Effect of Environmental Temperature and Humidity on Different Metal Oxide Gas Sensors at Various Gas Concentration Levels

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Abstract. Metal Oxide (MOX) semiconductor gas sensors have been widely used in monitoring targeted gases that are present in the environment. This type of gas sensor can also be utilized as a safety device to detect the source of gas leakage. Their uses in many applications are due to being user-friendly, lower in cost, high sensitivity and relatively quick response time. However, there are several factors that could affect their performance. This work investigates the effects of the changes in ambient temperature and humidity on the readings of these sensors at various gas concentration levels. A PCB board was developed, which consists of temperature and humidity sensors, as well as eight different MOX gas sensors (TGS2600, TCS2602, CCS803, MiCS552, GM-402B, GM-502B, GM-702B and MiCS6814). The board was subjected to various temperatures (16°C to 30°C) and humidity levels (45% to 75%). At each of these parameter settings, the gas sensor responses were recorded at different ethanol gas concentrations. The results of the study showed that the temperature and humidity affected all the gas sensor response. The magnitude of the sensors responses was observed to decrease with rising temperature and humidity levels, except for MiCS6814 (NH3 sensor) which responses in the opposite manner. Hence, there is the need to take into consideration of the drift of gas sensors’ responses when there are changes in temperature and humidity.

1. Introduction
Nowadays, the advancement in gas sensor technology to detect dangerous gases can improve human’s safety. There are many daily activities that expose human to toxic gases which includes the operations in painting, fumigation, fuel filling, construction, excavation of contaminated soils and landfill operations [1]. A gas detector for example, typically consists of arrays of gas sensors, which is able to detect the presence of targeted gases in an area. The equipment is also widely used to spot leakage of gases or other emissions through an interface with a control system. It is usually installed with an audible alarm to activate the alert sign when dangerous gas has been detected [2].

Common types of gas sensors include electrochemical gas sensors, MOX gas sensor, infrared imaging sensors, and photoionization detector sensor [3]. These sensors are used for a wide range of applications and can be found in industrial plants, vehicles, indoor air quality testing and homes. Among aforementioned gas sensors, MOX gas sensor is the most common gas sensor that has been
widely used [3]. MOX gas sensor attracted user due to lower cost, high sensitive, easy to use and has a wide range of gas target [4]. Many published work have reported on the development of gas sensors with minimal limitation as well as suitable in many applications. The most critical problem of the gas sensor is the cross-sensitivity of the MOX gas sensor with respect to the temperature of sensing layer and the humidity of air. Hence, this paper studies the effect of the environmental temperature and humidity on the metal oxide gas sensor response, with the final aim to improve the sensitivity of MOX gas sensor when exposed to odour.

2. Related Work

2.1 Temperature and humidity
According to the studies by Sinha et al. and Kamarudin et al., they reported that the sensitivity of MOX gas sensors were affected by the operating temperature [5-7]. Based on their discussions, there is direct correlation between the concentration of the target gas and the temperature of the gas sensors. The mechanism of the gas sensors, chemisorbed occurs on the surface of the sensing material. Thus, the activated surface area will increase with the temperature rises due to the increase in activation energy. However, applying relatively high temperature on the gas sensor will lead to the desorption of the analysed gas in which affected the sensor response. Sinha et al. showed that the adsorption of O₂ process on the surface of the sensing material increases as the operating temperature increase. The adsorption of O₂ occurred during the sensing process will decrease the sensitivity of the gas sensor. The active site on the surface of the sensing material was occupied with the O₂ instead of the analyse gas (target gas). Sensing material exposed to ambient condition with high availability of O₂ causes the sensing material surface covered by O₂⁻ or O⁻ molecule.

The factor that influence the sensitivity of the gas sensor also can be caused by the humidity in the environment. The water molecule binds on the sensing area causing the drift of the gas sensor responses. The reduce of the sensing surface lead to the decreased of the activities of chemisorption between the target gas with the metal oxide thin layer Blank et al. stated that the decrease of the gas sensitivity will also cause the decrease of the baseline resistance of the gas sensor [8]. Qi et al. discussed on the effect of humidity interference and stated that the water molecule act as a barrier against acetylene adsorption [8]. According to the datasheet, all the sensors are able to detect hydrogen which is an element of VOCs. Therefore, the sensors are able to detect ethanol, which is used in this research. Figure 1 shows the schematic diagram of the effect of humidity on the sensing layer, Sm₂O₃-Doped SnO₂.

![Figure 1. Sensing mechanism of Sm2O3-Doped SnO2 in the surrounding of a) acetylene, C₂H₂ and b) acetylene and humidity[9].](image-url)
3. Experimental

3.1. MOX Gas Sensors modules
MOX gas sensors have been utilized in this research due to the ability to give the desired respond to the set of parameters, temperature, humidity and MOX gas sensor’s type [10]. Eight different gas sensors have been selected based on organic compound detection range (as described in [11]) which are TGS2600, TCS2602, CCS803, MiCS552, GM-402B, GM-502B, GM-702B and MiCS6814. Figure 2 illustrates the main board integrated with all the sensor modules. The single-layer PCB modules for the gas sensors, and main PCB board were developed and tested for the proper functionalities of the gas sensor system. The development of the main PCB board integrates each type of gas sensors together with others two types of gas sensors (i.e TGS2600 and TCS2602) which will be used throughout the experiments. Therefore, the respond of all gas sensors could be compared and validated with respect to each other. Furthermore, the temperature and humidity sensors are also added to the main board in order to measure the actual environmental condition around the gas sensors.

![Figure 2: Main PCB board fitted with all gas sensor modules.](image)

3.2. Experimental Setup
Figure 3 shows the experimental setup for testing the effect of environmental temperature and humidity on the gas sensors. The gas sensor boards are placed inside a partially closed chamber, in a temperature-humidity controlled incubator. The chamber will partially contain the ethanol gas fed into it and at the same time allows the exchange of gas in the incubator for temperature and humidity control. Two pumps are used during the experiment which are inlet and outlet pumps. The former will pump in air for bubbling the gas ethanol solution into the incubator, and the latter is for draining out the ethanol gas from the incubator. The function of carbon filter in this experiment is to clean the intake air from the environment and also filter out other unwanted gases. The conical flask contains different concentration of ethanol gas for the bubbling process. The LabVIEW program is used to control the whole hardware setup and log all sensors reading.
3.3. Experimental Procedure

The experiments were conducted on several types of sensors namely MICS-6814, MICS5524, CCS803, GM-402, GM-502, GM-702, TGS 2600 and TGS 2602 to see their cross sensitivity to ambient temperature and humidity at different ethanol gas concentrations. The experiment using 0.02% ethanol solution and bubbled with clean air in different experimental settings. The experiment was conducted for 2 hours and 45 minutes per cycle at different humidity levels (45%, 55%, 65% and 75%) continuously. Figure 4 shows the sequence of the procedures of the experiment. The responses of gas sensors, temperature and humidity sensors were recorded at every one second intervals throughout the experiment.

Firstly, the outlet pump is turned on for 15 minutes in order to purge the sensors’ chamber, at the same time allowing the internal air temperature of the incubator adjusted to 16°C and 45% humidity. Meanwhile, to allow ethanol gas flow into the chamber, the inlet pump is turned on. The process was allowed to run continuously for 15 minutes to achieve an equilibrium condition of the gas. At the time interval between 30th to 75th minutes, the set value of the incubator temperature was changed from 16°C to 30°C uniformly. The procedure was repeated with opposite temperature control so that the effect of temperature can be compared when it is ramped up and down. The set value of the incubator’s condition is then adjusted to 20°C with 65% humidity. The incubator was allowed to reach the desired condition in 15 minutes. Then that same condition was maintained for another 30 minutes.
4. Results and Discussions

Figures 5 and 6 show the recorded temperature and humidity levels throughout the 1 hour and half experimental period, at different humidity level settings (i.e h45, h55, h65 and h75). Although the temperature increase was set to be from 16°C to 30°C, the actual temperature recorded was between 26°C and 42°C. The rise of around 10°C could be caused by the heat emitted from the gas sensor’s heater and the initial air temperature pumped into the incubator. Nevertheless, the sensor readings show upward or downward trends following the ramping up down of temperature and humidity levels respectively of the incubator. As for the humidity levels, it was observed that between the 30th to the 150th minutes, the recorded values were lower than that of the preset values by about 5 to 10%. This error may be caused by the initial air humidity pumped in the incubator. Additionally, the humidity level plotted showed around 5% difference when temperature was ramped up and down. This may be due to the incubator failed to control humidity levels as per preset values while temperature was changing.

Figure 7 shows the gas sensors (i.e MICS5524, CCS803, GM-402, GM-502, GM-702, TGS 2600, TGS 2602 and MICS-6814) responses at different temperatures and humidity levels when 0.02% ethanol solution was used in the experiment. In general, the same sensor response pattern could be seen across most of the gas sensors. The sensor resistance (Rs) decreases when temperature ramped up and increases with opposite temperature control. Similarly, the resistance (Rs) drops when the humidity is higher. However, an opposite relationship to temperature and humidity levels for MICS 6814 (NH3 sensor) was observed compared to the other sensors. This may be due to the fact that its sensing layer is built to react to NH3 gas, though it is also sensitive to ethanol gas [12].
Figure 5. Temperature control at different humidity level.

Figure 6. Influence of humidity with different concentration gas.
5. Conclusions
This paper presents the investigation on the effects of environmental temperature and humidity levels on MOX gas sensor response. The results show that the variations of temperature and humidity levels were found to result in a drift of gas sensors readings. Overall, the most of the sensors tested, namely MICS5524, CCS803, GM-402, GM-502, GM-702, TGS 2600, TGS 2602 and MICS-6814, exhibited a decreasing outputs over raising temperatures and humidity levels but increases over opposite pattern. However, one single sensor, namely the MICS6814 (NH3 sensor) behaved in the opposite manner. This shows that there is the need to take into consideration of the drift of MOX gas sensors' responses when there are changes in temperature and humidity levels.

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Figure 7. 2D plots for each gas sensors response agonist time for a fix ethanol concentration of 0.02% with different humidity levels for eight MOX sensors. (a) MICS5524, (b) CCS803, (c) GM-402, (d) GM-502, (e) GM-702, (f) TGS 2600, (g) TGS 2602 and (h) MICS-6814.
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