Application of stable carbon and hydrogen isotope technology in the determination of gas sources from limestone layers at Shuangliu mine, China

Wei Zhou1,2,4, Sheng Xue1,3,*, Yunchun Han1,2,4 and Chunshan Zheng1,3

1 School of Energy and Safety Engineering, Anhui University of Science & Technology, Huainan 232001, Anhui, China
2 Engineering and Technology Research Institute, Pingan Coal Mining Co., Ltd, Huainan 232001, Anhui, China
3 State Key Laboratory for Mining Response and Hazard Prevention and Control in Deep Coal Mines, Huainan 232001, Anhui, China
4 Huainan Mining Group Co., Ltd, Huainan 232001, Anhui, China

*Corresponding author: Sheng Xue. E-mail: sheng.xue@aust.edu.cn

Received 12 January 2021, revised 24 February 2021
Accepted for publication 12 March 2021

Abstract
Stable carbon and hydrogen isotope technology is used in determining gas sources in coal mines. Coal measures at the Shuangliu mine mainly contain nine coal seams (i.e. No. 2 to No. 10) and five limestone layers (namely, L1 to L5). The coal seams are interbedded with the limestone layers. A large amount of methane is adsorbed in the limestone layer, and the actual measured maximum gas pressure is 1.3 MPa, posing a serious gas emission safety risk in roadway excavation in the coal measures. In order to effectively manage the safety risk of gas emissions, it is necessary to determine gas sources and take necessary control measures. In this study, 50 gas samples were taken from the coal seams and 10 gas samples were collected from the limestone layers. These samples were measured for their composition and stable carbon and hydrogen isotopes. Stable carbon and hydrogen isotope tracer separation technique and multi-source linear calculation methods were used to analyze the measurement results. The study shows that 84% of gas in the L1, L2 and L3 limestone layers comes from the No. 8 coal seam and 11% from the No. 9 coal seam; gas in the L4 limestone layer is mainly from the No. 8 (44%), No. 7 (37%) and No. 6 coal seams (16%), and gas in L5 limestone layer mainly comes from the No. 6 (59%), No. 7 (23%) and No. 8 coal seams (13%). The research results can guide the design of gas drainage boreholes before roadway tunneling, so it has important guiding significance in the formulation of comprehensive gas control schemes.

Keywords: coal mine safety, limestone in coal measures, gas sources, carbon and hydrogen isotopes

1. Introduction

Gas emissions in coal working faces of an underground coal mine mainly come from the coal wall, broken or cut coal, goaf, overlying and underlying coal seams, roof or floor rock strata layers (Xie & Zhao 2005; Han et al. 2019). In order to optimize gas drainage engineering design and achieve effective gas control in a coal mine, it is necessary to understand the exact sources and contribution of gas emissions in coal working faces. Currently, there are two widely used methods in estimating the sources of gas emissions in coal working faces, namely the section measurement method and...
source-based prediction method. The principle of the section measurement method is as follows: first, divide the working face into several functional units; then measure the air flow and gas concentration at the inlet and outlet of each unit; finally, calculate the gas emission of the whole working face (Fan et al. 2004; He 2015). This method can estimate gas volume proportion from broken or cut coal, coal wall and goaf. However, it cannot obtain the gas volume proportion from overlying and underlying coal seams, roof and floor rock layers (Klaus 1998; Xu et al. 2009; Luo et al. 2011). The source-based prediction method is based on empirical parameters such as gas content and gas emission rate of overlying and underlying coal seams to calculate the volume proportion of goaf gas from coal seams. However, this method relies on empirical values and its results are often unreliable. Moreover, it can only get the volume proportion of goaf gas sources and cannot estimate sources of gas emissions into the working face from other sections (Wei & Li 2013).

In recent years, determination of gas sources in coal working face with isotope technology has been gradually developed (Zhou et al. 2018). In this study, gas samples from the No. 2 to No. 10 coal seams and L1 to L5 limestone layers in the Shuangliu coal mine were collected. The volume proportion of limestone gas coming from each coal seam was then determined using isotope technology and a multi-source linear calculation method. Results from this study form guidance for reducing the risk to safety from gas emissions and eliminating gas-related accidents in mining activities.

2. Principle of stable carbon and hydrogen isotope technology for gas source determination

There are only the $^{12}$C and $^{13}$C stable carbon isotopes with tracer significance in nature. Since the natural abundance of $^{13}$C is much lower than that of $^{12}$C, it is difficult to express its isotopic composition with absolute abundance, so its isotopic composition is usually expressed with a relative quantity, that is, with isotope ratio ($^{13}$C/$^{12}$C abundance ratio) value, namely:

$$
\delta^{13}C(\text{‰}) = \left[ \frac{\frac{^{13}C}{^{12}C}_{\text{sample}}}{\frac{^{13}C}{^{12}C}_{\text{PDB}}} - 1 \right] \times 1000.
$$

Carbon is one of the most widely distributed basic elements in nature. Meanwhile, it is also an element of variable valency. Carbon compounds of variable valency could be formed under different physical, chemical and biological conditions. Carbon compounds are widely distributed in the lithosphere, hydrosphere, atmosphere and biosphere. Carbon compounds of variable forms undertake cyclic exchange between organic carbons and inorganic ones in the above-mentioned four spheres. Carbon isotope fractionation happens by the valence process. Generally, light isotope $^{12}$C is easily enriched in organic matter (hydrocarbon and oil being rich in $^{12}$C), while heavy isotope $^{13}$C is easily enriched in inorganic salt (carbonate being rich in $^{13}$C). There are two ways in which isotopic fractionation happens: dynamic fractionation and equilibrium fractionation. The isotopic difference caused by fractionation is the basis of source tracing technology (Dai et al. 1992).

The technical principle of stable carbon and hydrogen isotopes used for tracer identification of gas contained in strata is as follows: in the formation process of strata, different formation ages and environments of strata could result in the difference in carbon and hydrogen isotope fractionation (i.e. dynamic fractionation and equilibrium fractionation) (Liu et al. 2007; Liu et al. 2007; Zheng et al. 2008; Zheng et al. 2008). Therefore, by measuring the carbon and hydrogen isotopes in samples and comparing them with the established reference map or atlas of carbon and hydrogen isotope distribution, the source layers can be inferred (Zhang et al. 2004; Chen et al. 2007).

However, in the study of volume ratio of desorption gas source in closely spaced multiple coal seams, due to the lack of reference system or atlas of carbon and hydrogen isotope distribution in the study area, it is impossible to determine the source layer through the isotope characteristics of desorption gas alone. Therefore, it is necessary to combine the isotope index with a multi-source linear calculation method to calculate the volume ratio of gas sources.

3. Gas geology in Shuangliu coal mine

Shuangliu coal mine is located in the middle section of the Hedong coal field and the east edge of the Ordos Basin. It is in the south of Sanjiao No. 3 coal exploration area of the Liulin Mining Area, Shanxi Province, China. This mining field is about 6 km long from east to west and around 5 km wide from south to north, with an area of 29.6072 km$^2$. Designed annual production capacity of this mine is 3.0 Mt.

Coal measures of Shuangliu coal mine belong to the Carboniferous–Permian System. Meanwhile, coal seams and limestone layers are interbedded with each other. Table 1 shows the sequential occurrence of main coal seams and limestone layers. There are nine main coal seams in the coal measure strata, numbered 2, 3, 4, 5, 6, 7, 8, 9 and 10 from the top to bottom. Limestone layers in coal measures are numbered L1, L2, L3, L4 and L5 from the bottom to top. This mine is gassy and methane is the main component of coal seam gas, followed by N$_2$, CO$_2$ and C$_2$–C$_8$. Based on the number of dynamic phenomena and the response of outburst risk prediction index during the production period of working face, Shuangliu coal mine completes the outburst prediction accuracy rate, non-outburst rate and outburst rate based on a certain number of statistics, and comprehensively
determines that the Outburst Sensitive Index of $3 + 4$ coal seam is gas content and the critical value is $7.24 \text{ m}^3/\text{t}$.

Although the limestone layer does not produce methane and other organic alkanes, the physical form of porous media creates a good condition for gas adsorption. Due to the interaction between limestone layers and coal seams, part of the desorption gas from the coal seam will enter the limestone and be stored in a free or adsorption state with the influence of tectonic movement. In the process of coal mining, limestone gas will be emitted into the mining working face. In the mining plan of the Shuangliu mine, No. 6 to No. 11 coal seams will be extracted, and their main mining roadways will be placed in the limestone layers. Gas pressure in the limestone layers is as high as 1.3 MPa, which poses a great threat to the roadway development safety in limestone layers.

### 4. Distribution characteristics of stable carbon and hydrogen isotopes in desorption gas of coal seams

#### 4.1. Desorption gas sampling and tests

In order to understand the stable carbon in desorption gas of coal seams in the Shuangliu mine, a total of 50 coal samples were taken from the No. 2 to No. 10 coal seams by drilling in-seam boreholes. Table 1 shows the number of coal samples taken from each coal seam. The weight of each coal sample was about 400 g. Those samples were placed in a sample tank, sealed and sent to the ground laboratory immediately after they were taken from borehole. Then, 40 ml of desorption gas was obtained from each coal sample by the thermal desorption method. Its gas composition and stable carbon and hydrogen isotope characteristic values were then analyzed.

Specifically, in compliance with the National Standard of China, the test work was divided into two parts. (i) For the gas composition test, a gas chromatograph (GC-7800, Beijing Purui Analytical Instrument Co.) was used to obtain the composition of desorption gas samples. (ii) The stable carbon isotopes of methane, ethane and carbon dioxide in desorption gas samples were tested with a mass spectrometer (DELTA plus XL, ThermoFinnigan Co.) in accordance with the Chinese Petroleum Industry Standard (Lan et al. 2017).

#### 4.2. Characteristics of desorption gas composition and stable carbon and hydrogen isotope distribution

Table 2 shows the test results of desorption gas composition of standard coal samples in every coal seam of the Shuangliu mine. It can be seen that the desorption gas is mainly methane, followed by carbon dioxide and nitrogen, and trace amounts of ethane. The measured stable carbon and hydrogen isotopes include $\delta^{13}\text{C}_{\text{CH}_4}$, $\delta^{13}\text{C}_{\text{C}_2\text{H}_6}$, $\delta^{13}\text{C}_{\text{CO}_2}$ and $\delta^2\text{H}_{\text{CH}_4}$. These results are shown in figure 1. In these figures, the hollow point represents measured average isotope distribution value, while the linear trend line indicates a change in trend of average isotope distribution value for each of the coal seams.

As shown in figure 1, the measured distribution values of stable carbon and hydrogen isotopes in desorption gas of each coal seam are significantly different. This might be due to the effect of hydrodynamic force of limestone aquifer. In figure 1a and c, the carbon isotope of coal seams No. 2 to No. 5 is lighter than that of coal seams No. 6 to No. 10. Meanwhile, the methane carbon isotope in coal seams No. 2 to No. 5 is 57.44‰, while that in coal seams No. 6 to No. 10 is 50.01‰. The carbon isotope of carbon dioxide in coal seams No. 2

### Table 1. Occurrence of coal seams and limestone layers in coal measurements from the Shuangliu mine

| Strata | Average thickness (m) | Average layer spacing (m) | Recoverable degree | Average buried depth (m) | Quantity of coal samples collected |
|--------|-----------------------|--------------------------|-------------------|--------------------------|-----------------------------------|
| 2      | 0.75                  | 10.13                    | Locally recoverable | −644.7                   | 4                                 |
| 3      | 1.4                   | 3.6                      | Recoverable        | −655.58                  | 8                                 |
| 4      | 3.28                  | 69.5                     | Recoverable        | −660.58                  | 8                                 |
| 5      | 0.35                  | 21.5                     | Non-minable        | −733.36                  | 2                                 |
| L5     | 4.7                   | 0                        | Non-minable        | −754.71                  | 4                                 |
| 6      | 0.56                  | 3.7                      | Non-minable        | −759.41                  | 4                                 |
| L4     | 9.8                   | 0                        | Non-minable        | −763.67                  | 4                                 |
| 7      | 0.37                  | 6.75                     | Non-minable        | −773.47                  | 4                                 |
| 7–1    | 0.24                  | 1.05                     | Non-minable        | −784.26                  | 4                                 |
| L2     | 4.1                   | 0                        | Non-minable        | −785.55                  | 8                                 |
| L1     | 4.3                   | 0                        | Non-minable        | −789.65                  | 4                                 |
| 8      | 3.92                  | 5.81                     | Recoverable        | −793.95                  | 8                                 |
| 9      | 4.61                  | 2.47                     | Recoverable        | −803.68                  | 8                                 |
| 10     | 0.74                  |                          | Non-minable        | −810.76                  | 4                                 |

(Average interval refers to the average vertical thickness of the strata between the roof of the lower coal seam and the floor of the upper coal seam.)
Table 2. Average composition and stable isotope values of desorption gas in coal samples of each coal seam

| Coal seam | CH₄ Average % | C₂H₆ Average % | N₂ Average % | CO₂ Average % | δ¹³C(CH₄) Average‰ | δ¹³C(C₂H₆) Average‰ | δ¹³C(CO₂) Average‰ | δH(CH₄) Average‰ |
|-----------|----------------|----------------|--------------|--------------|------------------|------------------|------------------|------------------|
| 2         | 91.16          | 0.009          | 4.74         | 4.09         | −44.23           | −44.23           | −16.22           | −13.15           |
| 3         | 88.29          | 0.007          | 6.15         | 5.55         | −49.87           | −49.87           | −16.88           | −16.04           |
| 4         | 89.3           | 0.006          | 6.32         | 4.38         | −51.06           | −51.06           | −15.09           | −16.17           |
| 5         | 89.3           | 0.01           | 6.56         | 4.04         | −53.42           | −53.42           | −18.86           | −16.79           |
| 6         | 85.65          | 0.008          | 6.94         | 7.41         | −52.24           | −52.24           | −16.47           | −16.77           |
| 7         | 86.44          | 0.005          | 6.56         | 7.00         | −50.78           | −50.78           | −14.74           | −16.37           |
| 8         | 86.32          | 0.004          | 6.12         | 7.56         | −54.86           | −54.86           | −14.22           | −16.08           |
| 9         | 85.79          | 0.005          | 5.83         | 8.37         | −60.01           | −60.01           | −15.07           | −17.70           |
| 10        | 86.31          | 0.004          | 5.37         | 8.31         | −60.44           | −60.44           | −13.8            | −18.29           |

Figure 1. Box-plots of isotopic distribution. (a) Average distribution values of carbon isotopes of methane; (b) box-plot diagram of carbon isotopes of ethane; (c) average distribution values of carbon isotopes of carbon dioxide and (d) average distribution values of hydrogen isotopes of methane.

to No. 5 is 17.14‰, when that in coal seams No. 6 to No. 10 is 15.81‰. Thus, with the increase in coal seam number (burial depth), values of methane carbon isotope and carbon dioxide isotope both gradually become heavier (the absolute value becomes smaller).

As shown in figure b and d, the ethane carbon and methane hydrogen isotopic values in desorption gas of each coal seam become slightly lower (the absolute value increases with the increase in coal seam number burial depth), but experience big fluctuation. Among them, the average ethane carbon isotope of coal seams No. 2 to No. 5 is 14.49‰, while that of coal seams No. 6 to No. 10 is 16.15‰. At the same time, the average methane hydrogen isotope of coal seams No. 2 to No. 5 is 174.71‰, and that of coal seams No. 6 to No. 10 is 177.49‰. These results show that carbon isotope value of ethane decreases slightly with the increase in
5. Identification of gas sources in limestone

5.1. Computational model

Taking a coalbed methane mixture from two sources as an example, according to the principle of mass conservation, it is assumed that the measured carbon isotope value of CH$_4$ in the first source gas is $\delta_A$ and the volume ratio of CH$_4$ is $V_A$. The measured carbon isotope value of CH$_4$ in the second source gas is $\delta_B$ and the volume ratio of CH$_4$ is $V_B$. The carbon isotope value of CH$_4$ in the mixture of gases from two sources is mixed, assuming that the mixture of gases is only a physical process. For the mixed gas per unit volume, $V_A = A \cdot X_A$ and $V_B = B \cdot X_B$. The formula is as follows:

$$\delta_{mix} = \frac{V_A \cdot \delta_A + V_B \cdot \delta_B}{V_A + V_B} = \frac{A \cdot X_A \cdot \delta_A + B \cdot X_B \cdot \delta_B}{A \cdot X_A + B \cdot X_B}$$

(1)

where $A$ and $B$ are the proportions of the gas from the first coal seam and the gas from the second coal seam in the mixed gas, respectively, and $A + B = 1$; $A$ and $B$ are unknown values. By extending this model, the source proportion of mixed gas can be solved (Schole 1983; Gao 1997). Based on the equation (1) derivation, when the mixed gas is $n$ end elements, the formula for calculating stable isotopes in the mixed gas can be expressed as equation (2):

$$\begin{align*}
\delta_{mix} &= \frac{A \cdot X_A \cdot \delta_A + B \cdot X_B \cdot \delta_B + \cdots + n \cdot X_n \cdot \delta_n}{A \cdot X_A + B \cdot X_B + \cdots + n \cdot X_n} \\
A + B + \cdots + n &= 1
\end{align*}$$

(2)

The $n$-element equation group can be set up and could be solved by MATLAB software for realizing its use in this study.

5.2. Source identification of desorption gas in limestone

During the roadway development in the limestone layer of the Shuangliu mine, exploratory boreholes are always drilled into the limestone in advance to reduce gas pressure and content. In this study, the gas sampling location is at the roadway excavation face. Figure 2 shows the borehole layout used for collecting gas samples in limestone layer. To analyze the source of limestone gas, the desorption gas samples from limestone layers L1 to L5 were collected in the return air flow during roadway development. Two samples were collected from each layer, thus a total of 10 gas samples were obtained.

Based on the measured results of composition and carbon and hydrogen isotopes in desorption gas of coal seams and limestone layers (shown in Tables 2 and 3). Limestone gas sources were calculated using equation (3), The results are shown in Table 4. Meanwhile, figures 3–7 are the source-distribution charts of limestone gas (in limestone layers L1 to L5).

The source structure characteristics of limestone gas in each layer reflected in figures 7–11 can be summarized as follows: gas sources of limestone layers L1–L3 are mainly No. 8 and No. 9 coal seams, with an average contribution of 84 and 11%, respectively, while the gas sources of limestone layer L4 are mainly the No. 8, No. 7 and No. 6 coal seams, with average contributions of 44, 37 and 16%. The gas of limestone layer L5 largely comes from the No. 6, No. 7, No. 8 coal seams, with average contributions of 59% 23 and 13%, respectively. Desorption gas of No. 9, and No. 10 coal seams have little effect on gas in limestone layers L4 and L5.

From these test and calculation analysis results, it can be concluded that the proportion of gas sources of adjacent coal seams in the limestone gas of the L1–L5 layers is quite different. According to the sources of limestone adsorbed gas, it can be divided into three groups: L1, L2 and L3 limestone desorption gas mainly comes from coal 8; L4 limestone desorption gas mainly comes from coal 7 and 8 and L5 limestone desorption gas mainly comes from coal 6. To explain these results, it is necessary to combine the components and
Table 3. Test values of gas components and carbon and hydro isotopes in limestone layers

| Sequence number of limestone | Time               | CH₄ (%) | C₂H₆ (%) | CO₂ (%) | N₂ (%) | δ¹³CCH₄ (‰) | δ¹³CC₂H₆ (‰) | δ¹³CCO₂ (‰) | δ²HCH₄ (‰) |
|-----------------------------|-------------------|---------|---------|--------|-------|------------|------------|------------|----------|
| L1                          | 7 January 2019 12:00 | 76.327  | 0.015  | 11.38  | 12.28 | −63.052    | −3.960      | −11.116    | −197.520  |
|                             | 7 January 2019 12:00 | 75.668  | 0.017  | 13.41  | 10.90 | −63.428    | −3.473      | −9.370     | −199.245  |
| L2                          | 7 January 2019 10:50 | 74.323  | 0.016  | 14.53  | 11.13 | −64.558    | −3.716      | −8.645     | −202.872  |
|                             | 7 January 2019 10:50 | 75.197  | 0.012  | 13.69  | 11.11 | −63.743    | −4.955      | −9.155     | −200.523  |
| L3                          | 5 January 2019 17:30 | 73.905  | 0.008  | 14.63  | 11.46 | −64.297    | −7.408      | −8.466     | −203.814  |
|                             | 5 January 2019 17:30 | 74.165  | 0.017  | 13.09  | 12.73 | −64.146    | −3.490      | −9.467     | −203.161  |
| L4                          | 18 January 2019 11:05 | 75.235  | 0.014  | 13.75  | 11.00 | −60.983    | −5.295      | −8.760     | −199.888  |
|                             | 18 January 2019 11:05 | 74.092  | 0.015  | 14.26  | 11.64 | −61.949    | −5.052      | −8.488     | −203.014  |
| L5                          | 14 February 2019 18:35 | 75.452  | 0.014  | 13.65  | 10.88 | −59.898    | −7.680      | −9.018     | −200.424  |
|                             | 14 February 2019 18:35 | 74.175  | 0.013  | 14.38  | 11.43 | −61.148    | −7.893      | −8.560     | −203.704  |

Table 4. Detailed list of the proportion of different sources of gas samples in each limestone layer

| Stratas | Time               | No. 6 coal | No. 7 coal | No. 8 coal | No. 9 coal | No. 10 coal |
|---------|-------------------|-----------|----------|-----------|-----------|------------|
| L1      | 7 January 2019 12:00 | 0.00      | 0.00     | 0.82      | 0.14      | 0.04       |
|         | 7 January 2019 12:00 | 0.00      | 0.00     | 0.85      | 0.12      | 0.03       |
| L2      | 7 January 2019 10:50 | 0.00      | 0.00     | 0.86      | 0.14      | 0.01       |
|         | 7 January 2019 10:50 | 0.00      | 0.00     | 0.86      | 0.14      | 0.00       |
| L3      | 5 January 2019 17:30 | 0.00      | 0.08     | 0.82      | 0.06      | 0.04       |
|         | 5 January 2019 17:30 | 0.00      | 0.06     | 0.84      | 0.08      | 0.02       |
| L4      | 18 January 2019 11:05 | 0.14      | 0.37     | 0.45      | 0.03      | 0.01       |
|         | 18 January 2019 11:05 | 0.17      | 0.36     | 0.42      | 0.01      | 0.04       |
| L5      | 14 February 2019 18:35 | 0.62      | 0.22     | 0.11      | 0.03      | 0.02       |
|         | 14 February 2019 18:35 | 0.55      | 0.24     | 0.15      | 0.03      | 0.03       |

Figure 3. Gas sources in limestone layer L1.

isotopes of mixed gas in limestone. The results show that the desorption gas of L1, L2 and L3 limestone mainly comes from No. 8 coal, which is also the result of physical mixing of gas components and hydrocarbon isotopes in each source layer according to the proportions in Table 4. This process can be checked according to the principle of mass conservation. Taking the methane carbon of the first group of desorption gas of L1 limestone as an example, equation (5) can be
After substituting equation (5) into the numerical value, the result is as follows:

\[
-63.052\% \times 76.327\% = 0 \times 85.65\% \times (-52.24\%) \\
+ 0 \times 86.44\% \times (-50.78\%) \\
+ 82\% \times 86.32\% \times (-54.86\%) \\
+ 14\% \times 85.79\% \times (-60.01\%) \\
+ 4\% \times 86.31\% \times (-60.44\%)
\]

According to equation (5), the carbon mass of mixed gas methane in L1 limestone is $-4812.57$ (dimensionless value). The influencing factors of this mass include not only the isotope and composition of the main source bed 8 coal, but also the hydrocarbon isotope and composition of the secondary source bed 9 and 10 coal. The mixed gas source of L2–L5 limestone can also be analyzed by this method.

In addition, the accuracy of the source separation conclusion can be explained from the spatial location of the coal seam and limestone. Similarly, taking the gas desorption of L1–L3 limestone as an example, according to
Table 1, the distance between No. 8 coal and L1 limestone is 0, and the farthest L3 limestone is only 2.36 m and its gas content and pressure first affect L1–L3 limestone. Therefore, if L1–L3 limestone gas has a significant impact on mining, it is a fundamental strategy for limestone gas control to take targeted control measures for the No. 8 coal seam gas in advance.

6. Conclusions

This study concentrates on determining gas sources in limestone layers of the Shuangliu coal mine by adopting stable carbon and hydrogen isotope technology. The following conclusions were obtained:

The measured distribution values of stable carbon and hydrogen isotopes in desorption gas of each coal seam are significantly different. This might be due to the effect of hydrodynamic forces of the limestone aquifer. With the increase in coal seam depth, values of methane carbon and carbon dioxide isotopes both gradually become heavier (the absolute value becomes smaller). Meanwhile, the ethane carbon and methane hydrogen isotopic values become slightly lighter (the absolute value rises) with the increase in coal seam depth, but experience big fluctuation.

By using a multi-source linear gas source calculation model based on the measured values of gas components and isotopes, gas source analyses in L1–L5 limestone layers are conducted. Gas sources of L1–L5 limestone layers are quite
different during roadway development. Gas in L1–L3 limestone layers comes mainly from the No. 8 coal seam, with an average contribution of 84%. Gas in L4 limestone is mainly from the No. 8 coal seam with an average contribution of 44%, and from the No. 7 (37%) and No. 6 coal seams (16%). The gas in L5 limestone largely comes from the No. 6 (59%), No. 7 (23%) and No. 8 coal seams (13%).

The main influencing factors include composition and the carbon and hydrogen isotopic values of limestone mixed gas, as well as composition and carbon and hydrogen isotopic values of each source layer. Therefore, the influences of gas description of each layer of limestone on mining engineering are different, and the main coal seam gas source corresponding to each limestone layer should have drainage measures taken in advance.

Acknowledgements

This research was funded by the National key R&D Program of China (grant no. 2018YFC0808000), and National Natural Science Foundation of China (grant no. 51904013). These funds are gratefully acknowledged.

Conflict of interest statement. None declared.

References

Chen, Z.H., Song, Y. & Qin, S.F., 2007. Geochemical characteristics of CBM reservoirs in southern Qinshui basin, Natural Gas Geoscience, 18, 561–564 (in Chinese).
Dai, J.X., Pei, X.G. & Qi, H.F., 1992. Natural Gas Geology of China, 1st edn. Beijing, China: Petroleum Industry Press, 143–145 (in Chinese).
Fan, M.C., Yang, S.Q., Wang, G.C., Xiao, J. & Yuan, C.Z., 2004. Element method measurement and analysis on gas resources and gas distribution in fully mechanized coal mining face, Coal Science and Technology, 32, 23–27 (in Chinese).
Gao, X.Z., 1997. Volume evaluation of the gas mixed with other gases using carbon isotopic compositions, Acta Sedimentologica Sinica, 15, 63–65 (in Chinese).
Han, Y.C., Yang, L.Q., Ren, B., Duan, C.R., Chen, B.L., Deng, D.S. & Li, Z.B., 2019. Research status of gas emission source prediction of coal mines in Inner Mongolia Coal Economy, 5, 553–556 (in Chinese).
He, H.P., 2015. Analysis on site measurement of gas sources and the dis-