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# Hardware Engineering of Hazardous Gas and Alcoholic Substances Detector in Meat Using Microcontroller and Gas Sensor

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**Abstract**

Meat may provide not only essential nutritional content but also possible harmful effects on human bodies. Unsafe consumption of meat potentially triggers colorectal cancer risks. Grilling is the most popular way to consume meat. However, meat grilling triggers the formation of hazardous chemical substances such as poisonous Polycyclic Aromatic Hydrocarbons (PAHs). This study conducted experiments using hardware engineering with microcontrollers and different gas sensors, aiming to identify gas substances produced by meat during grilling. The hardware prototype for the test simulation tool was assembled with integrated block systems and circuits. Evaluations were conducted on the direct grilling of three different types of meat. The data results were then utilized to analyze gas substances produced by meat during direct grilling. Based on the results, only five of the seven MQ-type gas sensors used in the research reacted to gas substances produced by all types of meat: LPG, alcohol, carbon monoxide, methane, and carbon dioxide, which were successfully detected in meat during grilling. Our research contributes to discovering a potential prevalence of increased alcoholic content in meat that has been grilled for five minutes. This finding is especially crucial for Muslims since it is highly correlated with halal certification of meat consumption. According to the results, Muslims should wait at least seven minutes or more after direct grilling to let the alcoholic content in meat thoroughly decrease so that it can be safely certified as halal to be consumed according to Islamic laws.

*Keywords:* Food Production; Compounds; Gas; Meat; Microcontroller; Sensor.

## 1. Introduction

The Central Bureau of Statistics of Indonesia, in its study publication of staple food consumption in 2019, stated that Indonesia has a high meat consumption. In terms of production, since 2017, Indonesia has produced 3.5 million tons of meat consisting of beef, buffalo, lamb, pork, and chicken [1]. However, the high consumption rate related to the need for meat in Indonesia, especially beef, demands a separate import policy [2]. In Indonesia, there has always been a gap between supply and demand for beef, with national beef production only meeting around 45% of the demand [3]. Meat ranks among the most important, nutritious, and preferred foods available to humans, which helps fulfill most of their bodily needs [4]. Meat certainly has good nutritional content for the human body, such as being a source of protein and some essential vitamins [5]. Beef and lamb are high-quality dietary protein sources for human metabolism due to their amino acid constituents [6].

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The nutrition and safety of dietary meat have a significant role in the quality of human life [7]. Proper food processing and preparation are necessary before the meat can be directly consumed [8]. Aside from its good nutrition for human bodies, meat might have negative impacts on them [9]. For example, processed red meat is suspected of having harmful effects on the colon and improving the risks of colorectal cancer [10, 11] and breast cancer [12]. Much evidence from long-term prospective cohort studies has shown that diets high in red and processed meats are associated with increased risks of type-2 diabetes (T2D), cardiovascular disease (CVD), cancer (especially colorectal cancer), and many other death causes [13]. There is also the term residue in heat-treated and fermented meat, which is potentially harmful to health [14]. Some examples of residues in meat that may be harmful to the body if they are present in high numbers are nitrites and nitrates [15].

One of the most popular ways to consume meat is by grilling. The grilling process of meat apparently triggers the formation of some chemical substances [16] that may be harmful to human bodies. Gas compounds (ethane, hexane, NO2, N2O, SO2, NH3, and HCl) are also produced during meat grilling [17]. Moreover, according to the Gas Chromatography and Mass Spectroscopy (GC/MS) analysis, meat grilling also forms Polycyclic Aromatic Hydrocarbons (PAHs). Several PAHs found in meat grilling are: naphthalene, fluoranthene, phenanthrene, anthracene, pyrene, and benzo(a)pyrene, which are included as poisonous gas compounds.

As mentioned above, it is known that some of the substances and compounds contained in meat are harmful to human bodies. These hazardous substances can cause disease in humans. Grilled meat consumption is associated with exposure to carcinogenic compounds and increases cancer risk [18]. The World Health Organization (WHO) has also included processed and red dietary meat in foods with carcinogenic compounds [19].

According to Islamic perspectives and views, the alcoholic content contained in food is a sensitive matter. Regulation of ethanol content limits in halal food industries is necessary for facilitating food production that fulfills Islamic criteria [20]. In Islamic views, halal means the food is certified and allowed to be consumed by Muslims [21]. On the contrary, the term haram means prohibited by Islamic laws. As for alcoholic content in food, it has been regulated using halal certifications applied in many Islamic countries [22].

Information technology improvements have penetrated various food system areas [23]. It is quite interesting that omics technology has been applied to investigate food as a component of a health or illness status [24]. Omics is a comprehensive or global molecular biological analysis [25]. "Omics" technology, including genomics, transcriptomics, proteomics, and metabolomics, has generated a large amount of data, such as sequences and expressions of gene-to-protein, as well as metabolite patterns [26, 27]. Industry 4.0 components, such as robotics [28], the Internet of Things [29], Big Data [30], augmented reality, cybersecurity, and blockchain [31], have recently transformed many industries and manufacturing, including the agri-food sector [32], such as the meat industry [33]. In addition, the Internet of Things (IoT), a popular technology, has been utilized to identify factors that damage food quality accurately [34].

Much research has been conducted to investigate and extend insights into meat cooking processes. Research by Sumer and Oz [35] analyzed the effects of the beef meat cooking process by direct and indirect grilling on the formation of Polycyclic Aromatic Hydrocarbons (PAHs). The evaluation was also conducted with two different degrees of doneness: medium and well-done. Apparently, all samples of well-cooked beef meat by the direct grilling method produced the highest levels of these gas substances: BaP (0.49 ng/g), ∑PAH4 (6.35 ng/g), and ∑PAH8 (11.34 ng/g). Another study by Fedorov et al. [36] identified the cooking degree of grilled chicken meat using electronic nose technology. Fedorov analyzed the physicochemical control technique during the grilling of chicken meat. Thermogravimetric, differential mobility, and mass spectrometric analyses were utilized to deepen fundamental insights into the grilling process. The electronic nose successfully detected the doneness state of grilled chicken meat. Similar research by Moran et al. [37] performed an analysis of the doneness and volatile profile of cooked meat. The grilling processes used in the research were used at extraction temperatures of 30, 60, and 80 $^{o}$C in 30 and 50 minutes, respectively. Study findings showed that a higher extraction temperature might increase the detection of heavy volatile compounds, while sample preparations had little influence on the volatile profile of the meat. Another study by Kafaouris et al. [38] conducted an analysis of the prevalence of polycyclic aromatic hydrocarbons in charcoal-grilled meat. melakukan analisis keberadaan hidrokarbon aromatik polisiklik dalam daging panggang arang. Research methods were based on saponification and liquid extraction steps, followed by solid phase extraction (SPE) cleanup of the extract, and lastly, PAH was determined using high-performance liquid chromatography by a fluorescence detector. The study results revealed that the highest concentration of PAH was found in samples with a higher fat content and a longer smoking or cooking process.

However, according to literature reviews, there has been no technical investigation and analysis on ethanolic content contained in meat during the grilling process within a particular period. A research gap can be found in those studies; generally, most studies only focused on analyzing PAH compounds during grilling. This research gap triggers authors to assess the potential ethanolic content of meat during grilling. Specifically, this research contributes to applying hardware engineering with microcontrollers and gas sensors to identify gas substances that may be produced by chicken, beef, and pork meat during grilling. Then, the gas substances found would be analyzed further to assess which type of direct-grilled meat has the most harmful gas substances for human bodies. Moreover, the ethanolic content potentially contained in meat during grilling will be associated with Islamic laws regarding halal-haram in food certification. In Islamic views, food may be considered haram if it contains ethanol at a particular concentration.

## 2. Method

An experimental method was used in the research. In the experimental method, several tests were conducted based on relevant literature study reviews. At least eight methodological steps were conducted in the research: defining the research questions, specifying research keywords, conducting a literature survey, analyzing the research gap, determining research contributions, and finally, performing hardware engineering to support the analysis of the experiments. The methodological steps can be illustrated as presented in Figure 1.

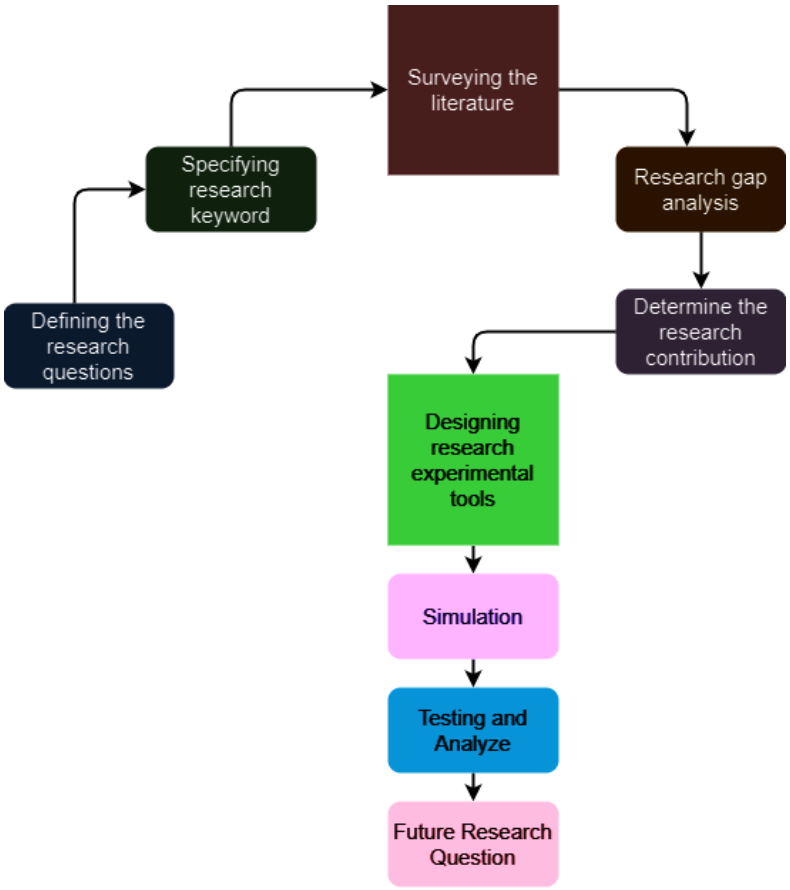


**Figure 1. Research flow using the experimental method**

### 2.1. Defining the Research Question

A potential prevalence of chemical gas substances and increased ethanolic content in grilled meat were assumed at the beginning of the research. Then, the research problem was formulated in these research questions: 1) What are gas substances that can be detected in grilled meat?" ; 2) "How are the characteristics of these gas substances during grilling at a particular cooking period?"; 3) "What is the concentration of alcoholic or ethanolic content in meat cooked by the direct grilling method?". These research questions became the key to the research that the experiments would evaluate.

### 2.2. Specifying Research Keywords

Based on the formulated research question, several main keywords were used as research tools used in literature surveys: halal, meat consumption, meat cooking process, ethanol content, and hardware engineering.

### 2.3. Literature Survey

This step collected research with topics related to the main keywords to support the experiment. Primary and secondary literature, such as books and academic papers, were used in this step. The literature survey results will be collected as a literature review and be analyzed further to determine the research gap in the next methodological step.

### 2.4. Research Gap Analysis and Contributions

The key points of previous research collected in the literature survey were summarized and analyzed to determine the research gap in the research gap and contribution analysis. The research gap and novel contributions were then determined and later used as fundamental supports in designing the system prototype in the next methodological step.

## 2.5. Design

The next step was to design hardware and software engineering systems. This includes designing the system's block diagram and wiring diagram. The block diagram of the system is shown in Figure 2.

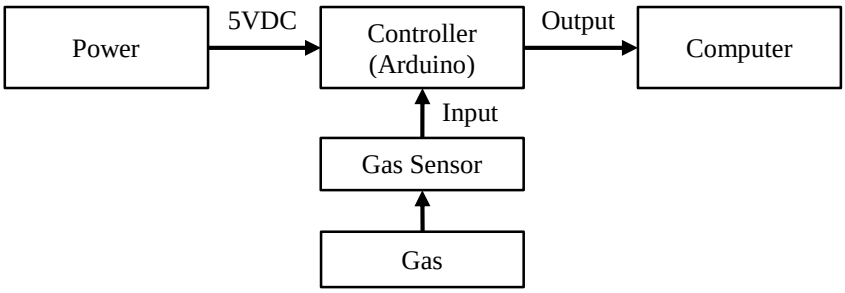


**Figure 2. System's block diagram**

The gas detector system in grilled meat was designed based on Arduino and a closed-loop control system. The closed-loop control system was used so that the resulting output of the system could be expected as a reference. The designed system started with electrical input generated from a 5V DC power supply to excite Arduino as the system's microcontroller. The resistance value was generated by gas sensors based on the gas substance detected in meat; these values were inputted by the gas sensors to be processed by the microcontroller. Then, the microcontroller would send an analog signal displayed on the computer in numeric values processed by the Arduino Uno microcontroller. The resistance values displayed on the computer would be used as experimental data and analyzed further to compare gas substances among several types of meat.

Seven gas sensors were used in the system: MQ-2, MQ-3, MQ-7, MQ-9, MQ-135, MQ-136, and MQ-137. Each type of gas sensor used in the system detects different gas substances [39-42]. MQ-2 gas sensor is also known as a smoke detector, which detects flammable gas concentration and reads it as an analog voltage. The sensitivity of MQ-2 gas sensor can be adjusted directly. MQ-3 sensor is a gas sensor used to detect alcohol in air. The MQ-3 sensor can also be used in security surveillance systems, fire prevention systems, and other applications that require alcohol detection. MQ-7 sensor detects carbon monoxide (CO) for daily use, industrial use, or automobile systems. MQ-9 sensor is an analog gas sensor that can detect carbon monoxide, methane, and Liquified Petroleum Gas (LPG); it is susceptible to pollutants and gas substances from motor vehicles. MQ-135 is a chemical gas sensor highly sensitive to NH3, NOx, alcohol, benzol, smoke (CO), CO2, and other gas compounds; the gas sensor works by changing electrical resistance value (analog) depending on detected gas substances. MQ-136 sensor is a semiconductor component that functions to sense tin oxide (SnO2) since its characteristic is highly sensitive to SO2 gas compounds. MQ 137 is a sensitive sensor made of tin oxide gas compounds (SnO2); the sensor's conductivity is low when located in places with clean air but increases with the detection of increased gas concentration.

The wiring of electrical components in the gas detector system is shown in Figure 3. As illustrated in Figure 3, the Arduino Uno microcontroller is connected to each gas sensor. The red cable is the ground/GND (-), while the blue cable is connected to the positive voltage input Vin(+). The yellow cable connects each gas sensor's output with the microcontroller's input/output (I/O) pins.

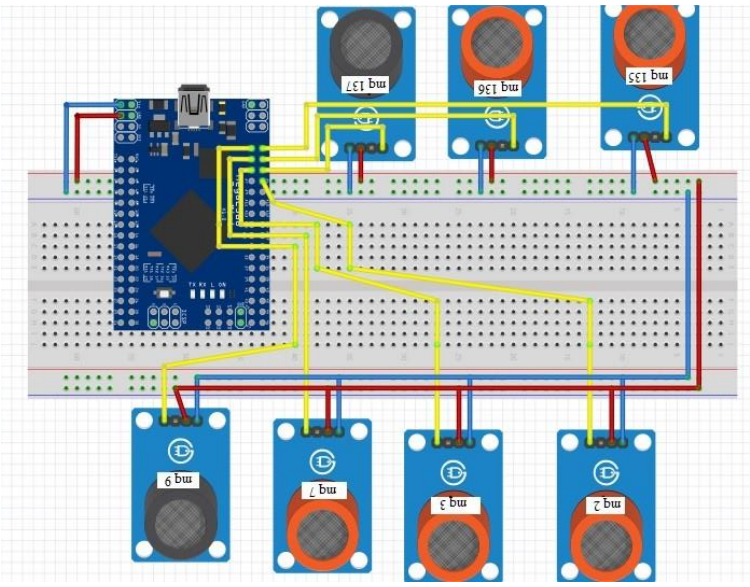


**Figure 3. Wiring diagram of proposed gas detector system**

The Arduino Uno is powered through a USB cable connected to the laptop. The microcontroller's analog input pins are connected to an output pin of each gas sensor: A0 pin to MQ-3, A1 pin to MQ-136, A2 pin to MQ-7, and so on. Vin and GND of those seven sensors are connected and wired in series to the microcontroller's Vin and GND pins. Then, the values generated from the sensor's output will be displayed through a serial monitor in the Arduino IDE application installed on a laptop.

The proposed gas detector system is designed as a tube-modeled tin container. The sides of the container are given holes where the gas sensors will be mounted so that the gas substances resulting from the meat grilling can be sensed directly by the gas sensors without any loss. The PCB and the Arduino Uno microcontroller are mounted on top of the tin container. The Inventor software program is used as a design software application to illustrate the design visually. The illustration design of the proposed gas detector system can be seen in Figure 4.

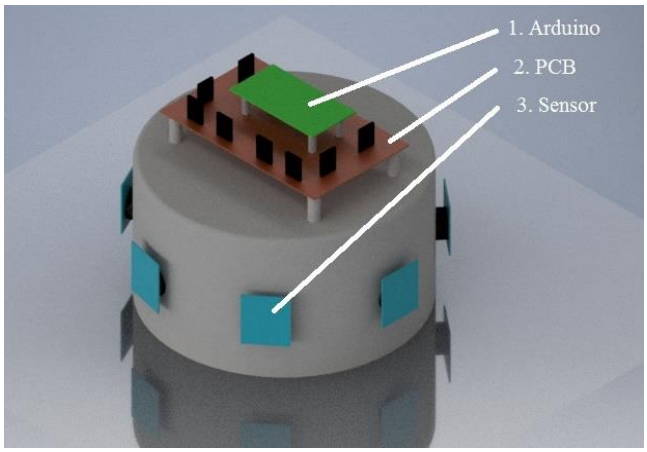


**Figure 4. 3D illustration design of the proposed gas detector system**

## 2.6. Simulation

Several experiments were conducted during the simulation regarding programming the modeled and controlled system. A program to detect gas in meat was debugged and simulated using the Arduino IDE application on the serial monitor. Experimental data from the sensor detecting gas substances in different grilled meat was collected. Types of meat used in the research are chicken, beef, and pork.

## 2.7. Implementation and Testing

The parameters used in the research were standard parameters of each gas sensor. Table 1 lists all standard parameters of each gas sensor used in the research.

**Table 1. Gas sensors Parameters**

| No | Sensor | Detection Range | Resistance of Sensitive Material |
|---|---|---|---|
| 1 | MQ-2 | 200 – 5000 ppm LPG | 2-20 KΩ(in 2000 ppm C3H8 ) |
| 2 | MQ-3 | 20~ 500 ppm alcohol | 1～400 KΩ(in air) |
| 3 | MQ-7 | 10 to 500 ppm co gas | 2-20K |
| 4 | MQ-9 | 20-2000 ppm carbon monoxide | 2K-20K(in 100 ppm CO ) |
| 5 | MQ-135 | 10-300 ppm NH3 | 30-200 KΩ |
| 6 | MQ-136 | 1-100 ppm H2S | 30-200 KΩ |
| 7 | MQ-137 | Rs(in air) / Rs(50 ppmNH3) ≥2 | 5～500 ppm NH3 |

In implementation and testing, all elements of the research were combined; communication between Arduino Uno as the microcontroller and seven gas sensors to detect gas substances in grilled meat was established. Testing was conducted partially to ensure no malfunction in the components, and entirely as a whole complete system. The proposed gas detector system was also implemented and tested in several steps. The first test was conducted with a grilling without any meat on the grill to observe the change in the sensor's output value. Then, the test was conducted with a grilling of different types of meat to compare the gas substances. Additionally, implementation and testing were conducted to assess whether the proposed gas detector system can perform as expected in the research objective: to accurately analyze and compare gas substances in different types of grilled meat.

## 3. Result and Discussion

After designing the overall hardware and software of the proposed gas detector system, a prototype was made to be implemented and tested. Testing was conducted to obtain experimental data, and implementation was conducted to obtain experimental data. In this section, the results will be analyzed comprehensively to assess and compare gas substances contained in different types of meat during the grilling process.

### 3.1. Building the Prototype

A prototype of the proposed gas detector system in grilled meat was made based on a visual and concept design in Figure 4. The result of this process can be seen in Figure 5.

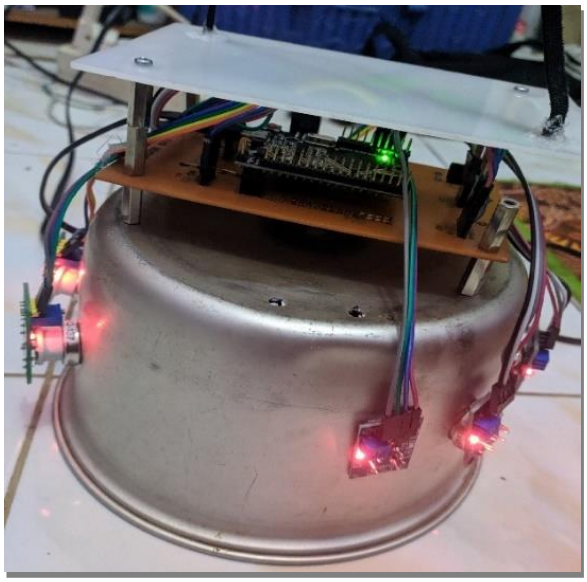

**Figure 5. Prototype Design of Gas Substances Detector in Meat**

The seven gas sensors used have distinctive characteristics in detecting gas substances. Ideally, the proposed system requires 30 minutes of initial preparation before operating normally; some gas sensors must be pre-heated before detecting gas substances. Based on the gas sensors' characteristics, gas substances that can be detected using the proposed system are LPG, alcohol, carbon monoxide, methane, nitrogen oxide, hydrogen sulfide, and ammonia. In line with the research objectives, the prototype system design was focused on determining gas sensors that can detect and react to alcoholic substances contained in meat during the grilling process.

### 3.2. Implementation and Testing

The first test was conducted without any meat to be grilled. Each sensor's output value in a specific time interval was recorded. The results of the first test can be seen in Table 2.

**Table 2. Gas sensors output in the first test**

| No | Time | MQ-2 | MQ-3 | MQ-7 | MQ-9 | MQ-135 | MQ-136 | MQ-137 |
|---|---|---|---|---|---|---|---|---|
| 1 | 5 seconds | 254 | 244 | 268 | 134 | 206 | 543 | 387 |
| 2 | 10 seconds | 254 | 245 | 268 | 134 | 206 | 543 | 386 |
| 3 | 15 seconds | 254 | 244 | 267 | 134 | 206 | 542 | 387 |
| 4 | 20 seconds | 254 | 244 | 267 | 134 | 206 | 542 | 386 |
| 5 | 25 seconds | 254 | 244 | 267 | 133 | 206 | 542 | 387 |
| 6 | 30 seconds | 254 | 244 | 267 | 133 | 206 | 543 | 386 |
| 7 | 35 seconds | 254 | 244 | 267 | 133 | 206 | 543 | 387 |
| 8 | 40 seconds | 254 | 244 | 267 | 134 | 206 | 543 | 387 |
| 9 | 45 seconds | 254 | 244 | 267 | 133 | 205 | 542 | 387 |
| 10 | 50 seconds | 254 | 244 | 267 | 134 | 206 | 542 | 387 |
| 11 | 55 seconds | 254 | 243 | 268 | 133 | 205 | 542 | 387 |
| 12 | 60 seconds | 254 | 244 | 267 | 134 | 205 | 543 | 387 |

Based on Table 2, the sensors' output tended to be stable in 30 seconds after the system was turned on. A slight change in output values is expected due to measurement noise and external disturbances. The next step of the test is to analyze the gas substances resulting from the meat grilling process. A piece of meat was grilled on fire inside the container, which resulted in an air full of smoke containing different gas substances. The gas sensors then detected gas substances in the smoke, resulting in different analog output values. Different types of meat were used in the research: chicken, beef, and pork meat; each was conducted in three conditions. Thus, three datasets can be obtained: test results taken directly after 5-minute grilling, test results taken at five minutes after grilling, and test results taken at seven minutes after grilling. The gas substances detected by seven gas sensors in each meat were then analyzed and compared.

The change of gas substances in the air inside the container resulting from grilling different meat detected by each gas sensor was then compared. For example, MQ-2 gas sensor, which detects inflammable gas substance such as LPG, were used to analyze which type of meat results in the highest inflammable gas substances. The meat sometimes burns during grilling due to its burnt oil. In other words, the output of the MQ-2 gas sensor can indirectly detect the oil content inside grilled meat. In the first evaluation, the measurement results of the MQ-2 gas sensor when detecting gas substances in different types of meat after being grilled for 5 minutes can be seen in Figure 6.

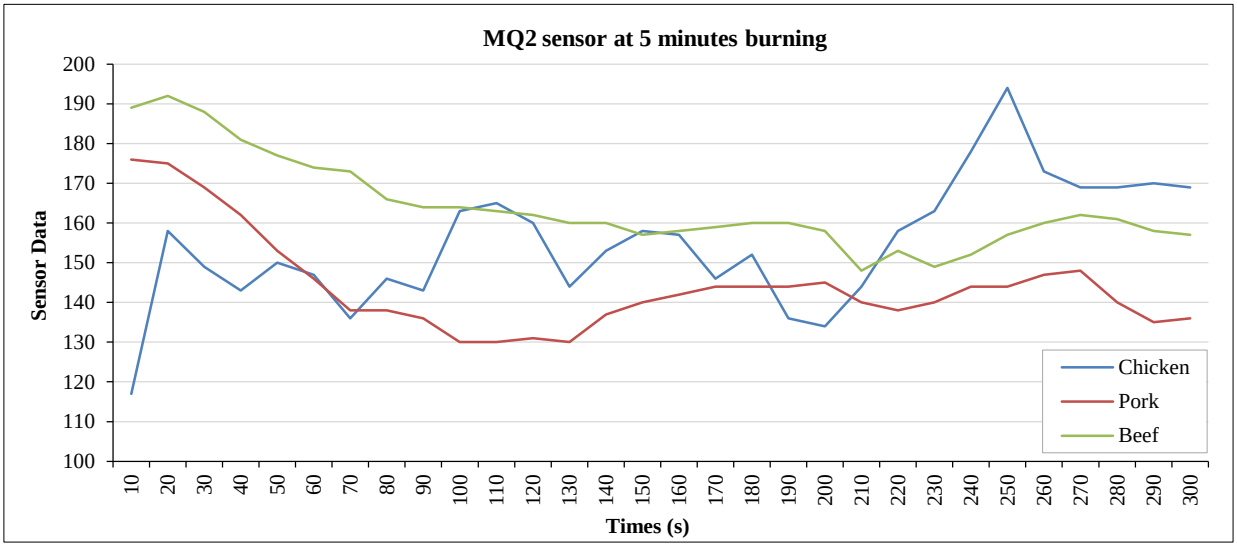


**Figure 6. Comparison of Gas Substance in Different Types of Meat based on MQ-2 Gas Sensor's Output at 5-minute Grilling**

According to Figure 6, the output of MQ-2 gas sensor in grilled chicken meat, which was shown by the blue line, increased from 117 to 169, while the results in red line, which indicates the result from pork, decreased from 189 to 136. Meanwhile, the green line indicating beef result also decreased from 188 to 157. This finding shows that the chicken meat was easier to become burnt than beef and pork meat when grilled.

According to Figure 7, gas substances detected by the MQ-2 gas sensor in chicken meat at 5 minutes after grilling decreased slightly from 129 to 117, whereas the results in pork increased from 151 to 214. The gas substance detected in beef at 5 minutes after grilling also increased slightly from 191 to 198.

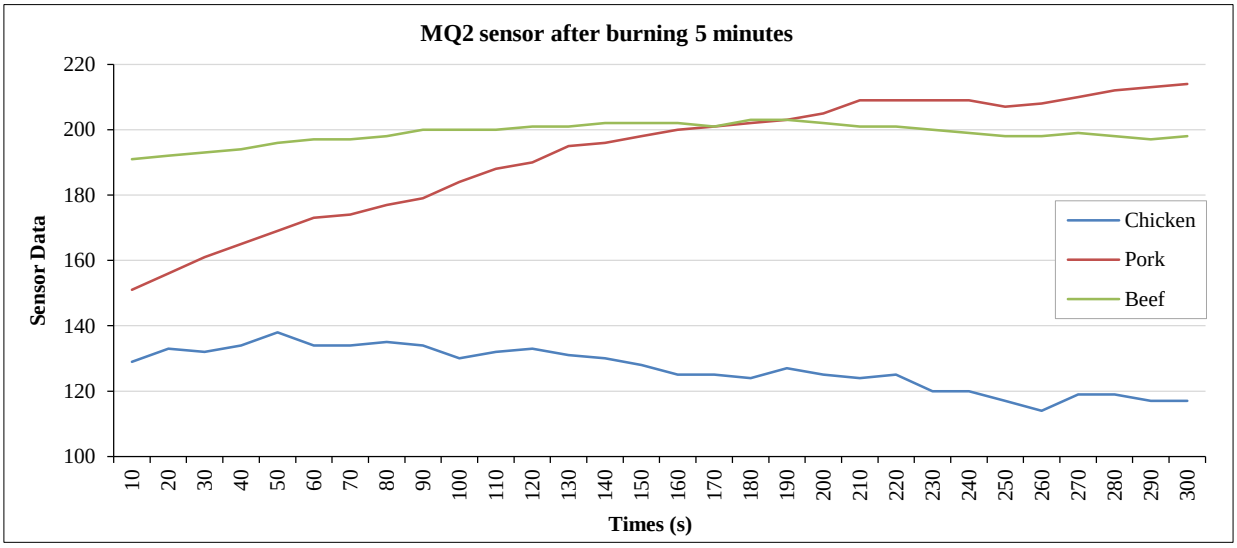


**Figure 7. Comparison of Gas Substance in Different Types of Meat based on MQ-2 Gas Sensor's Output at 5 Minutes After Grilling**

Based on Figure 8, no significant change in gas substances was detected by the MQ-2 gas sensor in chicken meat at 7 minutes after grilling. However, there was a slight increase of gas substances detected in pork from 125 to 146; similarly, the gas substances detected in beef also increased from 167 to 172.

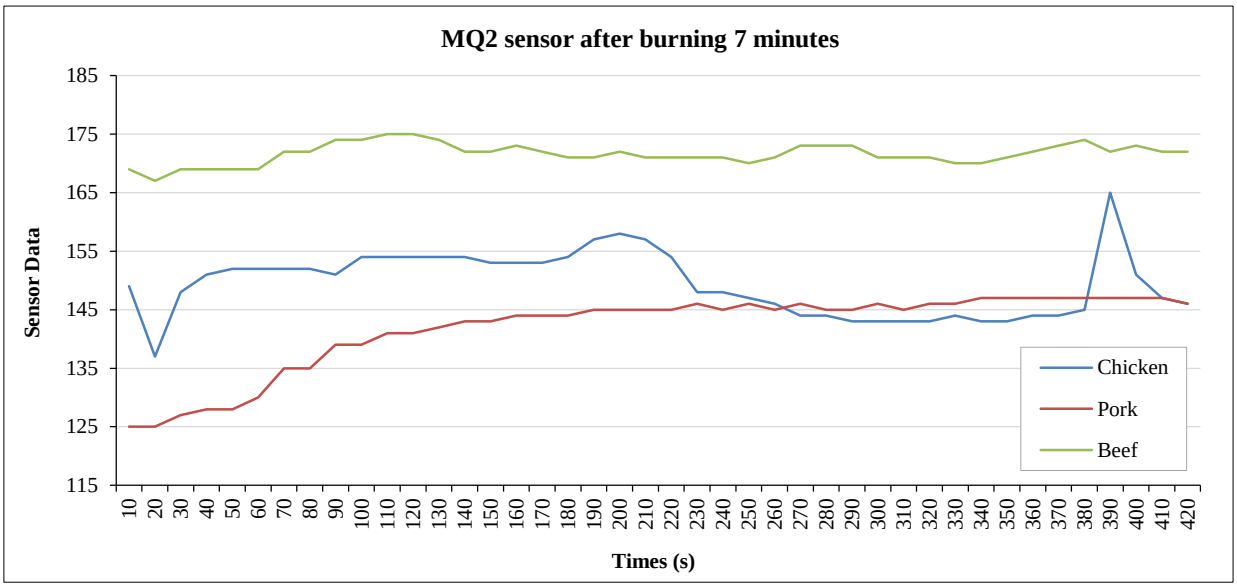


**Figure 8. Comparison of Gas Substance in Different Types of Meat based on MQ-2 Gas Sensor's Output at 7 Minutes After Grilling**

In comparison, MQ-3 gas sensor detects alcoholic substances. Therefore, the results from MQ-3 gas sensor can be used to identify which type of meat has the least and the highest alcoholic substances among chicken, beef, and pork. Similar to the prior test, three evaluations were conducted in this test. The measurement results of the MQ-2 gas sensor when detecting gas substances in different types of meat at 5-minute grilling can be seen in Figure 9.

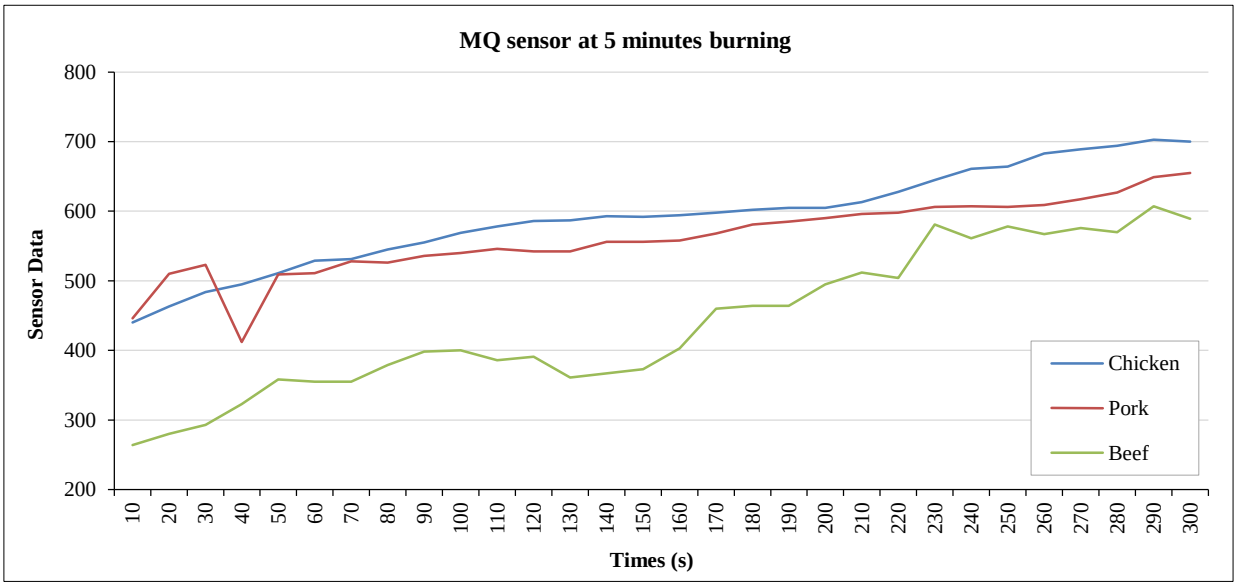


**Figure 9. Comparison of Gas Substance in Different Types of Meat based on MQ-3 Gas Sensor's Output at 5-minute Grilling**

Based on Figure 9, the output of MQ-3 gas sensor in chicken meat taken directly after grilling, which was shown by the blue line, increased from 446 to 700, while the results in red line, which indicates the result from pork, also increased from 510 to 655. Meanwhile, the green line indicating beef result increased greatly from 210 to 589. Thus, it can be seen that the alcoholic substances contained in grilled meat increased when measured directly after grilling.

According to halal certification, Muslims are prohibited from consuming pork [43] regardless of its food processing method. Unlike pork, beef and chicken are halal foods in Islam. However, a significant increase in alcoholic substances in grilled chicken and beef must be considered, especially by Muslims who directly consume grilled meat. Currently, many restaurants provide direct grilling on one of their menus. Thus, Muslims must be careful in consuming grilled meat directly due to its potential high alcohol content.

The measurement results from the MQ-3 gas sensor in different types of meat at five minutes after being grilled can be seen in Figure 10. According to the figure, the output of MQ-3 gas sensor in chicken meat detected five minutes after being grilled, as shown by the blue line, decreased from 737 to 647. The decrease in alcoholic substances is a good indicator for a safe consumption of grilled meat based on the halal criterion; Muslims must wait a few minutes until the alcoholic content decreases. The results in red line, which indicates the result from pork, decreased from 637 to 641. Meanwhile, the green line indicating beef result shows an increase from 372 to 420. Different from grilled chicken, grilled beef apparently still has increased alcoholic substances even in five minutes after grilling. Hence, the consumption of grilled beef must take longer than 5 minutes after grilling until the alcoholic content decreases. For comparison, the measurement results from the MQ-3 gas sensor in different types of meat at 7 minutes after being grilled can be seen in Figure 11.

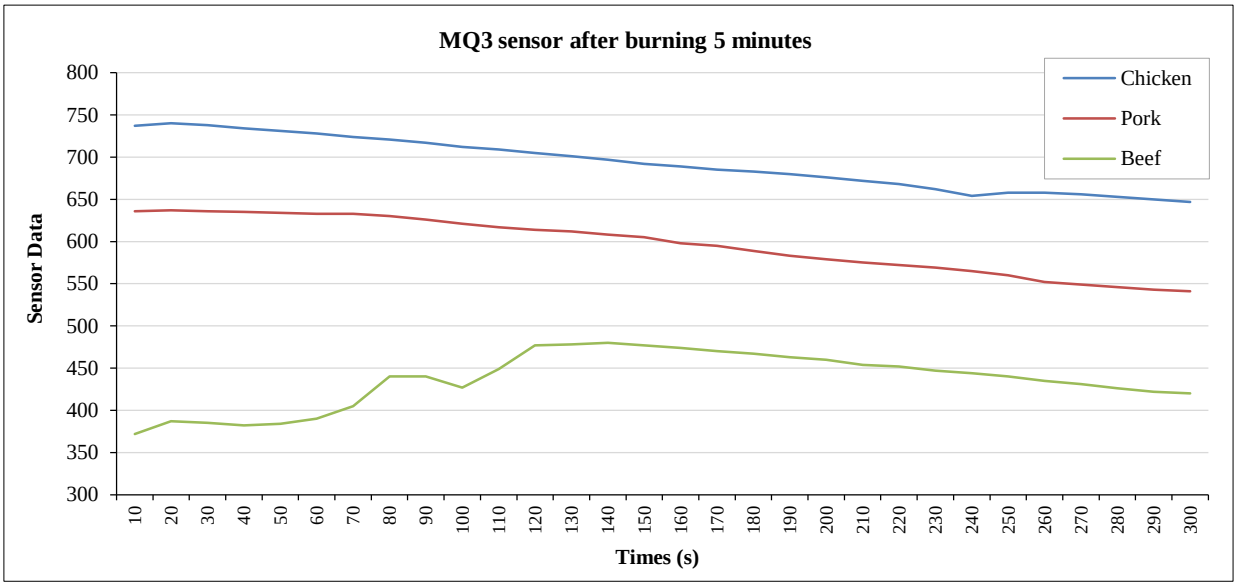


**Figure 10. Comparison of Gas Substance in Different Types of Meat based on MQ-3 Gas Sensor's Output at 5 Minutes After Grilling**

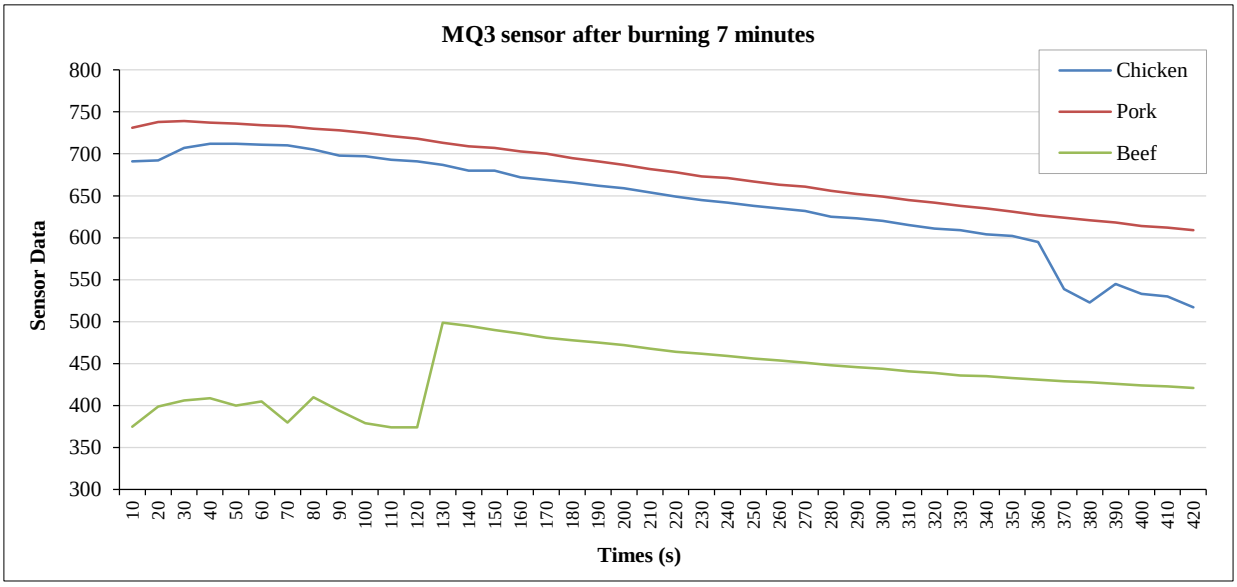


**Figure 11. Comparison of Gas Substance in Different Types of Meat based on MQ-3 Gas Sensor's Output at 7 Minutes after Grilling**

According to Figure 11, the output of MQ-2 gas sensor in chicken meat, which was shown by the blue line, decreased from 692 to 571. The red line, which indicates measurement in pork, also showed a decrease from 738 to 609. Besides, the green line indicating beef measurement results showed an increase from 375 to 421.

Within seven minutes, the alcoholic content of grilled chicken decreased, but apparently, the alcoholic content of grilled beef still increased. Thus, Muslims should not consume grilled beef directly after grilling due to its high alcoholic content. Grilled beef and chicken consumption should take longer than 7 minutes after grilling. However, these early identifications of alcoholic content in grilled beef and chicken must be studied further based on the Islamic halal criterion to decide the actual safe-consumption time.

The MQ-7 gas sensor detects carbon monoxide; the use of MQ-7 gas sensor in the research was to identify which type of grilled meat had the highest amount of carbon monoxide. Similarly, evaluations for MQ-7 gas sensor were done three times. The measurement results of the MQ-7 gas sensor when detecting carbon monoxide in different types of meat after being grilled for 5 minutes can be seen in Figure 12.

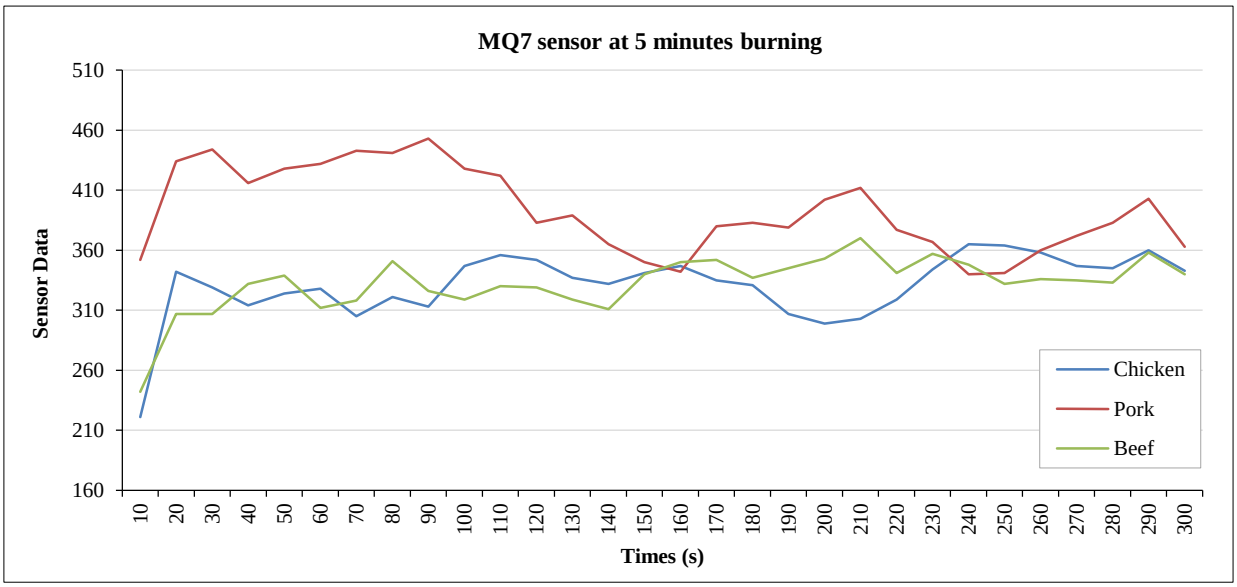


**Figure 12. Comparison of Gas Substance in Different Types of Meat based on MQ-7 Gas Sensor's Output at 5-minute Grilling**

As in Figure 12, the blue line shows the measurement results of MQ-7 in detecting gas substances in grilled chicken; the results fluctuated in a range of 221 to 365. Similarly, the red line, which shows measurement results in grilled pork, also fluctuated in a range of 350 to 453. Moreover, the green line shows that the measurement results in grilled beef had fluctuating values of 242 to 370.

In contrast, the measurement results in grilled chicken taken at 5 minutes after grilling decreased from 293 to 278, as can be seen in the blue line in Figure 13. Similarly, the red line, which shows the measurement results in grilled pork, decreased from 273 to 272. The measurement results in grilled beef also decreased from 312 to 278, as can be seen in the green line.

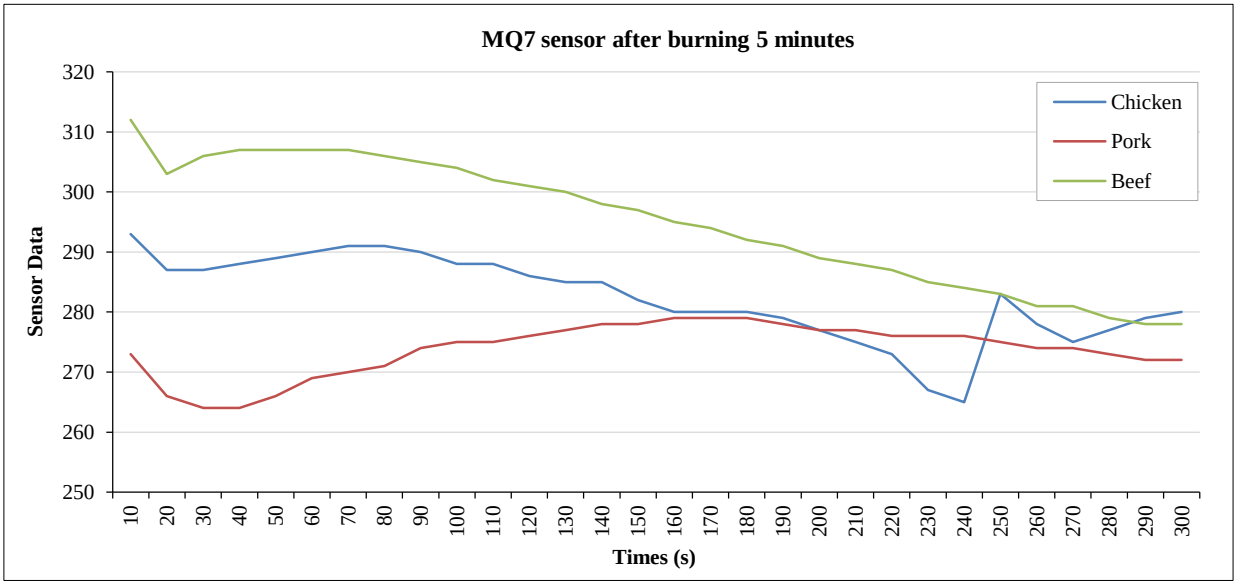


**Figure 13. Comparison of Gas Substance in Different Types of Meat based on MQ-7 Gas Sensor's Output at 5 Minutes After Grilling**

However, different results were found among grilled chicken, pork, and beef when the measurement was taken at seven minutes after grilling. As shown in Figure 14, the blue line showing the content of gas substances detected by MQ-7 gas sensor in grilled chicken has increased from 245 to 262. Similarly, the measurement results for grilled beef also increased from 245 to 262, as seen in the red line. In contrast, the measurement results in grilled pork decreased from 294 to 262, as seen in the green line.

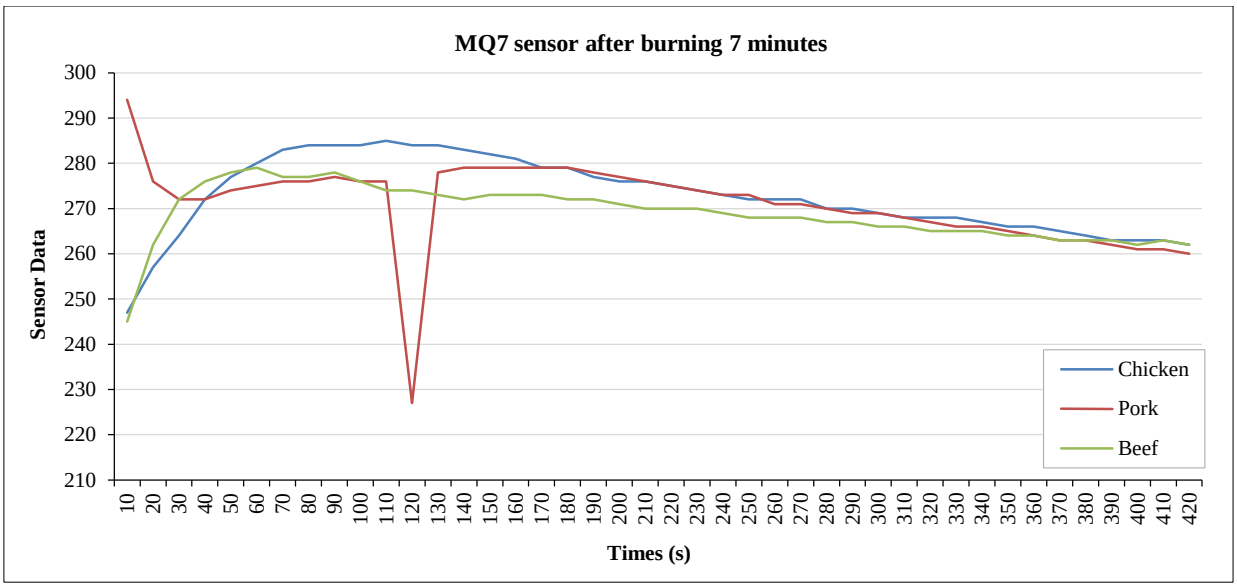


**Figure 14. Comparison of Gas Substance in Different Types of Meat based on MQ-7 Gas Sensor's Output at 7 Minutes after Grilling**

The MQ-9 gas sensor detects methane gas as the exhaust gas emitted by the grilled meat. Thus, the use of MQ-9 gas sensor in the research was to evaluate which type of grilled meat caused the highest methane gas. The evaluations were also done three times.

The measurement results of the MQ-9 gas sensor when detecting gas substances in different types of meat after being grilled for 5 minutes can be seen in Figure 15. According to the figure, the output of MQ-9 gas sensor in chicken meat detected five minutes after being grilled, as shown by the blue line, fluctuated greatly in a range of 185 to 512. The results in red line, which indicates the result from pork, also fluctuated greatly in a range of 328 to 458. Similarly, the green line indicating beef results shows fluctuating values ranging from 185 to 466. For comparison, the measurement results from the MQ-9 gas sensor in different types of meat at 5 minutes after being grilled can be seen in Figure 16.

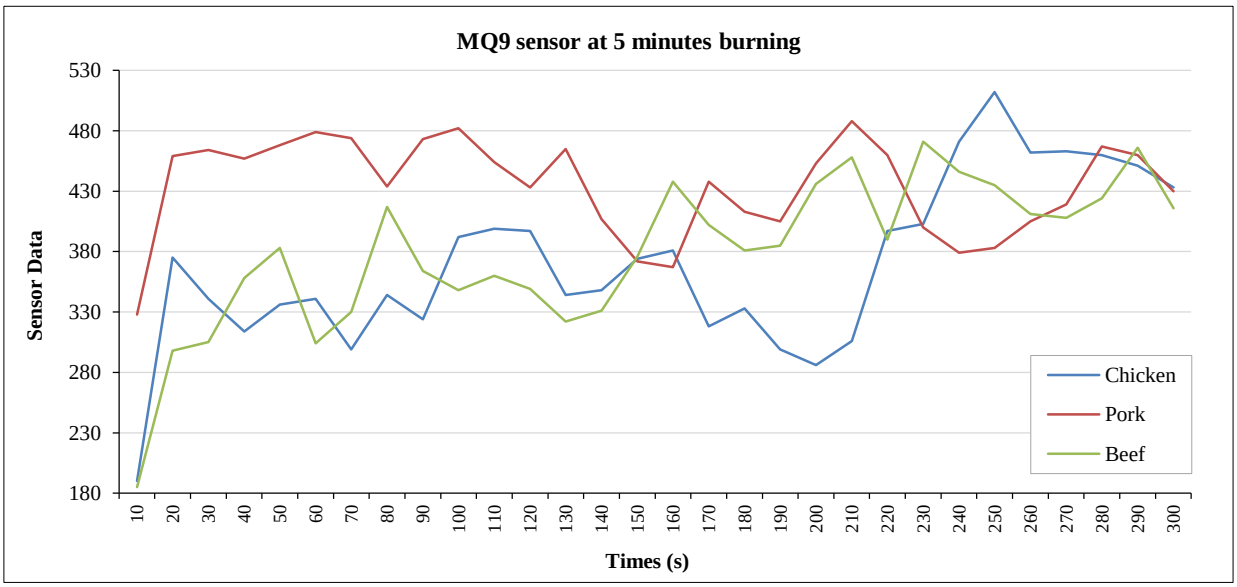


**Figure 15. Comparison of Gas Substance in Different Types of Meat based on MQ-9 Gas Sensor's Output at 5-minute Grilling**

According to Figure 16, methane gas detected by the MQ-9 gas sensor in chicken meat at 5 minutes after grilling, as shown by the blue line, decreased slightly from 289 to 229; whereas the results in pork, as seen in the red line, increased from 287 to 292. The gas substance detected in beef at 5 minutes after grilling also increased slightly from 245 to 262, as shown by the green line. For comparison, the measurement results from the MQ-9 gas sensor in different types of meat at 7 minutes after being grilled can be seen in Figure 17.

As shown by the blue line in Figure 17, the measurement results in chicken meat detected at 7 minutes after being grilled decreased from 244 to 227. Similar results were also shown by the red line indicating measurement results in grilled pork; the amount of gas substance detected by the MQ-9 gas sensor decreased from 303 to 290. However, the measurement results in grilled beef increased from 231 to 268, as seen in the green line.

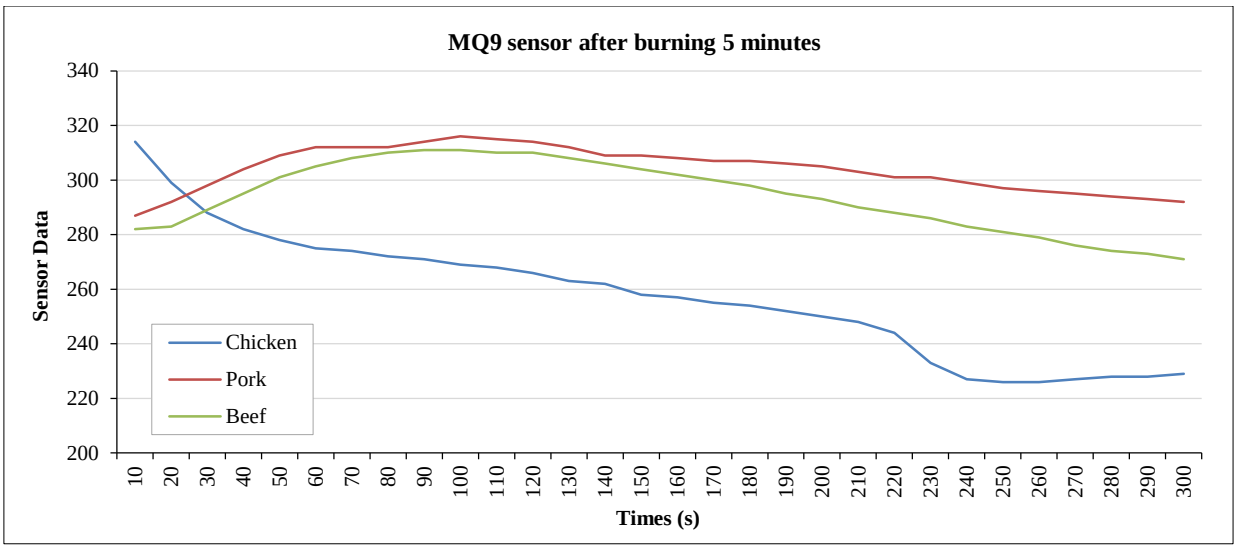


**Figure 16. Comparison of Gas Substance in Different Types of Meat based on MQ-9 Gas Sensor's Output at 5 Minutes after Grilling**

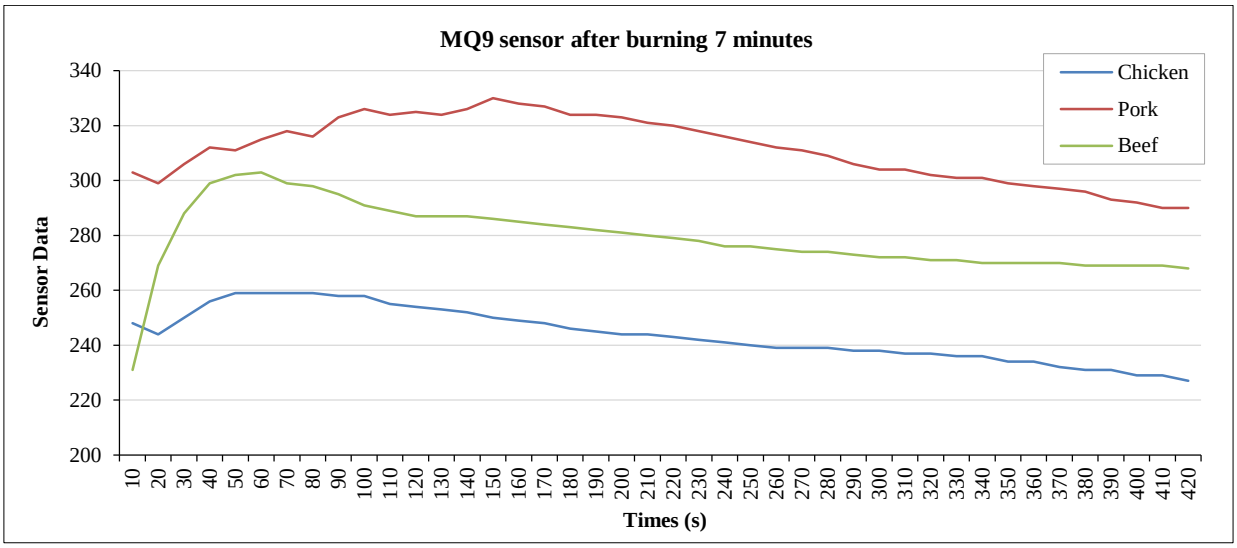


**Figure 17. Comparison of Gas Substance in Different Types of Meat based on MQ-9 Gas Sensor's Output at 7 Minutes after Grilling**

The MQ-135 detects another type of exhaust gas emitted during grilling: carbon dioxide. To identify and evaluate which type of meat emitted the highest amount of carbon dioxide during grilling, we used MQ-135 gas sensor in the proposed system. Three evaluations were also conducted for the MQ-135 test results. The first measurement results for MQ-135 gas sensor, which was taken directly after the meat was grilled for five minutes, were shown in Figure 18.

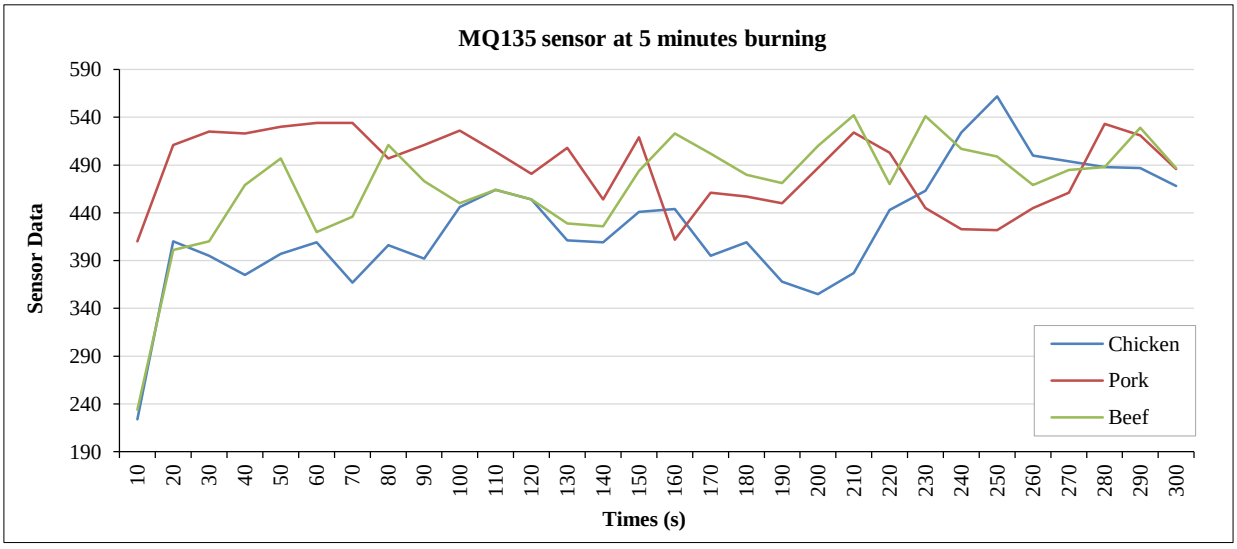


**Figure 18. Comparison of Gas Substance in Different Types of Meat based on MQ-135 Gas Sensor's Output at 5-minute Grilling**

According to Figure 18, the measurement results in grilled chicken, beef, and pork, fluctuated in different ranges of values. As seen in the blue line, the measurement results of MQ-135 gas sensor in grilled meat fluctuated greatly in a range of 234 to 562. Similarly, the measurement results in grilled beef also fluctuated greatly in a range of 234 to 542, as seen in the green line. In addition, the measurement results in grilled pork had fluctuating values ranging from 412 to 533.

The measurement results from the MQ-135 gas sensor in different types of meat at five minutes after being grilled can be seen in Figure 19. According to the figure, the output of MQ-135 gas sensor in chicken meat detected five minutes after being grilled, as shown by the blue line, decreased from 362 to 243. As seen in red line, which indicates the result from pork, the measurement results also decreased from 328 to 209. Similarly, the green line indicating beef results decreased from 341 to 289. For comparison, the measurement results from the MQ-135 gas sensor in different types of meat at 7 minutes after being grilled can be seen in Figure 20.

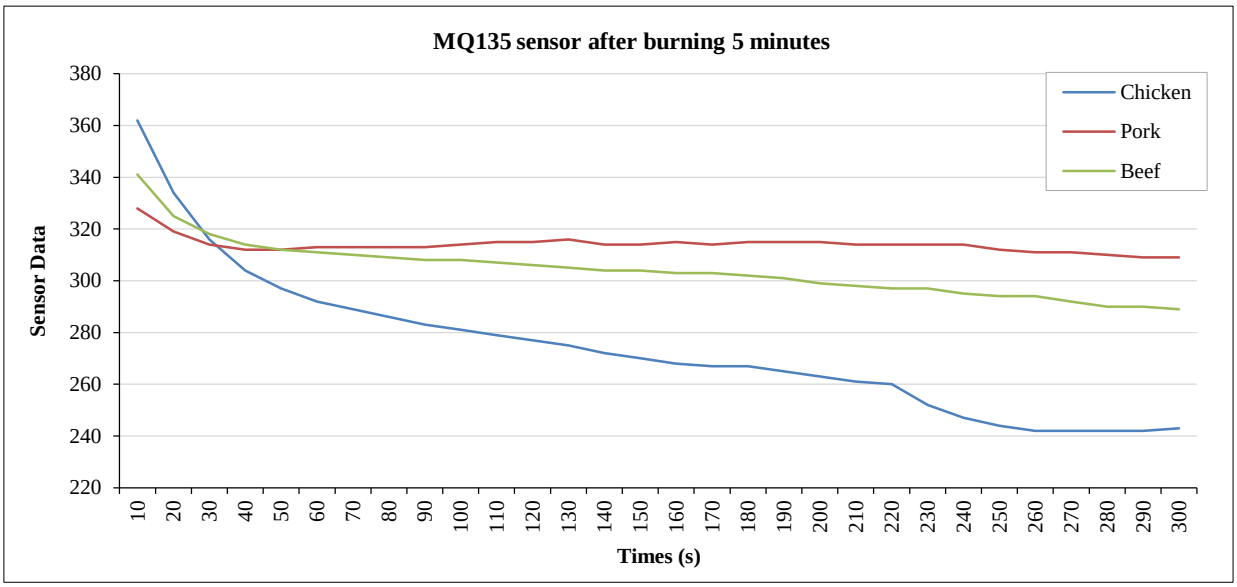


**Figure 19. Comparison of Gas Substance in Different Types of Meat based on MQ-135 Gas Sensor's Output at 5 Minutes after Grilling**

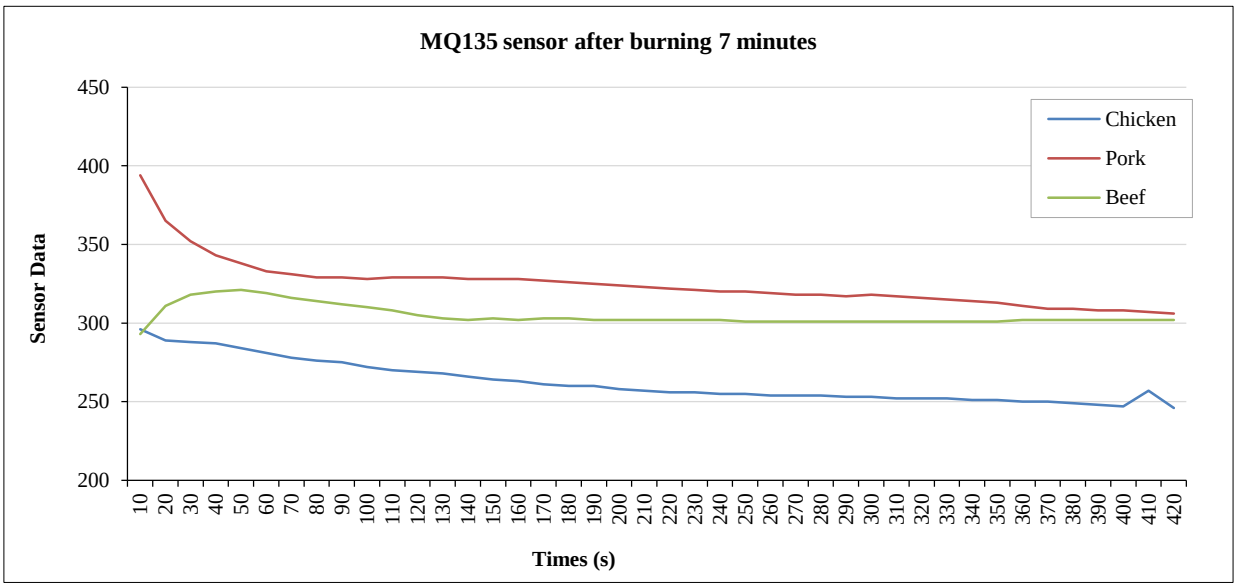


**Figure 20. Comparison of Gas Substance in Different Types of Meat based on MQ-135 Gas Sensor's Output at 7 Minutes after Grilling**

Based on Figure 20, the output of MQ-135 gas sensor in chicken meat detected seven minutes after being grilled, as shown by the blue line, decreased from 293 to 246. As seen in red line, which indicates the result from pork, the measurement results also decreased from 394 to 302. However, the green line indicating beef results increased slightly from 293 to 302. The MQ-136 gas sensor also detects another exhaust gas called hydrogen sulfide. Therefore, evaluations for MQ-136 gas sensor aim to identify the amount of hydrogen sulfide contained in different types of meat during grilling. The first measurement results for MQ-136 gas sensor, which was taken directly after the meat was grilled for five minutes, were shown in Figure 21.

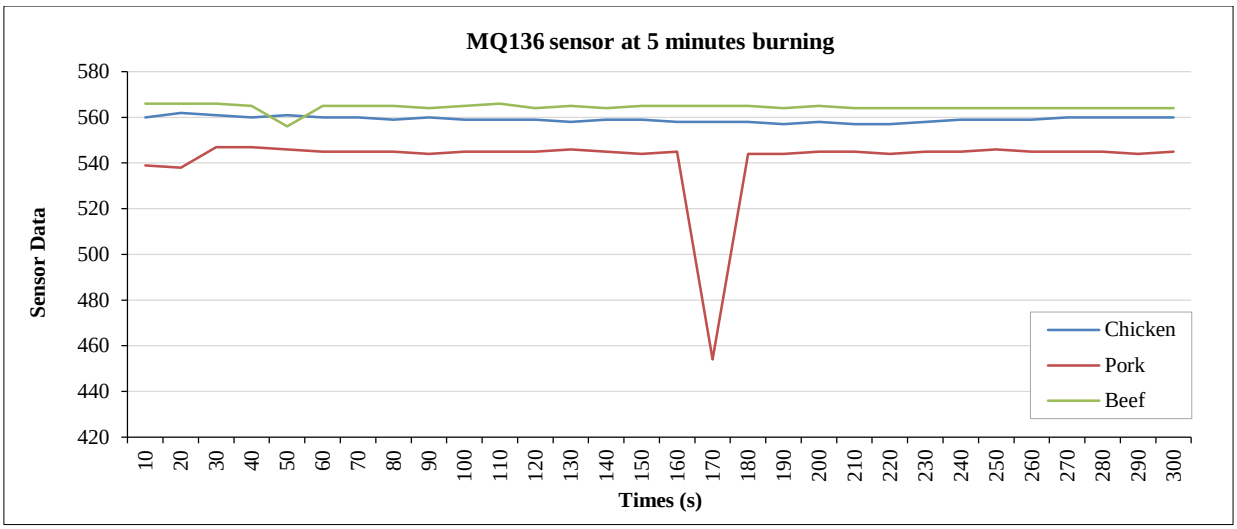


**Figure 21. Comparison of Gas Substance in Different Types of Meat based on MQ-136 Gas Sensor's Output at 5-minute Grilling**

According to Figure 21, hydrogen sulfide measurements in grilled chicken, beef, and pork were almost identical, with a flat-line tendency. Moreover, the values were almost identical to the first test of MQ-136 gas sensor's output without any meat to be grilled inside the tube container (Table 1). Due to this fact, the grilling process of chicken, pork, and beef can be said not to have gas substances that the MQ-136 gas sensor can detect. In addition, this finding was supported by the measurement results in grilled chicken, beef, and pork taken at five minutes and seven minutes after the grilling process, as shown in Figures 22 and 23, respectively.

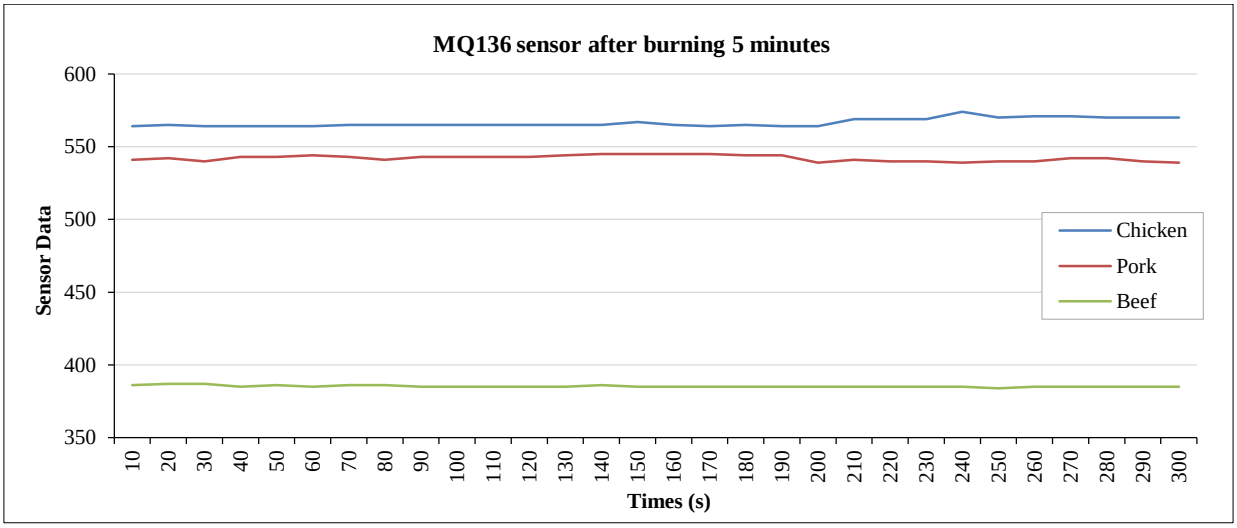


**Figure 22. Comparison of Gas Substance in Different Types of Meat based on MQ-136 Gas Sensor's Output at 5 Minutes after Grilling**

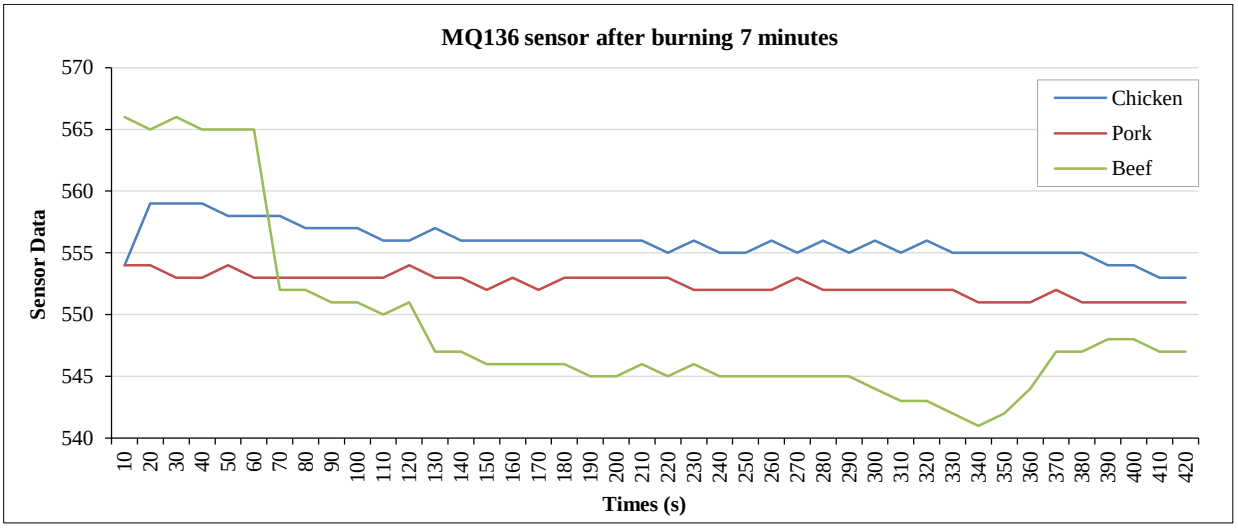


**Figure 23. Comparison of Gas Substance in Different Types of Meat based on MQ-136 Gas Sensor's Output at 7 Minutes after Grilling**

The MQ-137 gas sensor detects another exhaust gas known as ammonia. Thus, evaluations for the MQ-137 gas sensor were conducted to identify which type of meat had the highest amount of ammonia when grilled. The measurement results of the MQ-137 gas sensor in chicken meat, beef, and pork after being grilled for five minutes are shown in Figure 24.

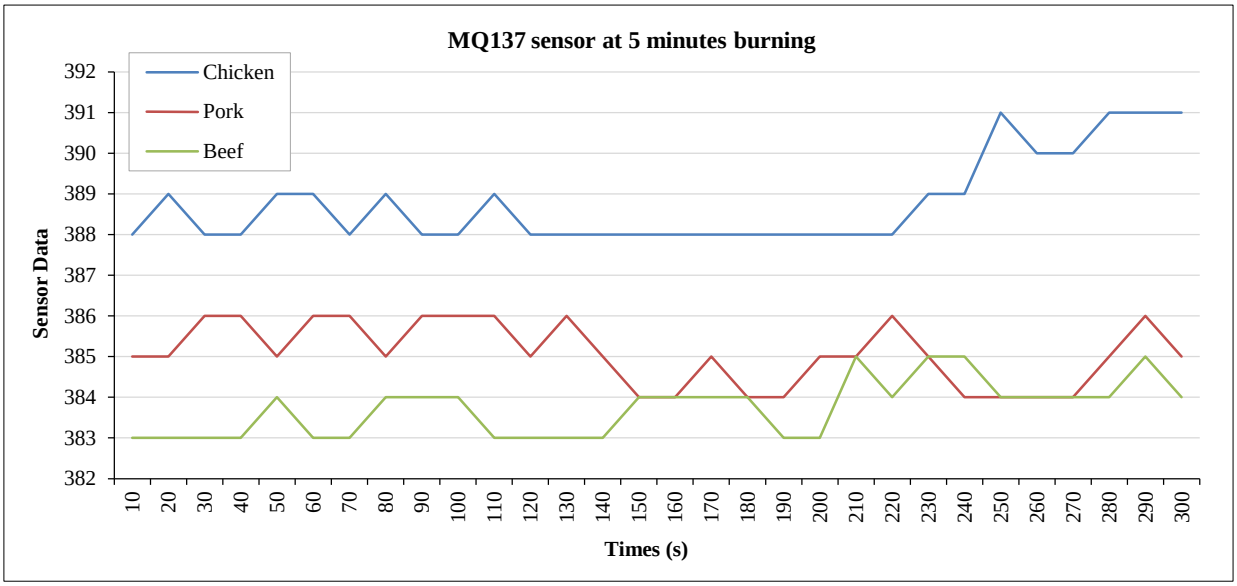


**Figure 24. Comparison of Gas Substance in Different Types of Meat based on MQ-137 Gas Sensor's Output at 5-minute Grilling**

The measurement results in Figure 24 interestingly show similar results to the measurement results of hydrogen sulfide by the MQ-136 gas sensor; the measurement results show insignificant change to the first test results without any meat being grilled inside the container (Table 1). In addition, this finding was supported by the measurement results in grilled chicken, beef, and pork taken at five minutes and seven minutes after the grilling process, as shown in Figure 22 and Figure 23, respectively. It can be seen more clearly in Figures 25 and 26 that the results tend to make a flat line. This means the grilled chicken, beef, and pork did not produce ammonia as exhaust gas.

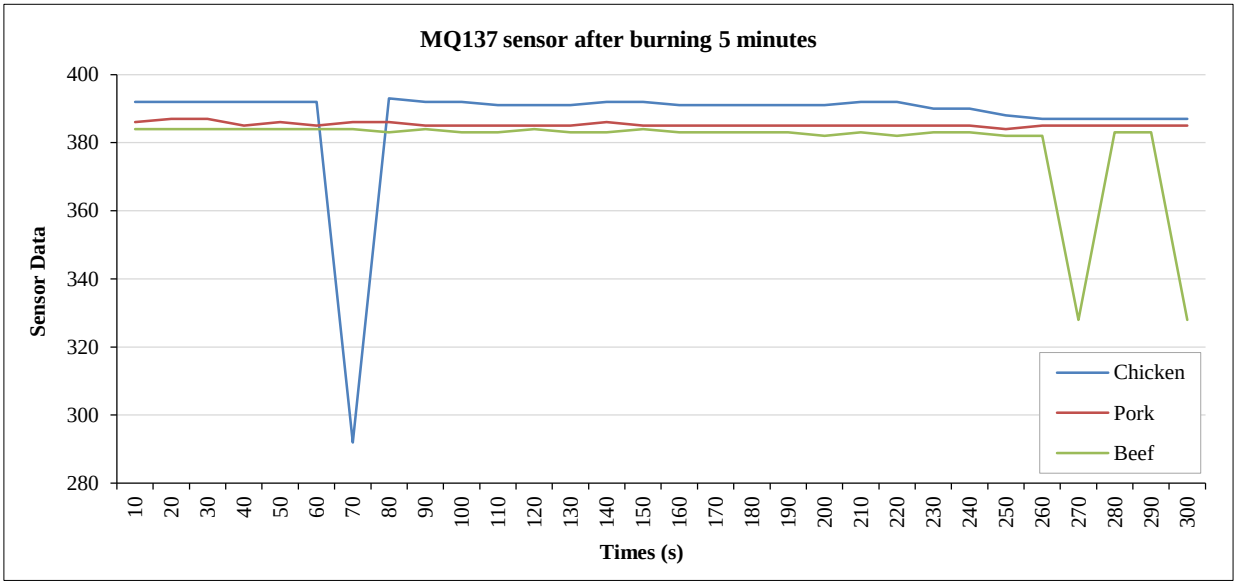


**Figure 25.Comparison of Gas Substance in Different Types of Meat based on MQ-137 Gas Sensor's Output at 5 Minutes after Grilling**

Based on the test results of MQ-2 gas sensor, the type of meat that has the highest to the lowest average LPG content, respectively, are: chicken meat (194), beef (192), and pork (176). However, the respective order always changes when measured after a particular period. Therefore, each type of meat has its own optimal waiting period after grilling for safe consumption. LPG or inflammable gas substances are commonly associated with PAHs, as LPG is considered one of the most popular combustion household fuels that are the major source of PAHs in indoor environments [44]. Meanwhile, PAHs are associated with cancer risk triggers [45]. Referring to Figure 6, the safest meat to be consumed directly after grilling is grilled chicken, followed by beef, and the most unsafe was grilled pork. This study finding aligns with study results by Rejeb et al. [31], that meat with higher fat content may contain more PAHs.

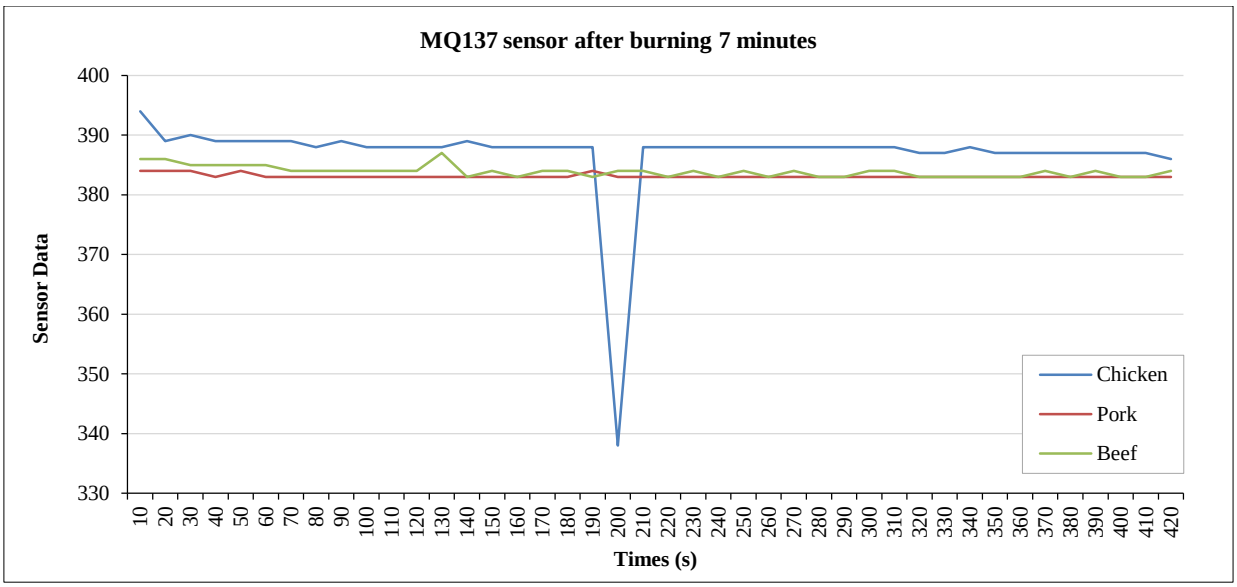


**Figure 26. Comparison of Gas Substance in Different Types of Meat based on MQ-137 Gas Sensor's Output at 7 Minutes after Grilling**

Regarding the alcoholic substances contained in the grilled meat, the highest alcoholic gas substance identified by the results of MQ-3 was found in pork (739), followed by chicken meat (737), and the lowest was found in beef (607). Most previous research found in the literature review only focused on detecting the formation of PAHs, and no investigation into the alcoholic content contained in grilled meat could be found. Another study was only focused on the cooking state of the meat and has not yet identified the ethanolic content contained in the cooked meat [29]. Whereas, investigating alcoholic gas substances in food is crucial, especially for Muslims, in making Islamic halal food certifications. According to the test results, the alcoholic content of the grilled chicken and beef increased even after a 5-minute grilling was performed. Thus, consuming grilled chicken and beef directly after grilling is considered unsafe for Muslims. Muslims are recommended to wait for at least seven minutes or more when consuming grilled chicken and meat so that the alcoholic content is thoroughly decreased.

Meanwhile, other air pollutants that could be detected in grilled chicken, beef, and pork were carbon monoxide, methane, and carbon dioxide. Ammonia, a food contaminant regulated in many countries, could not be found in all types of grilled meat in the research. According to Karim et al. [46], the ammonia content of frozen meat was found to be low even after high exposures. Therefore, the proposed prototype design could actually detect ammonia gas substances in grilled meat, but the grilled meat was not contaminated with ammonia gas substances. It could also explain why hydrogen sulfide could not be detected using the proposed prototype system design; it was simply because the grilled meat was not contaminated with hydrogen sulfide.

The highest carbon monoxide as exhaust gas based on test results of the MQ-7 gas sensor was found in grilled pork (444), followed by grilled chicken (347), and the lowest was found in grilled beef (340). The highest methane gas based on the test results of the MQ-9 gas sensor was found in grilled chicken (512), followed by beef (471), and pork (430). Based on the test results of the MQ-135 gas sensor, the highest carbon dioxide as exhaust gas was found in grilled chicken (562), followed by beef (541), and the lowest was found in pork (534).

## 4. Conclusion

According to the conducted experiment, the research successfully implemented new contributions of hardware engineering in the food industry by providing a novel gas substance detector and analyzer for grilled meat. Using the proposed prototype design, gas substances detected in grilled chicken, beef, and pork meat were inflammable substances (LPG), alcohol gas, carbon monoxide, methane, and carbon dioxide. Besides, it can be concluded, based on the research results, that consuming chicken and beef meat by direct grilling can be considered unsafe for Muslims due to the increased alcoholic content. It is suggested that Muslims wait at least seven minutes after direct grilling to consume grilled chicken and beef meat so that the alcoholic content will decrease thoroughly. This suggestion follows an appeal in Islamic views to consume only halal-certified foods.

Further investigations on detecting alcoholic substances in more types of meat, such as deer and other meat consumable by Muslims, are suggested. Moreover, since the prototype gas substance detector in meat can detect gas substances containing carbons and hydrogens, the prototype gas substance detector using MQ gas sensors proposed in the research may be utilized for other purposes in future research and investigations, such as: to differentiate types of meat contained in a grilled meatball; to distinguish the type of grilled meat or steak; or to detect grilled meat contaminated with ammonia.

## 5. Declarations

### 5.1. Author Contributions

Conceptualization, I.S.; methodology, I.S.; software, I.S.; validation, P.P. and A.M.; formal analysis, I.S.; investigation, I.S.; writing—original draft preparation, I.S.; writing—review and editing, P.P. and A.M.; visualization, P.P.; supervision, A.M. All authors have read and agreed to the published version of the manuscript.

### 5.2. Data Availability Statement

The data presented in this study are available in the article.

### 5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

### 5.4. Institutional Review Board Statement

Not applicable.

### 5.5. Informed Consent Statement

Not applicable.

### 5.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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