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Optimizing Gas Sensing Accuracy: Evaluating and Compensating TGS2602 Sensor Responses in Diverse Environmental Conditions

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ABSTRACT

Keywords
Compensation
Gas Sensor
H_2S
Monitoring
Volcano

This research aims to investigate the TGS2602 gas sensor's response to variations in temperature and humidity, focusing on the analysis of concentration reading offsets influenced by environmental humidity fluctuations. The TGS2602 sensor demonstrates high sensitivity to hydrogen sulfide (H_2S), making it relevant for gas monitoring in volcanic environments. However, the sensor's weakness lies in reading offsets triggered by changes in temperature and humidity. Calibration methods and mathematical analysis are employed to evaluate the sensor's performance. Testing is conducted by varying temperature and humidity in enclosed conditions, and the results indicate that temperature and humidity significantly affect gas concentration readings. As a solution, compensation methods, such as using temperature and humidity sensors and developing algorithms, are required to address reading offsets. This study provides insights into the reliability of the TGS2602 sensor in various environmental conditions and proposes compensation strategies to enhance gas measurement accuracy.

1. Introduction

Indonesia's volcanic tourism, fueled by the allure of active volcanoes, beckons adventurers to unparalleled natural wonders. Despite the captivating landscapes and astonishing phenomena, the inherent risks of toxic gas release during volcanic activities must not be overlooked[1]. The composition of fumarolic vents encompasses gases such as carbon monoxide (CO), carbon dioxide (CO2), hydrogen sulfide (H2S), sulfur dioxide (SO2), and Nitrogen (NO2), with other gases present in lower concentrations [2]–[5]. Certain gases may be undetectable by smell, emphasizing the potential toxicity at concentrations surpassing safety thresholds[6]. Toxic gases, inducing poisoning symptoms and organ failure, pose severe health risks, including fainting, difficulty breathing, increased heart rate, and even death[7][8]. Consequently, robust risk management is imperative for the safety of visitors and surrounding populations.

Effective preventive measures demand comprehensive risk understanding and implementation by volcanic area managers. This includes continuous air quality monitoring, mapping high-risk zones, and providing education to visitors on safety measures during their visits[9][10]. Mitigation measures encompass the installation of a toxic gas monitoring system in the crater area, utilizing sensors like TGS2602 known for high sensitivity to gases such as hydrogen sulfide[9]. The TGS2602 sensor, with a metal oxide semiconductor layer on an alumina substrate sensing chip, proves advantageous due to its heightened sensitivity to low concentrations of H2S, a common emission from volcanic activity.

However, the TGS2602 sensor has drawbacks related to environmental humidity changes affecting readings. The study focuses on analyzing sensor reading offsets due to humidity fluctuations, aiming to enhance reliability. Fluctuations can cause uncertainty in measurements, particularly in high humidity mountain environments where substrate heating delays sensor responsiveness. The study seeks to evaluate the TGS2602 sensor's reliability and develop compensation strategies for more accurate gas measurements in volcanic environments[9].

2. Method

The TGS2602 gas sensor is a sensing device formed by a metal oxide semiconductor layer on an alumina substrate. This layer creates a metal oxide semiconductor sensing chip responsive to H_2S gas. To enhance its performance, heating elements are added to the sensor module to achieve optimal operating temperatures. This sensor operates through changes in the conductivity of the material in resistance units (Ω), influenced by variations in gas concentration reaching the metal oxide semiconductor sensing chip[9]. Figure 1 (left) illustrates the sensitivity characteristics of the TGS2602 sensor, with the sensor resistance ratio (R_S/R_O) as the ordinate (Y-axis) and gas concentration as the abscissa (X-axis), measured in parts per million (PPM). The PPM unit is used to express gas concentrations, representing the number of molecules of a substance per one million molecules of a gas or air mixture. The use of this unit is beneficial in measuring gas concentrations, especially at very low levels, and is often employed in the context of air quality and gas analysis[11]–[13].

2.1. Standard Test Condition

The sensor effectively detects H_2S gas associated with volcanic activity, making it suitable for use in early warning systems related to the danger of toxic gas emissions from volcanoes. Its advantages include low cost, simplicity, and a long lifespan. However, its drawbacks involve the logarithmic nature of the sensitivity of gas concentration measurements to the R_S/R_O ratio and the offset caused by humidity influence. The first step in analyzing the sensor's offset value caused by air humidity influence is calibration by measuring the sensor resistance (R_O) under predefined environmental conditions. These conditions should align with the information on the datasheet, where the sensor's operating temperature is at the ideal temperature.

To obtain gas concentration values, basic measurement circuit instrumentation is required for the TGS2602 sensor. This sensor requires two input voltages: the heater voltage (V_H) and the sensor circuit voltage (V_C). V_H serves as the internal heater voltage on the sensor aimed at maintaining the optimal temperature of the metal oxide semiconductor chip, while V_C is applied to produce the measurement voltage V_{RL} across each external resistor R_L connected in series to the metal oxide semiconductor chip, forming a voltage divider circuit (Figure 1 (right)). The value of R_L is determined with a minimum value of 0.45 kΩ based on datasheet parameters, ensuring that the power dissipation value (P_S) by the semiconductor and R_L is below the 15mW limit. It is important to note that the P_S value peaks when the R_S value equals R_L during exposure to high-concentration gas. More detailed information regarding testing standards can be accessed in Table 1[9].

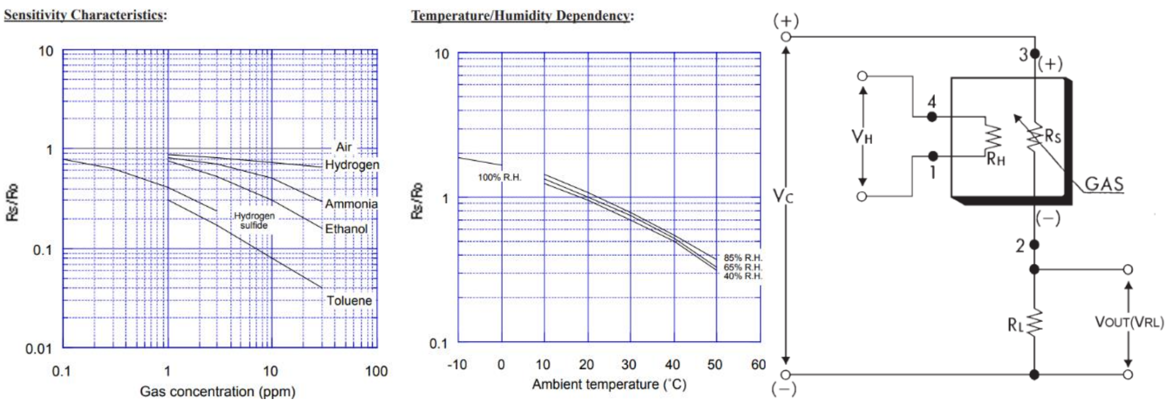

Fig 1. Sensor Characteristic Graph [12](left), Basic Circuit [12](right)

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Table 1. Standard Test Condition of TGS2602

Condition	Properties		
	Gloss	**Symbol**	**Value**
Standard circuit conditions :	Heater voltage	V_H	5.0±0.2V AC/DC
	Circuit voltage	V_C	5.0±0.2V DC Ps≤15mW
	Load resistance	R_L	variable 0.45kΩ minimal.
Electrical characteristics under standard test conditions :	Heater resistance	R_H	approx 59Ω at room temp.
	Heater current	I_H	56±5mA
	Heater power consumption	P_H	280mW (typical)
	Sensor resistance	R_S	10kΩ ~ 100kΩ in air
Condition	*Properties*	*Value*	
Standard test conditions :	Test gas conditions normal air	at 20±2˚C, 65±5%RH	
	Circuit conditions	Vc = 5.0±0.01V DC VH = 5.0±0.05V DC	

2.2. Equations

To determine gas concentration levels based on the characteristic curve (Figure 1 - left), a mathematical approach is suggested, although currently only assumptive. Calibration using standard measuring tools is essential. The initial step involves determining the Slope value using Equation 1, a logarithmic equation considering the TGS2602 gas sensor's logarithmic characteristic with RS/RO ratio on the Y and X-axes. The values of Y1, X1, Y2, and X2 are obtained from the characteristic curve, enabling the calculation of the Slope value, as indicated in Table 1. Post Slope value calculation, the subsequent phase is to determine the values of R_O and R_S under clean air conditions using Equations 2 and 3. This aims to establish the initial R_S/R_O ratio before the sensor measures gas levels. R_O denotes the internal resistance of the metal oxide semiconductor chip during calibration under clean air conditions, while R_S is the internal resistance during gas detection. The R_S resistance value changes inversely, and the V_{RL} value changes directly with gas concentration. The R_S or R_O value is denoted as V_{RL}, obtained from the voltage divider instrument circuit with the R_L resistor (Figure 1 - right). This instrument, requiring a 5.0 Volt V_C voltage source, detects changes in V_{RL} caused by shifts in R_S resistance due to gas detection, altering the R_S/R_O ratio. To determine gas concentration in ppm based on the R_S/R_O ratio, Equation 4, a logarithmic equation, is applied.

$$Slope(m) = \frac{\log Y_2 - \log Y_1}{\log X_2 - \log X_1} \quad (1)$$

$$Clean\ air\ fact\ .R_O = \frac{V_C - V_{RL}}{V_{RL}}\ .R_L \quad (2)$$

$$R_S = \frac{V_C - V_{RL}}{V_{RL}}\ .R_L \quad (3)$$

$$Gas\ Conc.(PPM) = 10^{\frac{\log\frac{R_S}{R_O} - \log Y_1}{Slope\ (m)} + \log X_1} \quad (4)$$

2.3. Testing Steps

In the testing context, an evaluation of the R_S/R_O ratio values on the TGS2602 gas sensor is conducted, considering variations in heating temperature and air humidity. The sensor is placed in a container that allows control over air humidity. The humidity adjustment is performed using a humidifier, while the sensor is heated to a temperature of 50º Celsius, starting from room temperature. The testing is carried out using ambient air enclosed in the container as the test gas. During the testing process, the R_S/R_O ratio values will be recorded and analyzed to understand the sensor's response to temperature and air humidity fluctuations. It is expected that the results of this testing can provide a deeper understanding of the sensor's performance under various environmental conditions. Detailed testing parameters can be seen in Table 2.

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Table 2. Test Condition of TGS2602

Condition	Properties		
	Gloss	***Symbol***	***Value***
Standard circuit conditions :	Heater voltage	V_H	5.0±0.2V AC/DC
	Circuit voltage	V_C	5.0±0.2V DC Ps≤15mW
	Load resistance	R_L	variable 0.47 kΩ.
Electrical characteristics under standard test conditions :	Heater resistance	R_H	60 Ω.
	Heater current	I_H	56±5mA
	Heater power consumption	P_H	280mW
Condition	*Properties*	*Value*	
Standard test conditions :	Test gas conditions normal air	at 25-50˚C, 40-85%RH	
	Circuit conditions	Vc = 5.0±0.01V DC VH = 5.0±0.05V DC	

3. Results and Discussion

Figure 2 shows the physical appearance of the sensor being tested in a closed container inside the chamber. In this test, the chamber is equipped with measuring instruments, including temperature and humidity sensors. The installation of temperature and humidity sensors aims to continuously monitor the sensor's performance parameters during the experiment. This step ensures that the temperature and humidity conditions around the sensor can be accurately monitored, allowing for a more detailed analysis of the sensor's response to environmental variations. The test results are presented in Figure 3, Table 3, and Table 4, where the X-axis indicates the sensor temperature in ° Celsius, and the Y-axis indicates the R_S/R_O ratio values of the sensor. Detailed measurement results corresponding to the test conditions listed in Table 2 can be found in Table 3. From the test results, it is evident that the air temperature and humidity around the sensor have a significant impact on gas concentration readings. Table 3 illustrates gas concentrations with temperature variations ranging from 20 to 50° Celsius, with humidity varying between 40% and 85%.

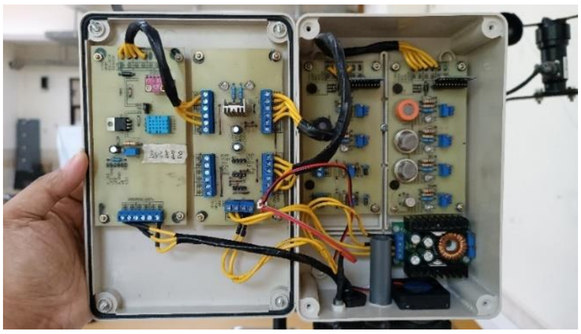

Fig 2. Gas Sensor on Board

The test results data, as presented in Tables 3 and 4, along with Figure 2, provides a deeper understanding of the TGS2602 sensor's response to variations in temperature and air humidity. Table 3 highlights the correlation between gas concentration, temperature (Temp), and air humidity (%RH) in ppm (Part per Million) units. In this observation, it is evident that an increase in temperature can enhance sensor sensitivity, but it should be noted that at the same operating temperature, with higher humidity, the sensor tends to lose its sensitivity. For example, at an operating temperature of approximately 25°C with 40% RH humidity, the sensor exhibits a sensitivity ratio of R_S/R_O at 2.06, indicating that the sensor reads an H_2S concentration of 0.0135 ppm. However, at the same temperature with 85% RH humidity, the sensor's sensitivity increases to 2.37, and it detects a gas concentration of 0.0098 ppm. This illustrates that high humidity can reduce sensor sensitivity, while high temperature tends to increase it. To address these impacts, compensation methods involving temperature and humidity sensors are required. Additionally, the development of specific algorithms or the implementation of more effective methods can be a solution to compensate for offset gas concentration readings. These steps need to be implemented to ensure the accuracy and consistency of sensor measurements in various environmental conditions, making the TGS2602 sensor more reliable for gas detection applications.

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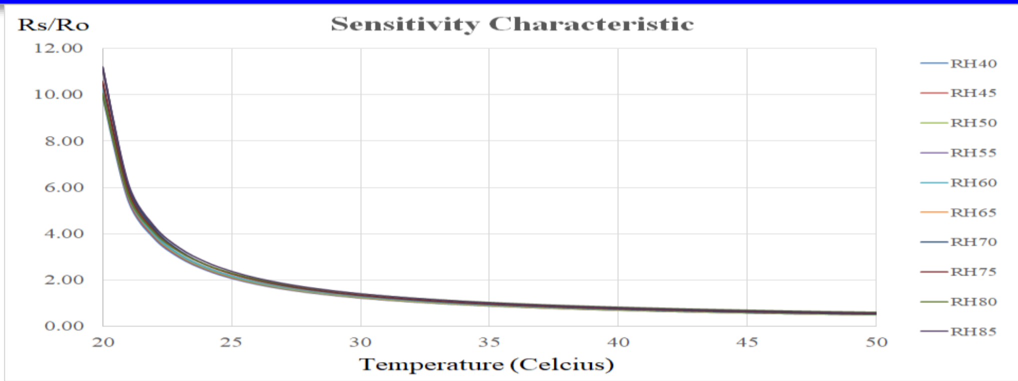

Fig 3. Test Graph of TGS2602

Table 3. Sensor Test Result (RS/RO)

Rs/Ro		%RH									
		40	45	50	55	60	65	70	75	80	85
Temp	20	9.98	10.22	10.42	10.44	10.34	11.20	11.20	10.57	10.04	11.21
	25	2.06	2.10	2.14	2.17	2.19	2.25	2.28	2.28	2.28	2.37
	30	1.21	1.23	1.25	1.27	1.29	1.31	1.33	1.36	1.38	1.40
	35	0.87	0.88	0.90	0.92	0.94	0.93	0.95	0.99	1.02	1.01
	40	0.69	0.70	0.71	0.72	0.74	0.73	0.75	0.78	0.81	0.80
	45	0.57	0.58	0.58	0.60	0.61	0.60	0.62	0.65	0.68	0.66
	50	0.49	0.49	0.50	0.51	0.53	0.52	0.53	0.56	0.59	0.57

Table 4. Sensor Test Result (PPM)

PPM		%RH									
		40	45	50	55	60	65	70	75	80	85
Temp	20	0.0004	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
	25	0.0135	0.0130	0.0125	0.0121	0.0118	0.0111	0.0108	0.0108	0.0107	0.0098
	30	0.0465	0.0448	0.0432	0.0415	0.0399	0.0390	0.0374	0.0357	0.0342	0.0332
	35	0.0996	0.0963	0.0929	0.0889	0.0845	0.0848	0.0808	0.0750	0.0699	0.0703
	40	0.1732	0.1679	0.1620	0.1544	0.1458	0.1490	0.1413	0.1286	0.1176	0.1214
	45	0.2674	0.2597	0.2508	0.2382	0.2237	0.2320	0.2191	0.1962	0.1768	0.1863
	50	0.3824	0.3720	0.3594	0.3405	0.3182	0.3341	0.3146	0.2780	0.2475	0.2651

4. Conclusion

This research concludes that the TGS2602 gas sensor demonstrates good sensitivity to variations in temperature and air humidity. An increase in temperature tends to enhance the sensor's sensitivity, but at the same temperature with higher humidity, the sensor may lose its sensitivity. The influence of environmental humidity on the offset of gas concentration readings poses a significant challenge, given that the sensor tends to be unresponsive to rapid changes in humidity. Therefore, compensation methods are necessary, including the use of temperature and humidity sensors, as well as the development of effective algorithms. This conclusion emphasizes the importance of considering environmental conditions in the use of gas sensors for volcanic monitoring applications. By implementing appropriate compensation strategies, gas measurement results can be significantly improved, enhancing the reliability of the sensor in various operational situations.

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