Conference Paper

Design and Development of Gas Sensor Based On Acoustic Resonance

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Abstract

Determination of the specific toxic, harmful, or flammable gases concentration i.e. butane, cannot be done directly. It requires devices that can do this measurement without any direct contact between the gas and human (observer) i.e. gas sensors. These sensors are typically used in security systems or early warning system. This research is about design and development of a gas sensor based on acoustic resonance. The sensor that has been developed is acoustic resonator based sensor, with two speakers as the sources of acoustic vibrations. This sensor is made to work at its resonance frequency. Since the resonance frequency of acoustic resonator is influenced by the speed of sound in the acoustic resonator, and the speed of sound is influenced by the density and concentration of the gas in the acoustic resonator, the changing of gas concentrations will cause resonance frequency shifting of the acoustic resonator. So, by taking measurement of resonance frequency shifting of resonator, gas concentration can be determined. This research was conducted in four stages, the first stage is designing of acoustic resonator, the second stage is manufacturing and initial testing of the acoustic resonator, the third stage is conditioning stage to make acoustic resonator works at its resonance frequency automatically, and the final stage is the testing stage of acoustic resonator using butane. Based on the research conducted, it can be concluded that the acoustic resonator system can work accurately and precision to detect the changing of butane gas concentration. Absolute error and relative error are relatively small, the largest of absolute error is 7.69% and the largest relative error is 0.47%.

Keywords: Acoustic resonator, gas sensor, gas concentration, resonance frequency, butane

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1. Introduction

The application of gas sensing mostly used in industry and academia, such as: in industrial production [3, 4]; in the automotive industry [5]; in medical applications [6]; in monitoring indoor air quality [7]; and in environmental studies [8]. Some studies have established as a subject of the gas sensing technology since past fifty years. There are three main investigation of gas sensing are various types of sensors, research on the principles of sensing, and fabrication techniques [9].

Gas sensor is a tool for gas sensing, these sensors typically used in a safety system. Gas sensor measures the concentration of gas in its vicinity. Gas sensor can be classified based on variations on electrical properties and other properties. For electrical properties, gas sensor consists of metal oxide semiconductor, polymer, carbon nanotubes, and moisture absorbing material. While other properties, gas sensor consists of optic methods, acoustic methods, gas chromatograph, and calorimetric methods. Many types of gas sensors have been developed. Each of them has advantages and disadvantages [1]. Based on the principles of gas detection, gas sensor can be categorized into two i.e. non-optical sensors and optical sensors [2]. Non-optical sensor is a gas sensor that detects gas by interacting directly with the gas to be tested. Advantages from non-optical sensor are low cost of fabrication and short response time, while the disadvantages are relatively low sensitivity and selectivity [15]. The optical sensor is a gas sensor that detects gas without interacting directly with the gas to be tested by utilizing the optical properties of the gas. Among these two types, the optical sensor has several advantages such as: long lifetime, reliable, stable at ambient temperature and easy to be designed and manufactured [15]. Here, the author will make a gas sensor by using two methods, namely optical methods and acoustic methods. By using the optical methods it is briefly easy to reach higher sensitivity, selectivity and stability than non-optical methods with longer lifetime. These methods have short response time. Its performance will not deteriorate with environmental changes or catalyst poisoning caused by certain gases, etc. the basic principle of optical methods for gas sensing is based on spectroscopy. However, the constraints of these applications for gas sensors are in miniaturization and cost is relatively high. Only a few commercial gas sensors are based on the principles of optics [15].

For acoustic or ultrasonic methods, it can improve the weaknesses of the gas sensor by chemical methods, such as short lifetime [15]. Measurements parameters involved in the acoustic method basically are divided into 3 categories namely speed of sounds, attenuation and the acoustic impedance. First parameter involved that is speed of sound determine many properties of gas and can be used for measuring speed of sound, such as to identify a specific type of gas through the speed of sound is different from others in the group [9], to detect gas concentration target, based on mathematical reasoning that is proportional to the time difference of sound propagation [4], and to calculate the molar weight of the composition or different gases in a mixture based on some equations of thermodynamics [11]. Attenuation is when an acoustic wave travels through a medium, there is the energy lost as thermal or scattered energy called attenuation [12]. Each of gas has different attenuation properties, hence providing a way to detect specific gases. Attenuation could also combine with sound speed to determine gas properties [13]. For acoustic impedance density of the gas can be determined by the acoustic impedance, because the acoustic impedance is given by a simple equation: $Z = \rho C$, where ρ is the density of gas and C is the speed of sound. Thus, the acoustic impedance is measured and the speed of sound, the gas density can be calculated [14].

For the initial stage, the author will use the acoustic methods to make the initial prototype of gas sensor using acoustic resonator. Acoustic resonator made to work

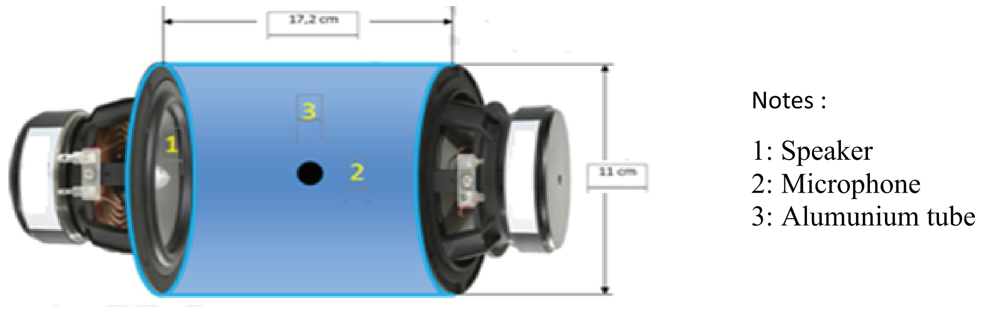

Figure 1: Resonator design.

automatically at its resonance frequency, and it is expected to detect changing in gas concentration contained in the acoustic resonator.

2. Methodology

This research was conducted in four phases. The first phase is designing the resonator, the second phase are manufacture of resonator and initial testing in order to obtain a resonance frequency of the resonator. The third phase is the conditioning resonator to work automatically at the resonance frequency. The final phase of this research is testing directly to butane. Resonator is designed by using alumunium tube, 2 speakers, and a microphone. Resonator is made using alumunium tube with diameter 11 cm, 17.2 cm in length, and 0.5 cm in thick. Design of resonator can be seen in Fig. 1.

3. Results and Discussions

Resonator will work in accordance with the principle of organ pipes, where the resonant frequency will be influenced by the speed of sound in a resonator which is influenced by the concentration of gas in the resonator. The resonator is designed to be able to work at the resonant frequency. This is done because the resonance of the resonator will be affected by the speed of sound in the resonator, while the speed of sound in the resonator will be strongly influenced by the type of gas contained in the resonator and gas concentration contained in the resonator. So it should work on the resonator resonance frequency. If the type of gas in the resonator is different and different concentration, then the resonance frequency of the resonator working will also vary. Based on this principle, resonators are constructed can be used as a simple gas sensor. The resonance frequency of the resonator can be seen in Fig. 2.

From Fig. 2 it can be seen, there are two of high peak amplitude of the output signal from the microphone on 400Hz and 3.8 kHz.

The system is used as a gas sensor based on the principle of resonance. As noted in the previous section that weight or concentration of gas in resonator will affect the speed of sound in the resonator, while the speed of sound in resonator changes will affect the resonance frequency of the resonator. So, to be able to detect changes in gas consentration, then the system needs to be conditioned in order to work at

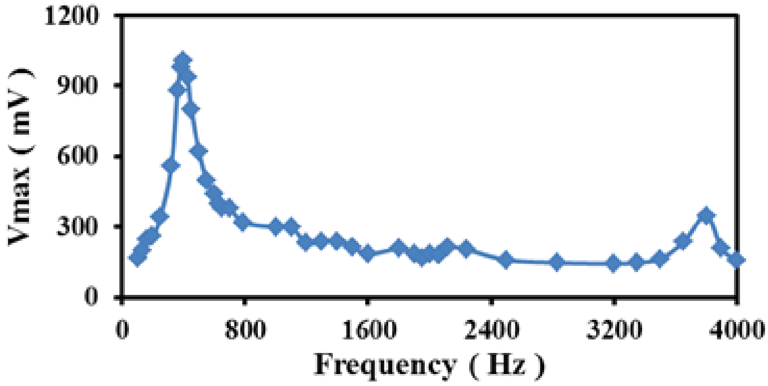

Figure 2: Resonance frequency of the resonator.

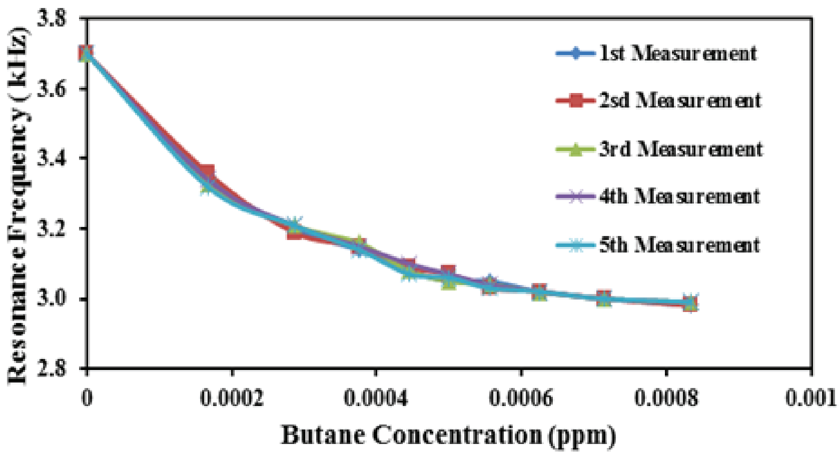

Figure 3: Effects of butane concentration changing against resonance frequency of resonator.

the resonant frequency automatically without a signal from frequency generator. In this test, the resonance frequency of resonator is approximately 3.7 kHz. Resonant frequency automatically obtained do not differ much from the initial measurements i.e. 3.8 kHz.

For direct gas testing, butane (C_4H_{10}) and nitrogen (N_2) gases were used. The purpose is to determine the effect of butane concentration changing in the resonator against the resonance frequency of the resonator system. The system is conditioned to work automatically. From the measurements that have been done, the effect of butane concentration changing against the resonance frequency of resonator can be seen in Fig. 3.

The purpose of this resonator is to determine the concentration of the gas contained in the resonator, so Fig.4 can be used to get the fuction of concenration to the resonance frequency of resonator. The fuction of concentration against the resonance frequency of resonator is:

$$Concentration = 99133.89 - 92357.75f + 28710.76f^2 - 2977.168f^3 \quad (1)$$

where f is the resonant frequency.

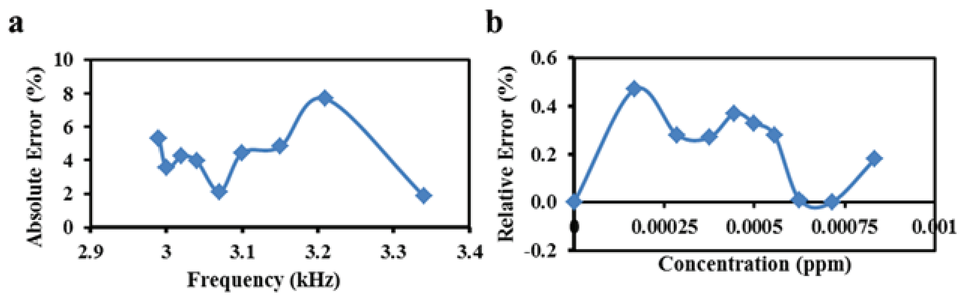

Figure 4: (a) Absolute error of the system and (b) relative error of the system.

The absolute error and the relative error of the system can be seen in Fig.5 (a) and Fig.10(b).

On Fig. 4(a) can be seen that the largest absolute error of the system is 7.69%, and on Fig. 4(b) can be seen the largest relative error of the system is 0.47%. It is mean the system resonator accurate and precision to detect the butane concentration changing.

4. Conclusions

According to the result, can be concluded that the resonator system accurate to detect the butane concentration changing, with the largest absolute error is 7.69%, and the resonator system has high precision with the largest relative error is 0.47%.

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