# Response of Semiconductor Sensor in An Electronic Nose with Multi-Sample Delivery System

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**ABSTRACT**
An electronic nose is a device designed to sense, classify, and recognize a product based on its aroma. The electronic nose is generally designed from four main parts, namely: sample handling and delivery system, detector system, signal conditioning and preprocessing, and pattern recognition software. The detector part plays an important role in determining the performance of the electronic nose. To speed up testing, the sample handling and delivery system can be designed by implementing multiple chambers assembled in one unit. However, the sampling rate is highly dependent on the characteristics of the detector system used. This study aims to determine the characteristics of the detector system on the speed of sample presentation by the sample handling and delivery system. The detector system is designed from eight of semiconductor sensors arranged in a row. The samples placed in the sample room are presented alternately with varying durations. Sensor responses recorded during the sample presentation were then analyzed. The sensor response results obtained for each sensor on the average of the three measurements are negative, so it can be concluded that in the re-flushing process, both sensors have recovered and are ready to be used for the second data collection. The value of the sensor response change in the flushing process is high enough so that the purging time can be reduced to shorten the sensor cleaning time from exposure to the sample aroma. The characteristics of detection system on the speed of sample presentation with the sampling period of 480 seconds can recover the response of the semiconductor gas sensor based on the results of ΔP, which is added with ΔF.

***Keywords:*** *Electronic nose, Sample handling and delivery system, Detector performance, Multi-chamber.*

## 1. INTRODUCTION

The electronic nose instrument is a technology used to identify aromas based on gas sensors [1]. Along with the development of the electronic nose in various fields of application, the design of the electronic nose is adjusted to the needs. Key improvements are gas sensor design, sample rendering system, data analysis innovations, and pattern recognition algorithms. These scent detection applications have improved product attributes, quality, uniformity, and consistency in a way that increases the efficiency and effectiveness of production and manufacturing processes [2]. Furthermore, the invention of various types and instruments of electronic nose sensors, based on different principles and mechanisms of electronic scent detection, has led to the development of electronic nose applications for various disciplines [3].

The food industry has become very dependent on electronic devices because of the ability of these instruments to recognize the presence of certain gas mixtures resulting from various manufacturing processes [4]. The aroma characteristics of products, especially in the food industry, make a huge contribution to the product's value and attractiveness to consumers [5]. For this reason, quality control of the aroma characteristics of manufactured products is very important because product consistency is crucial to maintain consumer brand recognition and satisfaction. Other common quality control manufacturing applications of the e-nose are product assessment, uniformity, mechanical processing control, and monitoring of environmental wastes released from manufacturing processes. The electronic nose device differs from most other instruments used in chemical analysis in that it is designed to recognize a gas mixture as a whole without identifying the individual chemical species in the mixture.


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The suitability of the electronic nose for a particular application is highly dependent on the required operating conditions of the sensor array and the gas composition of the detected target analyte [6]. Therefore, the proper selection of an appropriate electronic nose system for a particular application should involve an evaluation of the system on a case-by-case basis. Some of the key considerations involved in selecting an electronic nose for a particular application should include an assessment of the selectivity and sensitivity range of the individual sensor circuits for a particular target gas, the number of unnecessary sensors with the same sensitivity, as well as sensor accuracy, reproducibility (precision), response speed, recovery rate, resilience, and overall performance [7].

The effective design of an electronic device depends on several factors, including the specific gas sensor application to be used, the range of target chemicals to be detected, the required operating conditions of the instrument, the selectivity and sensitivity range for the required detection, and various operational requirements such as speed and cycle times between samples, sensor array recovery time, data analysis, and result interpretation requirements [7].

The working principle of the electronic nose developed by [8] is that the gas sensor of the sensitive element reacts with the sample gas then the response signal is transmitted to the PC via an analog to digital converter. After preprocessing the data, the model is built in combination with the recognition algorithm pattern to complete the detection. The gas sensor that is often used is the metal oxide semiconductor (MOS) sensor because of its advantages in fast response, high sensitivity, and strong stability [9], [10]. The selectivity of the sensor array for a particular target VOC is a major factor to consider in designing an electronic nose device or in selecting a particular sensor type [11]–[13].

Ideally, the sensor array should consist of individual sensors that produce different responses to a particular odor analyte so as to create a unique scent pattern. If there is difficulty in obtaining unique aroma patterns for different gas analytes, the sensor selection should be modified or the number of sensors adjusted when classification, performance, cost, or technological limitations are concerns. Improper sensor selection or poor sensor array configuration can result in decreased e-nose performance [7].

[14] designed an electronic nose that consists of the first three components, namely a sample presenting system, a detection system, and a computing system. The sample serving system consists of a solenoid valve which is used to control the airflow by switching between the sample chamber and the reference chamber. Based on this design, it is possible to design an electronic nose with multi-chamber samples to improve its performance. The electronic nose with a multi-chamber is able to increase work operations, such as the speed of the sampling process, but the detector system with the sample chamber design is not yet known for its performance and response characteristics. Therefore, this study aims to determine the characteristics of the detection system on the speed of sample presentation by the sample handling and delivery system.

## 2. METHODOLOGY

### *2.1. Preparation of sample*

The sample used for testing the electronic nose is a liquid synthetic flavoring with aroma variants, namely mocha. The number of samples for testing is 5 ml.

### *2.2. Design of electronic nose multi-sample*

The overall electronic nose design has 4 main parts as shown in Figure 1, namely: sample handling and delivery system (1), detector system (2), signal conditioning and preprocessing (3), and pattern recognition software (4) [15]. The sample handling and delivery system is the place used to place the samples to be tested. This section consists of 6 sample chambers so that sampling can be carried out 6 times during the data collection process. In addition, this section contains a heater and fan, which are used to control the temperature of the sample chamber box to reach a certain point during the data collection process. The detector section consists of 8 MOS-type gas sensors, namely MQ 2, MQ 3, MQ 4, MQ 5, MQ 6, MQ 7, MQ 8, MQ 9. The gas sensor has sensitivity to certain gases. The detector section serves to detect the aroma of the test sample. The signal conditioning section uses an Arduino Mega 2560 microcontroller board with an ATMega 2560 microcontroller. The microcontroller is used as an analog to digital converter (ADC) with a resolution of 10 bits. The microcontroller also functions to control all electronic nose components.

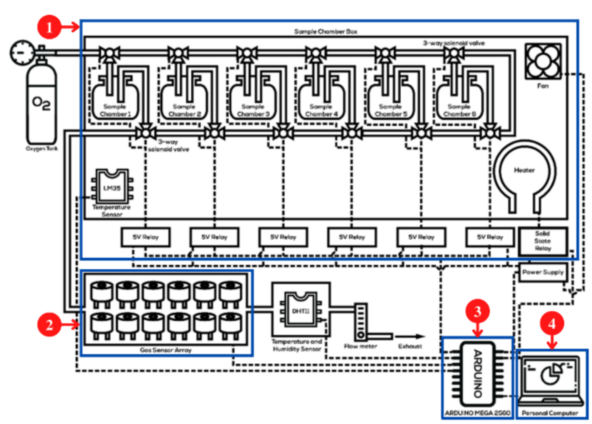


**Figure 1** Schematic diagram of the electronic nose with a multi-sample delivery system

### *2.3. Procedure of Data Collection*

The research continued with the data collection stage. Data collection for each sample was 30 replicates. The electronic nose is turned on then the data sampling process is carried out without using a sample to stabilize the gas sensor array. A sampling of one sample chamber consists of flushing, collecting, and purging processes (Figure 2). The flushing duration is set for 120 seconds, while the collecting duration is 180 seconds, and purging is 180 seconds. Flushing is the process of airflow towards the gas sensor array without being exposed to the sample aroma. The gas sensor response from the flushing process will be the reference value or baseline when the sensor array is exposed to clean air. Collecting is the process of airflow towards the gas sensor array that has been exposed to the sample aroma. When this process takes place, the sensor response will increase and tend to be stable. Purging is the process of airflow without being exposed to the scent of the sample again. The gas sensor response will begin to decrease in this process until it reaches the baseline point.

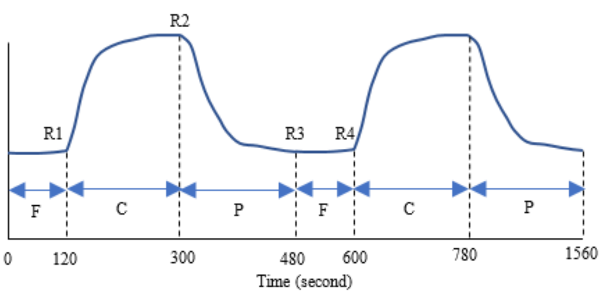


**Figure 2** Sampling process

Where F is flushing, C is collecting, P is purging, R1 is data range at point 1, R2 is data range at point 2, R3 is data range at point 3, and R4 is data range at point 4.

### *2.4. Analysis of Data*

The sample test data obtained using a set of electronic noses are then processed using a computer. The data from the sample test results are in the form of ADC value data (bits) for the response of eight gas sensors stored in microsoft excel. Then the ADC value is converted into voltage units using Equation (1).

$$v = \frac{\text{value x reference voltage (5V)}}{1023} \quad (1)$$

$\Delta F$ = R2 - R1

$\Delta C$ = R3 - R2

$\Delta P$ = R4 - R3

Where v is response of gas sensor in volt, $\Delta F$ is flushing change, $\Delta C$ is collecting change, and $\Delta P$ is purging change.

## 3. RESULT AND DISCUSSION

Based on the collecting process for 180 seconds, the average voltage increase for each sensor is shown in Table 1. Based on the average of the three measurements, MQ 2 became the sensor with the slowest response (0.07 volts) and the fastest MQ 8 (0.54 volts). On average, the MQ semiconductor sensor responds to the sample presentation of 0.34 volt.

Table 1. Collecting change ($\Delta C$)

| Sensor | M 1 (volt) | M 2 (volt) | M 3 (volt) | Average (volt) |
|---|---|---|---|---|
| MQ 2 | 0.05 | 0.08 | 0.09 | 0.07 |
| MQ 3 | 0.22 | 0.14 | 0.14 | 0.17 |
| MQ 4 | 0.06 | 0.12 | 0.12 | 0.10 |
| MQ 5 | 0.61 | 0.38 | 0.37 | 0.45 |
| MQ 6 | 0.77 | 0.38 | 0.35 | 0.50 |
| MQ 7 | 0.57 | 0.36 | 0.36 | 0.43 |
| MQ 8 | 0.83 | 0.38 | 0.39 | 0.53 |
| MQ 9 | 0.59 | 0.36 | 0.33 | 0.43 |

M : Measurement

Table 2. Purging change ($\Delta P$)

| Sensor | M 1 (volt) | M 2 (volt) | M 3 (volt) | Average (volt) |
|---|---|---|---|---|
| MQ 2 | -0.08 | -0.08 | -0.08 | -0.08 |
| MQ 3 | -0.24 | -0.15 | -0.13 | -0.17 |
| MQ 4 | -0.08 | -0.08 | -0.06 | -0.07 |
| MQ 5 | -0.57 | -0.37 | -0.34 | -0.43 |
| MQ 6 | -0.77 | -0.38 | -0.33 | -0.49 |
| MQ 7 | -0.50 | -0.34 | -0.30 | -0.38 |
| MQ 8 | -0.79 | -0.40 | -0.36 | -0.52 |
| MQ 9 | -0.55 | -0.35 | -0.29 | -0.40 |

M : Measurement

This recovery or purging is conducted at 180 s, the same as sample presentation. Based on the purging process for 180 seconds, the average voltage drop for each sensor is shown in Table 2. The sensor with the fastest response drop is MQ 8 (-0.52 volt), and the slow response drop is MQ 4 (-0.07 volt).

Table 3. Collecting change and purging change ($\Delta C$ + $\Delta P$)

| Sensor | M 1 (volt) | M 2 (volt) | M 3 (volt) | Average (volt) |
|---|---|---|---|---|
| MQ 2 | -0.03 | 0.00 | 0.01 | -0.01 |
| MQ 3 | -0.01 | -0.01 | 0.01 | -0.01 |
| MQ 4 | -0.03 | 0.04 | 0.05 | 0.02 |
| MQ 5 | 0.04 | 0.00 | 0.04 | 0.03 |
| MQ 6 | 0.00 | -0.01 | 0.02 | 0.00 |
| MQ 7 | 0.07 | 0.02 | 0.06 | 0.05 |
| MQ 8 | 0.03 | -0.02 | 0.04 | 0.02 |
| MQ 9 | 0.04 | 0.01 | 0.04 | 0.03 |

M : Measurement

The recovery of the sensor response in the purging process can be seen in Table 3. Table 3 is the value of the sum of the values of $\Delta C$ and $\Delta P$ (Table 2). A negative value means that the sensor response has returned to the baseline value at the purging stage. The MQ 2 and MQ 3 sensor responses have not reached the baseline value based on the average sensor response value from the three measurements.

Table 4. Flushing change (ΔF)

| Sensor | M 1 (volt) | M 2 (volt) | M 3 (volt) | Average (volt) |
|---|---|---|---|---|
| MQ 2 | 0.00 | -0.08 | 0.00 | 0.00 |
| MQ 3 | -0.01 | -0.15 | -0.01 | -0.01 |
| MQ 4 | -0.01 | -0.08 | -0.02 | -0.02 |
| MQ 5 | -0.05 | -0.37 | -0.04 | -0.04 |
| MQ 6 | -0.03 | -0.38 | -0.03 | -0.03 |
| MQ 7 | -0.07 | -0.34 | -0.06 | -0.06 |
| MQ 8 | -0.06 | -0.40 | -0.04 | -0.04 |
| MQ 9 | -0.05 | -0.35 | -0.04 | -0.04 |

M : Measurement

Table 5. Purging change, flushing change and collecting change (ΔP + ΔF + ΔC)

| Sensor | M 1 (volt) | M 2 (volt) | M 3 (volt) | Average (volt) |
|---|---|---|---|---|
| MQ 2 | -0.02 | -0.09 | 0.01 | -0.03 |
| MQ 3 | -0.02 | -0.16 | 0.00 | -0.06 |
| MQ 4 | -0.03 | -0.03 | 0.04 | -0.01 |
| MQ 5 | -0.01 | -0.37 | 0.00 | -0.13 |
| MQ 6 | -0.04 | -0.39 | -0.01 | -0.14 |
| MQ 7 | 0.00 | -0.32 | 0.00 | -0.11 |
| MQ 8 | -0.02 | -0.42 | -0.01 | -0.15 |
| MQ 9 | -0.01 | -0.35 | 0.00 | -0.12 |

M : Measurement

The recovery of the sensor response based on the flushing process for the second test can be seen in Table 5. If the value obtained is negative, the result indicates that the sensor response has returned to the baseline value during the flushing process in the first test. The sensor response results obtained for each sensor on the average of the three measurements are negative, so it can be concluded that in the re-flushing process, both sensors have recovered and are ready to be used for the second data collection. The value of the sensor response change in the flushing process is high enough so that the purging time can be reduced to shorten the sensor cleaning time from exposure to the sample aroma.

## 4. CONCLUSION

The characteristics of detection system on the speed of sample presentation with the sampling period of 480 seconds can recover the response of the semiconductor gas sensor based on the results of ΔP, which is added with ΔF. Collecting process with a duration of 180 s is enough. Purging process with a duration of 180 s is not enough to recover all sensors, so flushing process is required to restore the response of all sensors.

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## REFERENCES

[1] O. Kanoun, N. Derbel, and F. Derbel, Eds., Electronic Nose System and Principal Component Analysis Technique for Gases Identification, in Sensors, Circuits & Instrumentation Systems, De Gruyter Oldenbourg, 2018, pp. 167–180. doi: 10.1515/9783110448375-011.

[2] A. D. Wilson, Applications of Electronic-Nose Technologies for Noninvasive Early Detection of Plant, Animal and Human Diseases, Chemosensors, vol. 6, no. 4, Oct. 2018, p. 45, doi: 10.3390/chemosensors6040045.

[3] A. Wilson and M. Baietto, Applications and Advances in Electronic-Nose Technologies, Sensors, vol. 9, no. 7, Jun. 2009, pp. 5099–5148, doi: 10.3390/s90705099.

[4] P. Handa and B. Singh, Electronic nose and their application in food industries, FOOD Sci. Res. J., vol. 7, no. 2, Oct. 2016, pp. 314–318, doi: 10.15740/HAS/FSRJ/7.2/314-318.

[5] A. A. C. Illahi, E. P. Dadios, A. A. Bandala, and R. R. P. Vicerra, Electronic Nose Technology and Application: A Review, in 2021 IEEE 13th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM), Manila, Philippines, Nov. 2021, pp. 1–5. doi: 10.1109/HNICEM54116.2021.9731890.

[6] A. D. Alphus Dan Wilson, Recent progress in the design and clinical development of electronic-nose technologies, Nanobiosensors Dis. Diagn., Jan. 2016, p. 15, doi: 10.2147/NDD.S66278.

[7] A. Wilson, Diverse Applications of Electronic-Nose Technologies in Agriculture and Forestry, Sensors, vol. 13, no. 2, Feb. 2013, pp. 2295–2348, doi: 10.3390/s130202295.

[8] F. Mu, Y. Gu, J. Zhang, and L. Zhang, Milk Source Identification and Milk Quality Estimation Using an Electronic Nose and Machine Learning Techniques, Sensors, vol. 20, no. 15, Jul. 2020, p. 4238, doi: 10.3390/s20154238.

[9] A. D. Wilson, Review of Electronic-nose Technologies and Algorithms to Detect Hazardous Chemicals in the Environment, Procedia Technol., vol. 1, 2012, pp. 453–463, doi: 10.1016/j.protcy.2012.02.101.

[10] A. K. Maw, P. Somboon, W. Srituravanich, and A. Teeramongkonrasmee, A Hybrid E-nose System based on Metal Oxide Semiconductor Gas Sensors and Compact Colorimetric Sensors, in 2021 IEEE International Conference on Automatic Control & Intelligent Systems (I2CACIS), Shah Alam, Malaysia, Jun. 2021, pp. 352–357. doi: 10.1109/I2CACIS52118.2021.9495905.

[11] T. Seesaard, N. Goel, M. Kumar, and C. Wongchoosuk, Advances in gas sensors and electronic nose technologies for agricultural cycle applications, Comput. Electron. Agric., vol. 193, Feb. 2022, p. 106673, doi: 10.1016/j.compag.2021.106673.
[12] A. D. Wilson, Review of Electronic-nose Technologies and Algorithms to Detect Hazardous Chemicals in the Environment, Procedia Technol., vol. 1, 2012, pp. 453–463, doi: 10.1016/j.protcy.2012.02.101.
[13] W. Ad, Electronic-nose Applications in Forensic Science and for Analysis of Volatile Biomarkers in the Human Breath, J. Forensic Sci. Criminol., vol. 1, no. 1, May 2014, doi: 10.15744/2348-9804.1.S103.
[14] T. Seesaard, P. Lorwongtragool, and T. Kerdcharoen, Development of Fabric-Based Chemical Gas Sensors for Use as Wearable Electronic Noses, Sensors, vol. 15, no. 1, Jan. 2015, pp. 1885–1902, doi: 10.3390/s150101885.
[15] Radi, M. Rivai, and M. H. Purnomo, Study on Electronic-Nose-Based Quality Monitoring System for Coffee Under Roasting, J. Circuits Syst. Comput., vol. 25, no. 10, Oct. 2016, p. 1650116, doi: 10.1142/S0218126616501164.