Study on the Influence Law of Gas Pressure on Methane Concentration Measurement

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Abstract: The measurement accuracy of the infrared methane concentration sensor is greatly affected by the gas pressure. There is a large error between the measured value and the true value, when measuring under negative pressure of the underground gas drainage pipeline. The Methane concentration measurement experiment under negative pressure of 40～90KPa (absolute pressure) has been conducted in laboratory. The influence of gas pressure on methane concentration measurement was analyzed by the results. And then a nonlinear-segmentation pressure compensation model for negative pressure was worked out according to experiment data. The errors of measured methane concentration value after compensation were under ±0.05%CH_4 in the range of 0 to 1%CH_4 and under ±7.0% of truth-value in the range of 1% to 100%CH_4. The research results show that the pressure compensation model could adapt the negative pressure of gas extraction system, and meet the requirements of methane concentration measurement in the pipe for gas extraction.

1. Introduction

Methane concentration sensor can be divided into light interference sensor, catalytic sensor, infrared sensor and laser sensor according to the measurement principle [1]. The light interference sensor and catalytic sensor have problems of short tuning period and large influence on environmental factors. Laser sensors are costly, and infrared sensor is still the most widely used for gas drainage system monitoring. Methane only absorbs certain segments of infrared light in infrared light, so the methane concentration of the gas can be detected based on the difference between the intensity of the incident light and the emitted light. When the gas pressure changes, the energy absorbed by the infrared rays also changes. Therefore, the measured concentration value of the same concentration gas different pressures are different. There is a considerable error between the measured value and the true value. The measurement error can be reduced by pressure compensation, on the basis of analyzing the influence law of gas pressure on methane concentration measurement [2].

The pump forms a negative pressure lower than the external atmospheric pressure in the mine gas drainage system. The gas is pumped out in the coal seam and transported to the ground in the pipeline driven by the pressure gradient. The working condition of the methane concentration sensor is negative pressure environment. At present there are many research on the pressure compensation of infrared methane concentration under positive pressure environment, but less study on the compensation under negative pressure. The former compensation model is not applicable to the latter. Liu Yan et al proposed a design scheme of mine infrared methane sensor with temperature and pressure compensation function [2], but the test data was few and no clear pressure compensation model was proposed; Li Xiaogang and Wang Cong proposed the pressure compensation method of infrared methane sensor respectively [3,4], but the experimental pressure was mostly in the positive pressure range, which is not suitable for the pressure range of 40-80kPa which is common in current underground gas extraction systems. Therefore, it is necessary to study the influence law of gas pressure on methane concentration measurement according to the

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characteristics of mine gas drainage system, for improving the accuracy of mine gas drainage monitoring.

2. Working principle of infrared methane sensor

The measurement of the infrared methane sensor is based on the infrared selective absorption principle of gas molecules, and the infrared absorption spectra of different gases are different. When the infrared ray pass through the gas, the methane molecules absorb infrared rays of a specific wavelength. The absorption intensity and the methane gas concentration conform to the Beer-Lambert law [5]. The transmitted light intensity can be expressed by the formula (1),if the I_0 light intensity monochromatic light transmitted through a gas medium having a length L.

$$I = I_0\, e^{-kLc} \tag{1}$$

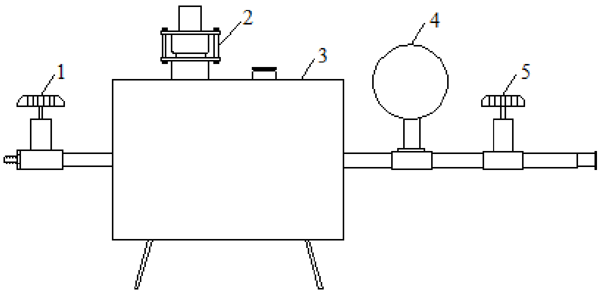
In formula (1), I is intensity of the emitted light; I_0 is intensity of the incident light; k is absorption coefficient per unit length; L is the optical path; c is gas concentration of the gas.

The absorption coefficient k is in the formula (1) is a comprehensive variable, which is affected not only by physical parameters such as gas type and light wavelength, but also by environmental conditions such as temperature and pressure. The absorption coefficient k and the pressure p have a specific correspondence relationship. According to the analysis data of the infrared sensor measurement test under different pressures, a corresponding pressure compensation model can be established to improve the measurement accuracy of the methane concentration.

3. The influence law of gas pressure on methane concentration measurement

3.1 Test method

In order to simulate different pressure environments, a test device with adjustable ventilation pressure was designed and prototyped, as shown in Fig.1.



1,5-needle valve 2. methane sensor 3. gas chamber 4. digital display pressure sensor;

Fig.1 Methane concentration measurement test device at different pressures

The device is equipped with infrared methane, pressure and temperature sensors. Each of the front and rear air inlets is provided with a needle valve. The air inlets are respectively connected to standard methane cylinders of different concentrations, and the air outlets are connected to the vacuum pump. For the same concentration methane, the pressure change in the gas chamber is controlled by the front and rear needle valves and the vacuum pump. During the test, the temperature of the chamber is not changed or is small, and the influence of temperature on the test results can be ignored.

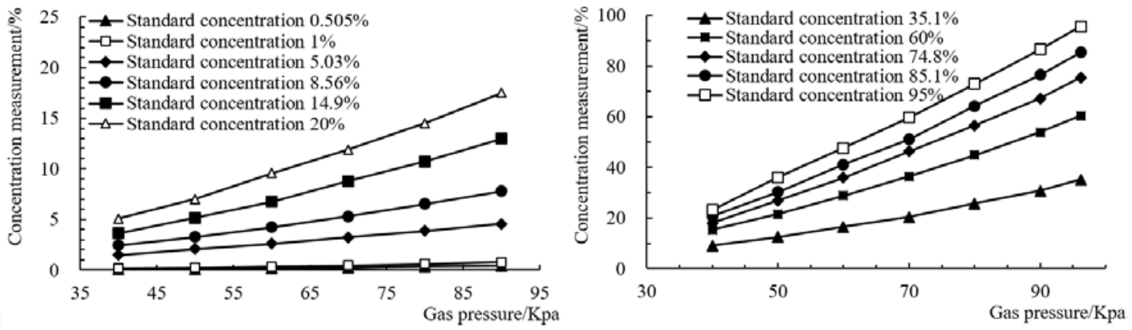
3.2 Analysis of Test data

The methane concentrations of the standard gas selected in this test were 0.505%, 1%, 5.03%, 8.56%, 14.9%, 20%, 35.1%, 60%, 74.8%, 85.1%, 95%. The test pressure was 40KPa, 50KPa, 60KPa, 70KPa, 80KPa, 90KPa, and the test temperature was 25 °C. The measurement results of methane concentration under different pressures are shown in Table 1. The measurement data in Table 1 had be plotted as a concentration measurement curve at different pressures, as shown in

Fig.2.

Table1 Concentration measurement data at different pressures

Gas concentration *c*[%]	Gas pressure *p* [KPa]					
	40	50	60	70	80	90
0.505	0.07	0.12	0.19	0.25	0.33	0.41
1	0.15	0.24	0.35	0.46	0.62	0.78
5.03	1.50	2.09	2.60	3.22	3.86	4.57
8.58	2.46	3.29	4.24	5.33	6.54	7.78
14.9	3.65	5.18	6.76	8.80	10.7	13.00
20	5.09	7.03	9.57	11.90	14.5	17.50
35.1	9.04	12.53	16.47	20.40	25.7	30.67
60	15.33	21.57	28.83	36.43	44.8	53.87
74.8	17.97	26.93	35.87	46.23	56.5	67.23
85.1	20.60	30.33	41.10	51.03	64.3	76.53
95	23.23	36.13	47.60	59.70	72.97	86.63



(a)Concentration measurement curve in the range of 0-20% (b) Concentration measurement curve in the range of 35.1%-95 %

Fig.2 Concentration measurement curve at different negative pressures

It can be seen from the test data that the gas pressure has a greater influence on the measured value of the infrared methane sensor. For the same concentration of standard methane gas, as the absolute pressure of the gas decreases (the negative pressure increases), the concentration measurement decreases and the error increases. The concentration measurement and the gas pressure are basically or exponentially related, so it can be determined that pressure compensation for methane concentration is feasible. However, different concentrations of standard methane gas have different degrees of influence, which needs further analysis.

3.3 Establishment of pressure compensation model

First, draw the corresponding relationship curves between the standard gas concentration and the measured concentration of methane sensor at different pressure, as shown in Fig.3.

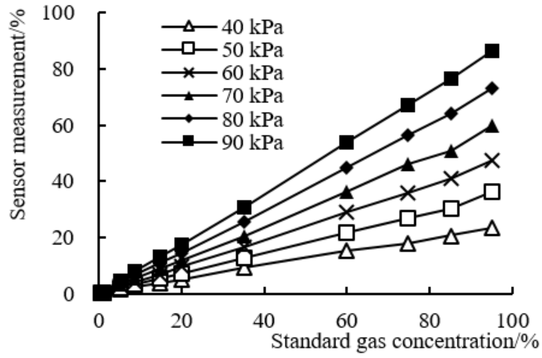


Fig.3 Correspondence between standard gas concentration and sensor measurement concentration

It can be seen from Fig.3 that the measured values of the methane sensor are linear with the standard gas concentration at different pressure conditions. The curve has been fitted by mathematical method to obtain the fitting formula of the relationship between the measured value of the sensor and the standard gas concentration [7]. The formula parameters are shown in Table 2.

Table 2 Equation parameters of Standard gas and sensor measurement concentration curve

Number	Pressure p [KPa]	Slope a	Correlation coefficient R^2
1	40	0.2454	0.9984
2	50	0.3654	0.9981
3	60	0.487	0.999
4	70	0.613	0.9989
5	80	0.757	0.9996
6	90	0.9014	0.9997

It can be seen from the correlation coefficient R^2 in Table 2 that the straight line in the form of y=ax can better describe the corresponding relationship between the standard concentration and the sensor measured value at different pressures. Then draw the relationship between the slope of the straight line *a* and the pressure, as shown in Fig.4.

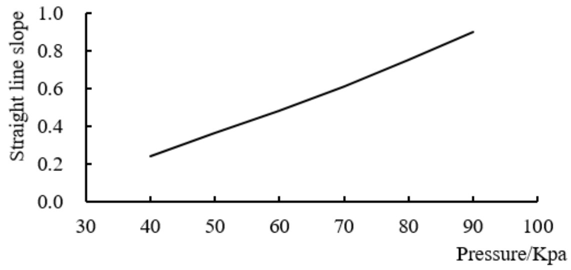


Fig.4 the relationship between the slope of the straight line *a* and the pressure

The regression analysis had performed on the curve in Fig.4, and the curve fitting equation a $a=0.0007p^{1.5933}$ was obtained. The correlation coefficient is 0.9988. The equation was substituted into y=ax and deformed to obtain the preliminary pressure compensation formula.

$$Y=C/(0.0007p^{1.5933}) \quad (2)$$

In formula (2), Y is the methane concentration after pressure compensated; C is the methane concentration before pressure compensated; p is absolute pressure of gas.

4. Error after pressure compensation

"AQ6211-2008 Coal Mine Non-dispersive Infrared Methane Transducer" requires that the basic error of Class C infrared methane sensors used for gas extraction pipeline monitoring is less than ±0.07% CH_4 in the range of (0-1%), at (1 -100%) ±7 % below true for the range [6]. Using the formula (1) to compensate the methane concentration data in Table 1, it is found that the compensated data in the range of (10-100%) meets the above requirements, and the partial data in the range of (0-10%) exceeds the basic error. Therefore, the segmentation pressure compensation model had been obtained in three ranges of (0-1%), (1-10%) and (10-100%), using the method established by the above compensation model.

$$\begin{cases} C/\left(7\text{E-}4\times p^{1.5933}\right)\le 1\%, Y=C/\left(8E\text{-}5p^{2.0498}\right) \\ 1\% < C/\left(7E\text{-}4\times p^{1.5933}\right)\le 10\%, Y=C/\left(0.0016p^{1.4087}\right) \\ 10\% < C/\left(7E\text{-}4\times p^{1.5933}\right), Y=C/\left(7E\text{-}4p^{1.5933}\right) \end{cases} \quad (3)$$

The data in Table 1 was compensated by the above compensation model, and the compensated concentration is shown in Table 3.

Table 3 Methane concentration after methane concentration

Standard concentration *c*/%	Pressure *p*/KPa					
	40	50	60	70	80	90
0.505	0.46	0.49	0.54	0.52	0.52	0.51
1	0.98	0.99	0.99	0.95	0.97	0.96
5.03	5.19	5.28	5.08	5.06	5.03	5.04
8.56	8.51	8.31	8.29	8.38	8.52	8.59
14.9	14.61	14.53	14.18	14.44	14.23	14.29
20	20.37	19.72	20.08	19.53	19.23	19.24
35.1	36.18	35.15	34.55	33.48	34.09	33.72
60	61.36	60.50	60.48	59.78	59.52	59.23
74.8	71.93	75.54	75.25	75.86	74.99	73.92
85.1	82.45	85.08	86.22	83.74	85.29	84.15
95	92.98	101.34	99.86	97.97	96.80	95.25

The error had been checked on the data in the table. In the range of (0-1%), the max error is 0.05% CH_4. In the range of (1-100%), the max error is 6.68% of the true value, which is in accordance with AQ6211-2008. Industry Standard requirements. It is indicated that the established piecewise nonlinear pressure compensation model can better eliminate the influence of pressure change on the measurement of gas methane concentration in the extraction pipeline.

5. Conclusion

(1) The negative pressure environment of the gas extraction pipeline makes the infrared methane sensor have large measurement error. The concentration measurement and the gas pressure are basically linear or exponentially related. The lower the absolute pressure, the lower the measured concentration value and the greater the error. The measured value must be pressure compensated.

(2) A piecewise nonlinear pressure compensation model had been obtained by experiments with different pressures and different standard gas concentrations. The pressure-compensated measurement data has maximum error of 0.05% CH_4 in the range of 0% to 1%CH_4 and 6.68% of the true value in the range of 1% to 100%CH_4. The error range meets the basic error requirements of the AQ6211-2008 standard.

(3) The establishment of the infrared methane sensor pressure compensation model provides a reference for other gas sensors used in the negative pressure environment, and provides a technical way to improve the accuracy of coal gas detection.

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