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Original Article

Alcohol Sensing Device using Glass Substrates Coated with Agarose Gel and HEC/PVDF Nanomaterial

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Abstract - *This paper reported the development of an alcohol sensor based on a glass substrate platform. The glass substrate was coated with two nanomaterial types: Hydroxyethylcellulose/Polyvinylidene fluoride (HEC/PVDF) and Agarose Gel, for comparison purposes. Three layers of coating material have been applied to the glass substrate to obtain the optimum sensing response. The coated glass substrate is kept dry for 24 hours before expose to variations of ethanol concentration to investigate the sensing response. A significant response to alcohol concentrations has been observed for both samples due to the changeable refractive index layer of the coating material. The sensitivity improved by a factor of 1.18 and 1.51, respectively, compared to the bared glass. The proposed sensor employed low-cost and commercially available components such as a glass substrate, LED light source and Arduino microcontroller to perform as an alcohol sensor. It prevents using expensive laser-based sensors, which is less practical in real industrial applications. Based on the experiment results, the HEC/PVDF-coated glass produced has demonstrated better results in terms of repeatability, hysteresis, stability and sensitivity as compared to agarose gel-coated glass. Hence the proposed sensor has a decent potential as an alcohol sensor.*

Keywords - *Alcohol sensor, Glass substrate, HEC/PVDF, Agarose gel.*

1. Introduction

More than 18.5 million adults in the United States are affected by alcoholism, making it the most commonly misused drug in the world. This leads to a loss of productivity as well as health, criminal, and other expenditures associated with alcoholism. Alcohol-related diseases account for more than twenty percent of all hospital admissions and less than one hundred thousand deaths annually in the United States [1, 2]. The Department of Forensic Science at Kuala Lumpur Hospital recorded 710 traffic-related fatalities between 2006 and 2009.

Researchers found that nearly a quarter (23.3%) of all drivers involved in fatal accidents tested positive for alcohol, another 11% tested positive for drugs, and 2.3% tested positive for a drug-alcohol combination. According to Ministry of Interior statistics, from 2010 to 2015, a total of 1,035 traffic accidents involving alcohol were reported, resulting in 618 deaths. According to research reports on driving under the influence of drugs or alcohol (DUI) in February 2015, 16.7% of drivers tested positive for alcohol (Kuala Lumpur), and 167 deaths occurred [3]. In order to diagnose high-risk drinking and alcohol-induced tissue damage, there is an urgent and unmet demand for the development of effective diagnostic tools.

Ethanol concentration in the blood is the most objective and straightforward approach for confirming its presence in a suspect. However, the limited specificity and very short detection window make ethanol itself a less accurate marker for diagnosing and monitoring long-term physiological and behavioural effects [4]. As ethanol can also be discovered in body fluids carrying sugar exposed to diabetes bacteria, it is not a reliable test for fluids other than blood. [5].

The ideal marker in various body fluids, not just blood, should be sensitive, accurate, and have a wide detection window. The biochemical markers ethyl glucuronide (EtG) and ethyl sulphate (EtS) for detecting alcohol have become increasingly popular in recent years. Due to the recent increase in EtG research and testing, reliable tests for evaluating new medications or therapeutic treatments for alcohol problems utilising biochemical indicators are necessary. According to the findings of a breath alcohol detector, the average amount of ethanol that is exhaled after drinking is 0.7% of the total amount of ethanol that was consumed. On the other hand, an additional 0.1% of the ethanol that is consumed is carried by the sweat to the surface of the skin, where it is then expelled from the body.

Other ethanol storage pathways in the blood include cytosolic enzyme oxidation, alcohol dehydrogenase and aldehyde dehydrogenase, and much less microsomal CYP2E1. Minor ethanol metabolites, ethyl glucuronide (EtG) and, more recently, ethyl sulphate (EtS), formed by conjugation pathways, have recently been studied as well-characterized markers of ethanol exposure and its pharmacokinetics. EtG is a minor alcohol metabolite formed in the liver when alcohol interacts with glucuronic acid, a product that aids in substance detoxification. [6, 7].

The amounts of ions and biomolecules can be monitored by using nanomaterial [35]. This is not the same as the conventional way, and there is no requirement for an elaborate system to run the system. Nanomaterial sensors are of the utmost importance when it comes to monitoring analytes in real-time. There are a few distinct varieties of the sensor. Among them is how the optical characteristics of biosensors and nanoparticles shift depending on the polymeric aggregate [9, 10]. Besides, a chemical sensor can detect changes in optical absorbance in gas atmospheres [11, 12].

The sensitivity of the humidity sensor, demonstrated by changes in wavelength well detected, is made of cobalt oxide sheets [12]. UV-Vis spectrophotometers are used to analyse ZnO for its optical characteristics like transmittance, absorbance, and refractive index [13-15]. ZnO-coated POF has improved performance, which is accomplished by measuring the amount of power transferred using a power metre [15]. As a result of this research, it has been established that the power output increases as the alcohol concentration does. In the process of DNA electrophoresis, agarose gel is frequently utilised. It is not only affordable and very simple to apply, but it has also been discovered to be a stable solvent that is insoluble in water. It possesses a chemically inert characteristic. It does this by soaking up water from its surroundings, which eventually causes a shift in the refractive index.

The capillary action and the humidity of the environment both result from the admission of water [16]. Agarose's high sensitivity and porosity make it an excellent material for humidity sensors. The hydrophilic nature of the gel in the polymer causes a shift in the refractive index, causing light to be transmitted through the fibre. The sensitivity will be affected by the pore size, typically around 100 nm, and the amount of agarose present [17]. For increased sensitivity, hydroxyethylcellulose (HEC) is combined with plastic optical fibre. As a probe, the sensor is manufactured. The improved sensor response directly results from the HEC's ability to raise relative humidity and modify light propagation because HEC coatings improve humidity resonance [18, 36].

There are numerous issues with the present optical alcohol sensor. The first issue is the transmission of light through the sensor zone of the glass substrate, which causes transmission losses that influence the output voltage. It is necessary to adjust the number of layers coated on the glass substrate to obtain the optimal output voltage. Due to the modest refractive index difference, the sensing sensitivity of uncoated glass substrates is quite minimal [20, 21].

To improve the sensor response, the glass substrate will be coated with a material that can increase the result along with a higher refractive index, such as Hydroxy ethyl cellulose/ Polyvinylidene Fluoride (HEC/PVDF) and Agarose Gel [22-25]. However, in terms of device setup, the sensor of modern devices has a sophisticated hardware design that may result in higher production costs due to its complexity. Thus, it is necessary to use low-cost, commercially available components to make low-cost sensors. In order to lower the cost of development, the light source for the proposed sensor is a Light Emitting Diode (LED).

LED is used to configure chemical sensors in devices, with a focus on transmittance absorption metric measurements [26]. LEDs have a long lifespan, require little maintenance, and can run autonomously. Since there is a growing concern for people's health and the environment, this is the most appropriate method to employ. The system sensitivity in LIF detection is lower than in other methods. Using brighter LEDs and photodiodes with greater sensitivity is proposed as a solution [37].

LEDs offer a number of benefits that are not normally associated with their use, including laser and laser-induced fluorescence (LIF). LEDs were first put into widespread usage as a response to the problems caused by everyday products. Many different kinds of detection systems can be utilised for analytical applications, particularly portable devices that are CE-certified (capillary electrophoresis). So, the purpose of this work is to produce an alcohol sensor that can be made at a low cost by using a glass substrate platform that has been coated with hydroxyethyl cellulose / polyvinylidene fluoride (HEC/PVDF) and agarose gel for use in ethanol sensing applications. This strategy has been shown to be effective for the very first time, to the best of our knowledge.

2. Literature Review

The goal of this study is to detect alcohol concentration rather than to detect different types of alcohol. Data analysis like optimization of coated-layer count, hysteresis, repeatability, stability, and Time Response will be performed to determine the connection between variables. An optical sensor is a device that measures light and turns that measurement into an electrical signal for use in electronic devices. One type of optical sensor is plastic optical fibre (POF). Alcohol concentration can be measured optically using POF [28].

The three variants include a tapered U-shape, a polished U-shape, and a polished coil as part of the shape the shape generated by indirectly heating sensor probes to 80 degrees Celsius. The use of plastic optic fibre (POF) for optical measurement has many benefits, including being inexpensive, requiring little maintenance, and not requiring an electric interface. Even water has a tendency to absorb the polymer network and cause the fibres to swell due to volume expansion, making this POF particularly sensitive.

The range of its sensitivity is 0.02% to 0.10% [29]. This small-diameter sensor head can be used for optical detection of alcohol concentration in the beverage of people's choice. In the brewing industry, it is indispensable. This polymer also responds to a leaking mechanism, including methanol [30, 31]. Methanol is much more likely to be discovered than ethanol because ethanol represents the sole standard or antidote used in alcoholic beverage detection. Thus, portable technologies with routine analysis that may be used by paramedics have been developed to replace the most expensive products. For accurate results, an alcohol sensor requires a specific humidity and temperature range. Preheating an existing sensor 24 hours before use is required to achieve the baseline [32]. According to the findings of this research, the resulting output an increase as the alcohol concentration rises. To optically characterize and then optimize the number of layers that have been coated. This is done to determine whether or not there is an impact of any kind on the output voltage results that are produced.

3. Experimental Setup

The specialized vantage point of the base is utilized in assembling the glass substrate and the covering of the Arduino Nano. The length of this casing was intended to be 65 mm, while the width was determined to be 45 mm based on the calculations. The body of the sensor device was fashioned out of material produced by a 3D printer. The program known as Fusion 360 was used to develop the design of the sensor's casing. The experimental setup used in this study is depicted in Figure 1. Fifty-degree angle is used when inserting the LED into the holder for LEDs. The photodiode is permanently attached in place within the photodiode holder.

A photodiode is a specific kind of light detector that, subject to how the device is set up to function, can transform light into either current or voltage. Optical filters, built-in lenses, and surface areas are all included in this. The sample holder is integrated with the glass substrate. After everything has been configured, the Arduino is linked to the computer using the Arduino IDE software's USB port to run the code for the output voltage results. The platform known as Arduino is one that is flexible, open-source, inexpensive, and easy to program [33]. Agarose gel and HEC/PVDF must also be put on the glass substrate for the best sensing performance in the application. Coating materials are put through their paces, and output voltage readings are recorded. Results and analyses of coating materials will be elaborated upon in the discussion section. The coated layer on the glass substrate is shown in Figure 2.

3.1. Synthesis Process

This work has chosen two coating materials: Agarose Gel and HEC/PVDF. Those coated solvents are applied on the glass substrate for three layers and kept to dry for 24 hours the steps to synthesise agarose gel start by mixing 0.1gm agarose powder with 10 ml distilled water. The substance was heated to 50ºC and continuously stirred at a speed of 130 revolutions per minute (rpm) until all of the components had dissolved. A minuscule portion of the mixture was left on the tapered glass region as a deposition. Then, the glass was left to dry for a day [34]. HEC/PVDF was made by dissolving 1 gramme of PVDF powder (Mw = 275,000) in 120 millilitres of dimethylformamide (DMF) at 90ºC in a water bath for five hours, or until the powder was completely dissolved (using a hot plate with 50 rpm). Following cooling the PVDF solution to room temperature, 4 g of hydroxyethyl cellulose (HEC) was added to the solution. The mixed solution was constantly agitated (100 rpm) at room temperature for around 10 hours to achieve a homogenous solution. On the glass substrate, barely a portion of the mixture was coated. Then, the glass was left to dry for a day [24, 25]. The coated glass substrate is connected to the LED light source at one edge of the glass, and another edge is connected to the photodetector for output voltage analysis.

4. Results and Discussion

Figure 3 shows the repeatability of the agarose gel-coated glass with respect to the variation in ethanol concentration. It can be seen from the figure that the sample shows quite accurate results for every trial. Most of the readings show similar results over the entire concentration range. While Figure 4 shows the repeatability results of the HEC/PVDF coated glass surface with respect to the variation of ethanol concentration. It can be observed that the agarose gel-coated glass produces more accurate and precise results as compared to HEC/PVDF-coated glass. Nevertheless, the results are still acceptable because the deviation of the readings is still allowable.

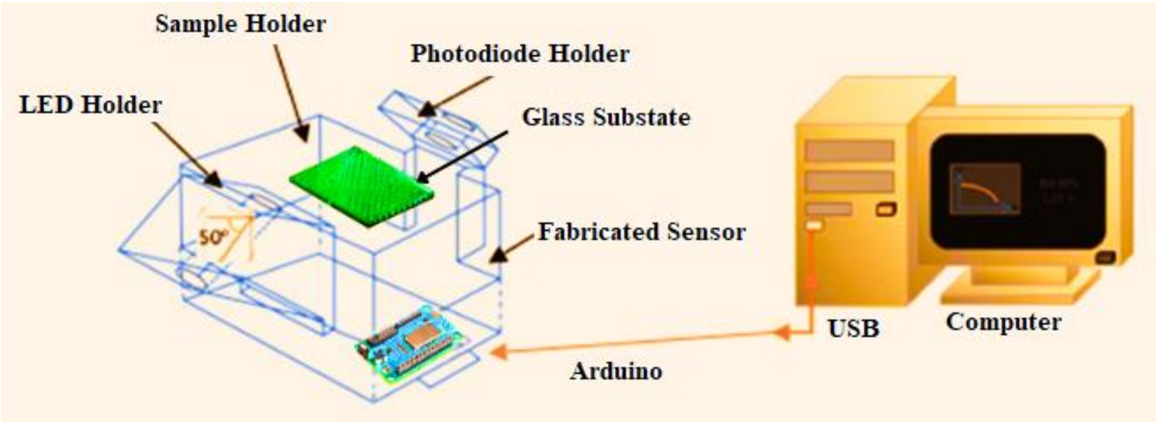

Fig. 1 Experiment setup

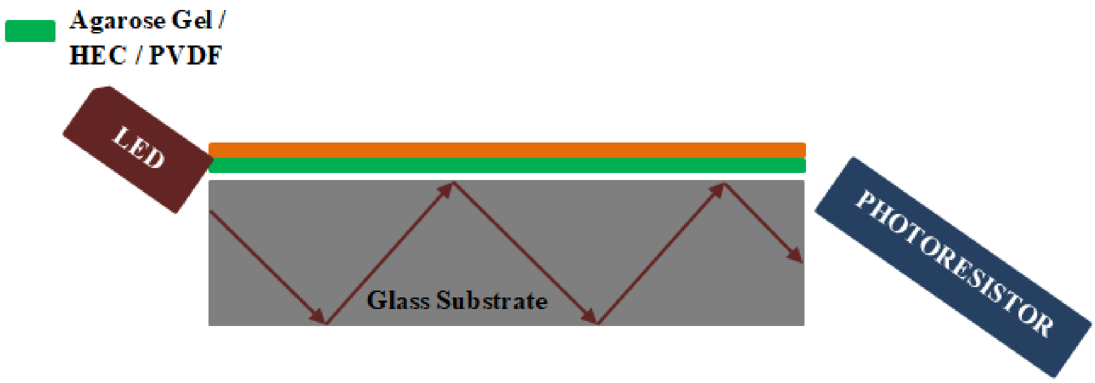

Fig. 2 Coated layer on the glass substrate

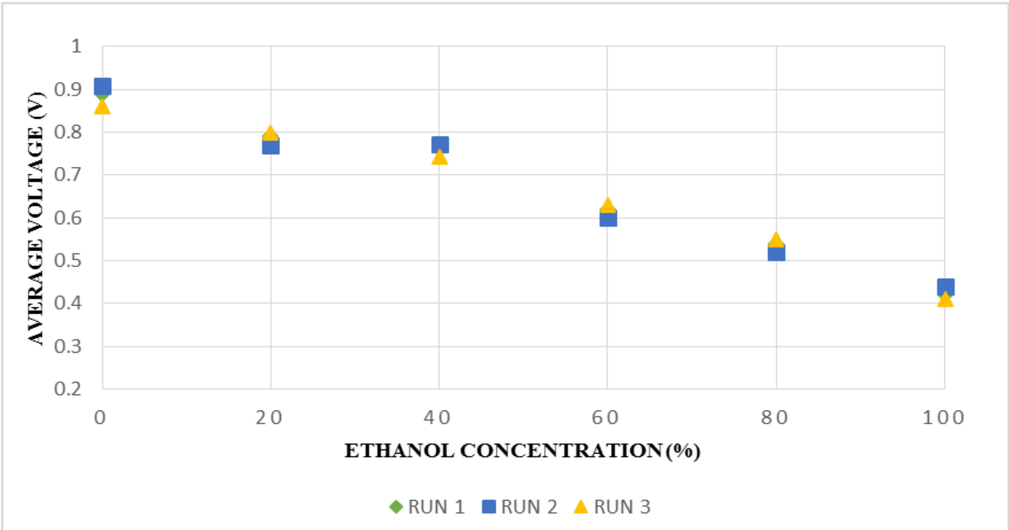

Fig. 3 Repeatability results of Agarose Gel coated glass

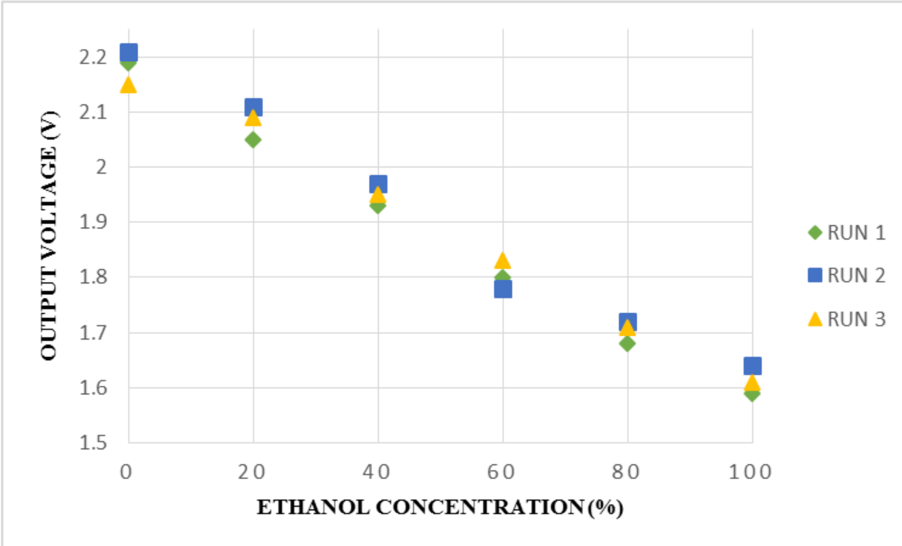

Fig. 4 Repeatability results of HEC/PVDF coated glass

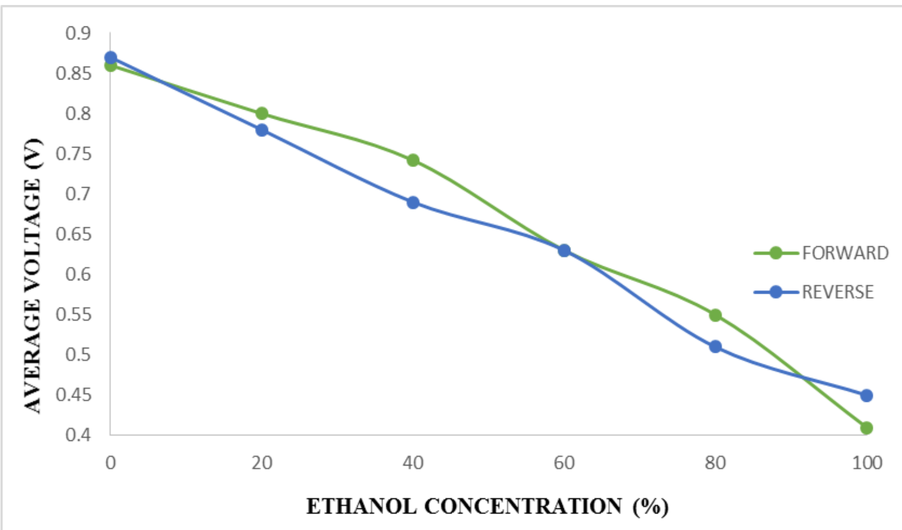

Fig. 5 Hysteresis of ethanol on the coated surface with Agarose Gel

Figure 5 shows the hysteresis performance of agarose gel-coated glass. It can be measured by recording the output voltage when running a forward and reverse test. It can be seen that the sample produces quite a large output voltage difference, especially at concentrations levels of 40%, 80% and 100%. Whereas for HEC/PVDF coated glass substrate, the output voltage does not have much difference between forward and reverse tests, as shown in Figure 6. Both forward and reverse output voltage has very small output difference. This shows that the HEC-coated glass exhibits more consistent hysteresis behavior during forward and reverse measurements, and the trend line patterns are quite similar.

Figure 7 shows the output voltage obtained during the 10 minutes stability test for five different ethanol concentrations for Agarose gel-coated glass. The stability test was performed to determine the most accurate value for the mean of the output voltage and to detect the differences in the output voltage for each second. The graph shows that the sample produces evidence amount of noise and distortion throughout the 600 seconds of exposure to different concentration levels.

While Figure 8 shows the output voltage of the HEC-coated glass substrate during the 10-minute stability test. Compared to Agarose gel-coated glass, the stability for the output voltage of the HEC-coated glass shows the least distortion. The stability of the transmitted signal for the HEC-coated glass surface improved greatly over the entire 600 s period compared to the agarose gel-coated surface.

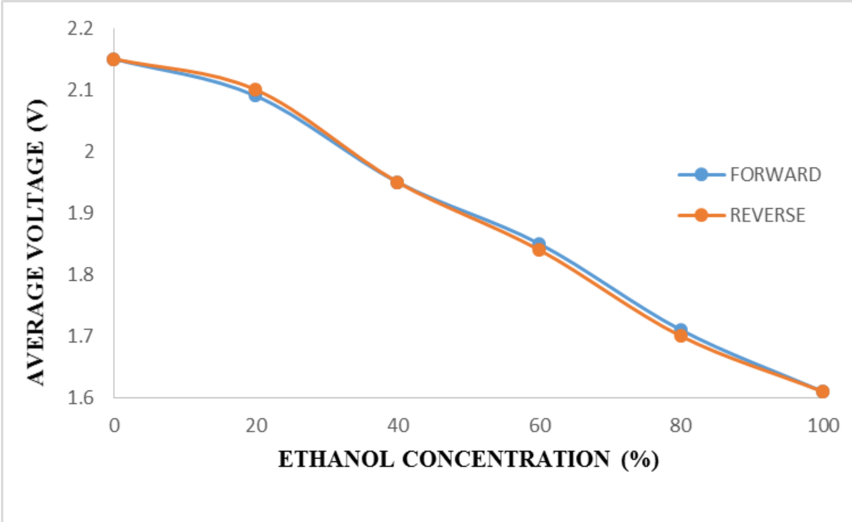

Fig. 6 Shows the hysteresis of ethanol on the coated surface with HEC

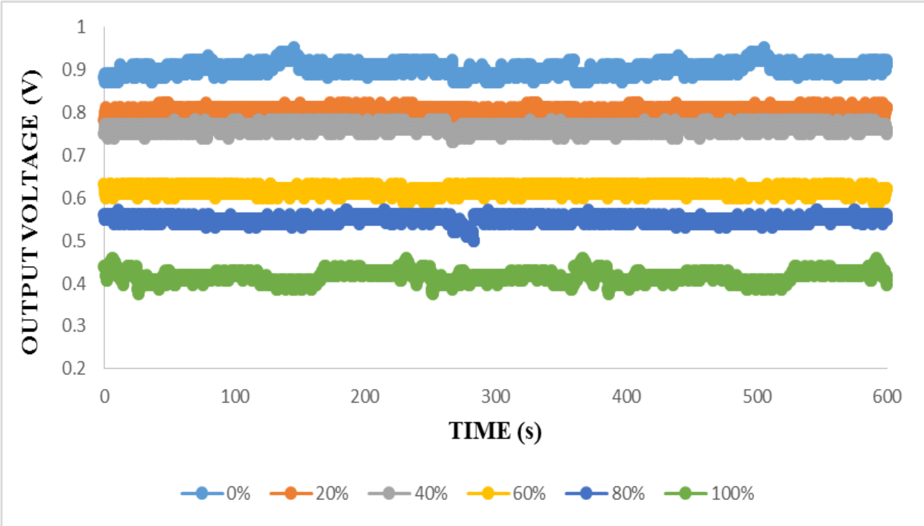

Fig. 7 The stability of agarose gel-coated glass sample

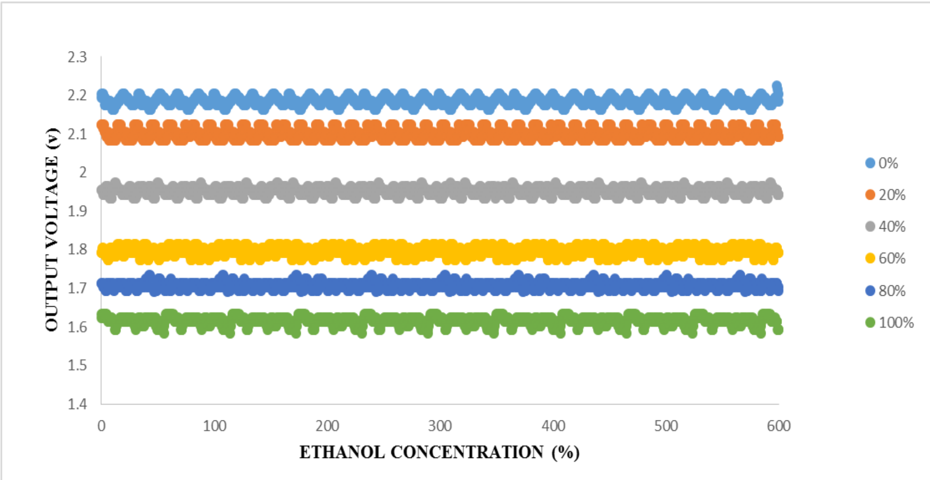

Fig. 8 The stability of HEC/PVDF coated glass sample

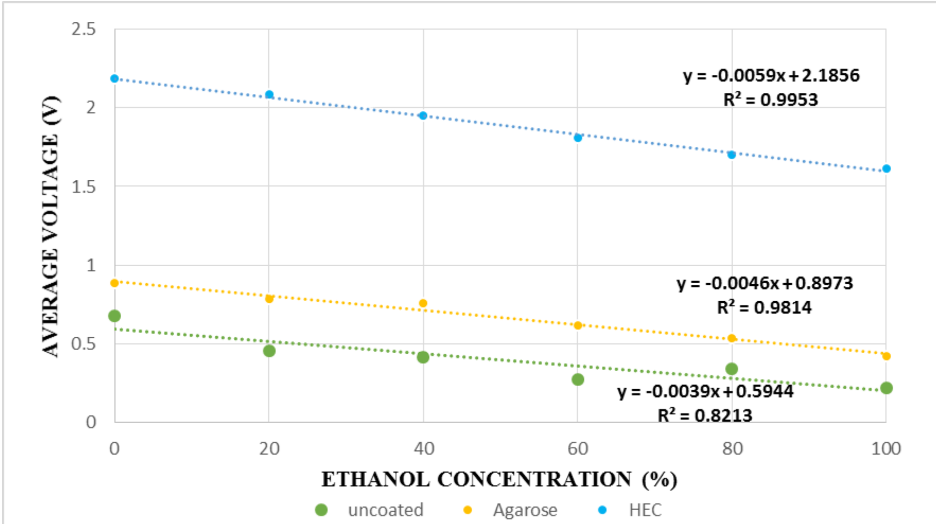

Fig. 9 Trend line graph of the uncoated glass, agarose gel-coated glass and HEC/PVDF coated glass samples

Figure 9 shows the data obtained for the uncoated glass substrate, glass substrate coated with agarose gel and glass substrate coated with HEC/PVDF. The output voltage shows that HEC-coated glass samples have the highest output voltage at 2.18V compared to the agarose gel and uncoated glass substrate. The trend line plot of all three samples during the forward measurement shows that the output voltage decreased proportionally when the alcohol concentration level increased.

The sensitivity of the HEC/PVDF-coated glass was the highest. At the same time, the uncoated glass produces the lowest sensitivity value. This aligned with the theory that different light interactions would be exhibited with the variation of the refractive index of the coating material. The highest refractive index contrast between the coating layer and the surround analyst would lead to the improvement of sensing response. It is noteworthy to mention that the refractive index of the HEC/PDF coating material is the largest among the other two samples.

5. Conclusion

This work utilizes low-cost and commercially available components such as green LED as a light source, Arduino microcontroller as a data acquisition system, and photodetector as a data receiver. Based on the analysed results, it has been observed that HEC/PVDF coated glass substrate produce the best results for alcohol sensing. The sensitivity for HEC/PVDF is 0.0059 V/%, followed by Agarose Gel with 0.0046 V/% and uncoated with 0.0039 V/%. Besides that, the HEC/PVDF exhibit the highest linearity of 99.67%, producing the most accurate output voltage measurement for repeatability. It also exhibits the most stable response and has small output voltage differences (Δv) occurring during forward and reverse measurements. This is due to the increase in alcohol concentration (%) would increase the effective refractive index of the HEC/PVDF coated glass, which allows more light to pass through the sensing region. It can be concluded that the proposed sensor provides a stable and efficient alcohol detector with numerous advantages, such as simple design and low production cost

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