from traditional gas well drainage to mining-induced stress relief

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HIGHLIGHTS

- The gas reservoirs characteristics are measured and analyzed.
- A sequential approach to control gas of multi-gassy coal seams is proposed.
- The design of gas drainage wells has been improved.
- The utilization ways of different concentrations of gas production are shown.

ARTICLE INFO

Article history:
Received 26 November 2013
Received in revised form 19 May 2014
Accepted 13 June 2014

Keywords:
Coalbed methane
Gassy multi-seam
Outburst risk
Gas control

ABSTRACT

As coal resources become exhausted in shallow mines, mining operations will inevitably progress from shallow depth to deep and gassy seams due to increased demands for more coal products. However, during the extraction process of deeper and gassier coal seams, new challenges to current gas control methods have emerged, these include the conflict between the coal mine safety and the economic benefits, the difficulties in reservoirs improvement, as well as the imbalance between pre-gas drainage, roadway development and coal mining. To solve these problems, a sequential approach is introduced in this paper. Three fundamental principles are proposed: the mining-induced stress relief effect of the first-mined coalbed should be sufficient to improve the permeability of the others; the coal resource of the first-mined seams must be abundant to guarantee the economic benefits; the arrangement of the vertical wells must fit the underground mining panel. Tunlan coal mine is taken as a typical example to demonstrate the effectiveness of this approach. The approach of integrating surface coalbed methane (CBM) exploitation with underground gas control technologies brings three major benefits: the improvement of underground coal mining safety, the implementation of CBM extraction, and the reduction of greenhouse gas emissions. This practice could be used as a valuable example for other coal mines having similar geological conditions.

1. Introduction

The strong dependence of Chinese economic development on energy has led to the increasing use of coal products [1,2], which accounts for 70% of the nation's total energy supply [3]. Industrial coal consumption from 2008 to 2035 is expected to grow by 67% [4]. As a result, the mining depth of coalbeds has increased annually by 10–50 m from shallow to deep deposits. The recoverable reserves of coal resources, which is deeper than 1000 m, account for 2.95 trillion tons, or nearly 53% of the total reserves [5]. Based on the demands for coal and the abundance of deep resources, the shift of mining depths from shallow to deep will be inevitable.

With the increase of the mining depth, more and more low gassy mines will be replaced by high gassy outburst-prone mines. The protective seam mining and underground gas pre-drainage are the primary measures to reduce the gas content and to control the outburst [6]. Protective seam measure, through mining the low gassy coalbed (called protective seam) for releasing the gas in adjacent high gassy coalbeds (called protected seam) to ensure the

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http://dx.doi.org/10.1016/j.apenergy.2014.06.015
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safety in mining process, has been widely used in the coal fields of Huainan, Huaibei, Yangquan, Shenyang and other regions [7]. The application of these measures in different geological conditions – short-interburden protective seam [8], distant-interburden protective coal seams [9], and extra-thin protective seam [10] – have been studied by many scholars. The regional pre-drainage measure, i.e., degassing the in situ coalbed through underground boreholes [11], has been used in many coal fields without the use of the protective seam mining measure.

However, for gas control in a deep and gassy multi-coalbed location, a new challenge exists not only in the protective seam mining but also in the regional gas pre-drainage. For protective seam mining, it is difficult to find the appropriate coalbed to be first-mined as the protective seam, because almost all the coalbeds have the risk of an outburst, while the less risky coalbeds are either too thin or high ash content with no economic value to mine. For gas pre-drainage, it requires adequate roadways in strata and boreholes to ensure the effectiveness of drainage. The maintenance costs associated with roadways in deep strata are unavoidable. In a multiple-coalbed formations, a large volume of pressure-relief gas from adjacent coalbeds will migrate into active mining panels as a result of mining excavations. This situation causes the gas emissions of coal mines to increase dramatically to hundreds of cubic meters per minute. The output of coal production is consequently limited by the prevailing ventilation system, due to the excessive high gas emission.

Known as a hazard to mining safety and a powerful greenhouse gas, coalbed methane is also a form of clean and efficient energy [12]. The CBM industry are well-developed in America, Canada, Australia, Poland [13–17] and also in China [18,19]. Surface vertical wells have been introduced to the field of gas control in underground coal mines. The functions of vertical wells can be classified into three major categories: firstly, to conduct hydro-fracturing and improve coalbed gas reservoirs for CBM recovery from surface; secondly, to drain the pressure relief CBM resulting from mining activities [20]; thirdly, to perform gob gas drainage after the coalbed was mined [21,22]. But in most cases, the CBM projects which have been run as a standalone system are not related to the mining process of the coal mine.

Aiming at the problems mentioned above, a concept of gas control was proposed. In general, it can be divided into three stages in chronological order: stage one, the first-mined coalbed reservoir is selected and improved by surface vertical wells and hydro-fracturing to increase the reservoir permeability and eliminate the outburst risk. Stage two, the gas content will get lower by the enhanced underground gas drainage to ensure the efficient and safe mining of the first-mined coalbed. Stage three, during the mining process of the first-mined coalbed the permeability of other adjacent coalbeds will enhanced by the pressure-relief effect. Through the pressure-relief gas drainage by the surface vertical wells and underground boreholes, the outburst risk of all the coalbeds will be eliminated. By integrating the present coal mine gas control method with surface CBM extraction technologies, we improve the selection of the first-mined coalbed standard and maximize the usage of vertical well to achieve high-efficiency co-exploitation of coal and methane. The concept is implemented in practice in the Tunlan coal mine. This case study sets a good example for other coal mines with similar geological conditions.

2. Reservoir characteristics in Tunlan

The selection of Tunlan coal mine for a case study was significant because of following typical reasons: Firstly, it has characteristics of multi-coalbed formations and is generally representative of most of the coalfields in China; Secondly, as more coal mines are aging and have to explore coalbeds in greater depth, gas problems have become a bottleneck for resource exploitation. From 2004 to 2009, Tunlan mine exhibited a record of zero fatality in the metric of DRPMT (death rate per million tons), however, on 22nd February 2009, an extremely serious gas explosion occurred, causing 78 deaths and 114 injuries due to insufficient gas drainage [23]. As a key state-owned coal mine, Tunlan mine has received widespread attention and played an important role in gas control and mining safety.

2.1. Geology

As shown in Fig. 1, Tunlan coal mine is located in the middle part of the Xishan coalfield, which is one of the six major coalfields in Shanxi province at the northern rim of the Qingshui basin. The mine started operation in 2002 with a designed annual capacity of 4 million tons. The main coal bearing strata are the 100 m thick Taiyuan group in the upper series of the Permian and the 60 m thick Shanxi group in the lower series of the Carboniferous. The main minable coalbeds for economic production are the No. 2, No. 4, No. 8 and No. 9 seam, which have an average dip of 7° and are to be extracted by longwall mining method. The permeability of the main minable coalbeds is less than 0.01 md, which is unfavorable for gas drainage in virgin coalbeds. The sequence of the coalbeds is illustrated in Fig. 2.

2.2. Characteristics of gas reservoirs

2.2.1. Coal samples and preparation

The characteristics of the gas reservoirs depend on various deposition environments [24]. The variations of the overburden thickness over each coalbed may influence the sealing effect during methane migration in the hydrocarbon generation period. In the Yanshanian, the temperature field of the coal-bearing strata was changed by the magma intrusion, which resulted in different volumes of thermogenic gas [25,26]. To obtain better understanding of the reservoir characteristics, a series of tests were performed. One coal sample of each coalbed was taken from the tunneling or mining workface (Table 1). The samples were sealed in the package from the site and prepared for the proximate analysis, petrographic analysis, pore size distribution tests and methane adsorption tests.

2.2.2. Method and tests

By using the Automatic Proximate Analyzer 5E-6600, the proximate analysis was performed according to the ISO 17246:2010 [27] test method with particle sizes of 0.074–0.2 mm. The maceral group composition was determined in accordance with the ISO 7403-3:2009 [28]. The pore size distribution was determined by following the ISO 15901-1:2005 [29], using the mercury intrusion method with the AUTOPORE IV 9500 porosimeter and the adsorption of CO_2 method with a gas sorption instrument AUTOSORB-1. Following the GB/T19560-2008 [30] test method, the methane adsorption isotherm was tested at 303 K under standard atmospheric pressure. The samples were all air dried ash-free basis with particle sizes of $0.2\sim0.25$ mm.

2.2.3. Results and discussions

The proximate and petrographic analysis results, as shown in Table 2, indicates that the four samples have similar content of moist, ash and volatile matter. All samples are low-moisture and with moderately ash content. The percentage of volatile and fixed carbon is approximately 20% and 60%, respectively.

Limited by the intrusion pressure, the mercury porosimeter can only be used to measure the distribution of pores larger than 3 nm. The total pore volume, total pore area and porosity of samples are given in Table 3.