Characterization of Sensing Chamber Design for E-Nose Applications

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***Abstract*—An electronic nose (e-nose) is a device that mimics the function of the human nose and is able to recognize odours using gas sensors. The e-nose consists of a sampling system, a sensor array (in the detection system), with data acquisition and pattern recognition algorithm for computing system. The sensing chamber in an e-nose plays an important role in the detection system for any types of application. The design of the sensing chambers will determine several performance characteristics of the sensor's response signals which include the response time, stagnant region and gas to the sensor contact area. Several sensing chambers (rectangular, hemisphere & cylindrical) were designed using SolidWorks and printed (in 3-dimensional (3D)) to characterize and determine the design which is able to provide the optimum performance. Data analysis of the response time and parameters such as concentration and pressure were analyzed using NI LabView. Results show that the hemisphere shaped sensing chamber displayed the best performance in terms of a small stagnant region and a large gas to the sensor contact area even though the time response between sensing chambers is almost the same. The performance was due to the flow of the gas from the inlet to the outlet and the volume of the sensing chamber**

***Index Terms*—Electronic Nose; Gas Sensing; Odour Detection; Sensing Chamber.**

I. INTRODUCTION

An electronic nose or commonly known as e-nose is a device that is able to recognize and differentiate the identity of odours using the technology of gas sensors [1]. Generally, an e-nose consists of several important parts which include the sampling system, detection system, and the computing system. The sampling system allows injection of the gas sample to the detection system and cleans the sensing chamber with fresh air to set it to an initial state [1, 2]. This is important to ensure that there will be no disturbance when analyzing new data. The computing system which comprises of pattern recognition and data acquisition algorithms plays an important role in data analysis and recording purposes.

The detection system in an e-nose consists of the sensing chamber and an array of gas sensors. The sensing chamber is a closed loop area that allows gas flow to ensure maximum contact with the sensors array for accurate gas detection and measurements of different gas parameters. The closed loop area of the sensing chamber prevents gas leakage during the detection stage that may affect the data analysis. The most essential part of the whole e-nose system lies in the sensor array that reacts to different gas compounds according to their own way.

The applications of e-nose have been widely implemented in various fields and improvements in various areas are developed to suit the advanced technologies in sensors development. Several examples of the applications of e-nose are as a breath analyzer to detect the percentage of alcohol from a person [3], in industrial areas that are exposed to dangerous gases [4], in the quality control of food products by detecting the presence of bacteria that may cause contamination [5], distinguishing different types of teas with different processing conditions [6], determining the optimum fermentation time for black tea manufacturing [7].

II. LITERATURE REVIEW

One of the main concerns involving the efficiency of the detection stage in an e-nose is poor performance of sensors' response to signals. The common issues related to the poor performance of sensors' response signals include longer duration for sensors' response to reach steady condition [8], large stagnant region and small gas to the sensor contact area [2].

Several factors related to the sensing chamber that may affect the performance of sensors' response signal include the volume of the sensing chamber, the shape of the sensing chamber and the position of inlet and outlet. These factors affect the flow of gas and gas concentration in the sensing chamber [9].

A study conducted by Lezzi *et al.* in 2001 showed that a smaller volume chamber required a longer time to reach steady state compared to a larger volume chamber as the smaller chamber has a large stagnant region which means there is more amount of gas trapped in the chamber which affects the gas flow [9]. Another study by Ji *et al.* proved the importance of inlet and outlet's position to the sensors' response signal in the sensing chamber [10]. In the study, the inlet was placed at a lower position to allow gas to flow constantly through the gas sensors. On the other hand, the outlet was placed at a higher position, which forced gas to flow through it as the temperature in the chamber was higher than the temperature outside [10]. The shape of the sensing chamber also plays an important role in the design of a sensing chamber as it were proven to affect the flow of gas and the sensors' response signals. Several studies were conducted on the performance of the sensors based on different shapes of sensing chamber designs [2, 8, 11, 12, 13, 14].

A. *Rectangular Chambers*

A study by Gardner *et al.* used a rectangular sensing chamber in the detection system to predict the types of bacteria and culture growth phase in an electronic nose [11]. The sensing chamber was simple to implement and used eight (8) sensors which included six (6) metal oxide sensors, a temperature sensor and a humidity sensor. The research was successful in developing an analytical device for bacteria cultures. Nevertheless, the sensing chamber used had a poor performance, as the stagnant region was large due to the edges of the rectangular shape that trapped the gas. Another study conducted by Nicolas *et al* implemented the electronic nose as a warning device for a safety system application. A 160cm^3 metallic rectangular chamber was used with six (6) commercial metal oxide sensors [12]. The chamber was able to show a good performance as it is successfully functioned as a warning device which was able to detect the odour emergence. Nevertheless, the chamber had low sensitivity towards compost emissions and less stability in terms of the signal to noise ratio.

B. *Cylindrical Chambers*

Cylindrical chambers were used by Francesco *et al.* to conduct a research on sensor's response signal. In the study, the performance of the sensor' response signal was evaluated based on several factors which include the time required to achieve uniform state and the volume of the chamber [13]. The design of a cylindrical chamber showed a good performance as the stagnant region was small as it was less complex in design. In 2012, Viccione *et al.* also did a research to refine sensor's response signals by examining the behavior of a sensing chamber in terms of its reproducibility, stability and response time [2]. The sensing chamber was designed using a 3D cylindrical shaped model and cylindrical diffusers were placed in the chamber. The results showed that the chamber gave the best performance with the presence of the diffusers as steady state was almost achieved by the time required and the smallest value of voltage was achieved in stagnant region. Nevertheless, the sensing chamber was too complex to be implemented. Another cylindrical chamber was implemented by Pace *et al.* for safety monitoring applications [14]. In the research, a cylindrical sensing chamber was designed with five (5) metal oxide sensors, a temperature and humidity sensor, and a pressure sensor. The data analysis was done using LabWindows/CVI™ environment. The advantages of the sensing chamber were it was relatively cheap and small in size which made it portable.

C. *Conical Chambers*

A conical chamber was used for a research conducted by A. Sklorz *et al.* in 2012 to test the ripeness and quality of fruits. The chamber was 215mm x 25mm x 40mm in size and has a volume of 40ml. The conical shape was chosen to improve the efficiency of infrared radiation and results showed that the chamber gave good signal intensities and high efficiency in detecting the ripeness and quality of fruits [15].

D. *Spiral Chambers*

In 2013, Tukijan *et al.* did a research on sensing and monitoring system to monitor hazardous gas level that exists in an area A spiral chamber was designed to allow gas sample to flow smoothly as there were fewer edges inside the chamber [8]. It has sixteen (16) specifically designed metal oxide sensors. Results showed that the gas flowed constantly inside the chamber and the time required to reach steady state was short. Besides that, the chamber was also low in cost, portable and required less space. Nevertheless, for the chamber, the sensors need to be custom designed as the commercially available sensors could not fit into the chamber.

From the review of most literatures, there are many factors that contribute to the performance of the sensor's response signals, which are mainly addressing the sensing chamber design. Among the major factors are the position of inlet and outlet, shape of the sensing chamber and volume of the sensing chamber. Thus, these factors need to be considered in any sensing chamber design to ensure an optimum performance of an e-nose system.

III. METHODOLOGY

A. *Sensing Chamber Design*

Different shapes of sensing chambers (rectangular, hemisphere and cylindrical) were designed using SolidWorks as in Figure 1(a) to Figure 1(c) and were printed using a 3D printer. Several conditions were taken into account when designing the sensing chamber. The size of the sensing chambers was required to fit all of the sensors to be used and to ensure the gas to the sensor contact area is wide. All of the sensing chambers had two (2) inlets and one (1) outlet. The inlets are connected to a pressure sensor and a bubbler, respectively and allow gas to be injected to the sensing chamber, while the outlet is for releasing the used gas.

The volume of each sensing chambers is obtained from Equation (1) to Equation (3) which represents the volume for the rectangular, hemisphere and cylindrical shaped sensing chambers respectively.

$$V_{rectangular} = l * w * h \tag{1}$$

$$V_{hemisphere} = \frac{2}{3}\pi r^3 \tag{2}$$

$$V_{cylindrical} = \pi r^2 h \tag{3}$$

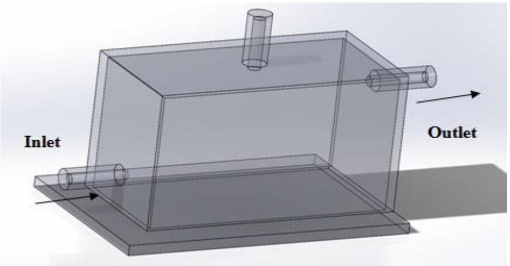
where: V = Volume of the chamber
l = Length
w = Width
h = Height
r = Rradius

B. *Hardware Design*

Figure 2 displays the detection stage of the e-nose system. Alcohol is used as the gas sample for the sensing chamber and the bubbler which is located at the inlet of the sensing chamber is used to 'bubble' the alcohol liquid to produce and release alcohol gas. The bubbler is made of a glass bottle with two (2) tubes at the cap. The longer tube is connected to the vacuum pump to allow clean air to enter the bubbler. The vacuum pump (NMP 850 KNDC) will pump clean air that creates a bubbling effect to the liquid inside the bubbler. The bubbling effect will create vapour inside the bubbler and the produced gas will flow out of the bubbler through the shorter tube. The bubbler also functions as a storage for alcohol liquid.

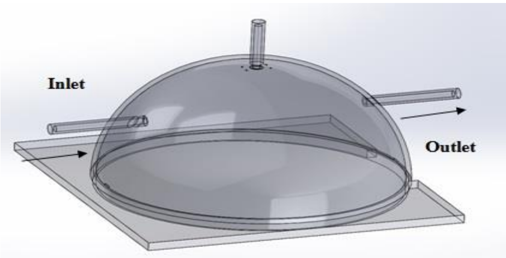
An alcohol sensor (MQ-3) is placed in the sensing chamber and used to detect the existence of any alcohol gas and measures the concentration level of alcohol in the sensing chamber. The alcohol sensor (MQ-3) is a semiconductor gas sensor and has a high sensitivity towards alcohol. The Arduino Uno board microcontroller controls the sensing circuit and data obtained from the sensing circuit is analysed using NI LabVIEW. The Arduino Uno board has fourteen (14) digital input/output (I/O) pins and six (6) analog input/output (I/O) pins.

Length: 42mm
Width: 21mm
Height: 27mm
Volume: 23,814mm^2



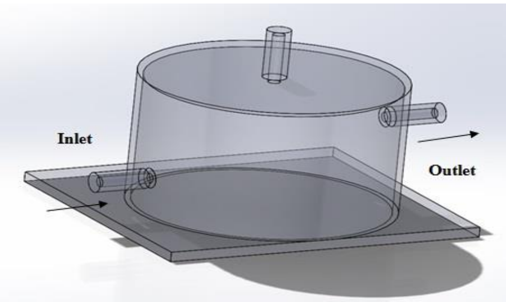
(a)

Radius: 21mm
Height: 27mm
Volume: 18,386mm^2



(b)

Radius: 21mm
Height: 27mm
Volume: 37,407mm^2



(c)

Figure 1: Shapes, measurements and volumes of the (a) rectangular, (b) hemisphere and (c) cylindrical sensing chambers

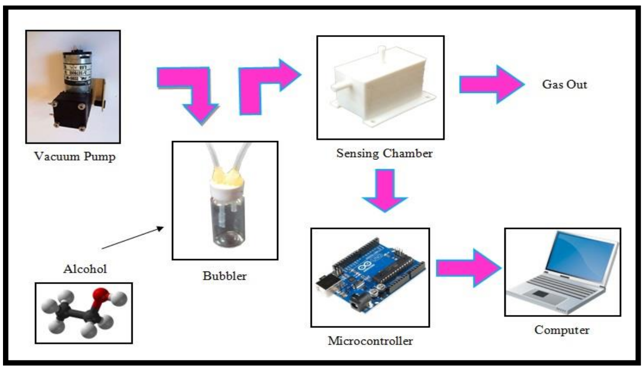


Figure 2: Detection stage of an E-Nose system which consists of a bubbler, sensing chamber and gas sensor (in the sensing chamber)

C. Sensing Process

The EAGLE software is used to design the sensing circuit on the PCB board and Arduino is used to program the sensing circuit. The sensing process in the sensing chamber is illustrated in Figure 3. The first step in the process is to store the alcohol liquid inside the bubbler. The vacuum pump will then pump clean air into the bubbler to create a bubbling effect which will release alcohol gas after a few seconds. The vacuum pump forces the alcohol gas to flow into the inlet of the sensing chamber through a tube. The alcohol sensor in the sensing chamber will detect the gas and measure its parameter (alcohol concentration level) when in contact with the sensor. Lastly, data analysis based on the parameters measured will be conducted using NI LabVIEW.

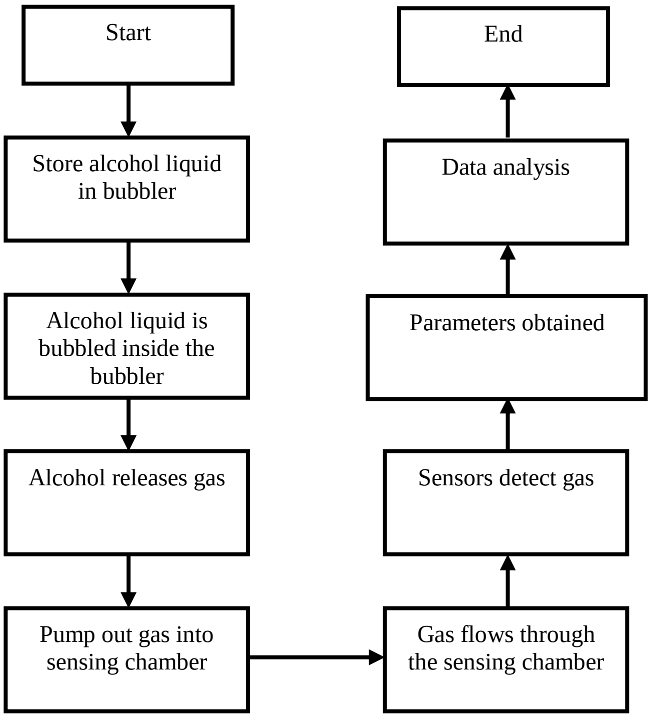


Figure 3: Sensing process of the detection stage in an E-Nose system

Figure 4 shows the front panel (graphical user interface, GUI) of the monitoring system to display the data analysis using NI LabVIEW. The Front panel consists of a waveform chart and several other features such as 'STOP' symbol and a display of alcohol concentration measurement. Once the Serial Monitor from Arduino is successfully communicating with NI LabVIEW, a waveform will be displayed on the waveform chart of the Front Panel to show the sensor's response signal. The 'STOP' symbol is used to stop the signal from running. The display of concentration of alcohol is used to show the concentration values which are displayed at the Serial Monitor of Arduino software.

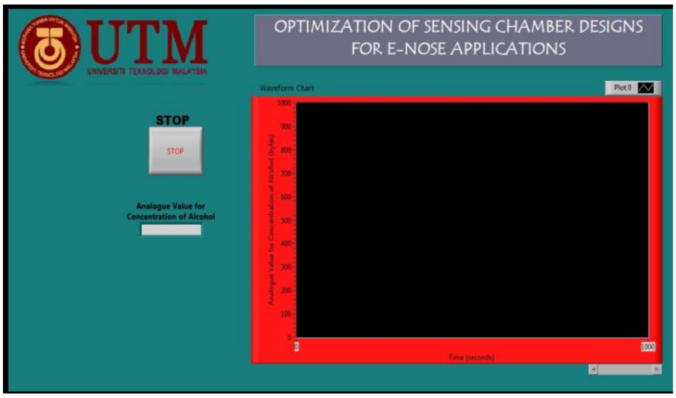


Figure 4: Front panel of the monitoring system to display alcohol concentration measurements

IV. Results & Discussion

A. Gas Flow Simulation

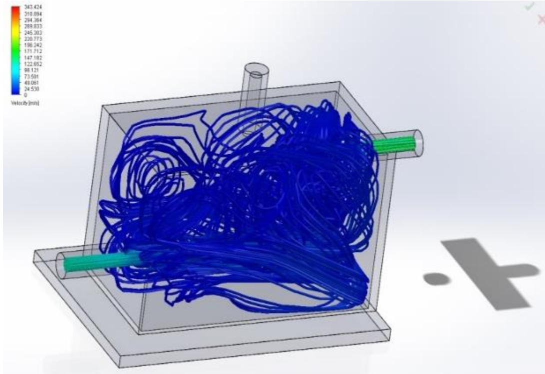
The gas flow simulation was conducted to illustrate the expected gas flow in different sensing chambers. From the simulation, the stagnant region (the region of remaining gas trapped in the sensing chamber) and gas to the sensor contact area can be obtained, as in reality the actual gas flow is not able to be seen. The simulations were done for all sensing chambers using the floExpress function in SolidWorks.

Figures 5 (a), (b) and (c) show the gas flow simulation in the rectangular, cylindrical and hemisphere sensing chambers with the gas sensor being fixed at the bottom and facing up of the sensing chamber. The colour bar indicates the velocity of the gas flow inside the sensing chamber with the highest velocity in red and the lowest velocity in blue. The gas flow simulation in the rectangular sensing chamber shows that the inlet has a lower velocity (~90m/s) compared to the outlet (~200m/s). It is observed that the gas was not uniformly distributed in some spaces (bottom area and top left area) inside the sensing chamber which may lead to less gas to the sensor contact area.

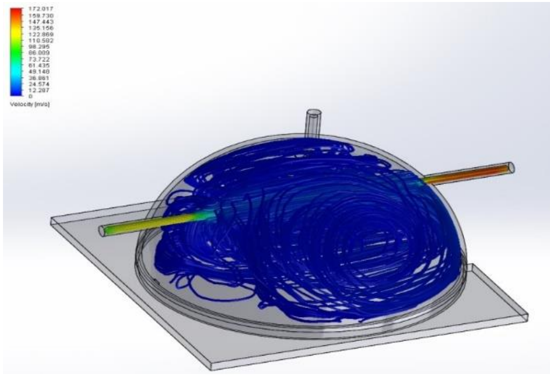
In the hemisphere sensing chamber (refer to Figure 5 (b)), the velocity of the gas in the inlet is lower (~120m/s) than the outlet (~150m/s), which is similar as the rectangular chamber. Gas flow is evenly distributed in the spherical chamber as it is observed that the flow of gas covers through most of the spaces inside the sensing chamber. Therefore, a larger gas to the sensor contact area may be achieved.

In Figure 5 (c), the velocity pattern of the inlet and outlet gas flow is similar to the rectangular and hemisphere sensing chambers with the outlet having a higher velocity (~150m/s orange) compared to the inlet (~65m/s). The gas to sensor contact area for the cylindrical sensing chamber is smaller than the hemisphere sensing chamber, but higher than the rectangular chamber as the gas flow missed some spaces at the top left of the sensing chamber.

Among these three sensing chambers, the hemisphere sensing chamber shows the best results in terms of a larger gas to the sensor contact area compared to the rectangular and cylindrical shaped sensing chambers.



(a)



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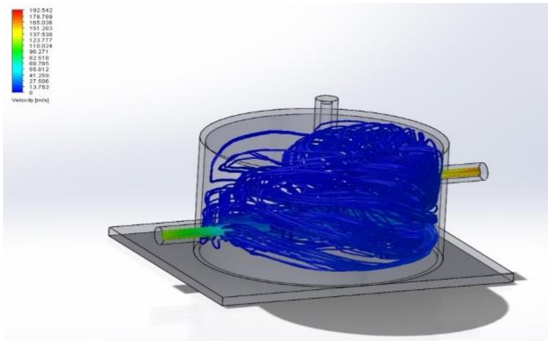

(c)

Figure 5: Gas flow simulation in (a) rectangular, (b) hemisphere and (c) cylindrical sensing chambers.

B. Sensor's Time Response & Stagnant Region

For a better performance of sensors' response signals, the time to achieve steady state must be short and the stagnant region should be as small as possible. A test was conducted to acquire the sensor's time response and predicting the stagnant region in three (3) different sensing chambers.

The average of three (3) measurements was obtained within 100 seconds for each sensing chambers and the concentration of alcohol was obtained using the analog value from the Serial Monitor of the Arduino software.

Referring to Figure 6, the alcohol concentration for all three sensing chambers were constant initially, that refers to when there was only clean air (550-600 bytes) in the sensing chambers. As time increases, there is a rapid increase of alcohol concentration level in all three sensing chambers, with a delayed response in the rectangular chamber compared to the hemisphere and cylindrical chambers. This happens when the gas sensor (MQ-3) starts to detect the presence of alcohol gas inside the sensing chambers. The analysis shows a steady state condition between t = 10s to t = 45s. During the steady state, most of the injected alcohol gas remains inside the sensing chambers. The declination of alcohol concentration occurs at a slight difference in time which is around 48s, 50s and 52s for the hemisphere, cylindrical and rectangular sensing chambers respectively. At this stage, the alcohol gas may have started to flow out of the sensing chambers. A delayed declination may indicate that there are portions of the gas trapped in the sensing chambers that will lead to a larger stagnant region. This may be due to the edges of the sensing chamber [13]. In a larger scale of sensing chamber design where more sensors are placed, the difference in sensor's time (inclination and declination of gas concentration) may be more significant when compared in different shapes of sensing chambers.

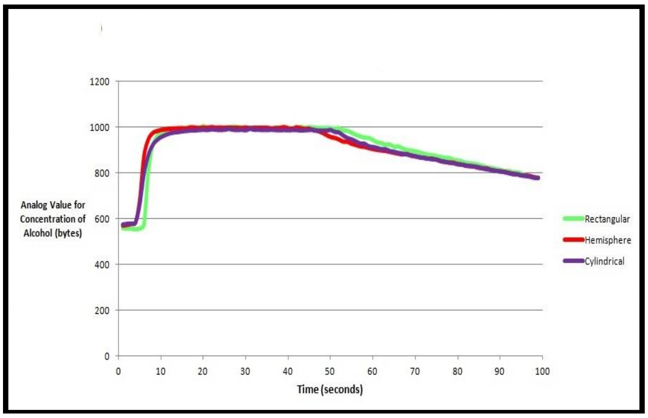

Figure 6: Sensor's response time (alcohol concentration versus time) for different sensing chambers (rectangular, hemisphere and cylindrical)

V. Conclusion

As a conclusion, it is proved that the sensing chamber plays an important part in the detection stage in any e-nose application. In this study, the scope of performance of the sensor's response signals for each sensing chamber was mainly focused on the time response, stagnant region and gas to the sensor contact area. It can be concluded that the hemisphere sensing chamber showed the best performance compared to the rectangular and cylindrical sensing chambers in terms of a smaller stagnant region and a larger gas to the sensor contact area. Nevertheless, the time responses between all sensing chambers were slightly similar with small differences. The performance is affected due to several factors which are volume of the sensing chambers, position of the inlet and outlet, and flow of the gas. The characterization of different designs of sensing chambers in this study can be used for future researches that are related to e-nose applications.

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