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Monitoring System for Laboratory Scale Digestion System

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Abstract

A monitoring system for laboratory scale digestion system was designed and installed for experiments. The system was designed to measure biogas production and system parameters. These included flow rate, temperature, methane concentration and level of water. The main objective was to collect real-time data during digesting period. The digestion system consisted of seven digestion tanks which were placed in a controlled temperature water tank. Each digestion tank had a volume of 20 liters. Seven flow meters, seven thermocouples, one methane concentration sensor and one optical level sensor were installed. The monitoring system was controlled by two Microcontrollers. Data were collected using a Visual C# program. The monitoring system was calibrated after installation. The monitoring system was tested by operating the digestion system using Napier grass as feedstock. Data collection during one month digestion period was performed. The monitoring system was able to measure data from different transducers satisfactory.

Keywords: Monitoring system, Digestion system, Biogas production, Microcontroller

1. Introduction

Energy prices increases continuously due to rapid economy growth and limited fossil fuel supply. Renewable energy has been promoted in Thailand during the past decade. Biogas is an important renewable energy developed in different sectors. These include biogas from industrial waste water, pig and chicken manure and organic waste. A new concept of digestion technology is used to produce biogas from energy crops such as corn, grasses and agricultural residues.

Biogas [1] can be produced by difference inputs such as manure, corn silage and other energy crops, food processing by-products, and household organic waste. Biogas is a mixture methane gas (CH_4) and carbon dioxide gas (CO_2). Biogas is basically low grade natural gas because it is about 50-65% methane compared to Natural gas which contains about 90-95% methane. Biogas is produced by bacteria that convert organic matters to methane gas. This process is very similar to that of an animal's digestive system and the most common method of producing biogas is called anaerobic digestion.

A laboratory scale digestion system consisted of seven digestion tanks which were placed in a controlled temperature water tank. Transducers used to monitor system performance included seven flow meters, seven thermocouples, one methane concentration sensor and one optical level sensor. Data recordings were previously done manually. For observing the system performance, hourly and daily data recording were done depending on parameters to be measured. For example, flow of biogas which was considered very low flow rate was measured using a turning cup which trapped the bubble of biogas. The cup would turn when it was filled up. Rotation of the cup was measured using digital counter. Therefore, data need to be recorded manually. Temperature of digestion materials was also measured using liquid-in -glass thermometer, hence, manually observing and recording were time consuming.

This research aimed to design and develop a monitoring system that detected signals from all transducers. The system was able to monitor and record data at specified period. Recording data could be transferred and analyzed conveniently. The monitoring system was controlled by two microcontrollers [2]. The first microcontroller received signal from all sensors except level control sensor. For transferring data, the first microcontroller was connected to a PC computer by using RS232 Serial port and C# programming. Second microcontroller was used for safety and controlling the system. Its functions were to control the function of flow meter and controlling water level in the tank.

The system was tested by operating the laboratory scale digester using Napier grass as feedstock. Data were monitored and recorded during thirty days digestion period. Monitoring results were observed and compared with manual measurements.

2. Digestion System

2.1 Biogas Production in Digestion System

Biogas [1] can be produced by difference inputs such as manure, corn silage and other energy crops, food processing by-products, and household organic waste. Biogas is a mixture methane gas (CH_4) and carbon dioxide gas (CO_2). Biogas is basically low grade natural gas because it is about 50-65% methane compared to Natural gas which contains about 90-95% methane. Biogas is produced by bacteria that convert organic matters to methane gas. This process is very similar to that of an animal's digestive system and the most common method of producing biogas is called anaerobic digestion.

2.2 Digestion Tank in this paper

Seven of 20-Liters Digestion Tanks with Feed Materials hole, Stir Blade and the Thermocouple were put in the Large Tank. Water in Large tank was heated to controll temperature using a Heating Coil.

Fig. 1 Digestion Tank

Fig. 2 7 Digestion Tank in large tank

The Stir Blade with DC Motor were installed for stirring the gas and operated 10 minutes every hours

Fig. 3 Stir blade

Material was prepared in Inoculums tank before feed in to Digestion Tank and Operated the Digestion System. The catalyst was add to the material, after a few days there was some gas produced so it can feed it in to the digestion tanks.

Fig. 4 Inoculums Tank

3. Designing the Monitoring System

3.1 Reed Switch

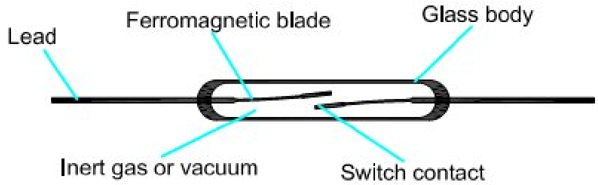

Fig. 5 The basic (normally open) Reed Switch

A Reed Switch[3] consists of two ferromagnetic blades hermetically sealed in a glass capsule with a gap between them, and makes contact with each other when in the suitable magnetic field. The gas in the capsule usually consists of Nitrogen or some equivalent inert gas. Poles of opposite polarity are created and the contacts close when the magnetic force exceeds the spring force of the reed blades. As the external magnetic field is reduced so that the force between the reeds is less than the restoring force of the reed blades, the contacts open.

3.2 Flow Meter

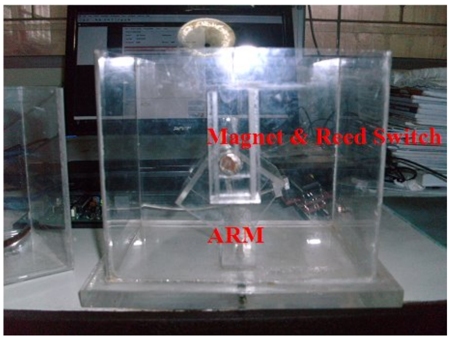

Fig. 6 Flow Meter at and Reed Switches

The box of Flow Meter were filled with water. Flow of biogas which was considered very low flow rate was measured using a turning cup which trapped the bubble of biogas. The cup would turn when it was filled up then . Rotation of the cup was measured by magnet attached with the cup and pass Reed Switch and be counted by using digital counter and send signal to Microcontroller.

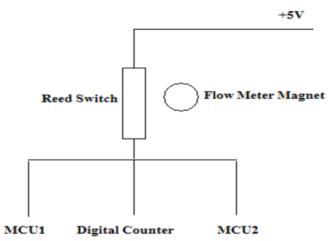

Fig. 7 Reed Switch Circuit

Fig. 8 : Install Flow Meters

Microcontroller Collect and count Pulse from Reed Switches that mean the number of the cup rotation when it was filled up then and calculate the amount of gas

3.3 Setup Servo Motors

Servo Motor was attached outside of the Flow Meter box with magnet attached at the servo's arm. The Magnet have to pass the middle position of Flow Meter's arm and Reed Switches in order to make the flow meter's arm move together with servo motor and return to normal moving.

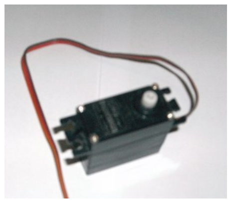

Fig. 9 Servo Motor

In normal moving state of flow meter's cup, Servo Motor won't move but when the flow meter's cup was stop at the middle for a long time because of high flow rate and control Servo motor to make the flow meter's cup move to normal and servo motor return to the normal position again and pass Reed Switch, the counter counted again so when the flow meter's arm was stop and servo motor moved, the counter counted by two times and double amount of gas were collected because the gas was filled in both side of flow meter's arm space and be releases at the same time.

3.4 Thermocouple

Seven Thermo Couples were installed in each digestion tanks to detect temperature of gas installed for each digestion tanks. Signal from Thermocouple will send to Microcontroller.

Microcontroller Collected data in millivolt from thermo couple and calculate temperature manually.

3.5 Methane Sensor

Methane Sensor use for detect Concentrate of Methane in gas. In this research used up to 3 Monicon IR100 NDIR[11] Methane Sensors, installed at the connection before gas enters the container bags.

Microcontroller Collected data in millivolt from Methane Sensor and calculate Methane Concentration

Fig. 10 Monicon IR100 NDIR Methane Sensor

3.6 Distance Sensor

For safety, Distance Sensor[4] use for detect level of water in tank was installed about 60 centimeters over the lowest allowable level of water in the tank with the reflecting object at the surface of water.

GP2D12 infrared distance sensor interface comes with Sharp GP2D12 sensor. Sharp GP2D12 can precisely and reliably read distance from 10cm-80cm. Sharp GP2D12 provides your RCX with capability of measuring distances from an obstacle.

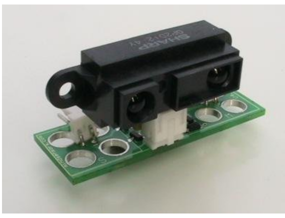
Fig. 11 : Distance Sensor

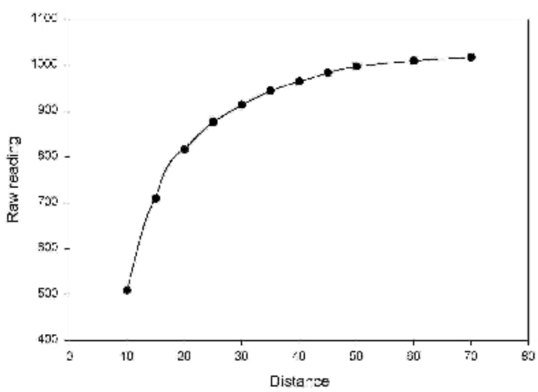

Fig. 12 : Caliberation plot for Distance Sensor

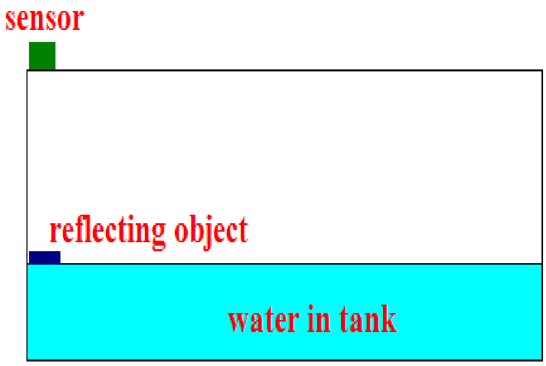

Fig. 13 Installing the Level Sensor

Microcontroller was received data as voltage from distance senser and calculated the distance between sensor and water.

3.7 Microcontroller PIC16F877A [2]

2 PIC16F877A Microcontrollers were use in this research. The first microcontroller received signal from Reed switches, thermocouples and Methane sensors. Second Microcontroller received signal from level control sensor and controlled Servo Motors and DC Motor. For transferring data, the first microcontroller was connected to a PC computer by using RS232 Serial port and C# programming. Second microcontroller was used for safety and controlling the system.

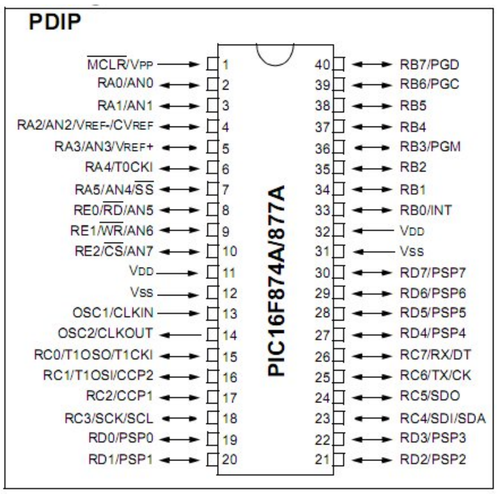

Fig. 14 Pin diagram of PIC16F874A and PIC16F877A

Table. 1 PIC16F87XA DEVICE FEATURES

Key Features	PIC16F873A	PIC16F874A	PIC16F876A	PIC16F877A
Operating Frequency	DC – 20 MHz	DC – 20 MHz	DC – 20 MHz	DC – 20 MHz
Resets (and Delays)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)
Flash Program Memory (14-bit words)	4K	4K	8K	8K
Data Memory (bytes)	192	192	368	368
EEPROM Data Memory (bytes)	128	128	256	256
Interrupts	14	15	14	15
I/O Ports	Ports A, B, C	Ports A, B, C, D, E	Ports A, B, C	Ports A, B, C, D, E
Timers	3	3	3	3
Capture/Compare/PWM modules	2	2	2	2
Serial Communications	MSSP, USART	MSSP, USART	MSSP, USART	MSSP, USART
Parallel Communications	—	PSP	—	PSP
10-bit Analog-to-Digital Module	5 input channels	8 input channels	5 input channels	8 input channels
Analog Comparators	2	2	2	2
Instruction Set	35 Instructions	35 Instructions	35 Instructions	35 Instructions
Packages	28-pin PDIP 28-pin SOIC 28-pin SSOP 28-pin QFN	40-pin PDIP 44-pin PLCC 44-pin TQFP 44-pin QFN	28-pin PDIP 28-pin SOIC 28-pin SSOP 28-pin QFN	40-pin PDIP 44-pin PLCC 44-pin TQFP 44-pin QFN

3.8 Programming

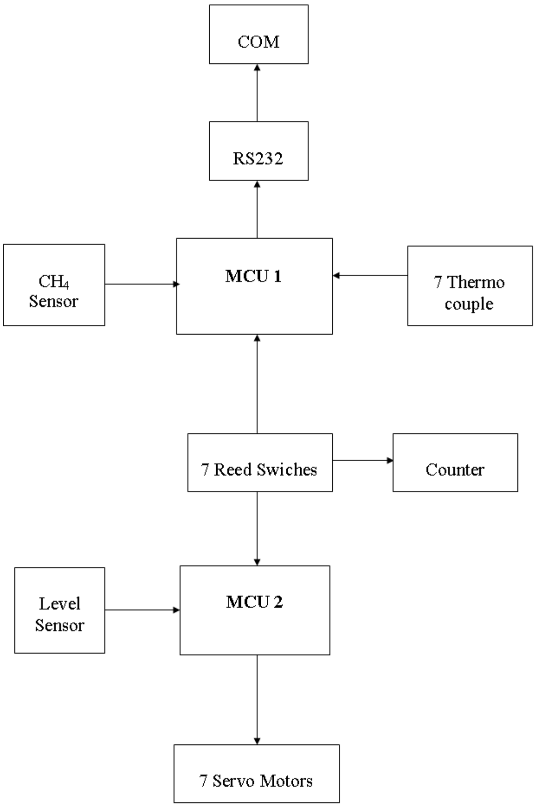

Fig. 15 diagram show Equipments in the system

Microcontrollers PIC16F877A and its programming board with signal ports and programming ports. PX-200 and ET-ADAPT PIC USB40A were used for loading program to microcontrollers This Research use C++ language with MPLAB IDE to write and CCS compiler to compile source code for Microcontrollers and then use PIC Kit Programmer to load program to Microcontroller with PX-200 and ET-ADAPT PIC USB40A.

Table.2 Input and Output type of each equipments

Equipment	Input / Output type
7 Reed Switches	Input (Pulse 0/5V)
Thermo couple	Input (mV)
Methane Sensor	Input (mV)
Level Sensor	Input (mV)
7 Servo Motors	Output (Pulse / ms)

This Research use C++ language with software MPLAB IDE to write and CCS compiler to compile source code for Microcontrollers and then use PIC Kit Programmer to load program to Microcontroller with PX-200 and ET-ADAPT PIC USB40A.

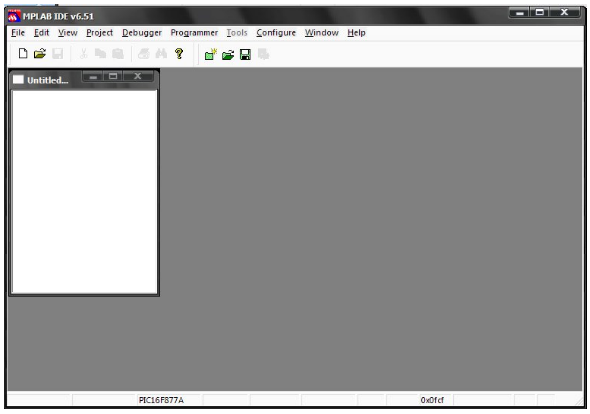

Fig. 16 : MPLAB IDE Software

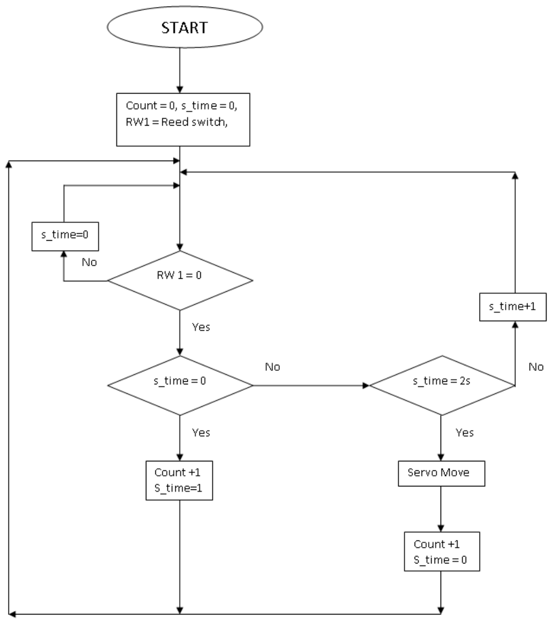

Fig. 17 Blog Diagram of Counter System Program

For reading data, first Microcontroller was connected to computer with RS232 serial port and reading data using Microsoft Visual C# software.

The software included
1. RS232 setting and connect
2. Amount of gas produced in each tank (cm^3)
3. Temperature of gas in each tank(mV)
4. Methane Concentration (% Methane)
5. Reset Program
6. Reset Microcontroller
7. Start and Stop Program

Fig. 18 Program for reading data

4. Experimental Procedure

4.1 Testing the Monitoring Ststem

Before installed the monitoring system in Laboratory-scale digestion system, the system was test manually without Digestion system for all equipments using the testing program.

1. Reed Switches
2. Reed Switches with Flow Meter was tested by feed normal air into Flow meter manually
3. Servo Motors were tested by stop the cup at middle manually
4. Reed Switches and Servo Motor
5. Thermo Couples
6. Distance Sensor

The normal air was feed into Flow meter manualy to saw the working of Flow meter and Reed switches. Then connected all equipments with Microcontroller and test Flow meter manually again to saw the working of Reed switches. The cup was stop at middle manually to saw the working of Servo Motors.

After testing each part then connected all equipments with Microcontroller and test Flow meter manually again to saw the working of Reed switches. to saw the working of Servo Motors using full program and full circuit.

4.2 Installed Monitoring System and Pre-Test the system with Digestion Tank

Data were monitored and recorded during 2 weeks for Pre-test. Monitoring results were observed and compared with manual measurements to saw that the digestion system and monitoring system worked as planning.

Prepare the Materials

Use Napier grass as feedstock. Material was prepared in Inoculums tank before feed in to Digestion Tank and Operated the Digestion System. The catalyst was add to the material, after a few days there was some gas produced so it can feed it in to the digestion tanks.

Calibrate the Methane Sensor

Using gas produced from preparing state for calibration compare with Digital Methane Sensor and plots the calibration curve of IR100 NDIR Methane Sensor then put the calibrated equation in to program of first Microcontroller.

Calibrate the Distance Sensor

Plot calibration curve of Distance and Voltage output. Design the lowest allowable level of water, place Distance Sensor and then calculated voltage output value of selected level of water and put in to program of second Microcontroller

Pre-Test the System

The system was tested by operating the laboratory scale digester using Napier grass as feedstock. Data were monitored and recorded during 2 weeks for Pre-test. Monitoring results were observed and compared with manual measurements using thermometer, digital counter and digital Methane Sensor to saw that the digestion system and monitoring system worked as planning.

4.3 Full Experiment of the Monitoring System with Digestion Tank

After Pre-test and was sure that the system was working satisfactory the system was tested by operating the laboratory scale digester using new Napier grass that was prepared during pre-test.as feedstock. Data were monitored and recorded during thirty days digestion period.

During 30 days of Digestion period, data was collected every 3 days. Monitoring results were observed and compared with manual measurements like pre-test

5. Result and Discussion

Biogas is a mixture methane gas (CH_4) and carbon dioxide gas (CO_2). Gas flow rate was very high at the beginning and the flow rate was continuing lower. In the first week the cup of flow rate was stop and Servo motor had to fix it to normal move. After 2 weeks there was no problem with high flow rate to make the cup stopped anymore.

After 1 digestion period or 30 days, collected data and compared with manual measurement. Results showed that the monitoring system performed satisfactory.

The designed and developed system was very useful for research work on digestion testing because it provided real-time monitoring and reduced time needed for data recording and analyzing.

In the Future work Researcher will develop the Monitoring system that should detect more parameters and can be observed real time online.

6. Conclusion

Biogas is a mixture methane gas (CH_4) and carbon dioxide gas (CO_2). Biogas is produced by bacteria that convert organic matters to methane gas.

Monitoring System for for Laboratory Scale Digestion System was aim to design and develop a monitoring system that detected signals from all transducers. The system was able to monitor and record data in real time and can detect very low or very high flow rate of gas.

The Monitoring System was installed with 7 of 20-Liters Digestion tanks including Flow Meter, Methane Sensor, Thermocouples Servo Motors, DC Motors. System was controlled by two PIC16F877A Microcontrollers which programming using C++ language and reading data in computer using Visual C# Software.

Gas flow rate was very high at the beginning and the flow rate was continuing lower.

The system was tested by operated in a laboratory for thirty days digestion period, collected data and compared with manual measurement. Results showed that the monitoring system performed satisfactory.

7. Reference

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