Design and Calibration of a Microcontroller Based MQ-4 Gas Sensor for Domestic Cooking Gas System

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Abstract
In many processes it is important to have automatic control in the modern life. For example, a car can be automatically driven by computer through a software program and also sensors can be automatically controlled through a program. This project involves the development of microcontroller based MQ-4 gas sensor for domestic cooking gas system. The MQ-4 sensor has been used to detect the leakage of cooking gas which is mostly methane gas. Methane gas is flammable and very dangerous when used incorrectly. All gas manufacturing companies in the world resort to find secure methods which have low cost and are reliable to solve this problem. Most of these methods are using techniques which make the use of gas cooker systems safe. This project studies and shows one of simple way of calibrating the MQ-4 gas sensor using standard prepared solution of methanol. The calibration has been done so as to obtain optimum value for automation. Interfacing of the MQ-4 gas sensor has been done with Arduino UNO and other electronic components like buzzer, global system for mobile communications (GSM), subscriber identity module (SIM 900) and liquid crystal display (LCD). All these components are integrated and controlled by the Arduino UNO. The Arduino UNO controls all communication signals between these electronic instruments in this system through a developed program.

Keywords — *Automation, Arduino UNO microcontroller, calibration, MQ-4 gas sensor.*

I. INTRODUCTION

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The need to secure our homes, commercial complexes, industries and other related properties is of much concern. A home security system should provide security and safety features for a home by alarming the residents on natural and accidental dangers such as; fire, flooding, theft, invading animals and gas leakage. There are hundreds of products available today that allow the control of devices automatically either by remote control or voice command. Most of the systems are based on microprocessors or microcontrollers [2]. [3] designed a microprocessor based gate security system. [6] designed a microcontroller based car anti-theft security system using GSM network with text message as feedback. This was achieved also through integration of sensors. According to [8], the incorporation of active piezoelectric elements and fluidic components into micro-electromechanical systems (MEMS) is of great interest for the development of sensors, actuators, and integrated systems used in microfluidics. [5] presented both design and the implementation of a microcontroller based security door system. In their design a computer set connected to the microcontroller was used to key in secret code and send signals to a mobile phone. If a wrong code was entered, then a message would be sent to a mobile phone. [1] studied the design and construction of microcontroller mains switch control system. The result achieved in the design and construction of the microcontroller- based mains switch control system was actually a move away from manual mode of switching to that of automation. For the fact that the materials used are locally sourced make room for cost effectiveness of design and economic application viable. [4] worked on the design and implementation of a Smart Home System. [7] researched on high performance piezoelectric materials and devices for multilayer low temperature co-fired ceramic based micro fluids systems. Afzal *et al*. (2016) investigated SnO_2-Surfactant Composite Films for Superior Gas Sensitivity. Their results revealed that the successful enhancement of gas sensitivity of SnO2-Triton X-100 composite thin films as compared with pristine SnO2. This paper focuses on design and fabrication of a simple microcontroller based gas leakage monitoring system using the MQ-4 gas sensor. The MQ-4 gas sensor is an electrochemical gas detector operating under diffusion controlled conditions. The sensitive material of MQ-4 gas sensor is tin (IV) oxide (SnO2), which has low conductivity in clean air. When the target combustible gas exists, the sensors conductivity increases with increase in the gas concentration. The principle of operation is described as follows: gas molecules from the sample are adsorbed on an electro catalytic sensing electrode after passing through a diffusion medium, and are electrochemically reacted at an appropriate sensing electrode potential. This reaction generates an electric current directly proportional to gas concentration. This current is converted to voltage for meter or recorder readout.

The diffusion limited current, $I_{\lim}$ is directly proportional to the gas concentration according to equation (1) below

$$i_{\lim} = \frac{nFADC}{\delta} \quad (1)$$

Where, $i_{\lim}$ is the diffusion limited current in amperes, *F* is the Faraday constant (96,500 coulombs), *A* is the reaction interfacial area in cm^2, *n* is the number of electrons per mole reactant, δ is the diffusion path length in cm, *C* is the gas concentration in $moles/cm^3$ and *D* is the gas diffusion constant (no units) and represents the product of the permeability and solubility coefficients of the gas in the diffusion medium. [8] worked on MQ-4 semiconductor gas sensor for natural gas using tin (IV) oxide as the sensitive material. Figure 1 shows the basic circuit of MQ-4 gas sensing unit.

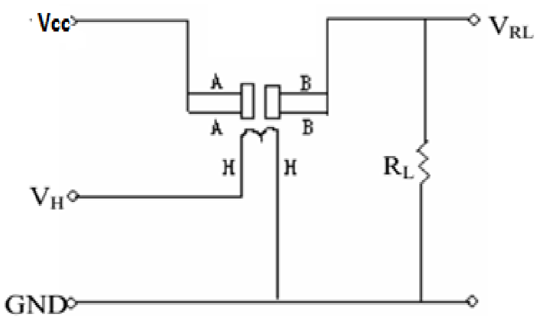


Fig 1: A schematic test circuit of MQ-4 gas sensor.

Where V_H is the heating voltage used to supply working temperature to the sensor; VCC is the loop voltage i.e. source voltage while V_{RL} is voltage drop across load resistance (R_L) and RA-B is the internal resistance between points A and B of the gas sensor which varies with the concentration of the target (methane) gas. The internal resistance is inversely proportional to the concentration of the methane gas.

The circuit can be simplified to form the circuit of Figure 2. The Arduino controls the output of the sensor through a software program. The internal resistance Rs of the MQ-4 gas sensor varies with the methane gas concentration. RL and RS resistors are connected in series.

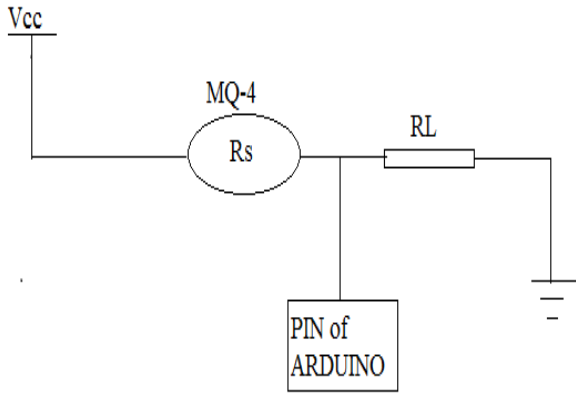


Fig 2: Simplified circuit of MQ-4 gas sensor.

The formula of resistance RS can be deduced as:

$$\frac{R_L}{R_L + R_S} = \frac{V_{RL}}{V_{CC}} \quad (2)$$

Where RS is sensing resistance, R_L is loading resistance, V_{RL} is loading voltage and V_{CC} is supply voltage. Making V_{RL} of equation (2) the subject of the formula, values of V_{RL} and R_S can be found as:

$$V_{RL} = \frac{V_{CC} \times R_L}{R_L + R_S} \quad (3)$$

Reformulating equation (3) further we have:

$$R_S = (\frac{V_{CC}}{V_{RL}} - 1) \times R_L \quad (4)$$

RS is the internal resistance which varies with the target gas concentration and RL is fixed load resistance chosen to stabilize the system. Figure 3 shows ideal sensitivity characteristics of MQ-4 gas sensor of different gases provided by the manufacturer (Pololu Robotics and Electronics 2013). The gas of interest in this research is liquid petroleum gas (LPG), whose characteristics can be seen in the figure 3. As depicted in Figure 3, alcohol was used to substitute for LPG, since their sensitivity characteristics are similar. RS is the sensing resistance of the gas sensor and it has a range which depends on the type of the gas and concentration. As a result, the R_S can be understood as a variable resistor and its resistance will be changing depending on gases type and concentration.

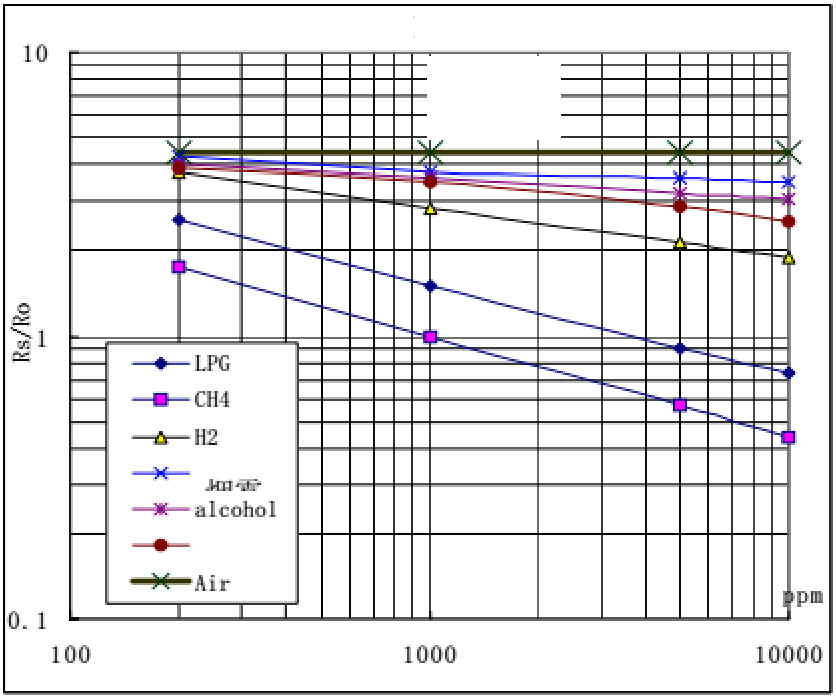


Fig 3: Ideal sensitivity characteristics of MQ-4 gas sensor (Pololu Robotics and Electronics 2013).

II. MATERIALS AND METHODS

Figure 4 below shows the schematic diagram of the circuit topology for the MQ-4 gas sensor designed and simulated in electronic work bench software. The circuit consists of a battery (5V) which is the voltage source of the circuit. Resistor R_1 represents the internal resistance of the MQ-4 gas sensor. The variable resistor R_2 was connected in series with R_1. This procedure was necessary to investigate the optimum resistance R_2 of the design and establish the working value. The virtual circuit was there after tested by mounting it on a solder-less breadboard and the data collected was compared with the synthetic data as depicted in Table 1.

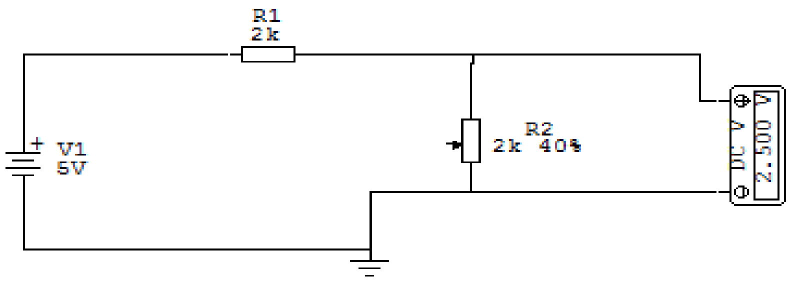
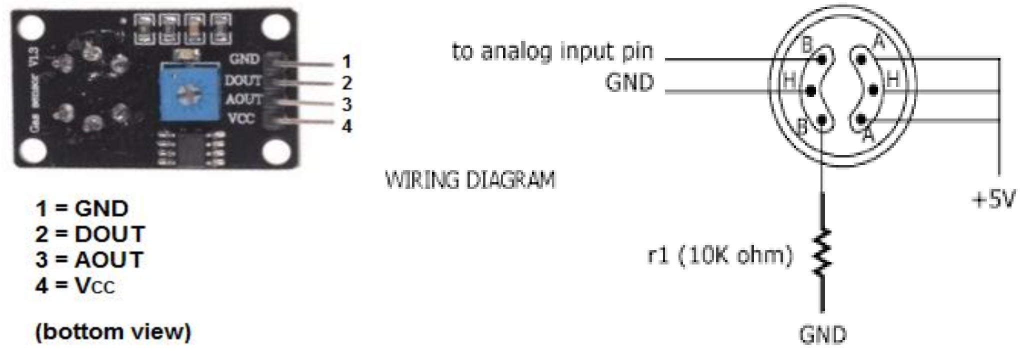


Fig 4: Simulation circuit of finding optimum resistance

A. Heating of MQ-4 gas sensor

The first step in the experimental process was to investigate heating time of MQ-4 gas sensor. The MQ-4 gas sensor needed heat-up time before the first usage. Figure 5 below shows the pin out diagram of MQ-4 gas sensor. The enveloped MQ-4 has 6 pins, four of them are used to fetch signals, and other 2 are used for providing heating current (pin 1 and 4) in Figure 5 (a). The two central pins of the MQ-4 gas sensor were used to provide the heating current. Figure 5 (b) shows the simplified (wiring) diagram of the pin out diagram of MQ-4 gas sensor.



(a) (b)

Fig 5: Pin-out diagram of MQ-4 gas sensor and its wiring diagram.

B. Preparation of methanol solution

Eleven different methanol solutions of concentrations (ppm) 500, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000 and 10000 were prepared through the procedure as outlined by Tinas (2008). Volumes of 99.8% concentrated methanol were measured using graduated pipette fitted with rubber pipette filler and solutions prepared using de-ionized water. The measured concentrated methanol was added to a 250 ml volumetric flask which contained de-ionized water. The mixture was swirled for 5 minutes so as to ensure formation of homogenous solution. The solution was then topped up with de-ionized water up to the mark. The concentration is a measure of the volume of methanol in 1000 ml of aqueous solution with de-ionized water. In this case, de-ionized water is considered 0% concentration. The proportion of methanol in 1000 ml of the solution is taken as the parts per million (ppm) concentrations. The volume of methanol to be added to make the required concentrations was deduced through several steps. The density, mass and volume calculation is done as follows:

$$M = \rho \times V \qquad (5)$$

Where M is mass, ρ is density and V is volume of the methanol. Equation (5) holds in case of a pure fluid. As in this case a 99.8% methanol is chosen hence we add the factor of concentration in our equation (5) so as to obtain

$$M = \rho \times V \times C \qquad (6)$$

Where M is mass of alcohol in standard concentration fluid ρ is density of pure methanol, V is volume of methanol and C is concentration of methanol. After reformulating equation (6), the value of V can be found:

$$V = \frac{M}{C \times \rho} \qquad (7)$$

In this step, 1 liter 10000 ppm standard concentration of methanol fluid is mixed. According to equation 5, the purpose is to get 1 liter 10000 ppm standard fluid and 10000 ppm equal to 10000 mg/l. Therefore; there is 10000 mg pure methanol in the fluid. The mixing process was done by the mass of pure methanol, the density of methanol at 20 degrees Celsius and the concentration of methanol fluid. Using equation (2), 3 V equals to 12.6 ml. So, 12.6 ml of methanol was mixed with de-ionized water until the whole volume was 1 litre. Now, there is a 1 litre 10000 ppm standard concentration of methanol fluid mixed. This fluid includes 10000 mg pure alcohol and it follows that 10000 ppm equal to 10000 mg/l.

C. Experimental set up for gas sensor module

Figure 6 below shows the flow chart of the experimental procedure which was followed in the laboratory. The warm up included heating up of the MQ-4 gas sensor for several days.

An almost closed glass pot was used to create a closed and stable measurement environment. An aluminium foil was used to totally cover the open part of the glass pot. The glass pot had a volume of 250 ml so as to provide space for the gas sensor and the connecting wires of the circuit. Knowing the latent heat of vaporization of methanol at 25°C (77°F) to be 37.43 kJmol-1, the normal room temperature could vaporize the methanol solution. Plate 1 below shows a schematic diagram of the set up.

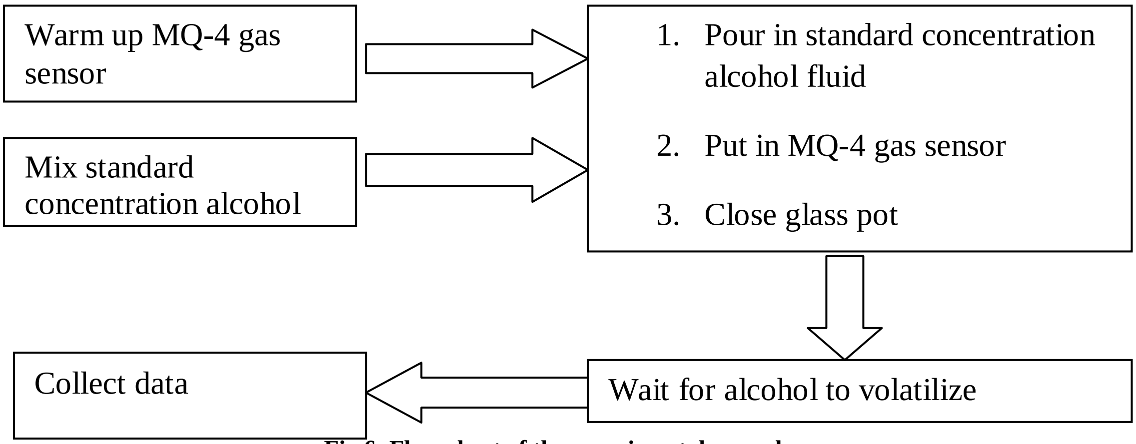


Fig 6: Flow chart of the experimental procedure.

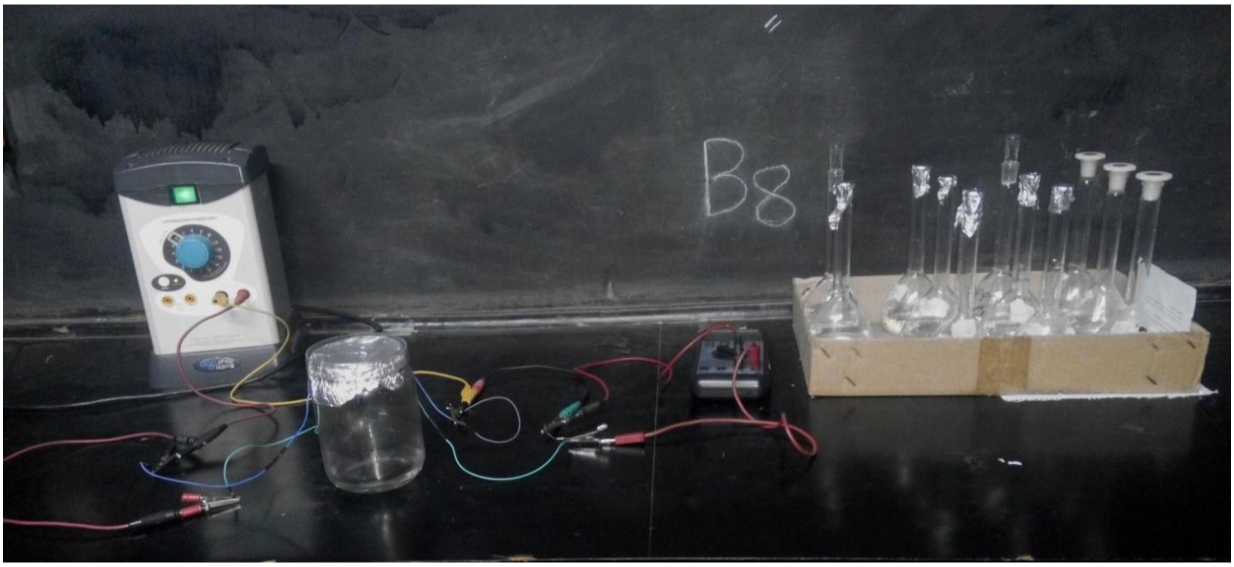


Plate 1: The experimental set up to measure voltage drop across resistor R L when the MQ-4 gas sensor is exposed to different concentrations of methanol.

III. RESULTS AND DISCUSSION

Table 1 below depicts the ideal output voltage of MQ-4 gas sensor in different concentration of methanol as given by the manufacturer. In practical, the best output voltage was achieved after the sensor was warmed up more than two days.

TABLE 1
Ideal Output voltage of MQ-4 sensor in the different alcohol concentration

Concentration(ppm)	Rs/Ro	Rs	V_{RL} (mV)
500	3.80	12.654	696.06
1000	3.70	12.321	712.24
2000	3.60	11.988	729.20
3000	3.50	11.655	746.98
4000	3.40	11.322	765.65
5000	3.30	10.989	785.80
6000	3.25	10.8225	795.48
7000	3.20	10.656	805.94
8000	3.10	10.323	827.72
9000	3.05	10.1565	839.06
10000	3.00	9.9900	850.70

Figure 7 shows a plot of the voltage (mV) against concentration (ppm) of the manufacturer. The line of the best fit of Figure 7 is given by the equation $y = 0.01599x + 697.01678$. From the equation it follows that the MQ-4 gas sensor registered a voltage of 697.01678 mV when it was not exposed to alcohol. As shown in Table 1, there are many different outputs between 2 days, 3 days and 5 days. The heat-up time is a factor that determines the accuracy of the output.

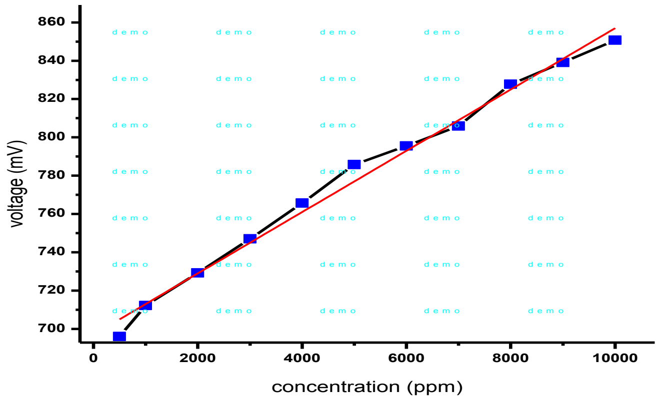


Fig 7: A graph of voltage (mV) versus concentration (ppm) in ideal conditions

The results of the voltage (mV) against gas concentrations for various heating and exposure times were taken and recorded in tables 2 to 6 and figures 7 to 12.

TABLE 2
Output voltage of MQ-4after one day heating in the different alcohol concentration

Conc (ppm)	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
After 5 mins	521	562	582	596	607	617	641	671	683	705	732
After 15 mins	552	578	592	609	618	638	665	681	694	719	743
After 30 mins	567	585	596	616	629	652	674	692	718	732	764
After 45 mins	582	591	614	623	638	664	681	712	736	762	783

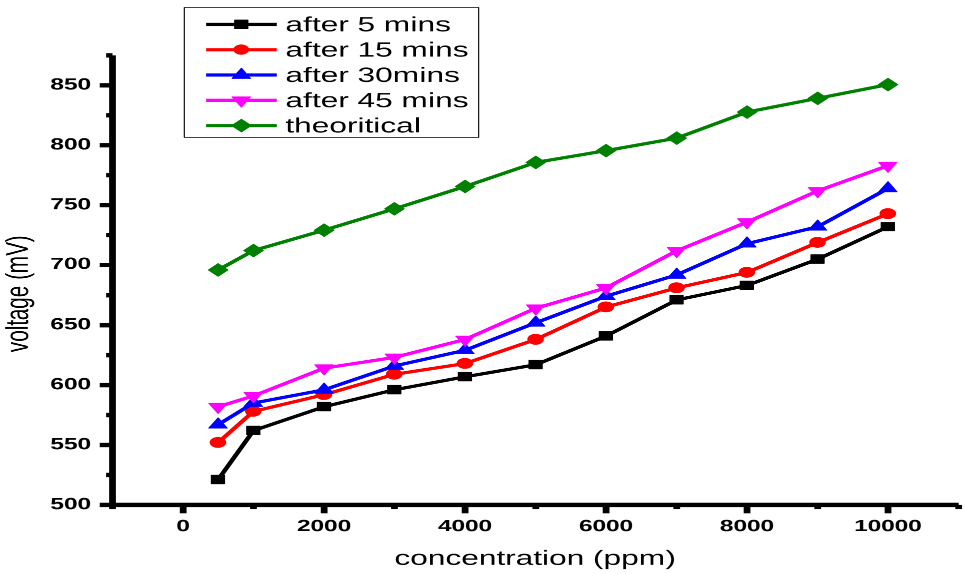


Fig 8: Graph of output voltage (mV) versus concentration (ppm) in different heat-time after 24 hours of heating MQ-4 gas sensor.

From Figure 8 above, the graph shows the profile of the theoretical and experimental values differ so much hence the optimum value could not be obtained after 24 hours of heating. This is attributed to the fact that the structure of the sensor is made up of a variable resistor that is depended on the concentration of the gas. In addition, it is necessary to in cooperate a load resistor so as to adjust sensitivity and accuracy of the sensor. For proper working conditions of the sensor, the in-built resistor needs to offer temperature at which the optimal sensitivity and accuracy of the sensor is attained.

After two days of heating the MQ-4 the following results were obtained.

TABLE 3

Output voltage of MQ-4 after two days heating in the different alcohol concentration

Conc (ppm)	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
After 5 mins	654	682	705	734	756	762	783	794	802	815	826
After 15mins	672	699	723	747	764	771	792	805	818	835	846
After 30mins	692	719	736	759	781	794	806	821	828	840	852
After 45mins	701	721	741	764	793	802	817	835	845	862	886

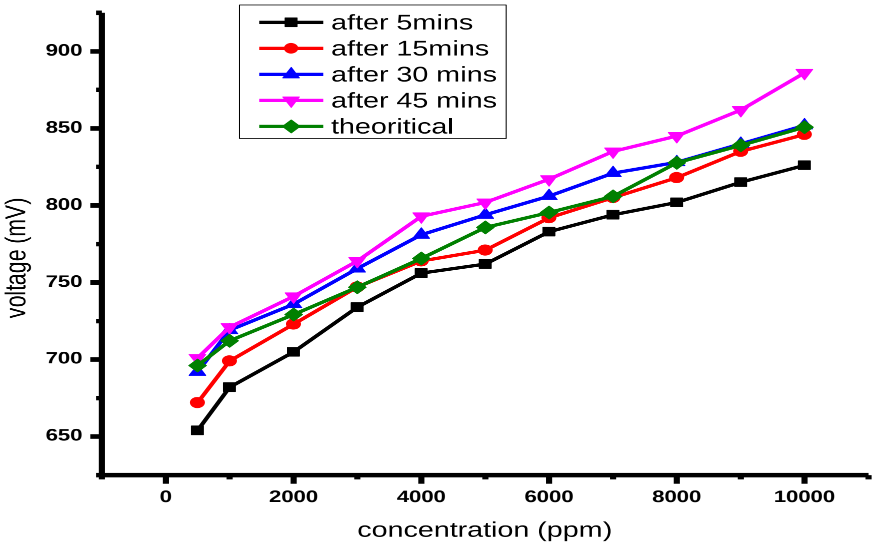


Fig 9: A graph of voltage (mV) versus voltage after 2 days in different heat-time.

From figure 9, the graph shows the theoretical values and experimental values obtained after 2 days heating of MQ-4 gas sensor were very close. As the heating time increases to two days the curves obtained tend to be too close to the theoretical values, an indication that the inbuilt resistor has attained the optimal temperature at which optimal sensitivity and accuracy is attained.

TABLE 4

Output voltage of MQ-4after three days heating in the different alcohol concentration

Conc (ppm)	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
After 5mins	715	741	752	763	785	798	821	832	845	854	873
After 15 mins	732	746	754	769	797	806	821	848	869	881	889
After 30 mins	754	762	787	801	807	816	826	865	877	892	907
After 45 mins	761	767	782	807	821	837	848	878	893	903	916

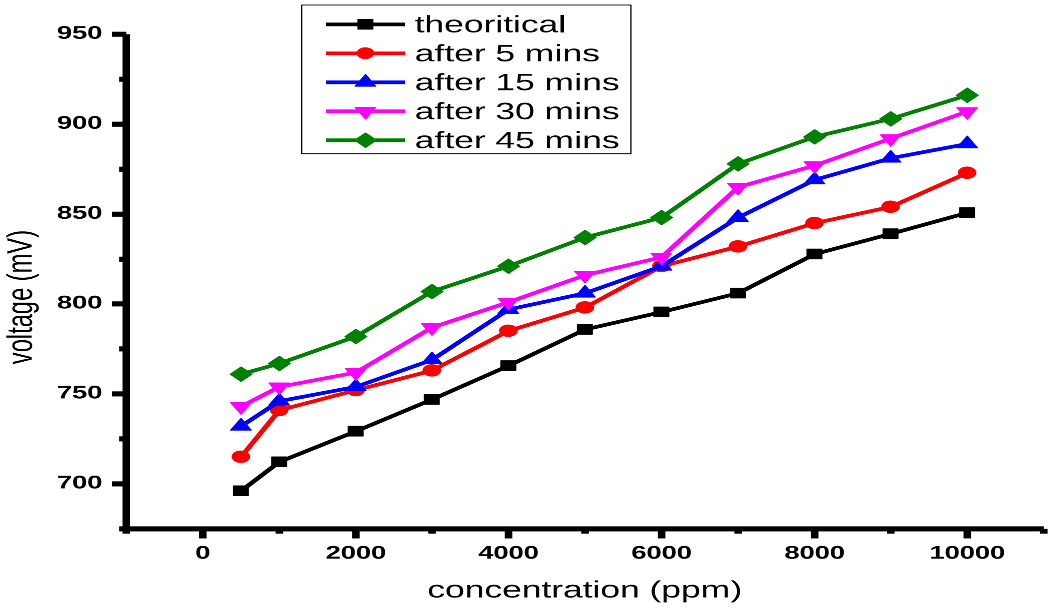


Fig 10: A graph of voltage (mV) versus voltage after three days in different heat-time.

From figure 10, the graph shows the theoretical values and experimental values obtained after 3 days heating of MQ-4 gas sensor were not very close as compared to heating after two days. As the heating time increases to three days the curves obtained tend to deviate slightly from the theoretical values, an indication that the inbuilt resistor has exceeded the optimal temperature at which optimal sensitivity and accuracy is attained. Hence, the theoretical curve deviated from the experimental curves in the third day of heating.

TABLE 5
Output voltage of MQ-4after four days heating in the different alcohol concentration

Conc(ppm)	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
5 mins	743	763	783	786	796	806	825	846	858	879	890
15 mins	756	782	792	796	812	824	836	864	875	886	898
30 mins	774	789	798	807	818	836	845	883	892	892	902
45 mins	782	821	841	864	893	902	917	935	945	962	986

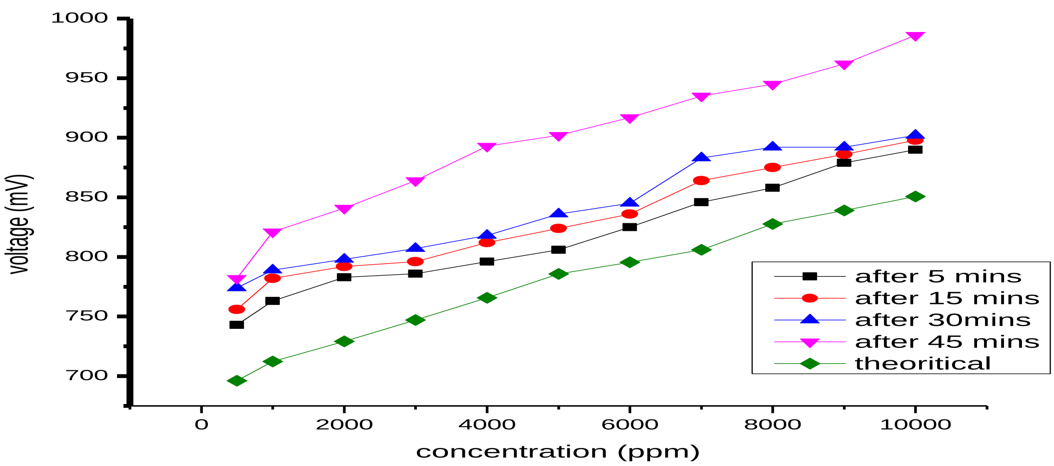


Fig 11: Graph of voltage (mV) versus concentration (ppm) after four days in different heat-times.

From figure 11, the graph shows the theoretical values and experimental values obtained after 4 days heating of MQ-4 gas sensor were too apart as compared to heating after two days. As the heating time increases to four days the curves obtained tend to deviate more from the theoretical values, an indication that the inbuilt resistor has exceeded the optimal temperature at which optimal sensitivity and accuracy is attained. Hence, increasing the heating time results in the theoretical curve deviating from the experimental curves in the fourth day of heating due to destabilization of the inbuilt resistor. This is attributed to the Zener effect of the resistor.

TABLE 6
Output voltage of MQ-4after five days heating in the different alcohol concentration

Conc (ppm)	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
After 5 mins	746	765	789	791	798	809	827	851	860	881	892
After 15 mins	759	785	795	799	815	825	839	869	879	892	902
After 30 mins	776	794	802	809	821	841	849	887	898	907	918
After 45 mins	787	822	842	867	896	906	919	941	953	971	992

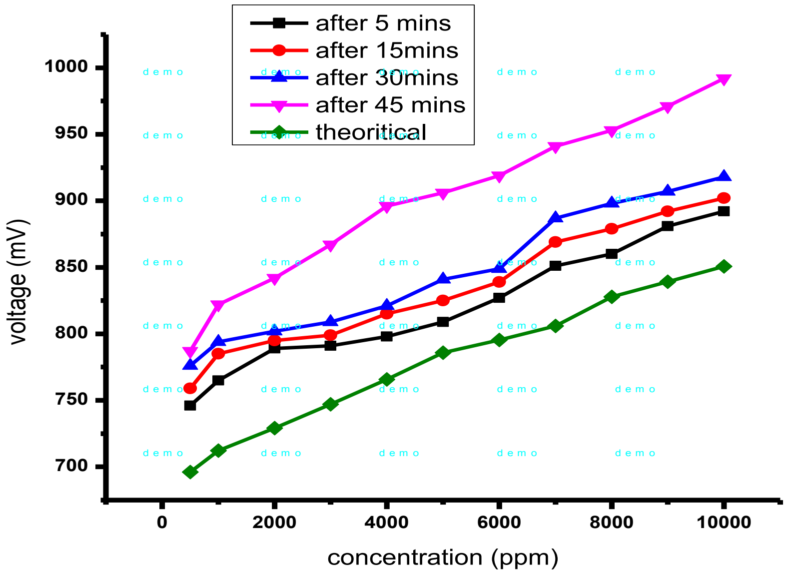


Fig 12: Graph of voltage (mV) versus concentration (ppm) after five days in different heat-times.

From figure 12, the graph shows the theoretical values and experimental values obtained after 5 days heating of MQ-4 gas sensor were too distorted as compared to heating after two days. As the heating time increases to five days the curves obtained tend to deviate more from the theoretical values, an indication that the inbuilt resistor has exceeded the optimal temperature at which optimal sensitivity and accuracy is attained. Hence, increasing the heating time results in the theoretical curve deviating more from the experimental curves in the fifth day of heating due to destabilization of the inbuilt resistor. This is attributed to the Zener effect of the resistor.

IV. CONCLUSIONS

From the research, it can be inferred that the output voltage is almost stable after 48 hours of heating the MQ-4 gas sensor which is shown in Figure 9. In Table 3 the output voltage increase depends on time and concentration. The methanol fluid is not easy to be volatilized. Hence the more time is allowed the more it volatilizes.

After the calculations of the gradients of the best fit lines of all the curves, the curve obtained after 5 minutes exposure time and 2 days heat up time was close to the theoretical value giving equation 8 below:

$$y = 0.01571x + 718.8108 \qquad (8)$$

It is within this curve the optimum value of concentration of the gas is obtained so as to be used in the programming of the Arduino (UNO). Comparing with the theoretical equation

$$y = 0.01599x + 697.01678,$$

the gradient percentage error is 1.75. This may be attributed to: volatilization time and diffusion rate of the gas.

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