The design of a PC-based real-time system for monitoring Methane and Oxygen concentration in biogas production

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Abstract. Limited fossil fuels nowadays trigger the development of alternative energy, one of which is biogas. Biogas is one type of bioenergy in the form of fermented gases of organic materials such as animal waste. The components of gases present in biogas and affect the biogas production are various, such as methane and oxygen. The biogas utilization will be more optimal if both gases concentration (in this case is methane and oxygen concentration) can be monitored. Therefore, this research focused on designing the monitoring system of methane and oxygen concentration in biogas production in real-time. The results showed that the instrument system was capable of monitoring and recording the data of gases (methane and oxygen) concentration in biogas production in every second.

1. Introduction

Energy has been a part of daily human life. Almost all sectors in human life require energy. Fossil fuels are the main source of energy that is widely utilized to meet their needs. Unfortunately, the human necessity for energy, especially fossil fuels, creates other problems. The increment in energy necessity is not followed by the fossil fuels reserves. Fossil fuels, just like another non-renewable energy, have a limit number of reserves. Furthermore, fossil fuels cause greenhouse-gas emissions. Based on this situation, a series of alternative energy development has been conducted.

A review by Adelekan in 2012 [1] said that Brazil and US had used ethanol as a biofuel alternative to gasoline since 2008. The review also said that several researchers had improved alternative energy production from various organic sources such as biogas from pretreated water hyacinth by Ofoefule et al [2], biogas from cassava peels mixed with poultry, piggy, and cattle wastes types by Adelekan and Bamgboye [3], and biogas from the peels of sweet potato and wild cocoyam by Adeyosoye et al [4].

According to the review, biogas is one of the most widely developed alternative energy sources and categorized as renewable energy. Biogas is a versatile renewable energy source, which can be used as a substitute for fossil fuels to generate power and heat, and it can be used also as gaseous vehicle fuel. Biogas production through anaerobic digestion process offers significant advantages over other forms of alternative energy production. Fehrenbach et al in Weiland stated that biogas is one of the most energy-efficient and environmentally friendly technology for alternative energy production. By making use of locally available resources, it is able to reduce greenhouse gases emissions dramatically compared to fossil fuels [5]. Biogas is a flammable gas comprised of organic wastes. Biogas mostly contains...
methane about 54-70%, carbon dioxide (20-30%), oxygen (0.1%), nitrogen (0.5-3%), and hydrogen sulfide (less than 1%) [6]. Methane gas –the main component in biogas- has a heat value between 4800-6700 kcal/m³, meanwhile pure methane gas has a more great heat value around 8900 kcal/m³ [7]. Daru in Roosganda and Rusdiana [8] also revealed that compared to coal gas and water gas, biogas has higher heat value. One m³ of biogas is equal to 0.5 kg of liquid petroleum gas (LPG) and able to generate electricity around 1,25-1,50 kWh. This fact makes biogas can be utilized as alternative energy.

Biogas is produced through a process called anaerobic digestion. The process of anaerobic digestion is carried out by methanogen bacteria under the oxygen-depleted condition to produce a large amount of methane gas. If the conditions are less appropriate or inappropriate, the methanogen bacteria will not work optimally or even die. The optimum condition in biogas production process will determine the maximum production of biogas. One of those optimum conditions in biogas production process is the concentration of oxygen available in the biogas reactor. The existence of oxygen concentration in a biogas production process will obstruct methanogen bacteria [9].

However, the concentration of methane as a result of anaerobic digestion and also the concentration of oxygen as a factor that contributed to methane production cannot be known for sure. The estimation of oxygen concentration in material for biogas is needed to know if there is an oxygen methanogenic inhibition appears during the production without removing oxygen in the initial process [9]. To find out whether the biogas production is already optimum or not, a real-time monitoring system is needed to monitor it. Monitoring is an important strategy to achieve a better stability and higher conversion efficiencies in the anaerobic digestion process. The less suitable process indicators/conditions can affect the optimization of biogas production process (anaerobic digestion) [9].

The monitoring system is an instrument system or an instrument device that intertwined and serves as a means of measuring and collecting the data of a certain object. In this research, the instrument system consisted of gas sensors system and a data acquisition system which was able to carry out a real-time monitoring of methane and oxygen concentration in biogas production.

2. Materials and Methods

In general, the real-time monitoring system built in this research consisted of the biogas and the data acquisition system (Figure 1).

![Figure 1. Block diagram of the instrument system in this research.](image)

The procedure of the PC-based real-time system for monitoring the concentration of methane and oxygen gases in biogas process production is shown in Figure 2 below. The methane and oxygen concentration were detected by the gas sensors system then being interpreted by the data acquisition devices to be presented on PC.
2.1. Biogas Production
The biogas produced in this research was made on a laboratory scale as illustrated in Figure 3. The biogas was produced by mixing the cow dung with an amount of water. The mixture composition had a ratio of 1:1 and should be mixed well. The mixture was then placed into an 8 dm$^3$ biogas reactor or biogas digester connected to an airtight container before it connected to a 6 dm$^3$ gas reservoir. The biogas reactor serves to accommodate the mixture of cow dung and water as well as in the process of fermentation by bacteria in anaerobic (anaerobic digestion). Whilst, the gas reservoir is to gather the resulted gas/biogas.

![Figure 3. Illustration of biogas production.](image)

2.2. The Data Acquisition System (DAS)
A data acquisition system (DAS) can be defined as a system that serves to retrieve, collect, and prepare data, to process it into the desired data [6]. Data acquisition system consists of a number of elements or components that are interconnected with each other formed in such a way that the system is able to retrieve, collect and store data quickly, accurately, and in real-time so that the data is ready for further processing [7].

A data acquisition system usually consists of a sensor or transducer, data acquisition devices, and a personal computer (PC). The figure below (Figure 4) shows the data acquisition system applied in this research.
The sensors system used in the research is gas sensors. The gas sensors detected the existence of methane and oxygen gases then transmitted them to data acquisition devices before continuing the data to the PC. The PC functioned to record, interpret, and display the information which retrieved from the data acquisition devices. The data acquisition devices converted the analog signal, produced by the gas sensors system attached to the measured objects, to its digital signal then relaying it to the PC.

2.2.1. The Gas Sensors System
The gas sensor system used TGS 2611 as methane gas sensor and KE-50 as oxygen gas sensor. TGS 2611 is a metal oxide semiconductor gas sensor which used PdO₂ as its sensing element. TGS 2611 requires two input voltage, heater voltage, and circuit voltage. KE-50 is a galvanic-cell type gas sensor. Compared to TGS 2611, KE-50 requires no heater voltage. Both TGS 2611 and KE-50 data output are still in the form of the analog data, therefore an analog-to-digital converter (ADC) is required. TGS 2611 has measurement range between 500-10000 ppm, while KE-50 has a measurement range from 0% to 100%. Note that this sensor system must be calibrated to obtain a comparable data as a conversion reference of sensor output unit.

2.2.2. Data Acquisition Devices
Generally, data acquisition devices consist of a signal conditioning and an analog-to-digital converter (ADC). Signal conditioning is a device works to condition the sensor output signal to be read by signal processing elements or an analog-to-digital converter. Although there were two gas sensors that were applied in the instrument system, the signal conditioning used in the data acquisition devices was non-inverting amplifier only. Both methane gas sensor –TGS 2611- and oxygen gas sensor -KE-50- used the ADC inside the AVR ATMEGA 8 microcontroller. Here, the microcontroller would process the input data, namely methane and oxygen level, derived from the measurement by the gas sensors system. After processing both methane and oxygen level, the microcontroller relayed them to the PC.

2.3. The PC-Based Real-Time System
A real-time system is a system that capable to produce an appropriate response in specific time arrangement. A real-time system is possible to send data to the computer centre, process the received data in the computer centre and then send them back to the sender at that time [11].
3. Results and Discussion

The first stage in this study was producing biogas in laboratory scale, then continued by monitoring the concentration of methane and oxygen in biogas production. The monitoring system would be held in real-time to find out whether the production process had already optimum or not.

3.1. Biogas Production

As mentioned before in the introduction part, besides methane, biogas also contains a little hydrogen sulfide. Even though the amount of hydrogen sulfide is just little, this gas is corrosive. If there is corrosion during the production, the biogas will stop producing. Therefore, the selection of materials used for biogas reactor and gas reservoir plays an important role. This study used glass material as the biogas reactor and plastic material as the gas reservoir to prevent corrosion occurred.

3.2. Data Acquisition in Gas Sensors System

Biogas production is the most commonly monitored indicator because it represents the overall process performance and can be measured by some sensor [10]. In this study, the methane gas sensor was put into the gas reservoir because according to the theory, biogas mostly contains methane gas. Meanwhile, the oxygen gas sensor was placed inside the biogas reactor to know whether there is leakage inside the reactor or not. Figure 6 below illustrates the data acquisition in gas sensors system.

Figure 5. Flowchart of PC-based real-time system.

Figure 5 depicts a flowchart of the PC-based real-time system in this study. If the data acquisition devices are in the ready state, the devices will transfer the information they get to the PC. Later, the PC would display and perform the data recording. On the contrary, if the data acquisition devices are not in the ready condition then the devices will return to their original condition i.e. START.
3.3. The PC-Based Real-Time System

A real-time system is a data communication with speed and accuracy. The necessity for information has to be fulfilled in recent time or the same treatise immediately [6]. In this system, the process is performed in a matter of a few seconds only. Therefore, it takes a fast-communication path and fast-processing system, as well as a huge memory and storage system.

Methane and oxygen concentration data -detected by the gas sensors system- were forwarded to the computer (PC) by a serial communication in turn after being processed by the microcontroller. The data sent earlier was then received by computer serial receiver and displayed on the screen in real-time. In addition to being displayed on computer screen, the measured methane and oxygen concentration data were also stored in the database.

The PC-based real-time system in this study comprised of three main pages, among others: the user page, main-monitoring page, and searching page. This monitoring system utilized Delphi as its data viewer software of methane and oxygen gas concentration in biogas production. User-friendly design for the beginner programmer, own a large number of components, also the resulting application is quite complex and realistic are the reasons behind the selection of Delphi as data viewer software. In addition, Delphi has a fast compilation speed making it easier to modify the software also it has the ease of creating User Interface [12, 13]. Before entering the main monitoring page, the user would meet the user page as the initial display in the PC-based real-time system. Meanwhile, Figure 7 presents the main-monitoring page in the instrument system. The main-monitoring page would begin to show and record the concentration of methane and oxygen gases detected along with the measurement time if we clicked the ‘START’ button.
The searching page (Figure 8) contained the record of measured physical parameters (methane and oxygen concentration) on specific dates. The measurement data recording was divided into two types namely graph and table, whereas each type was displayed on different tabs.
The two figures above (Figure 9 and 10) depict methane and oxygen concentration found on the 13th day of biogas production. As seen in Figure 9, the level of methane concentration has a drastic increase trend. According to Putri et al. [14], the increase in biogas production occurs on day 4 to day 25. Putri et al. [14] also stated that the ratio of cow dung to water namely 1:1 makes the methane production becomes inconstant because the water level is not comparable with the level of cow manure in the biogas reactor. Meanwhile, Figure 10 depicts stability of oxygen concentration in biogas reactor. Although the oxygen existence in biogas reactor was detected, it did not affect the methane concentration.

4. Conclusions
The instrument system built in this research had the capability to record and display the methane and oxygen gases concentration of biogas production based on the real-time system. This PC-based real-time system used Delphi as monitoring software, and there were three main pages in its appearance menu.

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