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Determining the Hydrogen Sulfide Concentration at Tangkuban Perahu Mount Using TGS-2602 Sensor

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Abstract

Indonesia is a country with numerous volcanoes which are a great hazard to people living in surrounding areas. As a result, eruption predictions and pre-emptive warnings are extremely important. In mount Tangkuban Perahu in particular, hydrogen sulfide is abundantly produced. By detecting hydrogen sulfide levels, volcanic activities in Tangkuban Perahu can be predicted and early warnings can be released to alert the people in the area. To obtain a reading of the concentration of hydrogen sulfide we use the TGS 2602 gas sensor equipped with Arduino to process the readings and ESP-32S to connect the system to IOT. This sensor system is equipped on a mobile robot which had been developed in previous research. Through field experiments, we have determined that our system has successfully obtained the readings of hydrogen sulfide in various parts of the day. Our readings showed that mount Tangkuban Perahu is safe and stable throughout the day with none of the average hydrogen sulfide reading in the morning, afternoon, and evening exceeding 0.3 ppm.

Keywords: volcanoes, hydrogen sulfide, TGS 2602, gas sensor, mobile robot

INTRODUCTION

Sitting between the ridges of several tectonic plates, Indonesia is home to 129 active volcanoes, some 13% of the total active volcanoes around the world [8]. These volcanoes have brought numerous perils to Indonesia, never failing to cause disasters year after year for the past 14 years. In fact, in 2018 alone there were 58 disasters caused by volcanic eruptions where the surrounding public is greatly affected. However, disasters caused by volcanic activities are unpredictable in nature. In both 2021 and 2022, there was only 1 eruption great enough to affect the people [7]. To predict these eruptions, various methods from direct observations to seismic readings have been used [6]. In other observation, monitoring the concentration of H2S was crucial for assessing the volcano activity, the ratio with SO2 can indicate the magmatic condition and the interactions between magmatic and hydrothermal fluid, which with this value insights into the volcano activity can be obtained [10]. However, it is still not the standard procedure to take readings of hydrogen sulfide or other gases commonly involved in volcanic activities. We believe that data readings of hydrogen sulfide are important in predicting volcanic activity. In another paper, there mobile robot was developed to monitor the volcano activity using some sensors, the mobile robot was named PRAWIRA [9]. This research is done to assess the performance of the sensor TGS-2602 to detect the concentration of the H2S gas. If then the performance was good, this method could be implemented into the mobile robot. The mobile robot used in this research is one that had been developed prior by Maria Evita et al. This mobile robot is a 4-wheeled robot that can monitor and obtain readings of physical parameters around the volcano [13]. In this paper, we design an early warning system based on hydrogen sulfide readings taken with a TGS 2602 gas sensor. We are testing our system in Mount Tangkuban Perahu, Bandung. Mount Tangkuban Perahu is a basaltic to andesitic stratovolcano located north of Bandung, Indonesia [4]. In recent years, all of Tangkuban Perahu's eruptions were phreatic eruptions which produced dense and blocky ashes [5]. The volcano features a thermal spring discharge rich in chloride and fluoride; varying in pH and TDS with a high

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concentration of gases such as carbon dioxide and hydrogen sulfide [3]. Hydrogen Sulfide (H2S) is one of the gases involved in the volcanic processes of volcanoes [1]. The concentration of H2S can provide insight into the magma condition inside the volcano [2]. At present, when changes to the volcano are observed, a surveillance officer will visit the crater to take samples of the gases around. However, these visits can be very dangerous. Thus, there is a need for a method to determine the volcano's condition without needing to go through the crater to collect information about the gases. TGS-2602 is a sensor that can detect gasses that can be used to predict volcanic conditions. These gasses include Hydrogen Sulfide, Sulfide, and CO2. This paper presents a method to utilize the TGS-2602 sensor to detect H2S concentration as well as a design of a platform that can be used to share information with nearby residents by a community group.

METHOD

The purpose of this paper is to obtain the gas characteristics of TGS-2602 to detect H2S concentration. The result of this research is implemented into a mobile robot that has been developed by the Instrumentation and Computational Physics, Department of Physics, Bandung Institute of Technology named PRAWIRA. The figure below shows a sketch of the mobile robot.

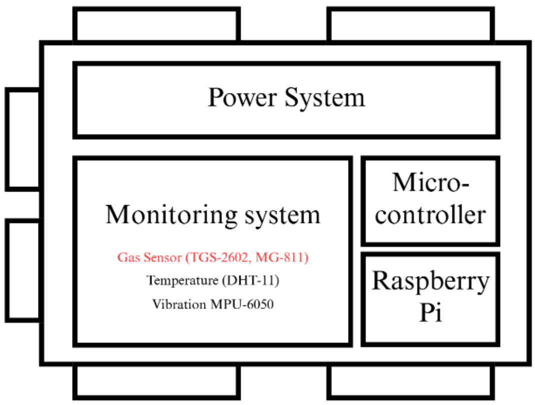


Fig 1. Sketch of the mobile robot PRAWIRA.

Sensor TGS-2602 is a sensor used to detect gases from the air. This sensor can detect gases such as H2, NH3, EtOH, and H2S. The specific gas concentration is differentiated by different resistance ratios. The ratio then joins the equation of the log-log graph that is given by the datasheet. The method used to collect data in this research is to get the output of the sensor, and store it into a database to be collected for further analysis. The flowchart of the system can be seen in Figure 2 below.

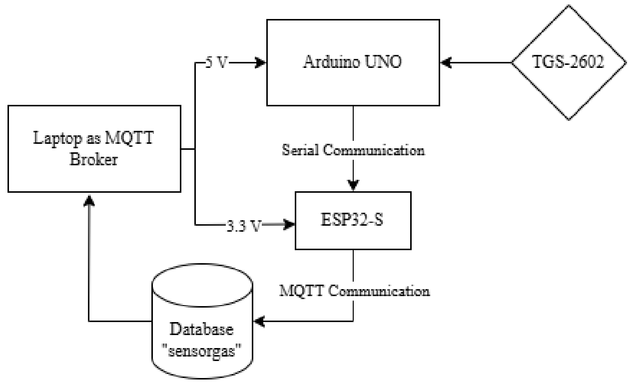


Fig 2. Working diagram of the research to get the concentration of H_2S using TGS-2602.

The system uses 2 microcontrollers, Arduino used to collect the output data of the sensor, and ESP32-S. ESP32-S is used as a means of communication between the sensor and the laptop using the MQTT protocol. This communication is used because it's fast and light compared to other protocols. In addition, this protocol can be used without using wires to store data from the sensor.

Characterization

Characterization was carried out to get the characteristics of the TGS-2602 sensor. In this sensor, voltage is used as an analog output. To get gas readings, resistance is involved in determining the concentration of each gas. The ratio of resistance is the ratio between the resistance of the sensor when detecting certain gasses and the resistance when the sensor is exposed only to fresh air. Firstly, the resistance output of the gas in the fresh air needs to be known. To get the resistance reading of the gas, this formula is used [11]:

$$R_s = \frac{V_c - V_{\text{out}}}{V_{\text{out}}} \times R_{\text{L}} \qquad (1)$$

Details:

R_s : Resistance output of the sensor (Ω)
V_c : Voltage input to the sensor (V)
V_{out} : Voltage output of the sensor (V)
R_L : Load resistance of the sensor (Ω)

To obtain a resistance reading in the fresh air, the sensor is run in fresh air to get the resistance output. The process lasts for at least 15 minutes. This time is set because the sensor needs to read the fresh air, the resistance output of the sensor then used for the calibration of the sensor, 15 minutes is the minimum to get the output read being stable. After getting the resistance output in the fresh air, the code of Arduino is set to get the ratio of the last resistance and resistance of the fresh air. The gas concentration can be measured by using the equation of the graph in the datasheet, as shown in figure 3:

In this research, the data that wants to be measured is H2S gas concentration. So, the equation used is the log-log equation of the H2S curve that was obtained from the data sheet of this sensor [11].

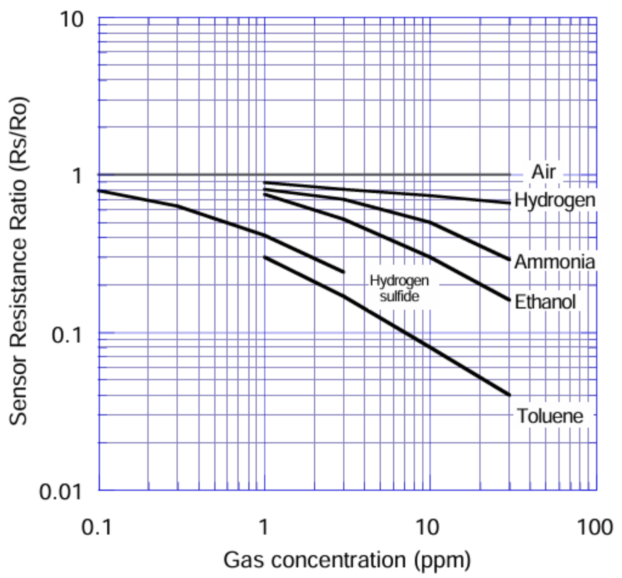


Fig 3. Log-log graph of TGS-2602 [11].

Laboratory Testing

The data was acquired at 3 different times, those are morning, afternoon, and evening. For each time, the sensor runs to turn on for 1 hour to get the gas concentration. The testing is done at Labtek V 2nd Floor, Bandung Institute of Technology. The weather conditions when the testing is rainy in the afternoon and evening.

Mountain Testing

The data was acquired at 3 different times, those are morning, afternoon, and evening. For each time, the sensor runs to turn on for 1 hour to get the gas concentration. The testing was carried out at Mt. Tangkuban Perahu, Subang, West Java. When the testing was carried out, the weather was different for the evening test. In the morning and afternoon tests, the weather was clear, but in the evening tests, the weather was a little bit rainy. During the testing at the mountain, the sensor was hoping to smell the air with the help of a fan to make sure the gas entered the sensor box. This fan is used to measure the gas to get inside the box of the sensor, to make more gases join the box.

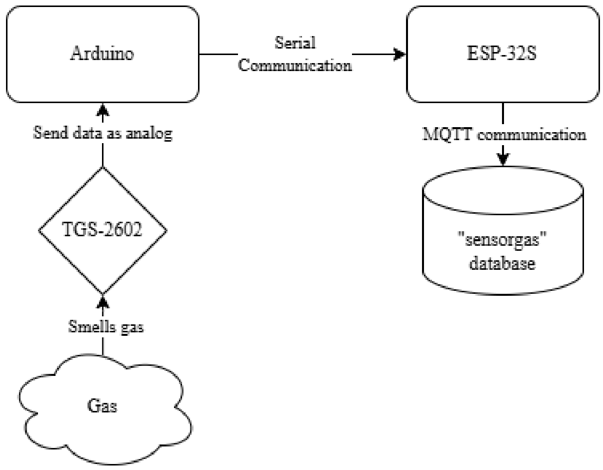


Fig 4. System flowchart.

Arduino is used for the data of the sensor output; Arduino is used because the ESP32-S ADC is troubled when the process of implementation. The sensor first smells the gas in the air, then the gas is calculated to get the ratio of the gas, then the ratio is calculated to get the gas concentration of the H2S.

Because Arduino doesn't have any Wi-Fi module, then here ESP32-S connects the system to communication using MQTT protocols. ESP32-S gets the data from Arduino using serial communication, the data is then stored in a database named "sensors" using MQTT protocol.

RESULTS AND DISCUSSION

System Calibration

In the calibration process, the resistance value read by the sensor was measured in free air condition. This is done to set the sensor reference point for measuring the ratio in the next calculation. As discussed earlier, the ratio value determines how much gas concentration is read by the sensor. The calibration was carried out in 15 minutes, because at that time the system was in a stable state, so the resistance data can be used as a reference for the starting point of the ratio comparison. The data was logged into a database and printed into a "CSV" data format. Furthermore, the data was visualized into a graph to see the fluctuation of the sensor while warming up.

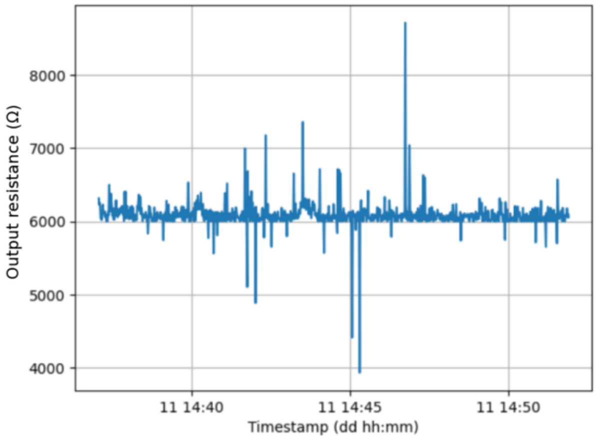


Fig 5. Calibration process curve (R_s).

The result shows that the data fluctuated in the early warm-up, then it became steady at the last 5 minutes. Therefore,t the data was collected for 15 minutes. In the "CSV" file, the data was averaged to get the average value of the resistance in the fresh air, and the value was set to 6088 Ω.

Laboratory Testing

The test was conducted at Labtek V 2nd Floor, Bandung Institute of Technology, West Java, Indonesia at three different times (morning (Fig. 7), afternoon (Fig.8), and evening (Fig.9)).

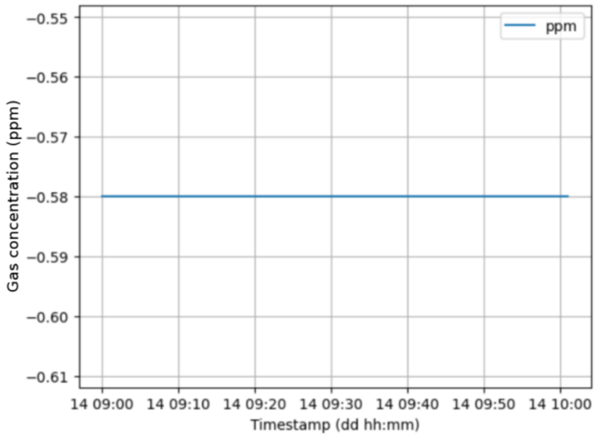


Fig 6. Morning Laboratorium test.

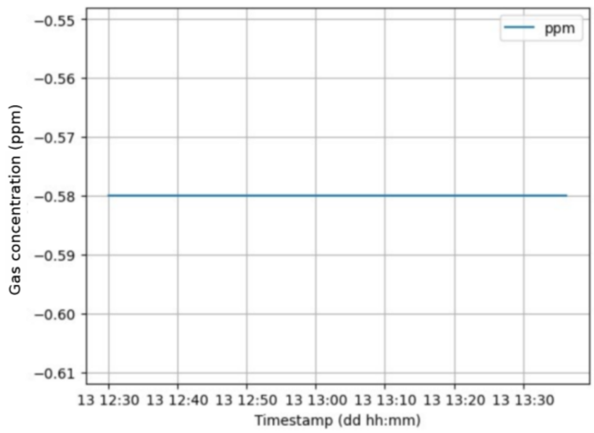


Fig 7. Afternoon Laboratorium test.

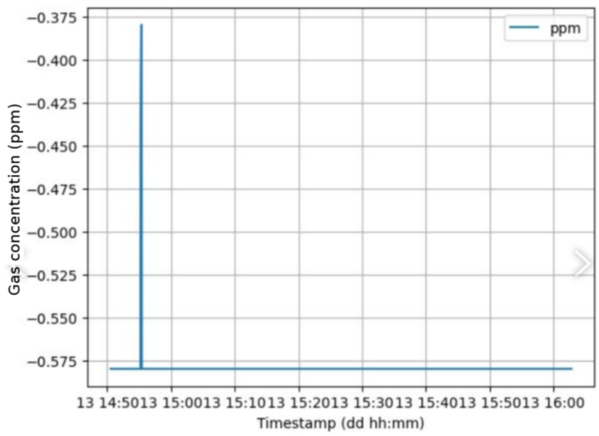


Fig 8. Evening Laboratorium test.

There is no H2S gas detected in the morning, afternoon, and evening indicated by -0,58 to -0,38 ppm gas concentration which was categorized as noise [11]. The spike in Fig. 9 shows that the scale in the Eq {(1) should be adjusted. This has been revised in the next testing in the field.

Field Testing

We tested the gas concentration levels at Tangkuban Perahu mountain in the morning, afternoon, and evening for one hour for each session. The results are as follows.

The first TGS 2602 sensor test was carried out in the morning for one hour, precisely from 09:40 to 10:40 am, precisely on the edge of the Ratu crater of Mt. Tangkuban Perahu. At that time the weather was very sunny with some bright clouds that covered it.

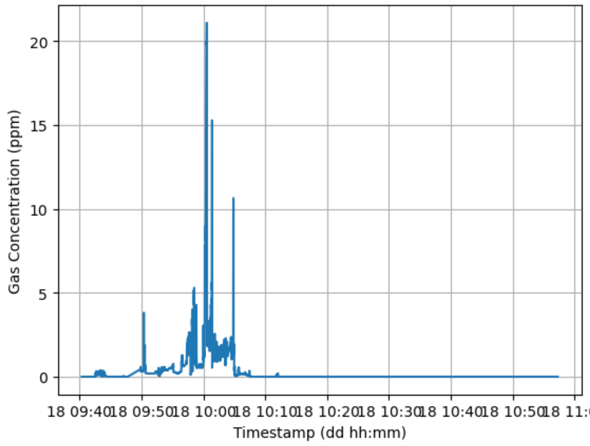
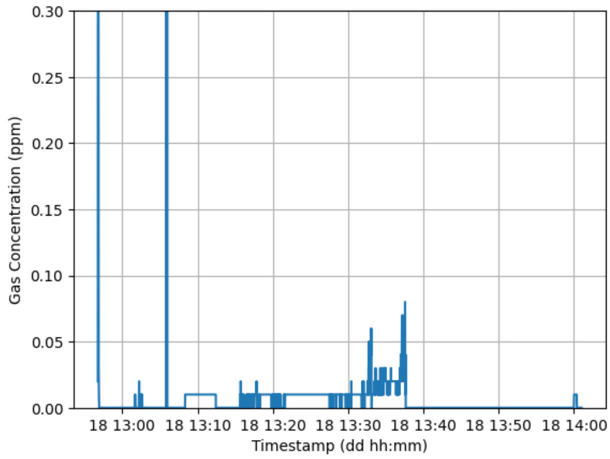


Fig 9. Graph of gas concentration (ppm) against time in the morning.

Based on the graph in Fig.3, and the reality at the testing site, the reading of the concentration of H2S compounds (ppm) was successfully carried out using the TGS 2602 sensor. However, there is an anomaly in the graph, namely at 09.50 to 10.10, there is a spike in the gas concentration value to above 20 ppm. This can occur because this sensor undergoes a "warm-up" process. At that time the sensor was just installed and turned on again. The sensor should have been switched on for a few days non-stop so that the sensor works properly when it is switched on again. [11] We have done the "warm-up" process for 24 hours but even then it was not nonstop due to device constraints. In addition, during that time we also unplugged the sensor with the device we were using because the connection between the ESP 32 and MQTT was lost.

However, the rest of the ppm value read on the sensor is quite appropriate, which is below 0.3 ppm. Based on the data obtained, the condition of Tangkuban Perahu mountain at the time of testing was "normal". Based on the reference we took, it is known that when the concentration of H2S is below 0.3 ppm, the volcano has a normal status. If the concentration is in the range of 0.3-0.5 ppm then the volcano has the status of "waspada". Then, if the concentration is in the range of 0.5-1.0 ppm, the volcano has the status of "siaga". Finally, the most dangerous is when the gas concentration is above 1.0 ppm, then the volcano has the status of "awas" or the mountain will erupt. [12]



Fri 10. Graph of gas concentration (ppm) against time of day.

The second test was conducted in the afternoon for one hour as well, from 1:00 to 2:00 pm, precisely on the edge of the Ratu crater of Mt. Tangkuban Perahu. At that time the weather was very sunny with some bright clouds that covered it.

It can be seen from the graph in Fig.4 that when the sensor is first turned on, the gas concentration value is suddenly high when compared to the value afterward, reaching 0.3 ppm. This could be due to the unstable circuitry of the sensor when it was first turned on so the value immediately shot up. However, since it had been switched on earlier, in the morning, the spike was not too large and did not last long. [11]

However, the results of this daytime test were very good because, for one hour, the gas concentration levels were not much different, only in the range of 0 to 0.3 ppm. It is said to be very good because at that time there was no strong smell of H2S, so it is very reasonable if the concentration value is in the range close to 0 or in the "normal" status. [12] The cause of the success of testing during the day is the TGS 2602 sensor that has been running optimally, unlike in the morning which has several obstacles such as the "warm-up" condition, and the ESP 32 connection with MQTT which was interrupted. During the day we also managed to use a fan that functions as a gas vacuum to collect into the sensor, so that the H2S gas concentration value is better than without a fan. Based on the explanation given in the method section, this fan is used to measure the gas to get inside the box of the sensor, to make more gases join the box.

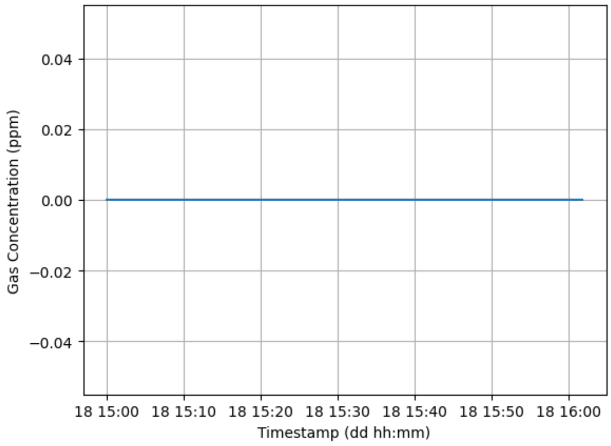


Fig 11. Graph of gas concentration (ppm) against time in the afternoon.

The second test was conducted in the afternoon for one hour as well, from 3:00 to 4:00 pm, precisely on the edge of the Ratu crater of Mt. Tangkuban Perahu. At that time the weather was cloudy and humid and there was even a brief drizzle of rain.

Based on Fig.5, it is found that the gas concentration value is almost flat at 0, it happens because when taking data in the afternoon the air is humid and it was raining as mentioned earlier. Air with high humidity can affect the sensitivity of the sensor. The more humid the air, the less sensitive the sensor will be. [11] Then, the rain can absorb the H2S gas so that the gas can be "picked up" first by the rainwater before reaching the TGS 2602 sensor. [13].

Based on the H2S gas concentration value detected by the TGS 2602, and the status of the volcano we have obtained references, namely.

Table 1. Volcano status based on H2S gas concentration values [12]

Status of the volcano	Gas Concentration of H2S (ppm)
Normal	< 0.3
Waspada	0.3 - 0.5
Siaga	0.5 -1.0
Awas	1.0 >

So we also made a notification about the status of the volcano to Discord through Grafana, and an example is as follows

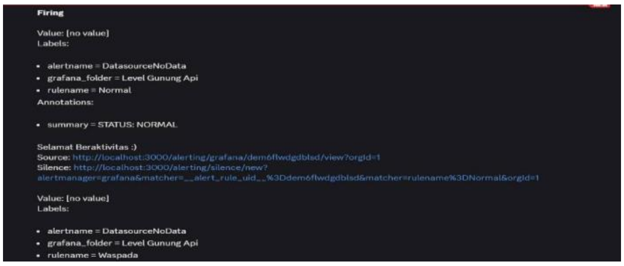


Fig. 13. Example of screenshots of messages containing the status of Tangkuban Parahu mountain is normal.

The screenshot above is an example of a message sent to a user's discord. For the example above, it is the state of Tangkuban Perahu mountain when it is normal. The normal state is sent to discord when the H2S gas concentration is below 0.3 ppm. It can be seen that the main concern is in the "summary" section which shows STATUS.

The "Waspada" (caution) status obtained in the message above occurs when the gas concentration is in the range of 0.3 to 0.5 ppm. This situation probably occurred during the daytime, as the concentration value had reached exactly 0.3 ppm. So the Grafana alerting system detected the status as "Waspada" (caution) and then the message was sent to Discord.

“Awas" (evacuate) is the status of Tangkuban Parahu mountain when the concentration value of H2S gas has exceeded 1 ppm. This situation is very dangerous and there is a high possibility that the mountain will explode. Then why does this status appear in the message sent by Grafana to Discord users? The reason is in the morning conditions, namely when the sensor is experiencing a "warm-up" condition and the disconnection of the ESP 32 connection with MQTT was explained earlier. During the morning, the H2S gas concentration value had reached more than 20 ppm for a long time. So the Grafana alerting system detected the value as an “Awas” (evacuate) status and sent it to Discord users to save themselves.

In conclusion, the alerting system on Grafana sent to Discord users has been successfully carried out. However, due to network constraints when at altitude (mountain), the message from Grafana to Discord cannot be immediately delivered. The Tangkuban Perahu mountain status message only reaches Discord users when the device used to open Grafana gets a

Network. So it is better to immediately ensure that the device that opens Grafana gets a network.

CONCLUSION

The calibration process was carried out by activating the TGS 2602 sensor in an indoor environment under clean air conditions. Based on the graph and recorded data, the sensor resistance (Rs) values varied within a range of approximately 6002 to 6200, with slight fluctuations likely due to signal noise or disturbances. From the collected data, the average Rs value was calculated to be 6088.04. This value serves as the reference Rs for clean air conditions, which is essential for accurately interpreting gas concentration levels during field measurements. The test results of the TGS 2602 sensor in the laboratory showed that in the morning, the gas concentration was recorded at -0.58 ppm, and during the afternoon, the value remained stable at -0.58 ppm. Meanwhile, in the evening, the gas concentration slightly changed to -0.575 ppm. The negative values in ppm are likely due to calibration offset or data processing errors. Based on the results of the TGS 2602 sensor testing at the Ratu Crater area of Mount Tangkuban Parahu, it was found that in the morning, the H_2S gas concentration was below 0.3 ppm after the sensor had stabilized, indicating that the volcano was in a normal condition. Furthermore, in the afternoon, the H_2S gas concentration was detected within the range of 0 to 0.3 ppm, which also indicates a normal status. Meanwhile, in the evening, the detected H_2S gas concentration was 0 ppm, again indicating a normal condition. Therefore, it can be concluded that during the entire testing period, the H_2S gas concentration around the Ratu Crater remained within safe limits and did not show any signs of increased volcanic activity.

However, because this sensor is non-selective to other gases and environmental conditions such as temperature and humidity, a careful calibration process is needed so that the measurement results are more accurate. Despite its limitations, the TGS-2602 sensor still provides an efficient and affordable alternative for monitoring hazardous gases in locations with volcanic activity. To improve the accuracy of the measurement, further research is needed by refining the environmental compensation model and comparing the results with more specific gas measuring instruments. This research contributes to the development of toxic gas monitoring systems and can support risk mitigation efforts in eruption-prone areas.

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