Automation of temperature sensor in biogas production from palm oil mill effluent (POME)

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Abstract. The purpose of this research is to obtain the monitoring system and temperature data recording a system based on National Instruments USB-6001 and to obtain a Human Machine Interface (HMI) which is suitable for monitoring the temperature process of the conversion POME into biogas on a laboratory scale using LabVIEW software. This study was conducted by two stages, hardware design and software design. In hardware design, a stirred tank and a PC were connected to the microcontroller hardware National Instruments USB-6001. The software design was consisted of the LabVIEW programming. The results indicated that the components were suitable for the monitoring process of the conversion POME were the National Instrument USB - 6001, series TC module to DC and 5 volt power source, as well as a temperature sensor used is a thermocouple type K. For HMI design using LabVIEW 2014 was in accordance with the needs with the graphic display of temperature conditions in real time from a stirred tank and the data logger was automatically stored in the Microsoft Excel. After completion of the design of HMI, thermocouple that is used is calibrated to obtained a linear equations of analog data versus temperature data from a digital thermometer so that the equation to be inputted into the program LabVIEW block diagram which was $y = 0.0064x + 0.2217$ with $R^2$ value was 0.993. Afterward, the research was continued using a set point 55 °C with a variation of hysteresis 1, 3, and 5°C. Data was obtained from this study then to be calculated the standard error values to compare the data generated from every variation of hysteresis. The results indicated that the best data on research was the data obtained using hysteresis 1°C from the set point temperature compared with the data on the hysteresis 3 and 5°C.

1. Introduction
The palm oil industry produces palm oil mill effluent (POME) in very large quantities. The use of water in very large quantities, which is about 1.5 m$^3$ consumed in the process of each ton of fresh fruit bunches and almost half of it is converted into POME [1]. Fresh POME is a brown, viscous colloidal compound containing 95 – 96% water, 4 - 5% of total solids, including 2 – 4% suspended solids, and 0.6 - 0.7% of oils and fats, at temperatures of 80 - 90 °C, and acidic [2]. POME contains amino acids, and inorganic compounds (Na, K, Ca, Mg, Mn, Fe, Zn, Cu, Co, and Cd), fibres, nitrogen compounds, free organic acids, and carbohydrates [3]. Characteristic of fresh POME can be seen in Table 1.
Anaerobic process is the most common type of process used in palm oil mill to produce biogas from palm oil mill effluent (POME). This process is a fairly complex and unstable process [4], due to the high concentration of organic compounds in the inlet feed [5]. This increase in the concentration of organic compounds may cause reaction instability in the reactor [6,7], which directly affects the production of biogas [8,9]. Increasing the result of POME conversion process into biogas is highly dependent on monitoring. Wolf, et al mentioned that computer-based monitoring can increase the conversion of POME to biogas by up to 20% compared to manual monitoring [4].

Anaerobic treatment is a degradation process of organic compounds in the absence of oxygen, with enzymatic and bacterial activity producing biogas that can be used as a renewable energy source, which has a final conversion product of POME in the form of biogas, with main components of CH₄ and CO₂ with a ratio of 65:35, the rest of the gas being hydrogen sulphide (H₂S), and nitrogen gas (N₂) with such a small value that it can be ignored so that it is almost undetectable. Using this anaerobic digester process, about 28 m³ of gas (a mixture of CH₄ and CO₂) is produced from 1 ton of POME [11, 12].

One example of equipment for surveillance of operating conditions, especially for data collection is the National Instrument, specifically the type of USB-6001. National Instrument USB-6001 can be applied on an industrial scale, such as process automation, machine automation, and production lines [10]. The choice of National Instrument USB-6001 in this study was caused by the excess of this microcontroller compared with that used by previous researchers, which is capable of receiving program input (programmable input). Some common problems that need to be solved in this research are how to apply National Instrument microcontroller USB-6001 as data center of acquisition and how to monitor of POME conversion process temperature into biogas on laboratory scale, how to know precision reading from National microcontroller Instrument USB-6001, how to build Human Machine Interface (HMI) suitable for monitoring the temperature of POME conversion process into biogas on laboratory scale.

The use of good control, and optimization of biogas production can offer economically suitable and feasible solutions to improve process productivity and ensure the stability of operating conditions [5]. One example of equipment for surveillance of operating conditions, especially for data collection is the National Instrument, specifically the type of USB-6001.

National Instruments USB is a tool that has high quality in measurement with very simple usage, built using the latest hardware and software. National Instrument USB-6001 can be applied on an industrial scale for example as a measurement tool. Analog Output of 10 V, with an output current to a device of 5 mA makes this device very compatible with various sensors [10].

Thermocouple is a temperature sensor that is often used because of its range of ability to read very high temperatures. Thermocouples have a wide variety of types depending on the range of temperatures they can read. Each microcontroller is able to process the program in accordance with the

| Parameter                  | Unit  | Values       |
|----------------------------|-------|--------------|
| pH                         | –     | 4.79 – 4.75  |
| Temperature                | °C    | 80 – 90      |
| Biochemical Oxygen Demand  | mg/l  | 33,500 – 36,400 |
| Chemical Oxygen Demand     | mg/l  | 69,500 – 88,150 |
| Soluble Chemical Oxygen Demand | mg/l | 33,500 – 64,700 |
| Total Solids               | mg/l  | 51,560 – 52,180 |
| Total Suspended Solids     | mg/l  | 23,180 – 29,100 |
| Volatile Solids            | mg/l  | 43,100 – 43,360 |
| Fat                        | mg/l  | 6830 – 7610  |
| Total Kjeldahl Nitrogen    | mg/l  | 1003 – 1053  |
| Ammoniac nitrogen          | mg/l  | 138 – 194    |
| Total Volatile Fatty Acid  | mg/l  | 300 – 500    |
needs of its users, in making the program, required a software compatible with the software, one such software is LabVIEW. LabVIEW is a product of National Instruments in the form of software development program application and input-output hardware for the purposes of acquisition and control. While software or software LabVIEW is a graphical programming language that uses symbols (icons) to create applications [13].

2. Material and Method
The research was conducted at the Laboratory of Environmental and Ecology, Department of Chemical Engineering, Faculty of Engineering, Universitas Sumatera Utara. Materials and Equipment used in the experiment were liquid waste samples of palm oil mill (POME), computer, microcontroller, AC to DC module, 5 Volt resources, thermocouple, stirrer, tank, and heater.

2.1. Research Stages
This research consists of several main stages, namely the stage of the instrument, the calibration stage, and the implementation stage. Stages of Instrument Sequencing the temperature sensor used is a K type thermocouple which has a temperature response capacity of 0 to 1150 °C. This thermocouple is connected to National Instrument USB-6001 microcontroller using jumper cable. Before being used, this microcontroller need to be tested first [13]. This trial uses the Measurement and Automation Explorer (MAX), which is presented in Figure 1.

![Figure 1. Measurement and Automation Explorer (MAX)](image)

The test phase is open MAX window, then open "Devices and Interfaces" then "NI-DAQmx Devices". Right-click on NI USB-6001 device and then "Self-Test" to run it. The appearance is shown on Figure 2. In the absence of an error report, the instrument set is properly connected and ready for use and mounted on the fermentor.
3. Results and Discussion

3.1. The design of the stirred tank
The stirred tank is the main tool in this study. Calculation of stirred tank design based on available literature which is equipped with stirrer and baffle. The mixer is equipped with two impellers and is driven by an electric motor. Technical images of stirred tanks are presented in Figure 3.

![Figure 3](Image)

**Figure 3.** Technical Drawing of Bioreactor

3.2. Hardware design
The hardware that is a major part of this temperature monitoring system is the National Instrument USB - 6001 microcontroller. Meanwhile, this microcontroller needs to be assisted by some additional components in the monitoring of this process, which is a series of TC to DC modules and 5 volts resources, and temperature sensors used are K type thermocouple. Hardware Circuit Temperature Monitoring System are shown on Figure 4.
3.3. Software Design
To run this process temperature monitoring system, the LabVIEW 2014 program is used. LabVIEW is a programming software programming language based graphics and block diagrams. The interface used in the temperature monitoring system of the bioreactor can be seen in Figure 5.

![Figure 5. Human Machine Interface (HMI) Monitoring Temperature Using LabView 2014](image)

The above interfaces are made from the temperature monitoring system program in the bioreactor by using Control and Simulation Loop at LabVIEW. Program temperature monitoring system is seen in block diagram on Figure 6.
The data storage on the monitoring system is done in Microsoft Excel, by using Write to Measurements File in block diagram LabVIEW 2014. Analysis of Thermocouple Sensor Tester Results on National Instrument Usb - 6001 Microcontroller. In reading the thermocouple sensor, the readable value is the analog value in the form of voltage quantity, therefore it is necessary to calibrate the thermocouple sensor temperature reading results to the digital thermometer and then obtain a linear equation that connects the two data.

3.4. Thermocouple Sensor Calibration
In this calibration it is necessary to extract the digital value data from the thermocouple sensor for any temperature change at 1 minute intervals. Temperatures read by digital thermometers range from 28.5 to 70.8 °C to obtain a linear equation of the calibration of this tool. Figure 7 shows the thermocouple sensor calibration graph.

An equation is obtained from the linear function of thermocouple sensor temperature which can be written with \( y = 0.0064x + 0.2217 \) with value of \( R^2 \) is 0.993. This equation is then fed to the LabVIEW 2014 block diagram for later use in process temperature monitoring.
3.5. Temperature Process Data Retrieval using Microcontroller

3.5.1. Microcontroller with Hysteresis 1 °C
In this research, the data obtained from the thermocouple sensor is carried out for every temperature change over an interval of 30 seconds for 14 hours with the temperature set on the temperature control device is 55 °C. The standard error retrieval is done by finding the average temperature of each data retrieval clock and then compared against the standard error value. Figure 8 shows the standard error of the average temperature obtained.

![Figure 8. Graph of Temperature Process Data Retrieval with Hysteresis 1 °C](image)

In Figure 8 it can be seen that the largest standard error value occurs in the first hour, i.e. with a value of 8.21 °C with an average temperature of 44.89 °C. This is because at the first hour, the water used is still in the process of heating, i.e. from room temperature to reach the set point that is 55 °C, so it has the largest standard error value.

3.5.2. Microcontroller with Hysteresis 3 °C
In this research, the data obtained from the thermocouple sensor is done for every temperature change over 60 second interval for 24 hours with temperature set on the temperature control device is 55 °C. The standard error retrieval is done by finding the average temperature of each data retrieval clock and then compared against the standard error value. Figure 9 shows the standard error of the average temperature obtained.
In Figure 9 it can be seen that the largest standard error value occurs in the first hour, i.e. with a value of 4.38 °C with an average temperature of 34.79 °C. This is because during the first hour, the water used is still in the process of heating, i.e. from room temperature to reach the set point that is 55 °C, so it has the largest standard error value.

3.5.3. Microcontroller with Hysteresis 5 °C
In this research, the data obtained from the thermocouple sensor is carried out for every temperature change over an interval of 60 minutes for 24 hours with the temperature set on the temperature control device is 55 °C. This data collection is performed to compare the data formed by the temperature obtained when using hysteresis 5 °C using hysteresis 1 and 3 °C.

In Figure 10 it can be seen that the obtained graph deviates far more than the 55 °C set point compared to the data obtained from experiments on hysteresis 1 and 3 °C.
4. Conclusion
Based on the results of research and discussion conducted, then obtained the components required in a series of temperature control automation system tools are National Instrument USB-6001 microcontroller, TC to DC module circuit and 5 volt power source, and the temperature sensor used is K type thermocouple. The data recording system used is to use the program Write to Measurements File in block diagram LabVIEW 2014 which is directly stored in Microsoft Excel. The design result of HMI design using LabVIEW 2014 is in accordance with the requirement with graphical display from the real time temperature condition of the stirred tank. The result of thermocouple sensor calibration test is shown with linearization equation with \( y = 0.0064x + 0.2217 \) with value of R2 is 0.993, and the initial process of heating to set point has direct effect to standard error from average temperature data, where in research data with hysteresis 1°C shows the highest error standard value with value 8.21 °C and in research data with hysteresis 3 °C has the highest error standard value that is 4.38 °C. The results of this study indicate that the best data obtained in the research data using hysteresis 1°C from the set point temperature compared with data on hysteresis 3 °C and hysteresis 5 °C.

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