Design and analysis of safety hazardous gas instruments for laboratory experiments

Cite as: AIP Conference Proceedings **2173**, 020006 (2019); https://doi.org/10.1063/1.5133921
Published Online: 11 November 2019

Siti Sendari, Mokh Sholihul Hadi, Yuni Rahmawati, Nur Cholis Hadi, Fauzy Satrio Wibowo, Danang Arengga Wibowo, Whyna Agustin, Ira Kumalasari, Indriyani Rachman, and Toru Matsumoto

Design and Analysis of Safety Hazardous Gas Instruments for Laboratory Experiments

Siti Sendari[1, a)], Mokh Sholihul Hadi[1], Yuni Rahmawati[1], Nur Cholis Hadi[1], Fauzy Satrio Wibowo[1], Danang Arengga Wibowo[1], Whyna Agustin[1], Ira Kumalasari[1], Indriyani Rachman[2], and Toru Matsumoto[2]

[1]*Department of Electrical Engineering, Universitas Negeri Malang, Jl. Semarang No. 5, Malang 65141, Indonesia*
[2]*Department of Life and Environment Engineering, the University of Kitakyushu, 1-1Hibikino, Wakamatsu-ku, Kitakyushu 808-0135, Japan*

[a)]Corresponding author: siti.sendari.ft@um.ac.id

Abstract. In this paper, a safety of hazardous gas instruments for laboratory experiments was designed using a microcontroller and connected to personal computer to save the data. Here, the carbon monoxide gas (CO) and methane gas (CH_4) sensors are applied to the systems to measure the concentration of gases in case of laboratory. Commonly, the gas instruments are used in object tested directly without considering the flow of gases toward the user. Comparing to that system, in order to protect the users' safety from of direct contact with the gases, inlet-outlet pipes and fill-discharge tubes are used in this proposed system. The performance of the proposed system is analysed trough experiments. Some results were presented according to the time of activating inlet to inject the gas. Thus, the effect of changing the gas concentration was analysed.

Keywords – Gas instrument, Laboratory experiments, Methane gas, Carbon monoxide gas, Safety operating, Concentration measurement**.**

I. INTRODUCTION

Some of gases have unique characteristics, which cannot be seen using normal eyes or smell it. Two of gases which have poissonic characters, i.e., Methane gas (CH_4) and Carbon Monoxide (CO), should be treated carefully. CH_4 gas is produced when certain types of microorganisms decompose organic matter under anaerobic conditions [1]. It is produced naturally at the time of decomposition of biomass. However, the application of CH_4 gas should be carefully since it is flammable and produces carbon dioxide (CO_2) as another hazardous gas [2]. Meanwhile, the CO gas is produced by imperfect combustion process [3]. This case usually occur in the machine and decomposition process of waste. However, those gases can still be measured to identify their existence using certain set of instruments, which could help the human to understand the patterns and characteristics depended on the purposes, such as, research purposes, safety or security environment purposes [4][5]. Therefore, the development of ideal instrument for gas measurement should be developed based on its characteristics.

There are many types of gas instruments intended for certain measurements [6]. Lately, the development of gas instrument has been developed using various methods, such as, dew-point [7], in-point and scanning method. A method of measurement using in-point could be built using a hand held instrument, i.e., laser methane detector (LMD), which is placed in a fix chamber representing a landfill in lab scale [8]. In case of scanning method, the measurement was done continuously in site of landfill using LMD strung between two poles with wire. This research is focusing a method how to measure gas in lab scale compared with that in landfill site by using manufactured instrument. Beside of only one certain gas is observed, the price of this instrument is also expensive. Low cost gas instrument can be developed using a micro controller as the main processor [9]. So, various gases could be measured using several sensors installed to the micro controller. Here, the measured data is compared using two chambers to observe the effect of temperature toward sensor output. Here, one chamber is filled in gas with various temperatures, while the other one is used as reference.

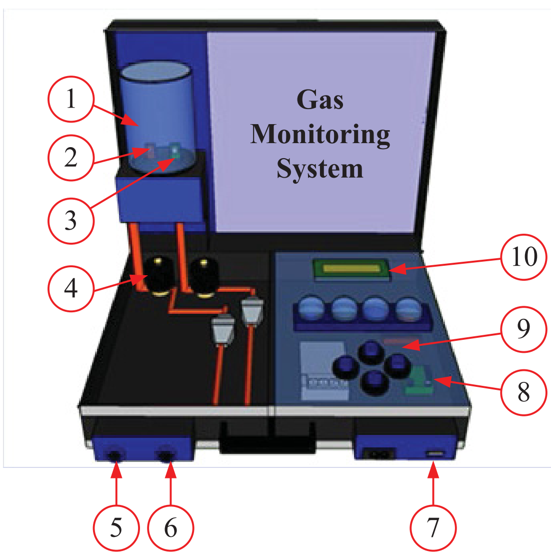
In order to collect the data from sensor, a micro controller can be connected to personal computer using serial communication. This method improves the ability to characterize the sensors output. One software for acquisition, which is linked to Excel spreadsheet and also can be plotted in real time without reprogramming when connected to Arduino interface, is using PLX-DAQ [10].

Comparing with those methods explained above, the objectives of these studies is to observe the performance of developing a gas instrument using flux profile with a chamber, which can be used for lab scale. Instead of determining the gas concentration based on instrument available, the gas concentration is controlled by various time of filling in gas to the chamber. The profile of gas concentration is observed when the gas is injected at a certain time. This instrument is developed using a micro controller as the main processing connected to PC for data logging, here PLX-DAQ is used. This method demonstrated the ability to measure the gas continuosly.

Thus, this paper is organized as follows. Section 2 describes the method of developing system, and Section 3 describes results and discussion. Conclusions are devoted at Section 4.

II. MATERIAL AND METHODS

The gas instrumentation has been developed with several unique features, including data logging for monitoring gas. Hence, the method is devided into the method of gas measurement and developing the system, consisting of (a) Diagram Block; (b) Design Instrument; and (c) Flowchart System. The proposed system is shown in Fig. 1 following with the whole description of the proposed system.



1. Gas chamber
2. CO gas sensor
3.CH4 gas sensor
4. Electrical valve
5. Pipe in
6. Pipe out
7. Communication port
8. Microcontroller
9. Function buttons
10. LCD screen

FIGURE 1. The designed system

A. Measurement of Gas Flux by Chamber

Rate flow per unit area is defined as flux in fluid dynamics, which is related to density of gas. Gas concentration inside the camber is diffused from tube. Here, the system is developed using small chamber built from tube with dimension of height is 13 cm and diameter is 11 cm. The gas is injected to the chamber using gas inlet valve and exhausted from it using gas exhaust valve. Gas flux is related to gas concentration as shown as following equation [8]:

$$F = \rho \,.\, V / A \,.\, \Delta C / \Delta t \,.\, \Delta T.3600 \tag{1}$$

where F is gas flux (g.m-2.h-1), ρ is gas density (g.m-3), V is volume of chamber (m3), A is area of chamber (m2), ΔC / Δt is slope of change of gas concentration (ppm) over time (h), ΔT average temperature in chamber (^{o}C).

According to the equation 1, the gas source is injected to the chamber via pipe in using electrical valve controlled ON by a micro controller at a certain time. Thus, the change of gas concentration could be known. In order to detect and measure the gas concentration semi-conductor gas sensors can be used, which act as variable resistors depending on gas leakage. Due to hazardous gases, this measurement is designed. Here, CO gas is measured using MQ-07 sensor module[11], while CH_4 gas sensor is using TGS-2611 sensor module [12].

B. Developing of Gas Measurement

The proposed system is developed using ten parts, i.e., (1) Gas chamber, (2) CO gas sensor, (3) CH_4 gas sensor, (4) Electrical valve, (5) Pipe in, (6) Pipe out, (7) Communication port, (8) Micro controller, (9) Function buttons (up, down, next and back button), and (10) LCD, as shown in Fig. 1.

The designed system works using a micro controller as the main processor, here Arduino Uno is used. It converts the data sent by CH_4 and CO gas sensors to be shown in LCD screen. Selecting appropriate sensor data to be converted, i.e., CH_4 sensor or CO sensor is choosen using function buttons. Then, gas concentration of gas is injected to the chamber in a certain time. Different duration of gas injection results various concentration of gases to be analysed. The time to injected gas can be selected as 10, 20, 30, 40, 50, or 60 seconds, which is controlled by micro controller by switching ON the electrical valve of pipe in. The process of exhausting the gas in chamber is controlled by switching ON the electrical valve of pipe out. In order to extend the ability to measure and monitor concentration of gases, the system is connected to personal computer (PC) or laptop via a serial communication as data logging feature. Meanwhile, the gas flux for measuring purposes is monitored using PC via serial communication (Port PC). The diagram block is shown in Fig. 2.

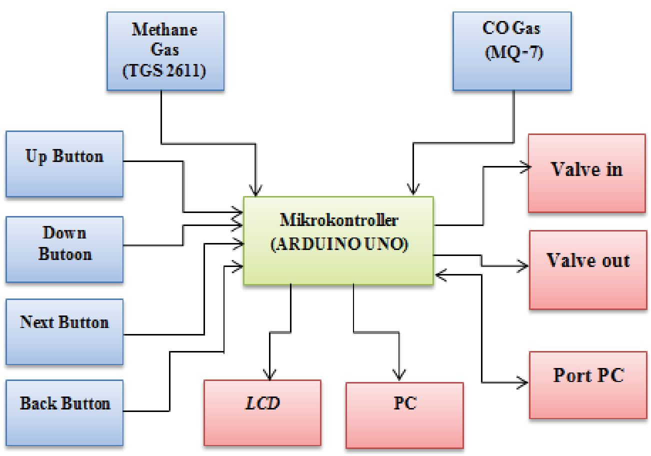


FIGURE 2. Diagram block of proposed system

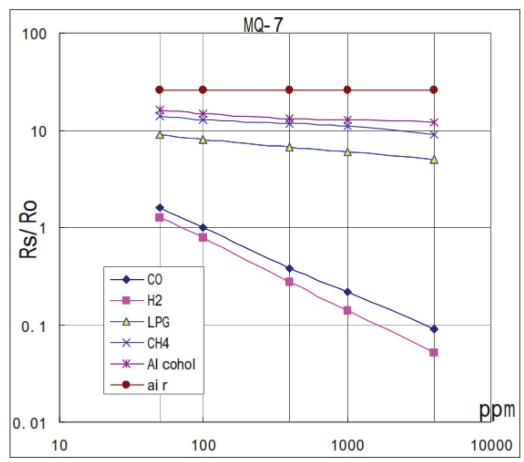


FIGURE 3. MQ-7 gas sensitivity characteristic

1) CO Gas Sensor

The CO gas sensor is designed using MQ-7 module, which has high sensitivity on carbon monoxide, which can detect carbon monoxide from 20 ~ 2000 ppm. Based on its datasheet, MQ-07 has stable condition and long life span. The graph in Fig. 3 shows the Rs/Ro ratio in CO gas sensor [11]. While Ro is sensor resistance at 100 ppm in the clean air, Rs is sensor resistance at different CO gas concentration.

A standard circuit of MQ-7 module consists of 2 parts, i.e., (1) the heating circuit with time control function, and (2) the signal output circuit, which can accurately respond to the changes of surface resistance of the sensor. A series-wound is used to determine the concentration of gas in a given area. The surface resistance of the sensor (Rs) is obtained through voltage signal output of the load resistance RL as follows,

$$Rs/RL = (Vc-VRL) / VRL \quad (2)$$

where, Vc is supply voltage, while VRL is voltage of load.

2) CH_4 Sensor

TGS2611 is a module of semiconductor type gas sensor, which combines sensitivity to CH_4 gas with low power consumption [12]. It requires small amount of heat current around 56mA for the operation. The detection range from the sensor is around 500 to 10.000 ppm. Here, the calibration of the sensor was using Rs/Ro ratio based on the datasheet as described on Fig. 4, the Rs/Ro ratio value affects the amount gas concentration.

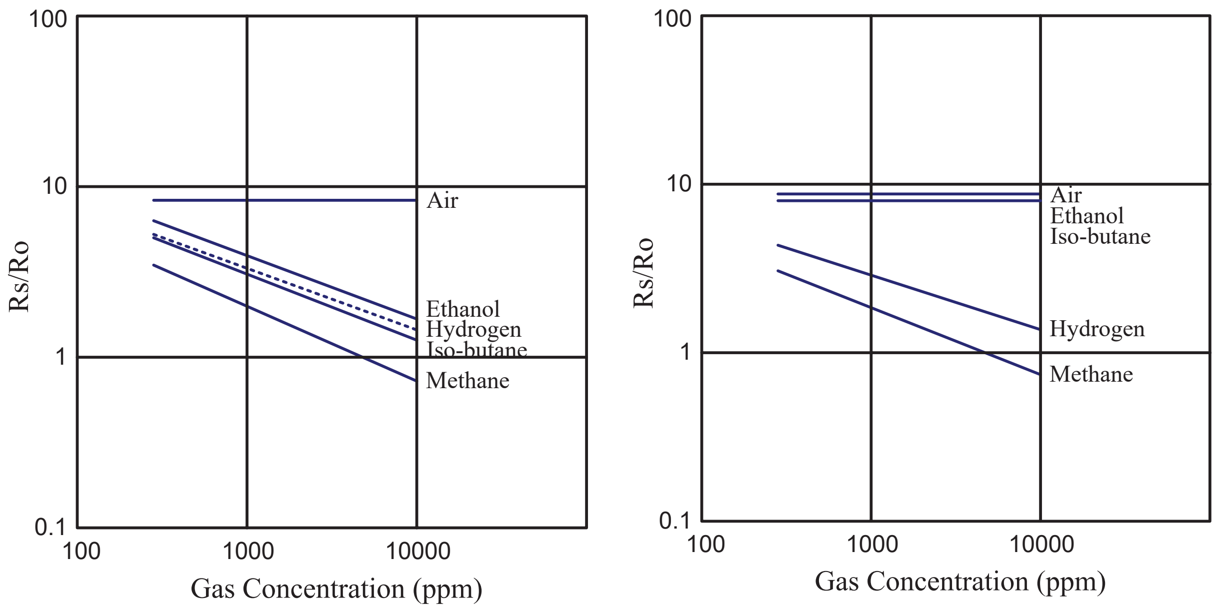


FIGURE 4. TGS 2611 Gas sensitivity characteristic

Regarding to the graph in Fig. 4, the Rs/Ro ratio would be at 1 when the gas concentration is 5000 ppm. Thus, the calculation of Rs/Ro ratio could be done using equation 2.

C. Flowchart System

The developed system works as the program, which is embedded to the micro controller. It is represented as the flowchart system shown in Fig. 5. After initialization, the system asks user to chooce which sensor will be activated by selecting appropriate menu displayed on LCD. Then, gas can be injected to the chamber via electric valve in. Gas concentration can be arranged by setting the time of switching ON the electrical valve of pipe in. Here, user can choose the setting by 10, 20, 30, 40, 50, or 60 seconds. Micro controller converts the sensor data to the appropriate gas concentration values in ppm and %volume. The data is also sent to the PLX-DAQ installed to PC via serial communication as the data logging. The gas concentration can be reduced or drained by exhausting the gas chamber by switching ON the electrical valve of pipe out.

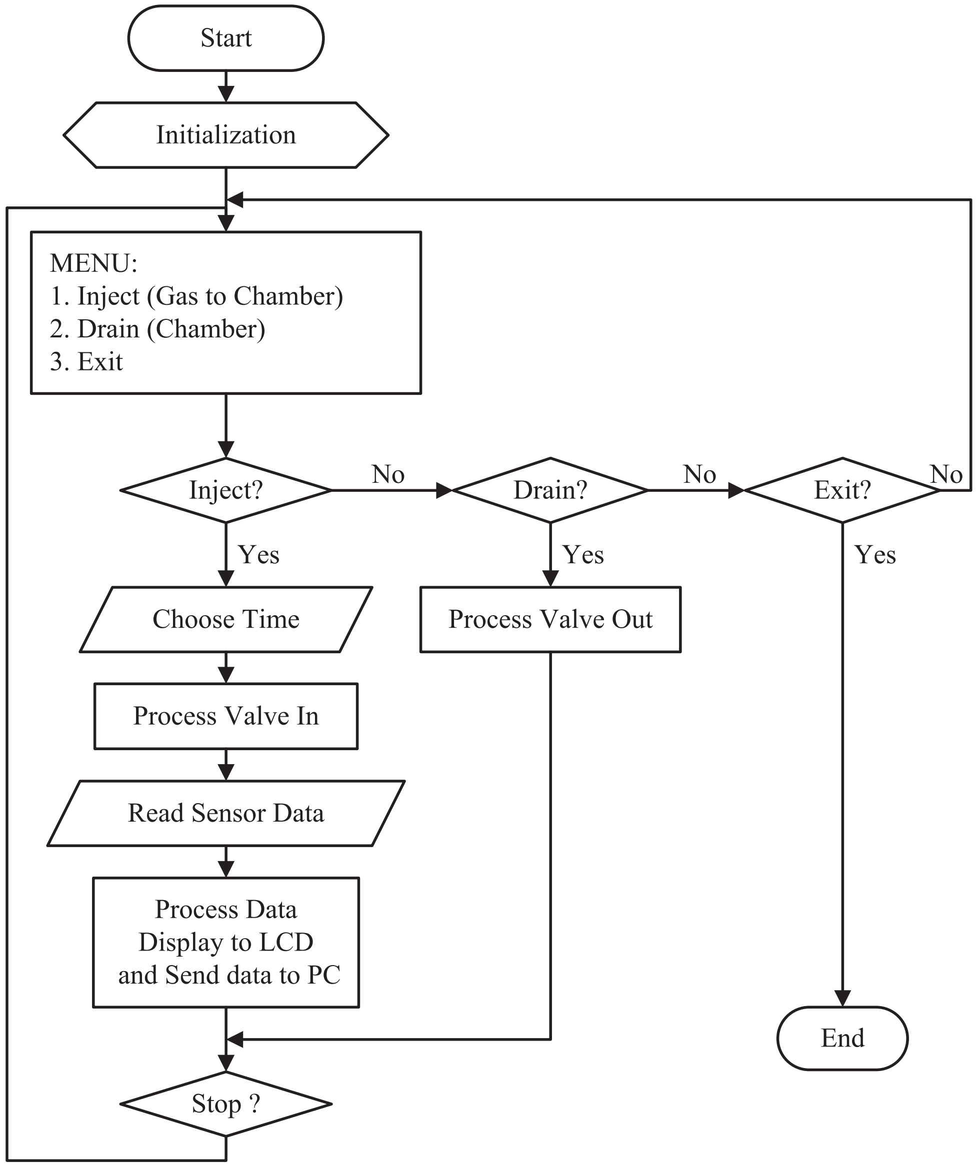


FIGURE 5. Flowchart System

D. Evaluating method

The evaluating method of the developed system works as program is done using several methods as follows. Firstly, the black box method is used to evaluate the function of each part of hardware module as shown by diagram block in Fig. 2. The second method, which is used is t-test method. It is used to evaluate the gas, which is injected to the chamber in a certain time. Here, the gas flux is tested with several time settings provided, i.e., gas flux of chamber with 0 second (means clear chamber), it is compared to that of chamber with 10 seconds; this process is continued for remain time settings. The third, the average of gas concentration will be compared with manual calcullation to measure the error occurs. The trial is done in 10 experiments.

III. RESULTS AND DISCUSSIONS

The results of evaluation methods are described as follows.

A. Hardware Testing

The developed system is shown in Fig. 6. The functionality of the hardware system are tested using black box method [13][14], which done for 10 parts consisting of (1) Gas chamber, (2) CO gas sensor, (3) CH_4 gas sensor, (4) Electrical valve, (5) Pipe in, (6) Pipe out, (7) Communication port, (8) Micro controller, (9) Function buttons (up, down, next and back button), and (10) LCD. The functionality is shown in Table 1.

TABLE 1. Functionality of Hardware

No	Block	Function
1	Gas Chamber	Can keep gas and no leakage gases, here lorored gas tester is used
2	CO gas sensor	Send analog data when environment changed by CO
3	CH_4 gas sensor	Send analog data when environment changed by CH_4
4	Electrical valve	Logic match with data sent by microcontroller
5	Pipe in	Pipe can inject the gas to chamber
6	Pipe out	Pipe can exhaust the gas from chamber
7	Communication port	Send data to PC
8	Micro controller	Read data from analog input, Read data from digital input, Send data to digital output, Send data to serial communication
9	Function buttons	Read logic of function buttons : -Up, Down, Back, Next
10	LCD	Send character from micro controller to LCD

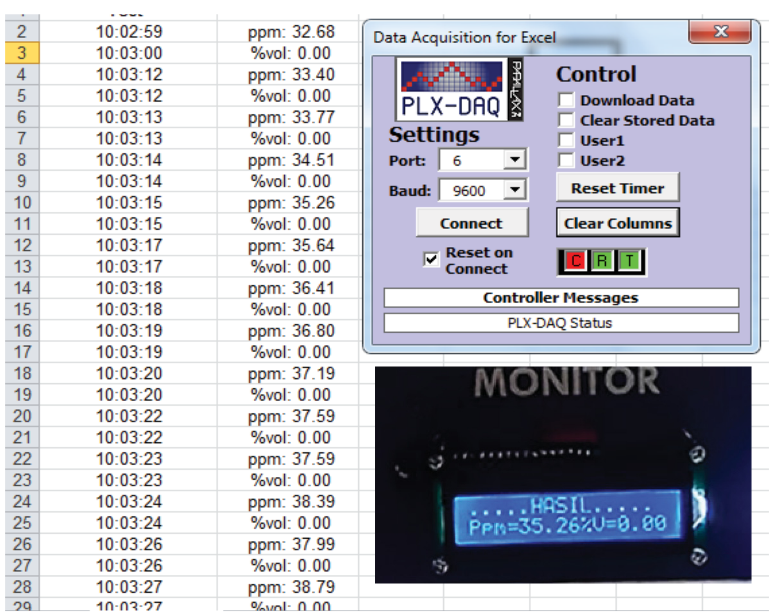


FIGURE 6. Developed system and an example of data shown

The errors are analyzed by the equation below. Where, "E" is errors found (%), "n" is number of testers, and "L" is problems found (%).

$$E = 100 \text{ x } (1 - (1 - L) \wedge n) \tag{3}$$

According to 10 experiments, each block in Table 1 shows that its function works appropriately, so it means E is 0%.

B. t-test Method

Here, t-test method is used to evaluate the gas flux, which is injected to the chamber in a certain time. Here, the setting times are done for 0, 10, 20, 30, 40, 50, and 60 seconds of injected gas to the chamber. Comparison is carried out as follows. Injected gas with 0 second is compared to that with 10 seconds; then, injected gas with 10 seconds is compared with that with 20 seconds. These processes are continued for remain time settings.

1) CO Gas Testing

Regarding to the sensor characteristic shown in Fig. 3, the sensor resistance Rs is decreased along with CO gas absorption. Thus, decreasing of sensor resistance indicates that the output voltage is increased. Sensitivity characteristics of MQ7 can be given as the following equation

$$R = KC{-}n \tag{4}$$

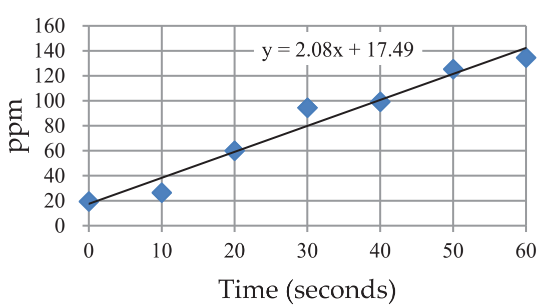
Where, R represents Rs/Ro, while Rs= sensor resistance at various concentrations of gases, Ro = sensor resistance at 100ppm CO in the clean air. Here, n = 1.4, while K is 25.12 as constant of the sensor material. C is CO concentration in ppm. So, the relation between output analog voltage obtained at the sensor output and the concentration in ppm can be determined by equation as follows [15],

$$(ppm) = 100.468[(5/ V\text{o}) - 1]{-}1.43 \tag{5}$$

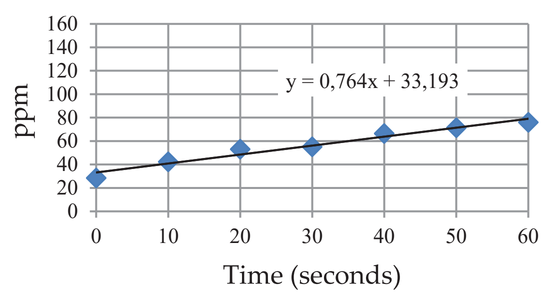
Gas testing is carried out with 10 experiments. The results are analyzed according to the mean and variance values. Then comparison is evaluated from p value of one tail. Here, the sample of data logging function was taken in 0 to 60 seconds injected of CO gas concentration in gas chamber. The results are shown in Table 2. Regarding to the p-value, it can be seen that p values are less than 0.05, which means that the flux gas according to time setting of gas injection show different respond. It can be said that the respond is different significantly.

TABLE 2. T-Test of CO Gas Testing

Time settings	Mean (ppm)	Variance	p value
0	19,40	0,02	-
10	26,43	6,99	1,32E-42
20	59,98	99,16	1,44E-53
30	94,40	56,71	4,59E-61
40	99,20	85,00	9,11E-05
50	125,37	156,71	1,58E-35
60	134,53	502,95	4,63E-04



(a)



(b)

FIGURE 7. Respon diagram of sensors over time setting: (a) CO; (b) CH4.

Furthermore, the respond of CO gas sensor toward the gas concentration over time setting is represented as linear diagram as shown in Fig. 7(a). The respond can be modeled as y = 2.08x + 17.49, which means y is gas concentration while x is time setting. The linear respond obtained here is because the range of CO testing is small.

2) CH_4 Gas Testing

CH_4 gas testing is carried out with 10 experiments. The results are also analyzed according to the mean values and variance values. Then comparison is evaluated from p value of one tail. Here, the sample of data logging function was taken in 0 to 60 seconds injected of CH_4 gas concentration in gas chamber. The results are shown in Table 3. Regarding to the p-value, it can be seen that p values are less than 0.05, which means that the flux gas according to time setting of gas injection show different respond. It can be said that the respond is different significantly.

TABLE 3. T-Test of CH4 Gas Testing

Time settings	Mean (ppm)	Variance	p value
0	28,53	0,27	2,07E-58
10	42,26	11,69	7,50E-28
20	53,08	43,47	1,38E-02
30	55,13	32,99	1,38E-02
40	66,49	69,91	1,52E-20
50	71,32	71,24	7,99E-05
60	75,99	69,90	1,28E-04

Furthermore, the respond of CH_4 gas sensor toward the gas concentration over time setting is represented as linear diagram as shown in Fig. 7(b). The response can be modeled as $y = 0.76x + 33.19$, which means y is gas concentration while x is time setting.

C. The Advantages of Proposed System

Generally, the gas instrument used in the object is tested directly without considering the gas flow to the user. This can cause a risk if the user continuously interacts with dangerous gases. This proposed system is designed to overcome this problem. Here, users can use the instrument using the inlet-outlet pipes and fill-discharge tubes without direct contact with the gas. so, the measurement process can be carried out safely. Table 4 show the comparison between purposed system and similar product that commonly used to meassure CO and CH_4.

TABLE 4. Comparison with Similar Peoducts

No	Comparison Aspect	BX615	Proposed System
1	Display		
2	Available for CO measurement	√	√
3	Available for CH_4 measurement	√	√
4	Easy to move		√
5	Easy to calibrate	√	√
6	There is an artificial environment (because of the calibration inside the chamber)	×	√
7	Safety (undirect contact with gas)	×	√

IV. CONCLUSIONS

A safety of hazardous gas instruments for laboratory experiments to observe CO and CH_4 is designed, while common gas instruments are used in object tested directly without considering the flow of gases toward the user. The designed system is developed using a microcontroller and connected to personal computer to save the data. Here, the users can use the instrument using inlet-outlet pipes and fill-discharge tubes as an artificial environment without direct contact toward gases. Since the observation used low concentration, the performance of the proposed system shows linear responds, which can be modeled using linear regression.

ACKNOWLEDGMENTS

We would like to thank the Directorate of Higher Education of Indonesia Government for supporting this research under grant Collaboration Research and International Publishing. This research is a collaboration result between State University of Malang and the University of Kitakyushu.

REFERENCES

[1] I. M. Joni, Y. A. Hidayati, T. B. A. Kurnani, E. T. Marlina, K. N. Rahmah, H. Ellin, *AIP Conference Proceedings 1927*. (AIP Publishing) Vol. 1927, pp. 30021-1-30021–4, 2018.

[2] A. Demirbas, *Methane Gas Hydrate*, vol. X. 2010.

[3] L. W. Cheng, L. Z. Qing, Z. Z. Xin, L. Hai, Applied Mechanics and Materials 220-223:517-520, 2016.

[4] N. Fareeza et al, IOP Conf. Ser. Earth Environ. Sci. 32 012042, 2016.

[5] M. B. Frish, *Proceedings of the SPIE*, Volume 9101, id. 91010H 12 pp. (2014)

[6] D.-D. Lee and D.-S. Lee, IEEE Sens. J., Vol. 1, no. 3, pp. 214–224, 2001.

[7] W. Vapor and H. Dew-point, Technical paper water vapor and hydrocarbon dew-point in natural gas, 2011.

[8] L. Asiyanthi, N. Hirofumi, S. Takayuki, Kyushu University Institutional Repository, Vol. 75, no. 1, pp. 29–46, 2015.

[9] D. Sudhir, S. N. Pawar, International Journal of Computer Applications, Vol. 121, no. 14, pp. 34–38, 2015.

[10] D. Gonzá, E. R. González, and M. M. D. Pérez, Journal of Laboratory Chemical Education, Vol. 1, no. 2, pp. 11–18, 2013.

[11] C. Monoxide, MQ-7 gas sensor, Vol. 1, pp. 3–5.

[12] P. Information, Product information TGS 2611 - for the detection of methane basic measuring circuit

[13] M. E. Khan, International Journal of Advanced Computer Science and Applications, Vol. 3, no. 6, pp. 12–15, 2012.

[14] T. Yumoto, T. Matsuodani, and K. Tsuda, *Procedia - Procedia Computer Science,* Vol. 22, pp. 551–560, 2013.

[15] K. Sunil, G. Aaklin, G. Deven, *Proceedings of the 10th INDIACom; INDIACom-2016*. IEEE Conference ID: 37465) pp. 3803-3807, 2016.