JASAE
Journal of Applied Science and Advanced Engineering
Vol. 2 No. 2 (2024); p. 61 - 65
e-ISSN: 2985-7252
https://jasae.org/

Real-time surveillance of formaldehyde gas levels in sugar carbonation processes through web-enabled MS1100 sensor monitoring

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ARTICLE HISTORY
Received: 1 August 2024
Revised: 12 September 2024
Accepted: 20 September 2024

KEYWORDS
Monitoring
Formaldehyde
MS1100
Sugar Carbonation
Website

ABSTRACT– ABSTRACT– The refining process of sugar cane juice includes a crucial stage termed carbonation, which is pivotal for achieving pH balance through the utilization of carbon dioxide (CO_2). The need for CO_2 is fulfilled by burning biomass, including rice husks and sugarcane bagasse. However, this process can generate hazardous compounds, notably Formaldehyde (CH_2O), posing significant health risks. To address elevated Formaldehyde concentration, a monitoring system is implemented, employing an MS1100 sensor for real-time monitoring within the carbonation tank. The data is transmitted to a web-based platform via Robotdyn Uno Wi-Fi R3, with direct data storage on a micro SD card to ensure persistence even during Wi-Fi disruptions. The system confirms the efficacy of monitoring the formaldehyde concentrations both indoors and outdoors, maintaining levels within the safe thresholds. The system demonstrates high accuracy, making it a viable solution for monitoring and regulating Formaldehyde emissions during biomass burning in the sugar industry.

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Introduction

In sugar processing plants, one pivotal phase in ensuring the production of high-quality sugar involves clarifying sugarcane juice intended to refine the final sugar product [1]. Clarification of sugarcane juice constitutes a refining process aimed at eliminating extraneous substances or achieving optimal balance in sugar production [2]. Sugar cane processing plants, or sugar factories, are integral to the global sugar industry, processing sugar cane juice through various stages to produce high-quality sugar products [3]. Among these stages, carbonation plays a pivotal role in refining sugar cane juice, balancing pH levels by reacting carbon dioxide (〖CO〗 _2) with lime milk [4]. The process used to produce 〖CO〗 _2 involves biomass burning, specifically using rice husks and sugarcane bagasse [5]. However, the carbonation process poses challenges due to the generation of hazardous compounds, notably Formaldehyde (〖CH〗 _2 O) during biomass burning for 〖CO〗 _2 generation [6]. Biomass materials such as bagasse and husks are commonly utilized for this purpose [7]. Formaldehyde, a known carcinogen, poses significant health risks to workers and nearby communities. Formaldehyde can also cause other diseases such as neurological impacts, skin irritation, and others [8].

Monitoring Formaldehyde concentrations is crucial to mitigate health hazards [9]. Advanced sensor technologies, like the MS1100 sensor, offer real-time detection capabilities for volatile organic compounds (VOCs), including Formaldehyde. These sensors utilize cutting-edge algorithms and sensitive detection mechanisms to accurately measure Formaldehyde levels, ensuring reliable data collection [10]. The accuracy value obtained by the MS1100 sensor in measuring formaldehyde concentration is 91 percent [11]. Coupled with web-based platforms, these sensors provide accessible means for displaying monitoring data, enabling prompt responses to potential hazards [12]. This integration allows for remote monitoring and management, facilitating proactive decision-making and ensuring the safety of workers and nearby communities [13].

This study focuses on developing a monitoring system that uses MS1100 sensor technology combined with a web-based platform to continuously track Formaldehyde levels during the carbonation process in sugar refineries. Current methods for monitoring Formaldehyde often depend on intermittent manual sampling, which may not capture real-time variations that could endanger worker safety and hinder compliance with health regulations. By filling this gap, the proposed system aims to improve workplace safety, ensure adherence to health standards, and support sustainable sugar production, ultimately safeguarding the health of workers and surrounding communities.

Material and Methods

A. Monitoring System

The process of system design involves the preparation of necessary tools and materials, systematic organization of crucial program code, meticulous testing procedures to

ensure smooth system functionality, meticulous finalization of packaging for the comprehensive monitoring system, as well as the presentation of data on a website for easy access anytime and anywhere.

This monitoring system is designed to have a layout comprising a sensing element, a signal processing, a communication unit and a data display as Fig.1. In preparing a good monitoring system, several tests are required, including voltage testing, communication testing, and sensor testing. The results of this testing will be used to ensure the performance of the monitoring system, whether it is functioning properly or requires improvement.

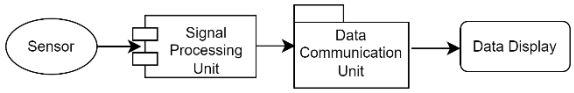


Figure 1. schematic diagram of monitoring system

B. Sample

Samples are being taken from the carbonation cylinder during the sugar refining process at the Kebonagung sugar factory. The sample being taken is a gas sample with a pressure of 0.1 bar that has been cooled through a cooler. From the samples being taken, it is hypothesized that volatile organic compounds (VOCs), including formaldehyde are present.

C. Formaldehyde monitoring

Fig. 2 shows the experimental setup in the process of monitoring formaldehyde levels. The analog values obtained from sensor readings are translated into parts per million (ppm) through conversion.

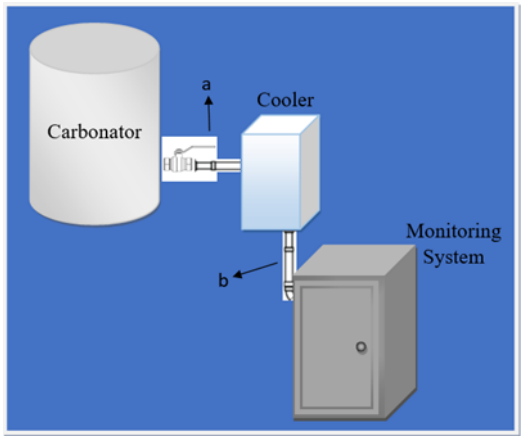


Figure 2. The Formaldehyde monitoring setup. (Note: a = pressure valve; b = connecting tube)

From the previous testing conducted, the equation derived from the graph of the monitoring test results is as follows

$$y = a\ln(x) + b \quad (1)$$

Then equation (1) is converted into an exponential equation to transform the analog sensor values into a formaldehyde concentration, as shown in the following equation

$$x = \exp\left(\frac{y-b}{a}\right) \quad (2)$$

Description :

y	=	The ratio of sensor resistance when not exposed to compounds to when exposed to compounds
a and b	=	The constant obtained from the equation on the graph
x	=	The variable that will be used as the result of converting sensor readings to a formaldehyde concentration (parts per million)

Equation (1) is subsequently integrated into the program code, enabling the real-time conversion of analog sensor readings into PPM values. The monitoring process was conducted for 3 days at the Kebonagung sugar factory, with samples being taken from the carbonation cylinder.

C. Data analysis

Data analysis is conducted to assess the system's performance in continuously monitoring the formaldehyde concentration in the carbonation cylinder. Additionally, the performance of the MS1100 sensor, utilized as the sensing element in this monitoring system, is also evaluated.

System testing is a determinant variable in the performance of the monitoring system. In the testing phase, standard deviation calculations are performed based on the obtained data. The obtained standard deviation can help in understanding the variation or dispersion of data by taking the square root of the variance, as shown in equation 3[14].

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \quad (3)$$

Results and Discussion

A. System Testing

The system has been tested on several variables, including voltage, sensors, and communication (data transmission on the website). For voltage testing, the test results data are obtained and presented in Table 1. The testing is conducted at 3 points to ascertain the stability and suitability of the voltage required for components in the monitoring system.

Table 1. Voltage testing data

	Adaptor Voltage (12V)	Stepdown Voltage (5V)	Microcontroller Voltage (5V)
Mean	11,89	5,03	5,04
STDEV	0,04	0,04	0,00

Subsequently, sensor testing is conducted by calculating the conversion equation from analog to ppm for formaldehyde concentration reading. The testing results

obtained are displayed in Fig. 3. and communication testing is performed to determine the optimal distance between the system and Wi-Fi transmitter with the setup as shown in Table 2.

Table 2. Communication testing data

Position	Safe Distance	Delay	RSSI	Accuracy
Indoor	0 – 20 meter	1,13 – 2,89 s	(-50)-(-80)	99,93 %
Outdoor	0 – 10 meter	1,21 – 2,71 s	(-40)-(-70)	96,00 %
Level	0 – 2,3 meter	1,32 – 2,86 s	(-30)-(-75)	97,00 %

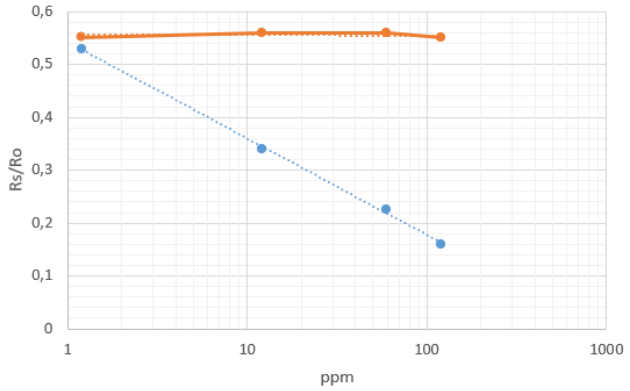


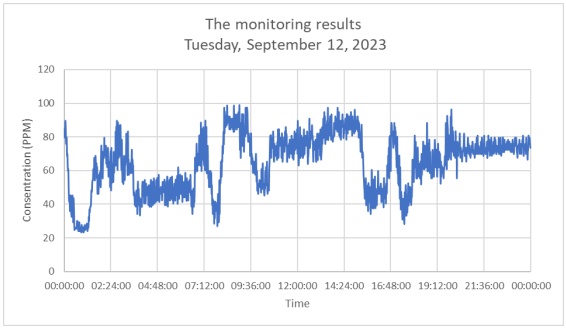
Figure 1. Comparison chart of the sensor resistance ratios and formaldehyde Concentration (Note: orange line = ambient air; blue line = Formaldehyde compounds)

The ratio displayed in the comparison graph of Figure 2. represents the change in resistance value when the sensor is exposed to a compound, which is inversely proportional to the ppm conversion value obtained. For ambient air, the obtained values tend to be stable due to the minimal formaldehyde compounds found in the free air.

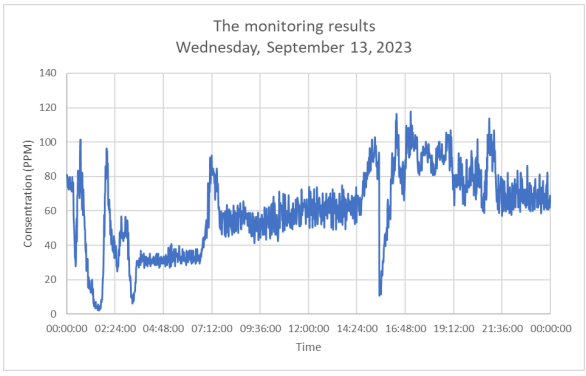
B. Total of Formaldehyde

The monitoring process was conducted from September 12, 2023, to September 14, 2023. Concentration levels of detected Formaldehyde are contingent upon combustion conditions. Lower concentration levels indicate optimal combustion, where Formaldehyde undergoes thorough oxidation. Conversely, elevated monitored concentrations signify suboptimal combustion conditions, resulting in incomplete formaldehyde oxidation.

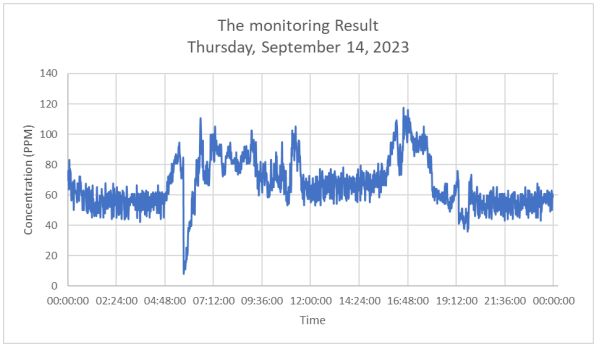
The fluctuations in Formaldehyde concentrations, as shown in Figure 3, can be explained by several factors that affect the stability of the carbonation process in sugar refineries. These fluctuations may result from variations in process conditions, such as temperature, pressure, and flow rate, which can lead to changes in Formaldehyde levels. Additionally, operational changes or equipment issues might cause sudden spikes or drops in concentration. Instability is characterized by significant and frequent deviations from the desired concentration range, where concentrations rapidly fluctuate, indicating a lack of control over the process. Stability is observed when the concentration remains within a more consistent and narrower range, as seen during periods where concentrations stabilized between 40-50 ppm or 50-70 \ppm.



(a)



(b)



(c)

Figure 2. Formaldehyde concentration monitoring result: (a) day 1 (September 12, 2023); (b) day 2 (September 13 2023); (c) day 3 (September 14 2023*)*

The monitoring results obtained are subsequently displayed on the website platform, as depicted in Figure 4. The data is presented in the form of a graphical representation, showing the latest 60 data points, which are also stored in a real-time data table.

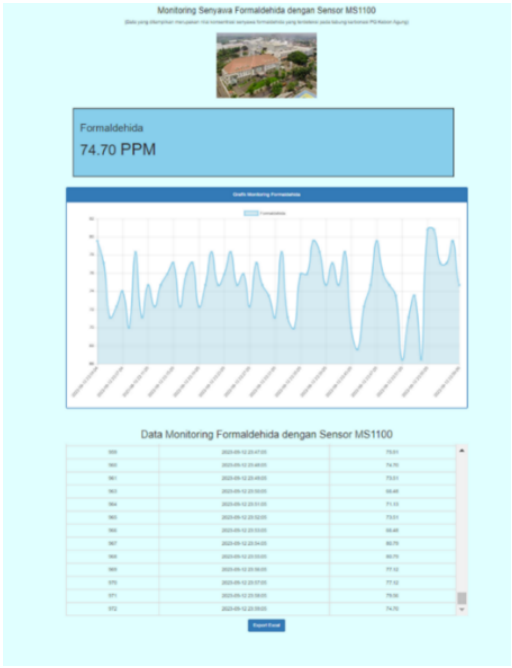


Figure 3. The website interface displays the monitoring data for formaldehyde levels

In the voltage test, the voltage values for each tested point were obtained, showing good voltage stability. This stability is evidenced by the low standard deviation values, ranging from ± 0 - 0.416. However, slight changes in the adapter voltage output were observed, possibly due to fluctuations in the connected load [15]. Conversely, the microcontroller voltage output remained stable, attributed to voltage regulators that maintain stability despite fluctuations [16]. With the low standard deviation values obtained from the voltage testing data, it can be concluded that the voltage generated by the adapter, stepdown, and microcontroller is sufficiently stable, ensuring the safety of the system components.

Subsequently, sensor testing was conducted to test the sensor for ambient air. The obtained data will be used for ratio testing compared to the graph in the datasheet. The results of this test will be depicted in a logarithmic graph, with the equation derived from it being converted into an exponential regression equation.

$$PPM_{Formaldehyde}\ a = \exp\left(\frac{y-0.5427}{-0.079}\right) \quad (4)$$

Data were collected on Tuesday (September 12, 2023), Wednesday (September 13, 2023), and Thursday (September 14, 2023), with each session lasting 24 hours. The data are presented in Figure 3. These observations yielded the concentrations of Formaldehyde within the carbonation cylinder. The monitoring system exhibited the capability to detect formaldehyde concentrations ranging from 1 to 120 parts per million (PPM) [17]. The acquired formaldehyde data displayed significant fluctuations, possibly attributable to variations in biomass combustion or internal processes within the carbonation cylinder. Given the propensity of Formaldehyde to remain unoxidized due to incomplete oxidation, temperature instability emerges as a critical factor.

Temperature fluctuations may alter the formation of intermediates, with elevated temperatures leading to an increase in Dimethyl Oxalate (DOM) and biodentate formate while monodentate formate diminishes. Formate, a compound produced before conversion into Carbon Dioxide (CO_2) or Water (H_2O), underscores the importance of temperature stability for optimal formaldehyde oxidation [18]. Additionally, the presence of other compounds may contaminate and impede oxidation processes, as these compounds may adsorb onto the catalyst, hindering its ability to oxidize Formaldehyde fully [19].

According to the National Institute for Occupational Safety and Health (NIOSH), the Immediately Dangerous to Life or Health (IDLH) threshold for Formaldehyde stands at 20 parts per million (ppm) when considering ambient air conditions [20]. However, in the context of the monitoring test conducted in this study, which involves a closed system where pressurized gas is directly connected to the carbonation cylinder, the Minimum Inhibitory Concentration (MIC) of Formaldehyde is determined to be within the range of 39 to 246 ppm, as stipulated by the Indonesian Food and Drug Authority [21]. Throughout the duration of the monitoring testing process, the detected concentrations of formaldehyde gas consistently remained below 120 ppm, thus falling within the safe concentration limits established by BPOM RI.

Conclusion

After conducting this research, it can be concluded that the designed monitoring system has been successful in doing Real-time surveillance of formaldehyde gas levels in sugar carbonation processes through a web-enabled MS1100 sensor.

The monitoring system obtained in this study demonstrates the capability to measure formaldehyde gas using the MS1100 sensor within a measurement range of 0 – 120 ppm. This system exhibits a delay time in transmitting data to the website platform of 1.13 ± 0.04 hours to 1.13 ± 0.04 seconds. The safe distance for this monitoring system is set at 0 – 20 meters, 0 – 10 meters for outdoors, and 0 – 2,3 meters for different levels from the signal transmitter in indoor locations, as the system was tested at Kebonagung sugar factory in Malang City, which is an indoor setting. The data accuracy is also reported to be within 96 ± 4 %. Furthermore, the data is also successfully displayed on the website platform to facilitate the monitoring process of formaldehyde concentrations.

Acknowledgments

This study was supported by Air Quality and Health Impact Brawijaya University. The author also thankfully acknowledges the help of Kevin Ramdhan, Gaizka Rifat M, and Lutfia Vitra E.

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