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A novel method for estimating methane emissions from underground coal mines: The Yanma coal mine, China

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HIGHLIGHTS

- Neglecting pre-drainaged methane affects the accuracy of most estimation methods.
- *MAIF* method considering the methane release of coal and rock seams was introduced.
- Methane emissions from typical gas outburst coal mines were accurately evaluated.

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ABSTRACT

As the world's largest coal producer and consumer, China accounts for a relatively high proportion of methane emissions from coal mines. Several estimation methods had been established for the coal mine methane (CMM) emission. However, with large regional differences, various reservoir formation types of coalbed methane (CBM) and due to the complicated geological conditions in China, these methods may be deficient or unsuitable for all the mining areas (e.g. Jiaozuo mining area). By combing the CMM emission characteristics and considering the actual situation of methane emissions from underground coal mine, we found that the methane pre-drainage is a crucial reason creating inaccurate evaluating results for most estimation methods. What makes it so essential is the extensive pre-drainage quantity and its irrelevance with annual coal production. Accordingly, the methane releases were divided into two categories: methane pre-drainage and methane release during mining. On this basis, a pioneering method for estimating CMM emissions was proposed. Taking the Yanma coal mine in the Jiaozuo mining area as a study case, the evaluation method of the pre-drainage methane quantity was established after the correlation analysis between the pre-drainage rate and time. Thereafter, the mining activity influence factor (*MAIF*) was first introduced to reflect the methane release from the coal and rock seams around where affected by mining activity, and the buried depth was adopted as the predictor of the estimation for future methane emissions. It was verified in the six coal mines of Jiaozuo coalfield (2011) that the new estimation method has the minimum errors of 12.11%, 9.23%, 5.77%, −5.20%, −8.75% and 4.92% respectively comparing with other methods. This paper gives a further insight and proposes a more accurate evaluation method for the CMM emissions, especially for the coal seams with low permeability and strong tectonic deformation in methane outburst coal mines.

1. Introduction

Methane is a type of clean energy but also a potent greenhouse gas (GHG) (Bibler et al., 1998; Zhou et al., 2014; Li et al., 2015a,b). It has a global warming potential (GWP) 25 times greater than that of carbon dioxide over a horizon of 100 years according to the IPCC fourth assessment report and accounted for 14.3% of the global anthropogenic GHG emissions (IPCC, 2007). Methane is often regarded as the second largest radiative forcing gas after CO_2 and has a remarkable effect on the ozonosphere level (Donald et al., 2002; Warmuzinski, 2008).

In 2009, China was the world's largest energy consumer. Coal still dominates Chinese energy supplies, accounting for 70 percent

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of its energy consumption (Robert and Williams, 2001; Liu and Chen, 2009; Cheng et al., 2011; Zhao and Chen, 2015). The coal production of China increases at a rate of 10% per year from 1 299 million tonnes (Mt) in 2000–3 050 Mt in 2009, and 95% of this coal production comes from underground coal mines (Global BP, 2010; He and Song, 2012; Li et al., 2015a,b). However, due to the coal in China has the characteristic of being more deeply embedded and is of higher rank, underground mines release more methane compared to open-pit mines for the coal embedding deeply and maturing thoroughly (Ju and Li, 2009). According to statistics, Chinese coal mines emit approximately 19 billon m^3 of CH_4 every year into the atmosphere, ranking first in the world and accounting for approximately 1/3 of the industrial total methane emissions in China (Zhang and Chen, 2010; Zhang et al., 2014). Such large-scale emissions not only waste valuable resources but also seriously damage the atmospheric environment.

To systematically evaluate the impacts of methane emission on global climate change and provide a scientific and accurate basis for formulating corresponding emission reduction measures and policies in China, several tools and methods have been developed for estimating them, as shown in Table 1. The IPCC recommends using Emission Factors (*EFs*) as the foundation of CMM emissions estimation, and provides three methods: Tier 1, Tier 2 and Tier 3, each having increasing levels of accuracy. The Tier 1 and Tier 2 approaches require that countries use *EFs* to account for CMM emissions on a national or coal-basin level. However, due to the complicated geological conditions, various reservoir formation types, and different CBM mining methods in quite disparate regions of China, the two approaches could not accurately estimate the actual CMM emission. The Tier 3 method requires the measurement of actual methane drainage quantity and ventilation air methane (VAM) content of every mine around the nation. It has high precision but there is great difficulty in carrying it out (IPCC, 2006). Ju et al. obtained a good estimating result of the CMM emissions in Huaibei–Huainan and Jincheng coalfield by the mining influence coefficient, which was based on the regression analysis of seven typical coalmines' data (Ju et al., 2016). Nevertheless, this method may not always work well, as shown in Fig. 1, from which it can be found that there is not a good linear correlation between methane emissions and coal production. This indicates that coal production is not the only factor determining the methane emissions, and many other factors (such as CMM emission characteristics, the range of disturbed coal and rock seams, the content of methane and the geological conditions) should be taken into consideration. Furthermore, the adoptive methane content in the calculation of mining influence coefficient is the original methane content of coal seam, which is not in line with the actual production. Wang et al. designed a coefficient-intensity factor methodology integrated with IPCC methodology, and obtained the national emission intensity factor is about 9.176 (Wang et al., 2015). Although this method can evaluate the CMM emissions of China to some extent, the relation between methane emissions and storage laws in Chinese is very complex, and even in the same province, there may be a great difference on the geological conditions. So it is difficult to reflect the actual CMM emissions in China solely by one emission intensity factor, moreover, this method is ineffective in forecasting CMM emission.

This paper focuses on the coal seams with low permeability and strong tectonic deformation in coal of methane outburst coal mines. It comprehensively combed the CMM emission characteristics and divided the methane releases into two categories: methane pre-drainage and methane release during mining. On this basis, a new estimation method of methane emissions from underground mines was proposed. Taking the Yanma coal mine as a research case, the estimation method of the pre-drainage methane quantity was established, and the *MAIF* is calculated. Moreover, the prediction indexes of emission were discussed according to the geological conditions of the coal mine. Finally the accuracy and rationality of the new method were ascertained with the six coal mines of Jiaozuo coalfield.

2. Geological setting

Geographically, the Jiaozuo coalfield is situated in the northeast of Jiaozuo city in Henan province, as shown in Fig. 2. Accordingly, the structural location with anarc structure shape is in the south of the Taihang uplift belt generated in the North China plate, which turns from nearly a NNE direction to an EW direction. In addition, the coalfield is located at the transitional zone between the Taihang orogenic belt and the Southern North China structural belt. The Fenghuangling fault, north of which structures develop primarily in the NE and NNE directions, is a divisional fault of the Jiaozuo mining area. The Yanma coalmine is located in the middle of the Jiaozuo coalfield, the specific tectonic position is in the middle of the triangle-shaped fault block, which was formed by three faults: the Jiulishan, Fenghuangling and Fangzhuang. The coalfield displays a stratum strike of N50°-70°E, a SE dip direction, and a dip angle of 4–14°, representing a monoclinal structure. The structure in constructing are mainly the faults in the region with several broad and gentle folds or fluctuation. The structure outline is shown in Fig. 3. The approved production capacity of the coal mine in 2005 was one million tonnes. The working face adopted a longwall inclined slicing experience mining method with full-caving roof management. The main coal seam is the No.2-1 coal

Table 1
The estimation methods of CMM emissions from underground coal mines.

Author(s)	Methods		
IPCC	Underground mining calculation formula: $Q = M \times EF \times Cf - U$ Q: CMM emissions, Gg/y; EF is emission factor, m^3/t; M: coal production, t; Cf: conversion factor; U: CMM utilization, Gg/y.	Methodology Tier 1 approach: EF is 10–25 m^3/t (mining depths of >400 m, EF = 25 m^3/t; mining depths of <200 m, EF = 10 m^3/t; intermediate depths, EF = 18 m^3/t).	EF uncertainty Factor of 2 greater or smaller
		Tier 2 approach: consider basin-specific emission factors.	±50%
		Tier 3 approach: The actual CMM drainage quantity and Ventilation Air Methane of each coal mine.	±2%–30%
Ju et al., 2016	Calculation formula: $M_{ne} = [\eta \times (Q_{ori} - Q_{res})] \times P \times \rho - M_u - 0.98M_f$ M_{ne}: CMM emission, Gg/y; η: mining influence coefficient; Q_{ori}: in-situ virgin gas content, m^3/t; Q_{res}: residual gas content, m^3/t; P: raw coal annual production, t/y; ρ: density of CH_4, 0.67×10^{-6} Gg m^{-3} (20 °C, 1 atm); M_u: annual amount of CMM utilization; M_f: annual amount of CMM simply combustion with no useful energy (flared); 0.98: combustion efficiency of natural gas that is flared.		
Wang et al., 2015	Calculation formula: $REIF = \sum_{i=1}^{3} COC_i \times \frac{P_{Ci}}{P_C}$ REIF: emission intensity factor of a region (m^3/t); COC_i: the classification emission coefficient of an i-type coal mine (m^3/t); P_{Ci}/P_C: the coal production weight of an i-type coal mine.		