# Application and Research of Wireless Laser Methane Sensor for enhanced Drainage Pipeline Monitoring

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**Abstract**

Laser methane sensor has been widely promoted and successfully applied in coal mines as a new and effective technology building on the approach of laser-based absorption detection. Compared with the traditional catalytic methane sensor, the laser methane sensor discussed offers the important advantages of a long calibration period, high detection precision, the absence of 'zero drift and low power consumption, all of which are significant advantages for use in coal mining applications. By compensating for the temperature and pressure of the gases present, the accuracy of the methane sensor is evident across a wide range of temperatures and pressures, making it suitable for gas detection, including methane, in pipelines as well. The wireless laser approach which is incorporated into the methane sensor allows wireless transmission and data uploading to a cloud server through NB-IoT. This tackles the problem in gas pipeline monitoring of the length of many pipelines and thus the wide distribution of the sensors, avoiding complicated wiring and thus high associated cost. Further, remote data management can then be achieved, all of which greatly improves the flexibility and security of the management of the pipeline and the data generated.

**Keywords:** Laser methane sensor, stability, temperature and pressure compensation, wireless function,Internet of Things (IoT)

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# 1. BACKGROUND

Enhanced control of gases in coal mines, using 'first pumping and then mining, using the ventilation volume to confirm mining being available' can be achieved using pipeline methane sensors as a means to provide better control and regulation in the management of gas drainage technology from underground, preventing gas accidents and ensuring the safer production of coal from mines. At the same time, in order to ensure the best utilization of the gas generated, gas power stations will be established near to coal mines to make full use of the high concentration of useful methane gas extracted from underground[1].It is necessary therefore to accurately measure the methane concentration in the gas drainage pipeline installed to provide control and thus the best use of these productive gas generating units. Most of the sensors installed in coal mines now are based on catalytic methane sensors, which have known shortcomings such as poor accuracy, 'zero drift', cross-sensitivity to other combustible gases, and a short calibration period, for example. Thus new solutions are needed and research and development into better laser methane sensors has been undertaken to successfully solve many problems of traditional electronic sensors and thus created a firm foundation for better coal mine safety and thus reliable production.

# 2. THE WORKING PRINCIPLE OF LASER METHANE SENSOR

Methane is detected by using the principle of gas spectral absorption where, according to the Lambert-Beer's law, parallel light of intensity $I_0(\lambda)$ passes through a gas chamber which contains the gas under investigation. If the light source spectrum covers one or more of the absorption lines of the gas, the relationship between the transmitted light intensity $I(\lambda)$, the incident light intensity $I_0(\lambda)$ and the gas concentration C is given by

$$I(\lambda) = I_0(\lambda) exp[-\alpha(\lambda)CL] = I_0(\lambda)\exp[-PS(T)\phi(\lambda)CL] \quad (1)$$

where $\alpha(\lambda)$ is the absorption coefficient of the medium; $L$ is the pathlength of the absorbing gas; $P$ is the total pressure of the gas medium; $S(T)$ is the line intensity of the characteristic line of the gas under investigation (indicating the absorption intensity of the line, only related to temperature); $\phi(\lambda)$

is a linear function that represents the shape of the measured absorption line (and is also related to the temperature, the total pressure and the content of each component in the gas mixture detected).

After performing a logarithmic operation on both sides of equation(1), integrating across the entire frequency domain, the following can be seen

$$PCS(T)L = \int_{-\infty}^{\infty} -\ln\left(\frac{I}{I_0}\right) d\lambda = \mathrm{A} \tag{2}$$

Therefore, the gas concentration can be directly calculated by using the following formula

$$C = \frac{\int_{-\infty}^{\infty} -\ln\left(\frac{I}{I_0}\right) d\lambda}{PS(T)L} = \frac{A}{PS(T)L} \tag{3}$$

In the case where parameters such as pressure, the absorption line intensity and the effective length of gas absorption are known, the integrated value of $-\ln(I/I_0)$ in the frequency domain is brought into equation (3) and the gas concentration value can then be obtained. Normally, the spectral absorbency signal is not directly integrated and the corresponding linear function is used for the fitting process. The integral value can accurately be obtained from the result of the line fitting result and thus the influence of the measurement error in the direct integration is reduced. It is assumed thus that the pressure and the absorption line of the gas considered are a constant in actual sensor design and the concentration of the gas can be measured only by measuring the change of the light intensity before and after absorption. In order to improve the accuracy and reliability of the measurement, temperature and pressure compensation to allow for these conditions changing in practice are required.[2-5]

## 3. SELECTION OF ABSORPTION SPECTRUM LINES AND THE WORKING PRINCIPLE OF A LOW POWER CONSUMPTION DEVICE

Following knowledge of the absorption peaks of methane in the near infrared band (data obtained from to the HITRAN database[6,7]), strong absorption peaks are found at the following wavelengths – 1645.53; 1648.24; 1650.96; 1653.72; 1656.55 nm where each absorption peak has an interval of more than 2.5 nm. There are no strong absorption peaks of other possible gases present in the mine in this band region, thus avoiding problems due to cross-interference, making this spectral region very suitable for detecting the methane absorption peaks (as shown in Figure 1) and thus the detection of the gas concentration[8].

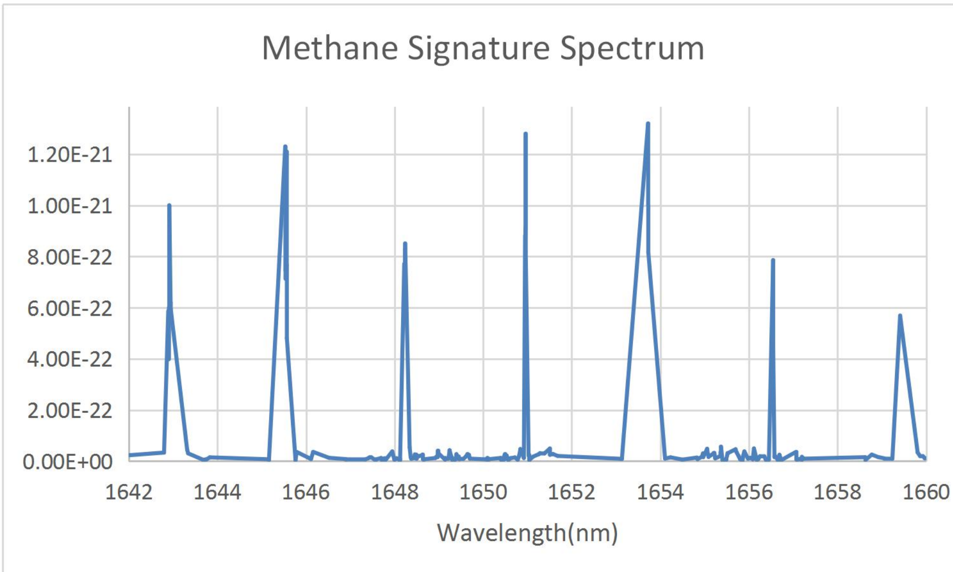


Figure 1. Methane spectrum showing a series of important absorption lines in the wavelength region 1642 to 1660 nm

The sensor uses a VCSEL laser source, this being chosen because of its excellent current-wavelength modulation performance in the appropriate spectral region. With the original wavelength-following technology used, the absorption peak in the scanning range (at the current ambient temperature) is locked by using current scanning to allow the determination of the methane concentration. The power consumption of the whole sensor is thus greatly reduced by eliminating the large amount of current consumption that would be required for temperature control of the device and thus the entire power consumption of the sensor can be controlled to within 0.2W.

## 4. COMPENSATION FOR TEMPERATURE AND PRESSURE CHANGES

The methane absorption spectrum varies according to the changes in the ambient temperature and pressure, and this is especially important in coal mine gas drainage pipeline monitoring, as shown in Figure 2. The temperature fluctuation can be between -10 and 50 degree C and the range of pressure fluctuation of the gas in the pipeline can reach 50 to 150 kPa. Dealing effectively with these two large ranges of fluctuations of either (or indeed both) pressure and temperature are beyond the capability of traditional methane sensors. In order to ensure that the accuracy of the sensor readout is always within 5% of the true value (needed for practical mine applications), effective temperature and pressure compensation is needed for methane measurement in practice.

Studying these effects in detail, it is found that the peak coefficient of the absorption spectrum decreases with the increase in temperature, while the absorption peak coefficient of the absorption spectrum increases with any increase of pressure[9].

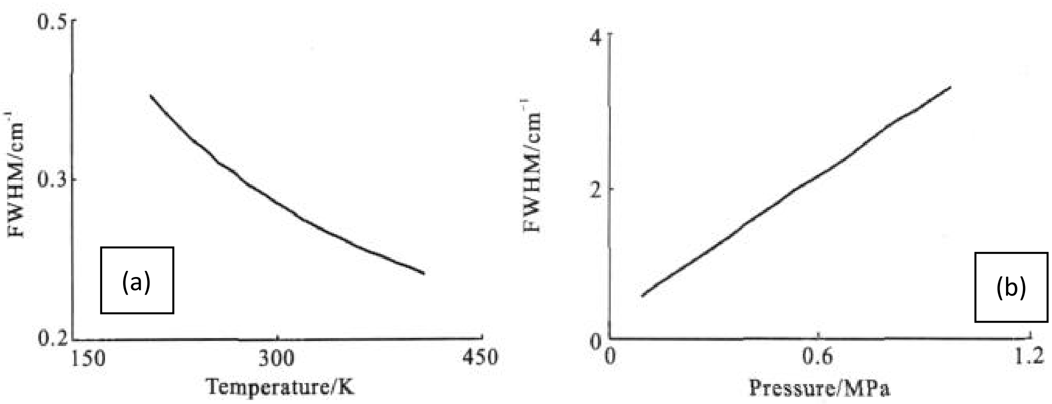


Figure 2. Effect of (a) temperature and (b) pressure on the absorption peak coefficient

The laser methane sensor measures the trend over the temperature region -10 to 50 degree C, as shown in Figure 3, for both pre- and post- the application of the correction factor (the accuracy of the measurement is within 5% of the true value).

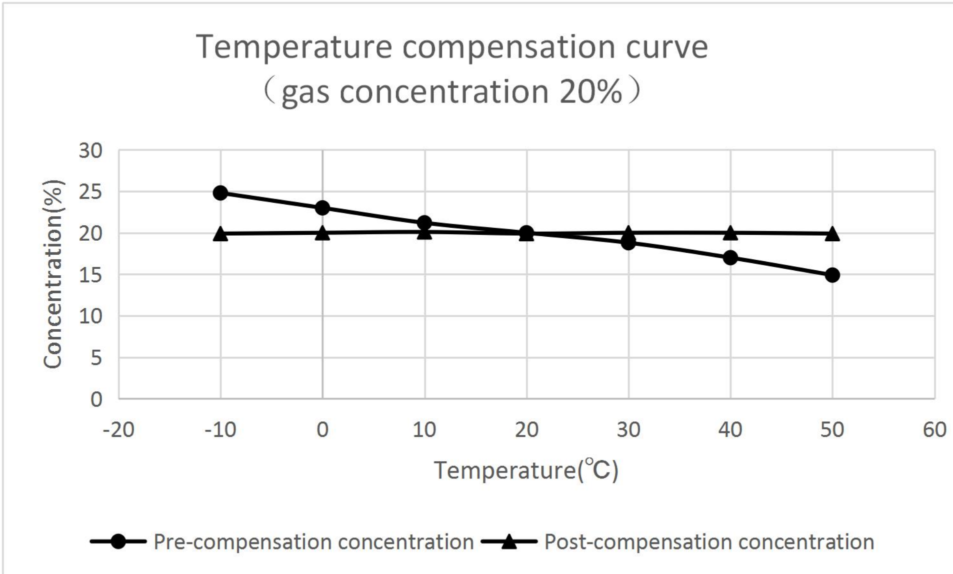


Figure 3. Illustration of the effect of temperature compensation on the gas concentration measurement(under 20% concentration of methane)

According to the requirements of the application, the temperature range could be extended to -30 to 70 degree C, to further improve the performance, using the same approach as is illustrated in Figure 3.

Similarly, the excellent performance of the laser methane sensor to measure the trend when the pressure varies within the range 30 to 200 kPa, as shown in Figure 4 (again the accuracy of the measurement is within 5% of the true value).

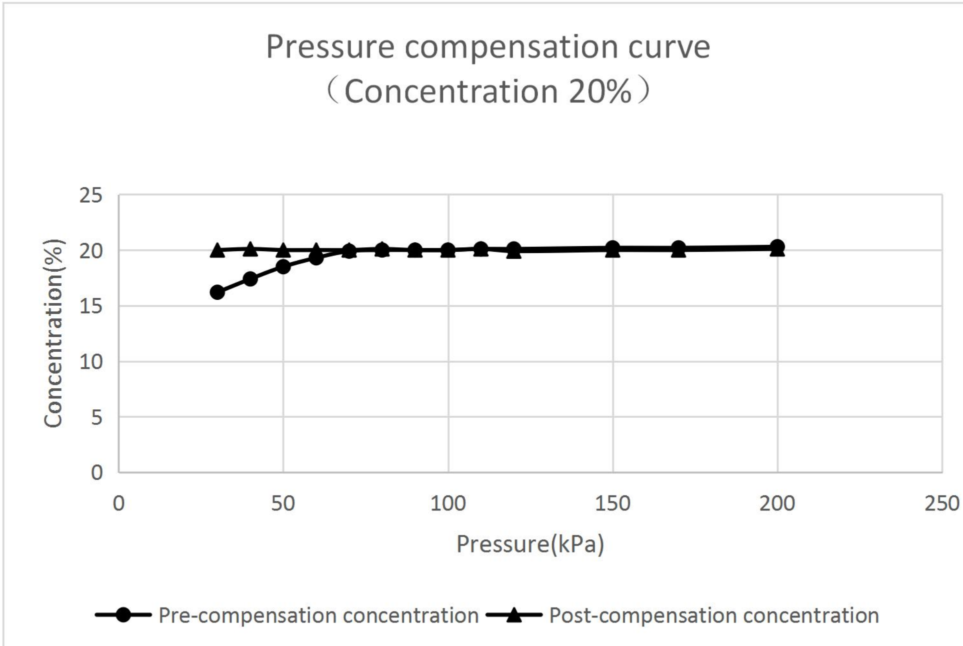


Figure 4. Illustration of the effect of pressure compensation on the gas concentration measurement(under 20% concentration of methane)

As a result of applying this correction, the monitoring accuracy obtained when using the pressure compensation is improved, and seen over the pressure range of 30 to 200 kPa.

## 5. REALIZATION OF WIRELESS FUNCTION OF THE SENSOR SYSTEM

The Internet of Things (IoT) is an important part of the new generation of information technology devices and an important development in the era of 'informatization'. The use of IoT technology in gas drainage pipelines also represents a timely advance through a synergy of technologies. To enhance control and monitoring, in real time and wherever the manager is located is important both for optimum coal mine production and safety. The wireless function employed in this sensor system mainly uses the 'User' module, which transmits data to between the manager and the sensor through the operator NB-IoT network. By setting it up in this way, the sensor can be operated bidirectionally: data can readily be transmitted from serial port to network and vice versa[10].

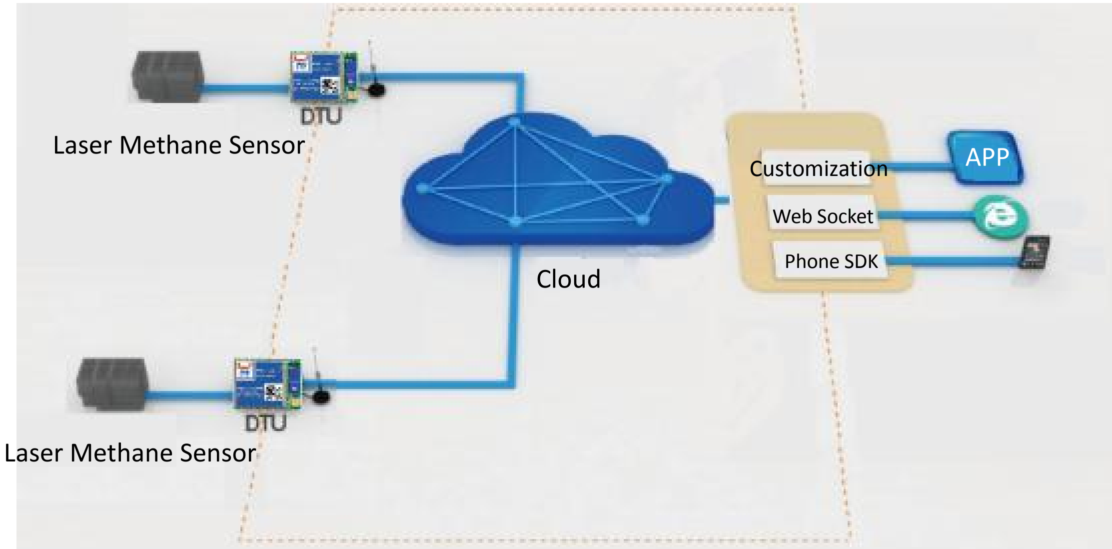


Figure 5. Illustration of the system structure, showing the key components

As shown schematically in Figure 5, the system uses a mine wireless laser methane sensor where the communication mode is via GPRS and the device data handling system is composed of a computer terminal, a mobile phone and other mobile device terminals. The server side uses the ‘User’ server to realize the connection between the sensor and the computer terminal/mobile phone for the purpose of real-time monitoring.

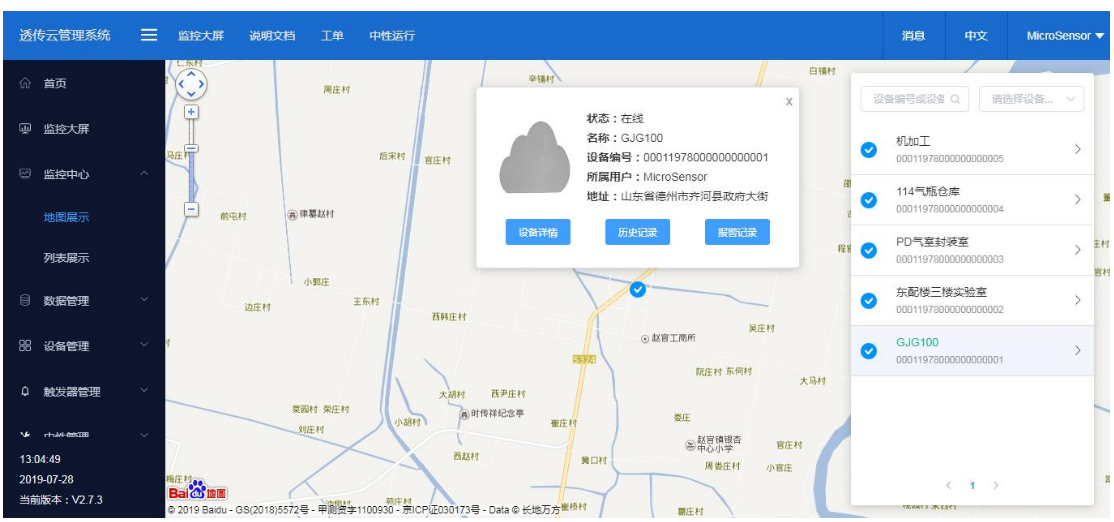


Fig6. Web client data viewing

## 6. APPLICATION IN METHANE DRAINAGE PIPELINE MONITORING

Combining the laser methane sensor technology with wireless technology solves the problem of creating an effective remotely interrogated system, avoiding the problems of the gas drainage pipeline having a wide distribution range, complicated wiring and high cost. The system also has built in a remote data management function, which greatly improves the flexibility and the security of the gas data management system. Figure7 shows the laser methane sensor installed on a gas drainage pipeline in a coal mine in Dezhou, China.

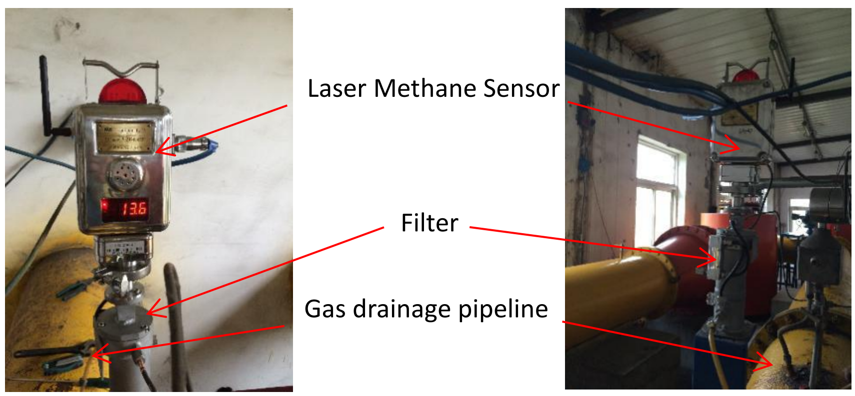


Figure 7. Photograph of the sensor system in field application

The normal operation of the sensor can be realized by providing a convenient 12V power supply, which allows for a flexible installation and effective data transmission, without setting up monitoring sub-stations. In order to ensure that the sensor system works well in the longer term, a micron-scale water filter and dust-proof device are used, which can effectively remove water vapor and impurities from the gas drainage pipeline[11].

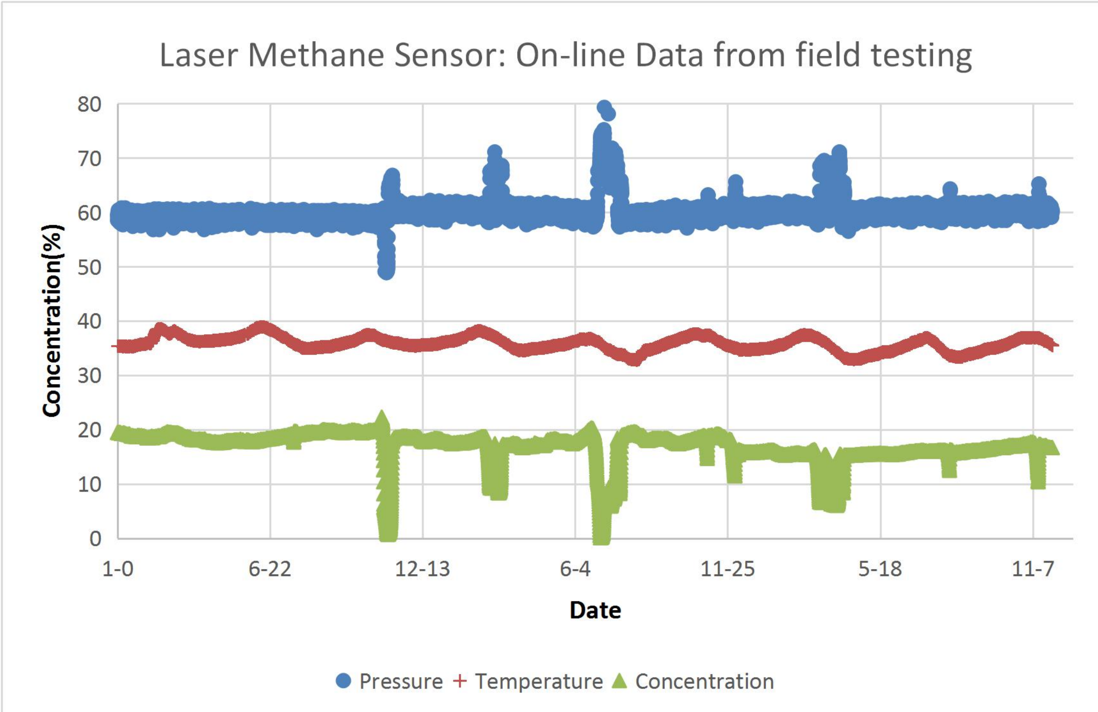


Figure 8. Data obtained from on-site operation, showing in blue the pressure data, in red the temperature data and in green the gas concentration

The mine laser methane sensor system developed is shown in Figure 8 to be able to simultaneously and accurately measure the methane concentration, the temperature, the pressure (and other information required). During tests carried out, showing the long-term operation of the sensor system, no major problems with the system were experienced, such as data mutations or disconnections.

From the work done illustrating the on-site operation and the data analysis then carried out, the laser methane sensor system has proven to be ideal for gas drainage pipeline monitoring applications. The system has a number of very good advantages over conventional sensors for coal mine applications, especially in more remote installation locations and where sensors are dispersed along the pipeline.

# 7. CONCLUSION

An innovative laser methane sensor which uses the principle of spectral absorption to detect the methane concentration has been demonstrated, showing high accuracy, good stability, no need for re-calibration and the absence of cross-interference from the presence of other interfering gases. Research carried out to achieve temperature and pressure compensation has been successful, as shown and further enlarges the application scope of the methane sensors developed. The low power consumption of the system makes it possible to use it a long distance from conventional power supplies and the wireless data transmission function developed for the gas drainage pipeline monitor further strengthens the feature of flexibility and timeliness in the data management achievable.

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