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Effect of Polyaniline/Graphene Oxide Thickness As A Gas Sensor Material for Robusta Coffee Aroma Tests

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ABSTRACT

The intricate aroma of coffee arises from a complex blend of volatile compounds, each characterized by distinct attributes and intensities. This study focuses on synthesizing and characterizing the PANI/GO composite. It explores the impact of sensor thickness, rooted in the PaNi/GO composite, on its responsiveness to coffee aroma. Moreover, the findings hold promise as a reference point for sensor development. The PANI/GO composite, doped with HCl, was synthesized using a chemical oxidative polymerization technique in an aqueous solution, employing ammonium persulfate (APS) as the oxidant. Functional group analysis was conducted on the synthesized PANI/GO composite via FTIR (Fourier Transform Infrared). Subsequently, the composite was employed to create a gas sensor with varying thicknesses—0.14, 0.21, 0.28, 0.35, and 0.44 mm. This PANI/GO gas sensor was evaluated using robusta coffee steam from the Sidomulyo region, with resistance measurements performed using a multimeter. The optimization process encompassed sensor conductivity, sensitivity, response time, and repeatability considerations. The most effective sensor thickness emerged as 'Sensor 4,' possessing a 0.35 mm thickness, showcasing a conductivity of 4.69 x 10^{-9} S/cm, sensitivity of 0.67, response time of 18 seconds, and repeatability of 2.10%. These outcomes hold significant implications for enhancing sensor design and performance, particularly in capturing intricate aromatic profiles such as coffee scents.

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INTRODUCTION

Sensors can convert chemical information into analytically proper signals [1]. A gas sensor is a tool that can measure or detect gas and then convert it into an electrical signal [2]. The working principle of gas sensors generally uses the chemoresistor principle, where the electrical conductivity of the sensor will change due to the influence of chemical elements from the gas hitting the sensor's surface [3]. Gas sensor technology that has been developed is solid-state sensors because they can detect several types of gas with good sensitivity, have a fast response, and are relatively cheap [4,5]. Solid-state semiconductor gas sensors can be fabricated using metal oxide materials in thin layers. SnO_2 thin film is the most widely used n-type semiconductor material as a primary material for gas sensors. Semiconductor gas sensors can be used to detect NO_2 [6], H_2 [7], and CO [8].

Besides having many advantages, semiconductor gas sensors also have a lack. Capone et al. [9] explained that the high water vapor content could affect the performance of semiconductor gas sensors.

This content resulted in a decrease in sensor sensitivity and stability. Water molecules interact on the sensor's surface, reducing gas sensor resistance so that it can interfere with gas measurement [10]. Another area for improvement of semiconductor gas sensors is that they are less selective and less stable at high temperatures, limiting their useful life [11]. Attempts made by researchers to improve the performance of gas sensors include developing conductive polymer-based gas sensors.

Conductive polymers can conduct electric current because it has conjugated double bonds whose electrons move around [12]. Gas sensors based on conductive polymers have been widely developed using various conductive polymer materials such as polyaniline (PANI), polypyrrole (PPy), and polyacetylene. This material is conductive, has high stability at room temperature, is easily synthesized, is easy to operate, and is relatively inexpensive [6].

Polyaniline is a conductive polymer with better properties than other conductive polymers. Polyaniline is a conjugated polymer whose conductivity can be adapted to specific applications through an acid doping process base [13]. Another advantage of polyaniline is its very high physical and chemical stability, and it is easily synthesized by chemical or electrochemical methods [14]. Polyaniline-based gas sensors can detect the presence of NH_3, H_2, HCl, NO_2, H_2S, CO, CO_2, SO_2, and volatile organic compounds [6]. In addition to gas-based sensors with conductive polymers, researchers are also developing graphene oxide-based gas sensors.

Graphene oxide is a two-dimensional nanosheet of carbon atoms covalently bonded and contains various oxygen functional groups in the ground plane and edges [15]. Oxygen-rich graphene oxide exhibits electronic properties, excellent electrical and mechanical properties with excellent flexibility, and a large surface area that makes it a material easily synthesized [16]. Graphene oxide is reported to be a promising sensor material based on these good electrical properties [17]. Gas sensors based on graphene oxide can be used to detect hydrogen gas [15] and NH_3 [18]. Efforts to improve the performance of gas sensors are then developed based on a combination of polyaniline/graphene oxide or gas sensors PANI/GO.

Much research has been done on the PANI/GO combination gas sensor. The study [19] discussed the synthesis of PANI/GO for detecting ammonia vapor and other volatile compounds at room temperature. The results obtained are that PANI/GO nanocomposite showed an excellent response to some organic vapors typically. Another study was also conducted. [15], discussing composites PANI/GO prepared by polymerizing aniline monomer with GO under acidic conditions as a methanol vapor sensor material. A PANI/GO composite was used as the vapor sensor methanol and compared with a pure PANI sensor. Sensor characteristics are monitored by measuring the change in electrical resistivity in methanol vapor with a concentration of different. The results obtained were that the presence of GO in the PANI/GO composite increases the sensor's sensitivity to methanol compared to the PANI sensor pure.

The thickness of the polymer on the gas sensor can affect the sensor's conductivity. It is said that by increasing the thickness of the film, the conductivity of the gas sensor will be increased. This conductivity is due to an increase in the number of conductors, specifically salt emeraldine [20,21]. Haberko *et al*. [22] have researched the conductivity of thin polyaniline polymer films. The range of film thicknesses used in the study was 0.05 μm to 10 μm. The result obtained is that the conductivity sensor increases with increasing film thickness.

Based on the description above, research on gas-based sensors was carried out on PANI/GO, which will be tested on water vapor, dry air, and robusta coffee steam. Coffee robusta from the Sidomulyo, Garahan, and Gumitir areas will be sampled for testing PANI/GO-based gas sensor feasibility. At several points within the plantations, coffee beans were sampled individually at each plantation and then mixed homogeneously. This study will use several variations of PANI/GO thickness. The selection of these variations aims to determine the effect of PANI/GO thickness as gas sensor material in the robusta coffee aroma test.

METHODS

1. *Synthesis of Graphene Oxide*

Regarding work by Chen et al. [18], the Hummers method was used to create graphene oxide. In a 250 mL beaker, 1 gram of graphite powder is dissolved in 23 mL of concentrated H_2SO_4. After that, the mixture was agitated for 30 minutes at a temperature below 20°C using a magnetic stirrer. The suspension was slowly given 3 grams of $KMnO_4$ while stirring, and the temperature was below 20ºC. The temperature was then raised to 40ºC after 15 minutes of stirring. The color of the mixture was changed from dark brown to yellow by adding 5 mL of 30% H_2O_2 and 150 mL of distilled water. An additional buchner funnel is used to filter the mixture. Three repetitions of washing were done using a 1:9 solution of distilled water and concentrated HCl (37%). After obtaining the GO residue, it was baked for 24 hours at 50 room temperature.

2. *Synthesis of PANI/GO*

The PANi/GO synthesis process was carried out by in-situ polymerizing aniline monomer in GO using ammonium persulfate (APS) as an oxidant. This synthesis uses modified research from Wu et al. [18]. 20 mL of 1 M HCl, 0.5 mL of aniline, and 0.2 grams of graphene oxide were combined with 80 mL of deionized water. Before polymerization, the solution was chilled in an ice bath (between 0 and 5 ºC) and agitated magnetically for 30 minutes. The cooled solution was topped off with 20 mL of a 1 M ammonium persulfate (APS) solution. The mixture was then stirred moderately for 15 hours at a temperature between 0 and 5 ºC. The resulting blackish-green precipitate was filtered and subjected to three rounds of washing with deionized water and technical hexane. The residue was then heated to 25°C for 24 hours in a vacuum oven to obtain PANi/GO composite in solid form.

3. *FTIR Characterization Test*

The functional groups and kinds of polyaniline bonds were compared before and after being produced using graphene oxide using Fourier Transform Infrared (FTIR) spectroscopy. Composites of polyaniline, graphite, graphene oxide, and PANI/GO will be investigated using FTIR. The 400–4000 cm^{-1} wavenumber range is employed.

4. *Manufacturing of PANI/GO Gas Sensors*

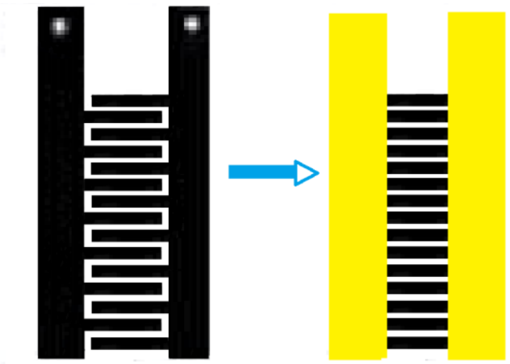

Figure 1. PCB before and after taping

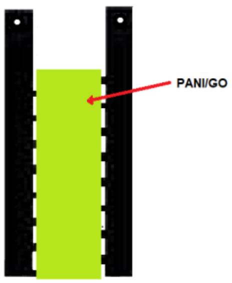

Figure 2. PCB Electrodes with PANI/GO Coating

Adding 3 mL of 96% ethanol and 7 mL of deionized water dissolved 0.02 grams of PANI/GO powder. The resulting mixture was then subjected to a 15-minute sonication. The PCB was exposed to the PANI/GO solution using the drip method. The PCB was cleaned for 10 minutes with methanol using deionized water, and then its sides were taped over, as illustrated in Figure 1. Figure 2 depicts how the center pattern of the PCB was entirely covered after several thickness variations of the PANI/GO solution were dripped on the PCB. The number of drops is used to vary the thickness of PANI/GO on the PCB. Variation: One drop, two drops, three drops, four drops, and five drops are utilized. The solvent was then evaporated from the coated PCB using a 50ºC oven. A coating thickness gauge (HW 300S) was then used to measure the thickness of the PANI/GO.

5. Analysis Method

The conductivity, sensitivity, response time, repeatability, and reproducibility of the PANI/GO sensor are used to determine its efficacy. Conductivity is a measure of a substance's capacity to conduct electric current. The conductivity of the sensor can be determined using the resistance value. Connecting the PANI/GO gas sensor to a multimeter and then measuring the sample resistance value with the multimeter is the method for measuring conductivity, as shown in Figure 3.

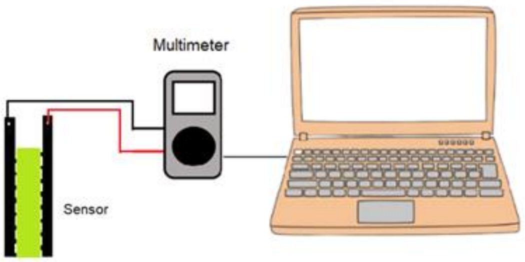

Figure 3. Resistance Measurement for The PANI/GO Sensor

The results were determined using Equation 1.

$$\sigma = \frac{l}{RA} \quad \text{...} \quad (1)$$

Where :

σ = Sensor conductivity value (1/Ω.m)
l = sensor length (m)
R = Sensor resistance value (Ω)
A = Sensor surface area (m2)

Sensitivity is an essential criterion for evaluating sensor performance, as it indicates the sensor's responsiveness to the measured quantity. Reproducibility is the ability of the sensor to produce the same output when given a fixed input without restarting the system. The reproducibility test is used to determine the consistency of the gas sensor performance. The PANI/GO gas sensor is used to test samples of robusta coffee that have been brewed. The sample repeatability test was carried out ten times a day, and the reproducibility test was repeated once a week for one month. The repeatability test method can be determined from the %RSD (Relative Standard Deviation) value.

6. Sensor Testing on Coffee Aroma

Figure 4 describes the design of a series of PANI/GO gas sensor testing tools on water vapor, coffee vapor, and dry air samples. The first test is steam water, which is used as a baseline. The second test is coffee steam, and the third is dry water. The brewed coffee is then placed in an acrylic canister covered with an acrylic lid. The PANI/GO gas sensor is mounted on an acrylic cover and connected to the UNI-T-UT 61E+ multimeter via a cable. Resistance value data can be displayed on a laptop/PC and then processed into a graph of the relationship between conductivity and time.

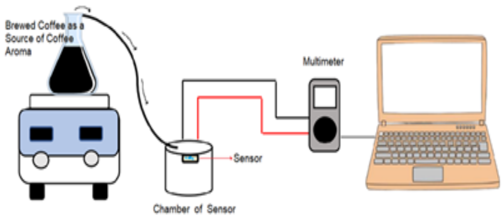

Figure 4. Depicts The Design of a Set of Sensor Testing Equipment

RESULTS AND DISCUSSION

1. Graphene Oxide and PANI/GO Synthesis Results.

Graphene oxide in this study was synthesized using the Hummers method from graphite powder with the help of H_2SO_4 and $KMnO_4$, which can turn graphite into graphite oxide. The result of the synthesis of graphene oxide is in the form of blackish-brown powder. H_2SO_4 solution accelerates the process of breaking bonds between layers of carbon. This bond is because graphite is composed of graphene sheets and has a strong bond structure. $KMnO_4$ solution serves to oxidize graphite so that inoculated graphite was obtained. This intercalation will cause the distance between the graphene layers to enlarge and the interaction between layers to weaken. The graphene oxide synthesis process with the Hummers method also uses distilled water and 30% H_2O_2, which works to stop the oxidation process. Hydrogen peroxide reduces residues of permanganate and manganese dioxide to a colorless solution of manganese sulfate, and the color will change from brownish-black to brownish-yellow [13].

PANI/GO in this study was synthesized using the oxidative polymerization method chemistry of aniline and graphene oxide monomers with the help of 1 M HCl as a dopant and Ammonium Persulfate (APS) oxidizing agent. Adding a dopant increases the conductivity value of PANI/GO. Hydrochloric acid will change the polyaniline inside the form of an emeraldine base (PANI-EB) into a conductive emeraldine salt (PANI-ES) [20]). Ammonium persulfate in the synthesis of PANI/GO acts as an agent oxidizer [18]. The result of the synthesis is in the form of a PANI/GO composite powder blackish green. The color change that occurs indicates that it has produced the PANI/GO composite. The color change occurs because of the shift of polyaniline in the form of an emeraldine base to become an emeraldine salt, which is marked with a color change from blue, which is the characteristic color of the final PANI-EB produces a blackish green color, which is the distinctive color of PANI-ES [21].

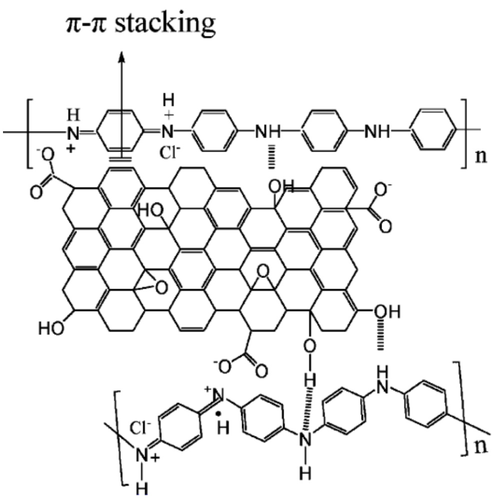

Figure 5. Interaction of Polyaniline with Graphene Oxide

Figure 5 shows the interaction between polyaniline and graphene oxide. Interaction PANI/GO can be divided into three main interactions: (a) π-π stacking, (b) electrostatic interactions, and (c) hydrogen bonds. GO can adsorb polar molecules in the gas phase via π–π interactions, causing a significant increase in the charge transfer resistance (Rct) of the electrode [23]. The interaction between PANI and Go has been reported by Mutalib et al. [24]. It is known that an increase in the amount of GO causes a decrease in the conductivity value up to 1.83×10^{-10} S/cm due to the weakening of the PANI-GO interaction, which affects the movement of electrons in the composite. Interaction between polar groups (polymer charge carriers) and oxygenated GO groups results in the possibility of ionic complex formation or coordination. Moreover, hydrogen bonds can form between amine groups in non-protonation with a hydroxyl hydrogen atom. It can also occur between clusters of epoxides and hydrogen atoms bonded to electrically charged nitrogen [22].

Analysis of PANI/GO Composite Functional Groups Using FTIR (Fourier Transform Infrared) Graphene oxide has been successfully synthesized from graphite monomers. It can be seen in Figure 6, which shows that there are differences in the FTIR absorption peaks produced from graphite and graphene oxide. FTIR GO spectra show broad and intense O–H absorption peaks at a wavelength of 3228.75 cm^{-1}. Absorption peak, the other is strong C=O stretching in the carboxylic acid group and the carbonyl group on wavelength 1716.00 cm^{-1}, aromatic C=C bond at a wavelength of 1619.50 cm^{-1}, the C–O–C peak at a wavelength of 1219.73 cm^{-1}. In addition, there is also a peak stretching C–O (alkoxy group) at a wavelength of 1044.87 cm^{-1}. Spectral analysis results FTIR of graphene oxide has similarities with the research of Konwer et al. [15].

Polyaniline has been successfully synthesized from aniline monomers. It can be seen in Figure 6, which shows that there are differences in the FTIR absorption peaks produced from aniline and polyaniline. The FTIR spectra of polyaniline show a characteristic peak at a wavelength of 3322.50 cm^{-1}, representing the absorption peak of the N–H stretching vibration of the leucoemeraldine component. The weak peak at a wavelength of 2895.87 cm^{-1} represents C–H stretching. The 1556.54 cm^{-1} and 1430.46 cm^{-1} peaks come from stretching C=C of the quinoid ring in emerald salts and the leucoemeraldine benzenoid ring. Peak the other is the C– N stretching of secondary aromatic amines at a wavelength of 1292.40 cm^{-1}, stretching C=N at a wavelength of 1189.46 cm^{-1}, and C–H bending of the plane at a wavelength of 694.76 cm^{-1}. The results of FTIR spectra analysis of polyaniline have similarities with Konwer et al. [15].

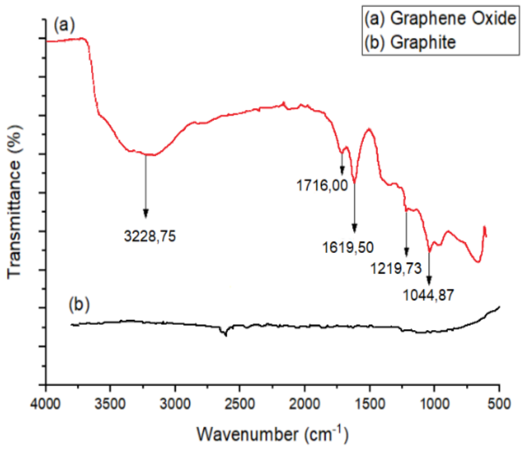

Figure 6. FTIR spectra of (a) Graphene Oxide and (b) Graphite

Figure 7 is the FTIR spectra of the PANI/GO, graphene oxide, and composites polyaniline. Based on Figure 8, it can be seen that in the FTIR spectra of the PANI/GO composite, its absorption peak is similar to PANI except for the characteristic peak of the O–H group at wavelength 3228.75 cm^{-1}, the C=O group at a wavelength of 1716.00 cm^{-1} and the C–O–C peak at a wavelength of 1219.73 cm^{-1}. The O–H group in the PANI/GO spectra decreased, or the peak was lower than in the GO spectra. This change is because the O–H groups on graphene oxide are hydrogen bonded to N on polyaniline, as shown in Figure 5. These events also cause stretching C–N (secondary aromatic amine) in the PANI/GO spectra was not formed. Absorption peaks at a wavelength of 1554.16 cm^{-1} and 1440.18 cm^{-1} represent the structure of quinoids and benzenoids from PANI in the PANI/GO composite. Based on these results, the presence of GO and PANI peaks has confirmed the formation of the PANI/GO composite, according to references from Konwer et al. [15].

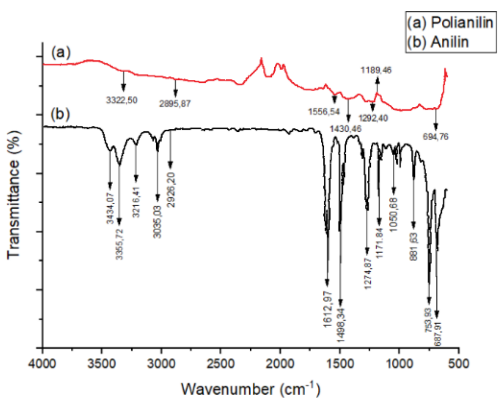

Figure 7. FTIR spectra of (a) Polyaniline and (b) Aniline

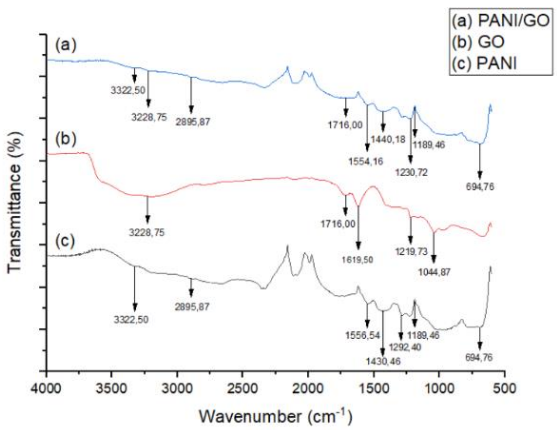

Figure 8. FTIR spectra (a) PANI/GO; (b) GOs; (c) PANI

The functional groups C-OH, C=O, O-C=O, C-N, and C=N, which have been identified using Fourier Transform Infrared (FTIR) characterization, play a crucial role in the chemical reactions occurring in graphene oxide (GO) and polyaniline (PANI) sheets. Functional groups significantly impact polar gas molecules' adsorption [25] produced during coffee brewing and are relevant to coffee scent analysis. The oxygen-containing functional groups present on the surface of graphene oxide (GO), which are formed by the oxidation process of graphene, serve as active sites for engaging with the gaseous molecules comprising the aromatic compounds found in coffee. The outcomes of this interaction will alter the conductivity measurement of the graphene oxide-polyaniline composite.

Optimization of the thickness of the PANI/GO gas sensor in terms of conductivity, sensitivity, response time, and repeatability in detecting robusta coffee vapor optimization of the thickness of the PANI/GO gas sensor can be viewed from the conductivity value, sensitivity response time and repeatability of gas sensors. The optimal thickness depends on the conductivity value, as this sensor operates on a resistive principle. The conductivity measurement is strongly linked to the resistance value, as these two quantities exhibit an inverse relationship. The optimal thickness is determined by the sensitivity, response time, and repeatability values to meet application-level sensor requirements. Variation of thickness used in this study using the number of drops. Variations of many drops are used to be precise 1 with successive thicknesses of 0.14, 0.21, 0.28, 0.35, and 0.44 mm. Determination of the optimum PANI/GO gas sensor with The first thickness variation is reviewed from its conductivity value. The conductivity value of five sensors with thickness variations can be seen in Figure 9.

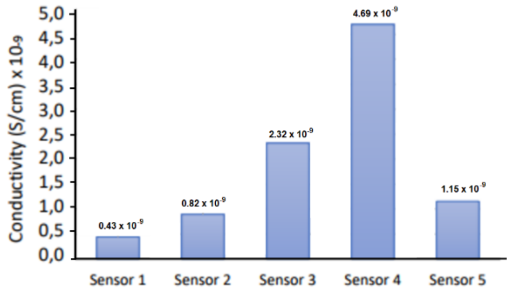

Figure 9. Graph of PANI/GO Gas Sensor Conductivity Values with Thickness Variations

Based on Figure 9, each sensor produces a value with different conductivity. Sensor 4, with a thickness of 0.35 mm, has a deal with the highest conductivity of 4.69x10^{-9} S/cm. This value is because The thickness of the polymer on the gas sensor can affect the sensor's conductivity. The greater the PANI/GO thickness value, the gas sensor conductivity value will increase. That matters due to an increase in the number of conductors, specifically emeraldine salts [26]. Haberko et al. [27] also explained that film thickness can affect value conductivity. This effect can be said regarding PCB drying time during processing coatings. Sensors with a higher film thickness have a more extended in-time formation of larger and more organized PANI domains, increasing the possibility of transfer of charge carriers between macromolecules in the higher domain and film conductivity. PANI/GO gas sensor conductivity decreased thickness by

0.44 mm (sensor 5). This value is because the thicker the PANI/GO gas sensor, the more density increases, causing less gas to be adsorbed into the sensor, and consequently, the value of the resulting conductivity decreases [28]. This result is also supported by data sensor response time, as shown in Figure 10. Based on time data response, sensor 5, besides having a long response time, also has low conductivity. This time indicates that the amount of gas (analyte) adsorbed into the sensor slightly.

Determination of the optimum PANI/GO gas sensor with the second thickness variation in sensitivity value. The sensitivity values of the five sensors can be seen in Figure 10.

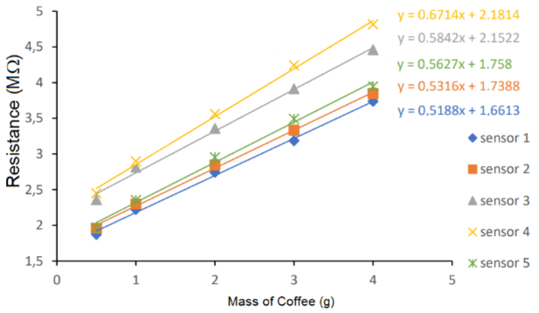

Figure 10. Sensitivity of PANI/GO Gas Sensors with Thickness Variations

Based on Figure 9, each sensor increases coffee mass, increasing the sensor resistance value. This value is because more and more as the mass of coffee increases, the resistance of the resulting coffee vapor decreases, so the difference between the average water vapor resistance and the moderate coffee vapor resistance increases. The results obtained are under research conducted by Albert et al. [29], which states that gas concentration is inversely proportional to the resistance sensor; if the gas concentration increases, the sensor resistance will decrease so that the conductivity will increase. The result of the sensitivity value of the five sensors shows that sensor 4 has the highest sensitivity value of 0.67. Based on these results, the thicker the gas sensor PANI/GO, the more significant the sensitivity value. This value is due to the composite PANI/GO containing OH groups. These results follow the literature by Safitri [30], which said that the thicker the film, the more OH groups play a role in the absorption of coffee vapor, affecting the sensor sensitivity.

Determination of the optimum PANI/GO gas sensor with the third thickness variation regarding its speed in response to coffee steam. The response time results of the five sensors can be seen in Figure 11.

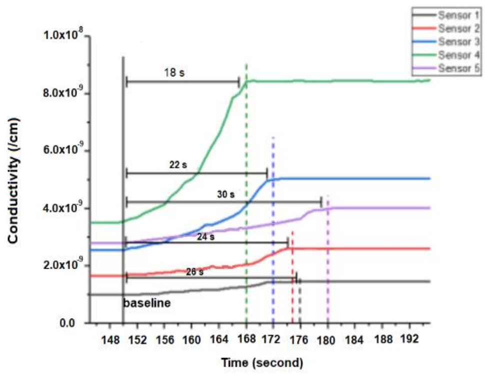

Figure 11. Response Time of PANI/GO Gas Sensors with Thickness Variations

The response time results of the five sensors with variations in PANI/GO thickness can be seen in that sensor four responds faster to coffee steam than the other sensors. Sensor 4 rose at 151 seconds and stabilized at 168 seconds, so it can be concluded that sensor four response time is 18 seconds. Ulfa's literature [31] says that the smaller the value of the sensor's response time, the better the quality of the sensor.

Determination of the optimum PANI/GO gas sensor with the last thickness variation regarding repeatability value (% RSD). The repeatability value of the five sensors can be seen in Table 1.

Table 1. Repeatability Values of PANI/GO Gas Sensors with Thickness Variations in Coffee Sidomulyo.

Type of sensor	Conductivity Value (S/cm)	RSD Value (%)
Sensors 1	4.37×10^{-10}	2.46
Sensors 2	8.92×10^{-10}	2.89
Sensors 3	2.32×10^{-9}	2,28
Sensors 4	4.69×10^{-9}	2,10
Sensors 5	1.15×10^{-9}	3,14

Based on Table 1, it can be seen that the %RSD (repeatability) values of the five sensors gas are below 5%. This value shows that the measurement results have a good level of precision. These results follow the references of Chen et al. [32], who state that the measurement has a good level of precision if it has a sensor reproducibility value of less than 5%. Sensor 4 has the most minuscule %RSD value, equal to 2.10%. Based on these results, it can be said that sensor 4 is a sensor optimum.

2. Characterisation of Optimum PANI/GO Gas Sensors for Coffee Variations from Plantations different

The optimum PANI/GO gas sensor is then characterized using coffee from different plantation areas, such as Sidomulyo, Garahan, and Gumitir. Characterization of optimum gas sensor PANI/GO regarding repeatability and reproducibility. Repeatability tests the closeness of each measurement result repetition, while reproducibility is used to determine the consistency of performance gas sensors. The sample repeatability test was carried out with ten repetitions of measurements daily, and the reproducibility test was repeated once a week for one month. Results of the repeatability and reproducibility tests of the PANI/GO optimum gas sensor coffee plantations in the Sidomulyo, Garahan, and Gumitir areas can be seen in Figure 12.

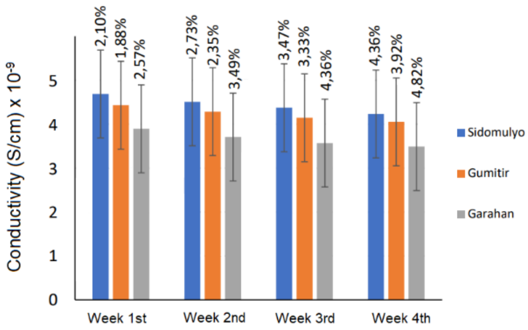

Figure 12. Optimum PANI/GO Gas Sensor Repeatability and Reproducibility Values at Different Coffee Variations During 1 Month of Measurement

Based on the data in Figure 12 regarding the conductivity value in the different areas, each coffee sample has another conductivity value. The difference in the conductivity values produced by the aroma of coffee is due to the additional content and the quantity of volatile compounds released by each coffee sample. Coffee from the Sidomulyo area has the highest conductivity value compared to the Garahan and Gumitir regions. The next characteristic test is repeatability and reproducibility values. The repeatability value was generated from the three types of coffee, including Sidomulyo coffee by 2.10%, Garahan coffee by 2.57%, and Gumitir coffee by 1.88%. Reproducibility values were generated from the three types of coffee in week 2 four: Sidomulyo coffee by 4.36%, Garahan coffee by 4.82%, and Gumitir coffee by 3.92%. Based on the data in Figure 12, it can be concluded that from the first week to the fourth week, the %RSD values of the three types of coffee experienced an increase. This value is because the performance of the PANI/GO gas sensor decreases with time increasing usage time. The intense interaction between the PANI/Go sensor and water is assumed to be causing the decline in sensor performance. Water molecules remain bonded to the sensor's surface after flushing with dry air. As a result, the sensor conductivity value tends to drop. However, the performance of the PANI/GO gas sensor is still good said to be good because it has an %RSD value below 5%. It shows that measurement results have a good level of precision. These results are under reference to Cheng et al. [28], which states that the measurement has a level of precision that is good if it has a sensor reproducibility value of less than 5%.

3. Optimum Consistency of PANI/GO Gas Sensor Preparation given Conductivity Values and Repeatability

The consistency of the optimum PANI/GO gas sensor performance can be seen in this way, repeating the manufacture of optimum PANI/GO gas sensors with a thickness of 0.35 mm. The optimal replication PANI/GO gas sensor is then measured by value conductivity and repeatability in coffee from the Sidomulyo area with a mass of 3 grams. The results of the measurements can be seen in Table 2.

Table 2. Conductivity values and %RSD values from the optimum PANI/GO Gas Sensor on Sidomulyo Coffee

Repetition	Conductivity Value (S/cm)	RSD Value (%)
1	$4{,}75\text{x}10^{-9}$	2,17
2	$4{,}82\ \text{x}10^{-9}$	2,11
3	$4{,}72\ \text{x}10^{-9}$	2,10

The optimum PANI/GO gas sensor has a conductivity value of 4.69 x 10^{-9} S/cm and a repeatability of 2.10%. Based on the data obtained from measurements of the optimum repeated PANI/GO gas sensors, it can be concluded that the replicated sensor 1, replicated sensor 2, and replicated sensor 3 have a conductivity value and %RSD value, which are not much different from the optimum PANI/GO gas sensor. To improve the consistency of performance in the preparation of this sensor, improved PANi/GO nanomaterials/nanocomposites, as well as appropriate casting and spinning processes, must be addressed. The use of nanocomposites improves PANI-Sensor compatibility, which improves the homogeneity of the sensor construction.

Testing the performance of the PANi/GO gas sensor on coffee aroma has given good results with conductivity, repeatability, and reproducibility parameters. This sensor does not have high selectivity for certain compounds that are contributing components of coffee aroma. This sensor responds to all compounds that are polar. So, this sensor cannot be used as a single sensor that only responds to one particular compound. Because this sensor can respond quickly to polar compounds, this sensor has a great opportunity to be developed towards making sensor arrays that can be used to detect coffee aromas in electronic nose devices.

CONCLUSION

The conclusion obtained from this study is that the optimum thickness of the PANI/GO gas sensor obtained is sensor 4, with a thickness of 0.35 mm, a conductivity value of 4.69 x 10^{-9} S/cm, a sensitivity of 0.67, a response time of 18 seconds and repeatability of 2.10%. The optimum PANI/GO gas sensor can respond to coffee vapor from coffee plantations in Sidomulyo, Garahan, and Gumitir areas with different conductivity values for each coffee. The optimum repeatability and reproducibility values of the PANI/GO gas sensors obtained are in the range of 2.10% - 4.82%, which indicates that the gas sensor performance is good and the measurement results have a good level of precision because the %RSD value is still below 5%.

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