MONITORING SYSTEM FOR A LABORATORY SCALE DIGESTION SYSTEM

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Thesis
entitled

MONITORING SYSTEM FOR A 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 thermistors, one methane concentration sensor and one optical level sensor were installed. The monitoring system was controlled by microcontroller. Data were collected using a Terminal program. The monitoring system was calibrated after installation. The monitoring system was tested by operating the digestion system using Napier grass and pineapple as feedstock. Data collection during two weeks for pre-testing and one month for full-experiment digestion period was performed. The result showed that flow counting system had no errors. Temperature measurement had an error of about ±3 degree Celsius. The optical distance sensor had error of about ±1 centimeters. The monitoring system was able to measure data from different transducers satisfactory.

KEY WORDS: MICROCONTROLLER / MONITORING SYSTEM / DIGESTION SYSTEM

112 pages

ระบบตรวจวัด สำหรับการทดสอบก๊าซชีวภาพ จากระบบหมักแบบไร้อากาศ
MONITORING SYSTEM FOR A LABORATORY SCALE DIGESTION SYSTEM

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บทคัดย่อ

ระบบตรวจวัดสำหรับการทดสอบก๊าซชีวภาพ จากระบบหมักแบบไร้อากาศได้รับการออกแบบและติดตั้งสำหรับการทดลองในห้องปฏิบัติการ ระบบถูกออกแบบมาเพื่อให้สามารถตรวจวัดอัตราการไหล อุณหภูมิ และความเข้มข้นของก๊าซมีเทน จากก๊าซชีวภาพที่ผลิตได้ รวมไปถึงการควบคุมระดับน้ำในถังควบคุมอุณหภูมิ วัตถุประสงค์หลักของงานวิจัยนี้ คือการออกแบบระบบที่สามารถตรวจวัดและบันทึกค่าได้อย่างต่อเนื่อง ตลอดระยะเวลาการทดลอง ระบบหมักก๊าซประกอบด้วย ถังหมักขนาด 20 ลิตร จำนวน 7 ถัง, อุปกรณ์วัดการไหลของก๊าซ จำนวน 7 ชุด, อุปกรณ์อุณหภูมิของก๊าซในถังหมัก จำนวน 7 ชุด เซนเซอร์วัดความเข้มข้นก๊าซมีเทน 1 ชุด และเซ็นเซอร์วัดระยะทางด้วยอินฟาเรด จำนวน 1 ชุด ระบบถูกควบคุมโดยใช้ไมโครคอนโทรลเลอร์ และอ่านข้อมูลโดยใช้เทอร์มินอล โปรแกรม ทำการทดสอบระบบตรวจวัดที่พัฒนาขึ้น ในห้องปฏิบัติการ โดยใช้หญ้าเนเปียร์ และ สัปปะรด เป็นวัตถุดิบ โดยมีระยะเวลา 2 สัปดาห์สำหรับการทดสอบเบื้องต้น และ 1 เดือน สำหรับการทดสอบขั้นสมบูรณ์ ผลการทดสอบแสดงให้เห็นว่าระบบตรวจวัดการไหลไม่มีความผิดพลาด ระบบตรวจวัดอุณหภูมิมีข้อผิดพลาด± 3 องศาเซลเซียส และเซ็นเซอร์วัดระยะทางมีความผิดพลาดประมาณ ± 1 เซนติเมตร ระบบการตรวจสอบสามารถที่จะวัดข้อมูลจากที่แตกต่างกันที่น่าพอใจ

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CHAPTER I
INTRODUCTION

1.1 Background

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. The digestion tank is shown in fig 1.1 which were placed in a controlled temperature water tank as shown in fig 1.2. Transducers used to monitor system performance included seven flow meters, seven thermistors, one methane concentration sensor and one optical level sensor.

Fig. 1.1 Digestion tank

Fig. 1.2 Seven digestion tank in temperature control tank

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 which trapped the bubble of biogas. The cup would turn when it was filled up. Rotation of the cup was measured using digital counter.

1.2 Statement of Problems

In previous research, flow meter can be measured very low flow rate using a turning cup but the measuring range was not high enough and could not measure high flow rate because the flow meter stopped working and data cannot be measured until researcher went to laboratory and fixed them.

Reed switches in Flow meter system were unstable, sometime it may not detect the magnet. It will cause volume of gas the system measured not equal to actual volume of gas produced. This error was uncontrollable and undetectable.

Data recordings were previously done manually. 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.

1.3 Objectives of the Study

This research aimed to design and develop a monitoring system that can 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 microcontroller [2]. The microcontroller received signal from all sensors including reed switches with displacement flow meter for flow counter, thermistor for temperature, methane concentration sensor and level sensor. Data was transferred from microcontroller connected to a PC computer by using RS232 serial port and Terminal program.

1.4 Scope of the Study

The monitoring system could detect flow rates, temperatures and methane concentration from seven digestion tanks. The system was controlled by microcontroller PIC18F8722 and was tested by operating in 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.

List of Sensors and Measuring Method

1. Flow rate measurement using mechanic flow meter with two Reed Switches for each tank and flow meter, single way reed switch for digital counter and 2 ways reed switch for microcontrollers.

2. Temperature measurement using a 10KΩ type thermistor with have a resistor value of 27 KΩ at 0°C and 10 KΩ at 25°C measuring temperature.

3. Methane Concentration Measurement using IR100 NDIR Methane Concentration sensor

4. Level of water in temperature control tank was measured by using GP2D12 Distance Sensor.

Fig 1.3 shows the blog diagram of all transducer with microcontroller and it signal input or output type

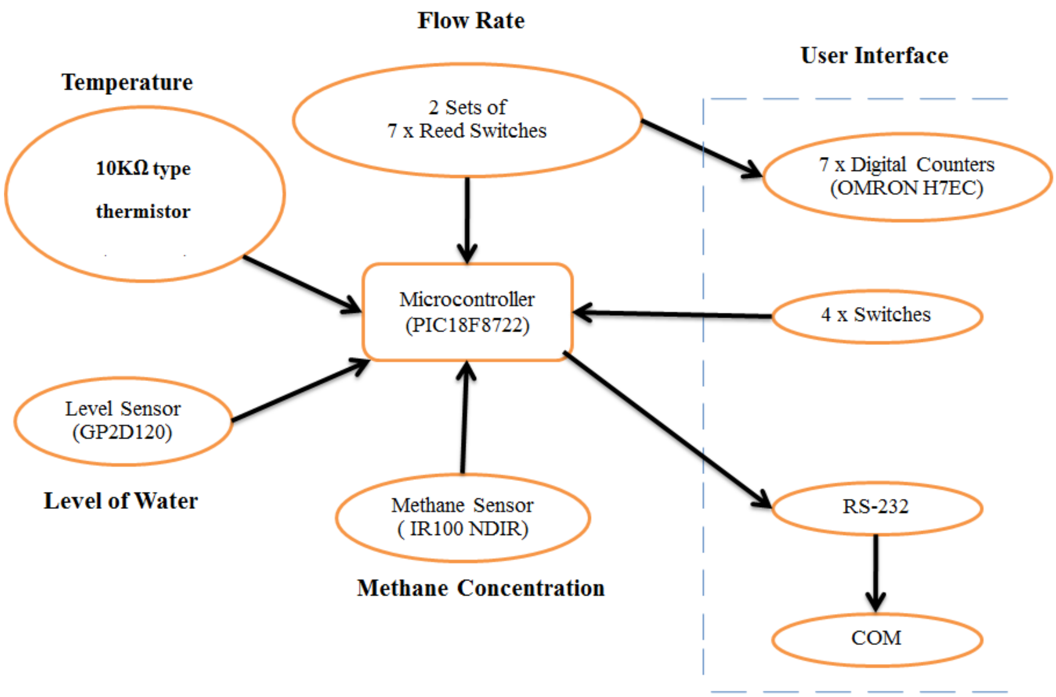


Fig 1.3 Block Diagram of the Monitoring System

1.5 Methodology

Fig 1.4 show the methodology of the development of the new monitoring system

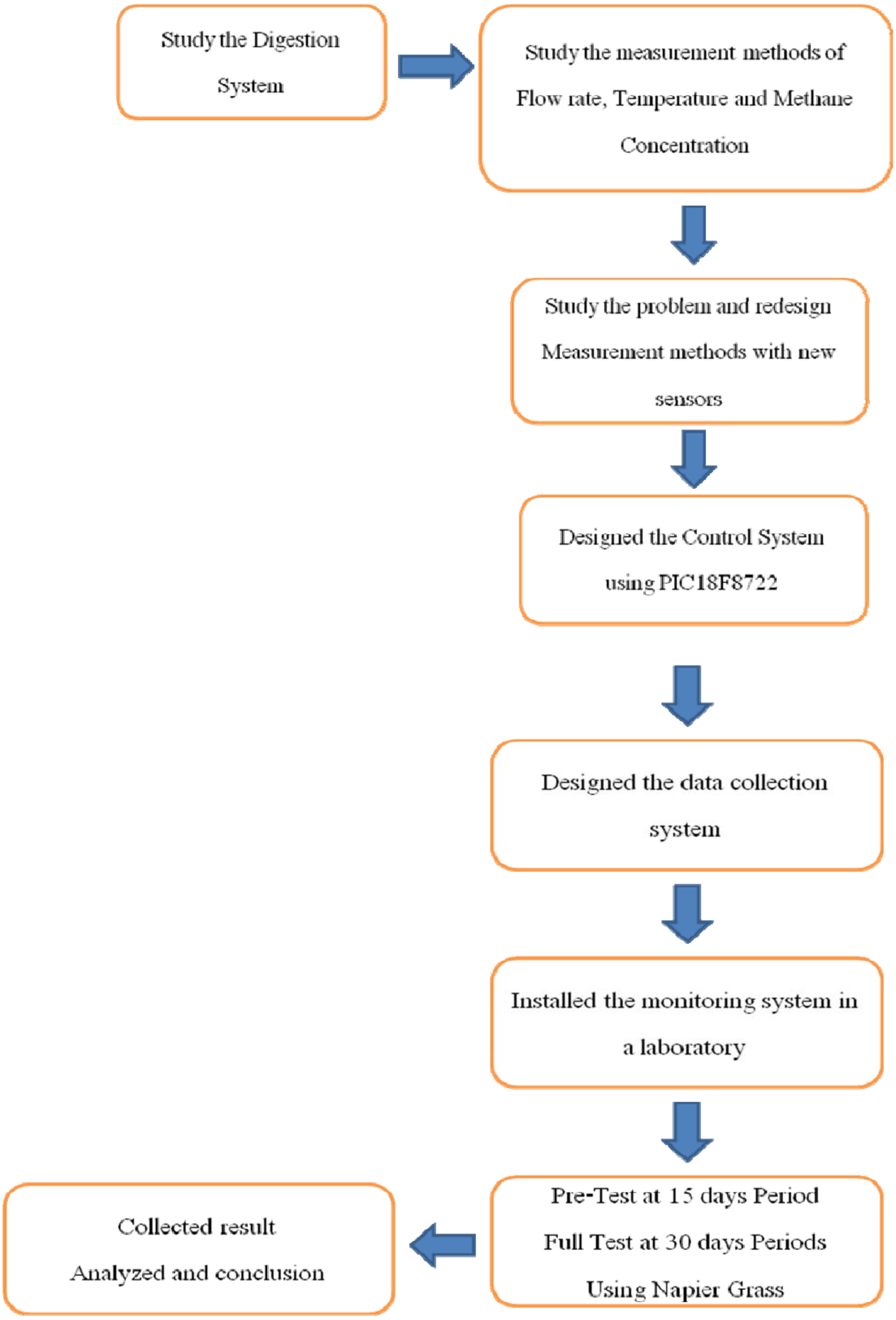


Fig. 1.4 Methodology of the development of The Monitoring System

CHAPTER II
LITERATURE REVIEW

2.1 Researches Review

2.1.1 Wantanee Anunputtikul and Sureelak Rodtong [2] have investigated the laboratory scale biogas digestion system production using a simple single-state digester of 5 Liters and 20 Liters digestion tank volume. The optimal concentrations of carbon and nitrogen was fed into the 5-liter working volume fed with. Table 2.1 shows the Physical characteristics of the digestion tank in that research.

Result show that gas produced of about 2liters/day and methane concentrate is about 68%. After 24 days operation time the concentration of methane was 67% that could be efficiently produced from Cassava Tubers.

In that research, using both dry and wet cassava tuber, result of dry cassava tuber experiment shown that biogas produced using 1 kilogram of dry cassava tuber had converted to 497 Liters, and result of fresh cassava experiment showed that biogas produced using 1 kilogram of fresh cassava tuber had converted 235 liters of biogas.

Table 2.2 shows the result of Biogas production in Wantanee Anunputtikul and Sureelak Rodtong research

Table 2.1 Physical characteristics of 5-L and 20-L working volume digestion tank in Wantanee Anunputtikul and Sureelak Rodtong's research [2]

Parameter	5 Liters	20 Liters
Digester height (cm)	25.00	13.50
Liquid height (cm)	13.50	41.30
Empty volume (L)	7.50	26.00
Filled Volume (L)	5.00	20.00

Table 2.2 Biogas production from cassava tubers in laboratory scale experiments in Wantanee Anunputtikul and Sureelak Rodtong research

Parameter	Reaction volume (L)	
	5	20
Total biogas yield (L/kg TS fed)	569.29	611.32
Total biogas yield (L/kg VS fed)	474.67	509.71
Total methane yield (L/kg TS fed)	263.90	339.53
Volatile solids (VS) reduction (%)	56.83	61.51

2.1.2 Alastair Ward, Phil Hobbs, Peter Holliman, Davay Jones [3] have designed a monitoring system and optimization input and output in four stage digester for 10 months and made it to develop an alkalinity predictor algorithm. The researcher use LabView Software which have Algorithm as shown in fig 2.1 f research using LabView to collects the sensor data and control the digester. The online measurement including pH, redox and conductivity. The offline measurement including Biogas volume, percent of methane, amount of hydrogen (ppm), dry meter, organic meter, Bicarbonate alkalinity and FT-NIRS. Data analysis showed that bicarbonate alkalinity is a key parameter for stability.

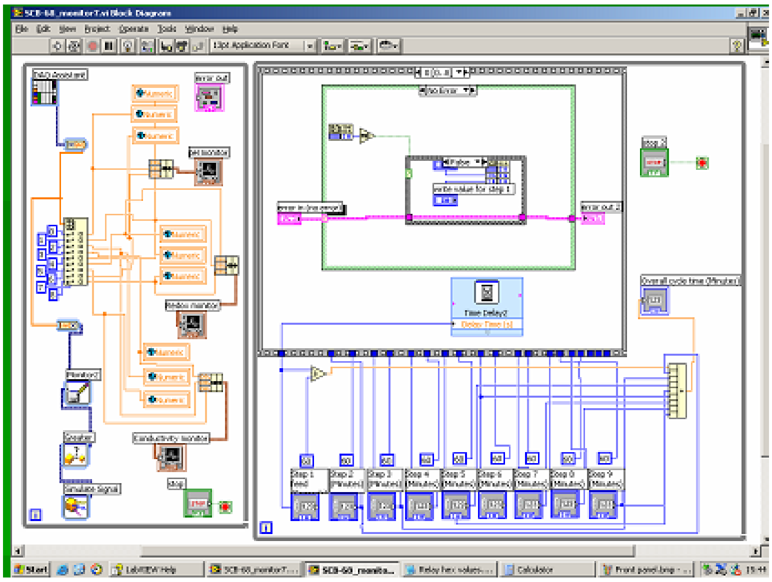


Fig 2.1: Algorithm of research using LabView

2.2 Biogas

Biogas can be produced by different inputs such as energy crops, household organic waste or food processing. Biogas is a mixture methane gas (CH_4) and carbon dioxide gas (CO_2) and also have hydrogen sulphide (H_2S) and moisture. Biogas has only about 50-65% of methane concentration compared to natural gas which contains about 90-95% methane concentration.

In biogas production system, the biological breakdown of organic matter and converted to methane gas by bacteria with without using oxygen gas in process. The most common method of producing biogas is called anaerobic digestion.

Biogas is a renewable energy which can be used for many purpose such as a fuel, heating and cooking because methane, carbon monoxide (CO) and hydrogen can be combusted or oxidized with oxygen. Much like natural gas, the energy in the gas can be converted into electricity and heat and be used in a gas engine using an anaerobic digesters to power motor vehicles and other operations that use an internal combustion engine. When biogas becomes bio methane and was cleaned, Biogas can also upgraded to natural gas standards.

The normal production of biogas is landfill gas (LFG) or digester gas. Anaerobic digester is a biogas plant witch fed using energy crops such as maize silage or wastes from farm and also using a sewage sludge or foods waste. During the digestion process of biogas, an airtight tank was use to converted biomass waste to methane gas.

Landfill gas produced by wet organic waste decomposing in the anaerobic condition. The Waste is cover, compress mechanically and prevents oxygen expose to the process by the weight of waste or materials which cover them from above allowing anaerobic microbes to thrive.

When biogas is produced and released into the atmosphere directly, it is hazardous in three reasons.

1. It can be explodes when it mixes with oxygen outside the landfill.

2. The lower and upper explosive limit is 5-15% methane.[9]

2. The methane contained in biogas has more effective as a greenhouse gas about 20 times more than carbon dioxide, it may significantly the effects of global warming.

Anaerobic digestion [6]

Materials which will be processed will be shredded to increase the surface area for the microbes in the digesters and hence to increase their speed of digestion. The Anaerobic Digestion process takes place in a digester which be an airtight container.

The first stage of anaerobic digestion is known as hydrolysis, a chemical reaction. The organic molecules will be broken into amino acids, fatty acids and also a simple sugar with a hydroxyl group in addition.

Anaerobic digestion system has three biological process

1. Acidogenesis: The organic molecules broken down into volatile fatty acids (VFAs) occurs, producing ammonia, Carbon monoxide and hydrogen sulfide by acidogenic bacteria.

2. Acetogenesis: The molecules produced from acidogenesis are further digested to produce Carbon monoxide, hydrogen and mainly acetic acid by bacteria called acetogens.

3. Methanogenesis: The molecules produced from Acetogenesis are further digested to produce methane, CO and water by bacteria called methanogens.

In order to maximize digestion rates, pH level should be controlled to be around 5.5-8.5 and the temperature should be controlled to be around 30-60^{o}C.

2.3 Reed Switch

Reed switch [7][8] has two or more ferromagnetic blades have a gap between them sealed in a glass capsule consists of Nitrogen or other equivalent inert gas. The blades in the reed switch are act as magnetic flux conductors that will made contact to each other or swing off between blades when there was an enough magnetic field and let electric pass through the reed switch.

The ferromagnetic materials which in nature and easy to anneal is iron, cobalt, and nickel. The two reed contacts are plated or sputtered with rhodium, ruthenium or iridium.

Fig 2.2 shows the component of a type 1 Form A (normally open (N.O.) reed switch or Single Pole Single Throw (SPST)) The blades was not contacted to each other and when there was an enough magnetic field they will made contact to each other and let electric pass through the reed switch.

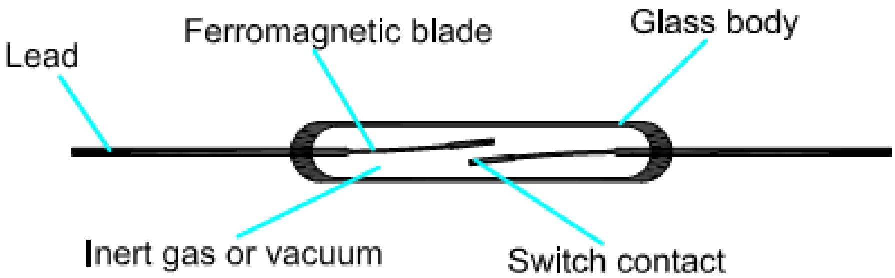


Fig 2.2 The basic hermetically sealed 1 Form A (normally open) Reed Switch and its component makeup. [7][8]

Fig 2.3 shows the component type 1 Form C (single pole double throw (SPDT)) reed switch which has 3 blades which only common blade or armature Blade can move. Without magnetic field, common blade was connected to the normally closed blade and swing over to the normally open blade.

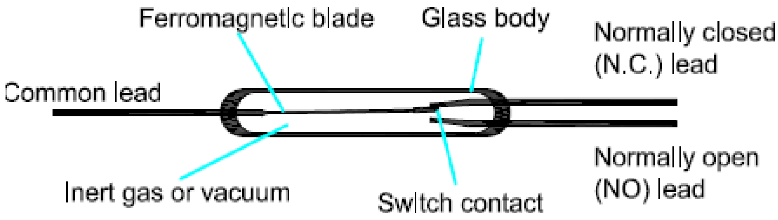


Fig 2.3 The 1 Form C (single pole double throw) three leaded Reed Switch and its component makeup.) [7][8]

2.4 Thermistor [25][26]

Thermistor is a temperature sensitive resistors transducer which changed its resistance depend on temperature; unlike most of other resistive devices. The equation of relationship between temperature and resistance is.

$$\Delta R = k\Delta T \tag{2.1}$$

R: Resistance value of thermistor

T: Temperature

k: First-order temperature coefficient of resistance

Thermistors can be classified into two types, depending on the value of k. If k is positive, the resistance of a thermistor would increases with increasing of measuring temperature, this class of thermistor was called positive temperature coefficient. If k is negative, the resistance of a thermistor would decreases with increasing of measuring temperature, this class of thermistor was called negative temperature coefficient.

This research uses the 10kΩ of negative temperature coefficient type of thermistor, which have normal value of 10kΩ resistance at 25^{o}C measuring temperature and 27kΩ resistance at 0^{o}C measuring temperature.

2.5 LM35DZ Temperature Sensor [11]

LM35DZ is the integrated circuit temperature sensors, which change the resistance depend on temperature in nearly linearly and produce an output voltage which can calibrate directly in degree Celsius (Centigrade) with +10.0 millivolts per degree Celsius scale factor and 0.5°C accuracy (at +25°C). It can measured temperature for full −55° to +150 °C range. The temperature can be calculated by using equation 2.2 or 2.3.

$$T\ (^\circ C) = \frac{\text{Output Voltage (mV)}}{10} \qquad (2.2)$$

$$T\ (^\circ C) = \frac{\text{Output Voltage (10 bits ADC)}}{2} \qquad (2.3)$$

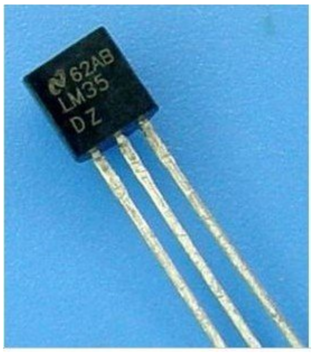


Fig 2.4 LM35DZ [11]

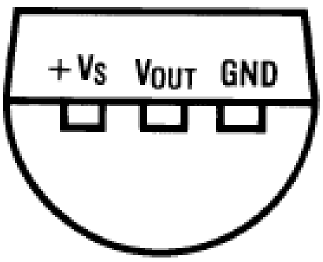


Fig 2.5 LM35DZ Pin Diagram [11]

2.6 LM358 Operational Amplifier [12]

Operational amplifier (op-amp) is a DC-coupled high-gain electronic voltage amplifier. It can produces an output potential (relative to circuit ground) that is larger than the potential difference between its input terminals.

LM358 OP-AMP was designed to operate from a single power supply over a wide range of voltage and operation from split power supplies is possible.

Fig 2.6 shows the pin diagram of LM358N operational amplifier and Fig 2.7 shows the circuit diagram of using operational amplifier

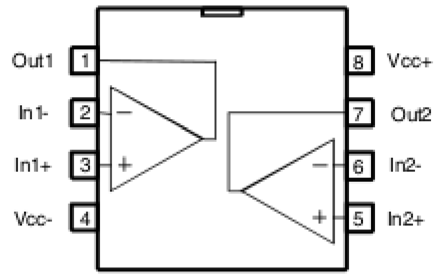


Fig 2.6 LM358N Pin diagram

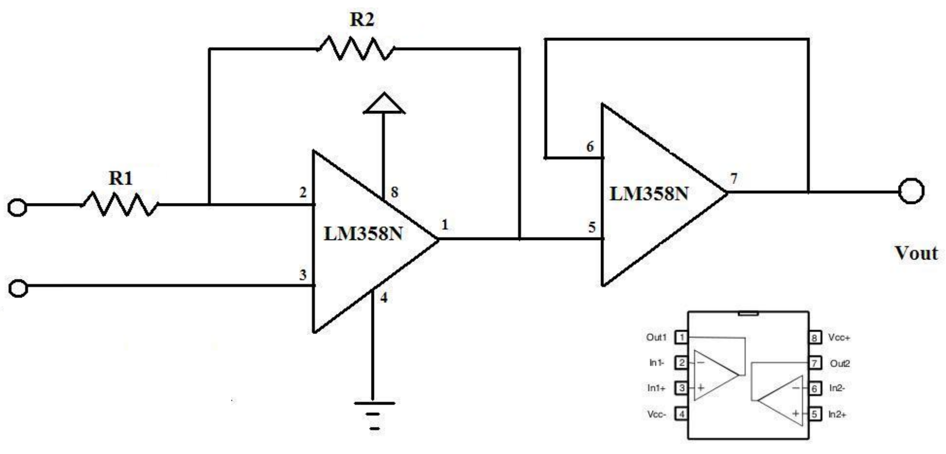


Fig 2.7 LM358N Circuit diagram

$$\text{Gain} = \frac{R2}{R1} \qquad (2.4)$$

In this research, operational amplifiers were designed with gain = 1 or the value of resistance R1 = R2. This circuit were used for controlling the stability of output voltage and not be dropped during measuring process and cause error in output voltage value and make an error in calculating the temperature of gas.

2.7 GP2D12 Distance Sensor [27]

The GP2D12 (Fig 2.9) is a distance measuring sensor which change the resistance depend on temperature and produced an integrated signal processing and analog voltage output. Effective range is 10-80 cm, output voltage range is 0.4-2.8 V and can be calculated by equation 2.5.

$$\text{Distance (cm)} = \frac{6787}{(V_{out\ 10\ bit} - 2)} - 5 \qquad (2.5)$$

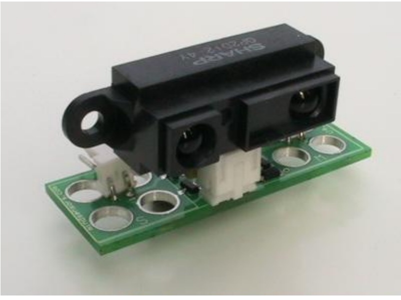
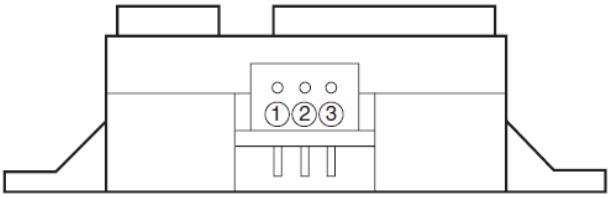


Fig.2.8 GP2D12 Distance Sensor

Fig 2.10 shows the pin diagram of GP2D12 Distance Sensor which have the 3 junctions of circuit

V_O	Output voltage
GND	Ground
V_{CC}	Supply voltage



PIN	SIGNAL NAME
1	V_O
2	GND
3	V_{CC}

Fig 2.9 GP2D12 Pin Diagram

2.8 Methane Sensor [21]

Monicon IR100 (Fig 2.11) sensor is an advanced NDIR (Non Dispersive Infra-Red) detector which can measure and monitor the concentration of gas including methane, carbon dioxide or carbon monoxide. Monicon IR100 sensor incorporating with a pulsed emitter, dual filters and dual detectors. This provides accurate and selective measurement of the gas being monitored.

The IR100 has a low drift and high accuracy. It requires a re-calibration only once per year. The build-in Temperature compensation has a very low temperature drift.

The electronics, pump and sensor are fitted in a rugged, IP65 rated metallic enclosure finished in powder coated grey (RAL7038). Applications for the IR100 include breweries, chemical processing, food processing, underground car parks, ventilation systems, mushroom farming and many others. Fig 2.12 show the circui diagram of Monicon IR100 NDIR Methane Sensor.

Fig. 2.10 Monicon IR100 NDIR Methane Sensor

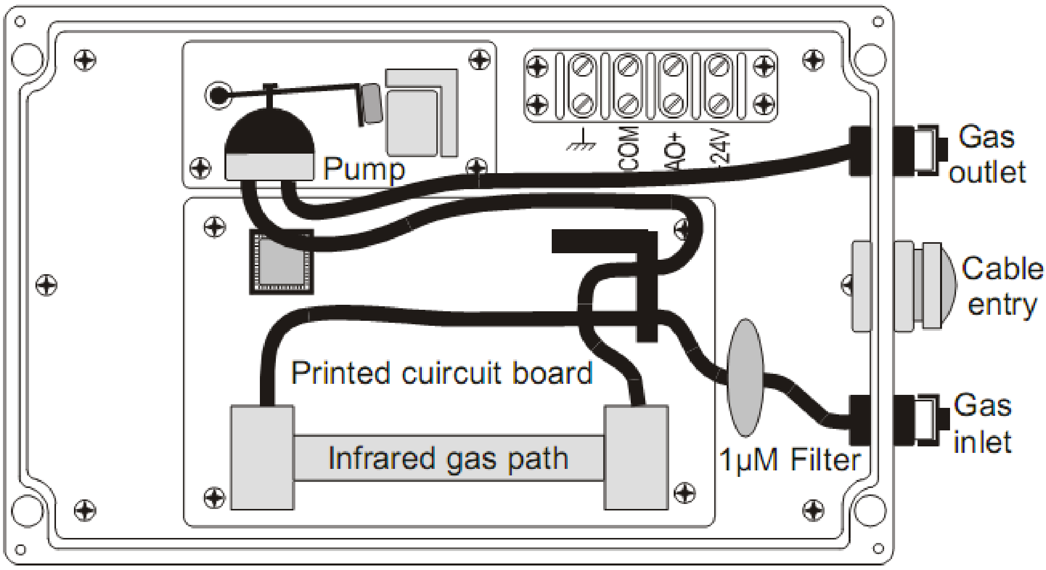


Fig.2.11 Monicon IR100 NDIR Methane Sensor Circuit

CHAPTER III
METHODS

3.1 Monitoring System Overview

The previous measurement methods for a laboratory scales digestion system has problems with flow rate, temperature. If level of water in temperature control tank was too low, it cause danger to the heating system and data had to be collected manually. This research aim to design the monitoring system which can measured and collect data from a Laboratory Scale Digestion system in real time. The data that were measured consisted of flow rate of gas, temperature of gas from each tank, methane concentration of gas and level of water in temperature control tank.

Main problems from previous research were:

- Data can only be collected manually and not memorized real time.
- The flow meter cannot detect very high flow rate and stop working.
- Flow meters have the undetectable and cannot be calculated error because reed switched may not detect magnets

The composition of monitoring system was divided into digestion tank (Fig 3.1), sensor system, control device, data collection and safety system. Seven 20-Liters Digestion Tanks were used in this research.

Fig. 3.1 Digestion Tank

Gas from digestion system entered seven mechanic flow meters (Fig 3.2) using a rotation cup detected by magnet and reed switch for measured amount of gas. Seven thermistors were used for measured temperature of gas in each tank, and analog Methane Sensor was using for measured Methane Concentration.

Fig 3.2 Flow meter at normal position

The control device used Microcontroller PIC18F8722 as a main Control device. Microcontroller received signal from all sensors except the temperature sensor in temperature control tank. For transferring data, the first microcontroller was connected to computer by using RS232 serial port. 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.

3.2 Digestion System in this Research

3.2.1 Digestion Tanks

In this research, seven 20-Liters Digestion Tanks as shown in fig 3.1 was used. Each tank has feeding materials hole, temperature measurement hole, DC motor with Stir Blade for stiring gas and materials 15 minutes every hours. Fig 3.3 shows the diagram of the cover of digestion tank.

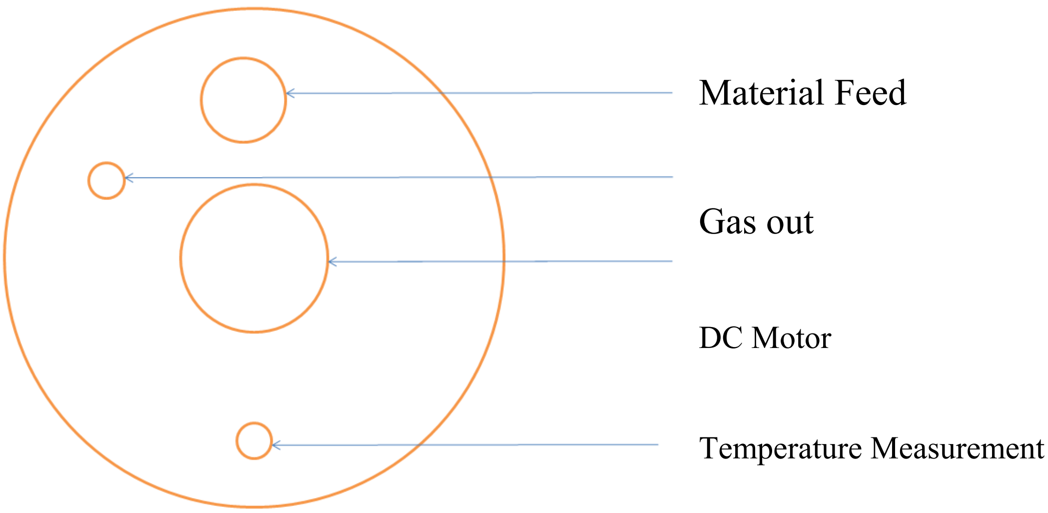


Fig. 3.3 Diagram of digestion tank

3.2.2 Temperature Control tank

Seven tanks were being installed in temperature control tank (Fig 3.4) which filled with hot water and control the temperature with shower heater in the heating System

Fig. 3.4 Seven Digestion Tank in temperature control tank

3.2.3 Heating System in Temperature Control Tank

For temperature control of water in temperature control tank, a temperature sensor was installed to measure the temperature of water. When the temperature of water in tank was lower than the setting temperature, water would be pumped from tank and was heated by shower heater shown in Fig 3.5 and refilled into Temperature control tank again.

Fig 3.5 Heating System

3.3 Previous Measurement Methods and Problems

3.3.1 Flow Meter

3.3.1.1 Flow Counting System

The boxes of Flow Meters were filled with water. Flow of biogas was measured using a turning cup separated in to two sides and has fixed point at middle of bottom of the box to allow it to move only circular way which trapped the bubble of biogas. The cup would turn when it was filled up then. The turning cup and flow meter drawing is shown in fig 3.6.

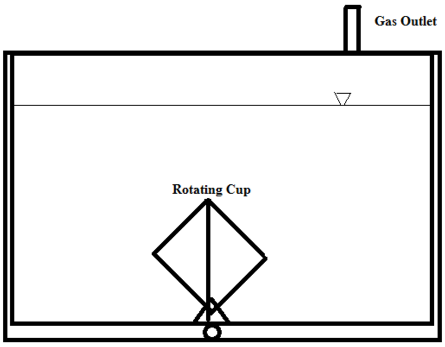


Fig 3.6 Drawing of flow meter

3.3.1.2 Flow Meter Calibration

In this research, syringe was used for calibrated the volume of gas per turning of cup. By feeding the air manually in to each flow meter and when the cup turned, read the volume of gas fed into the flow meter for the volume of gas per turning (cm^3). The result of calibration is shown in table 3.1 and Table A.1

Table 3.1 Volume of gas for the cup to turn

Flow Meter (Number)	Volume of Gas per turning (cm^3)
1	6.5
2	7
3	6
4	6
5	7
6	7.5
7	6.5

3.3.1.3 Counting the Number of Turning of Cup

To detach the number of cup turning, magnet was attached and turning along with the cup. Reed switch was attached outside the box and when the cup turning (Fig 3.7), magnet will pass reed switch and send signal to the digital counter (Fig 3.8). Pulse count from reed switches means the number of the cup rotation when it was filled up then and calculate the amount of gas.

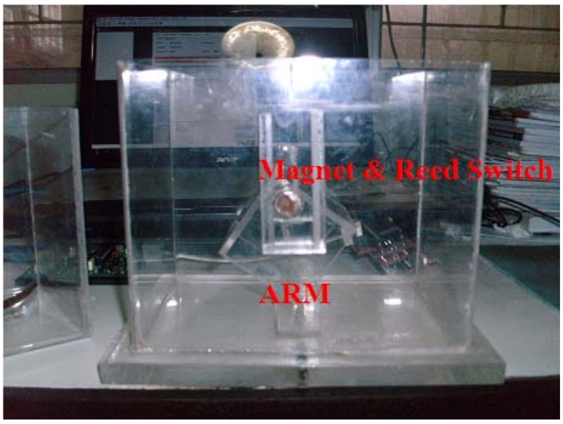


Fig 3.7 The flow meter with magnet and reed switch at the detected position

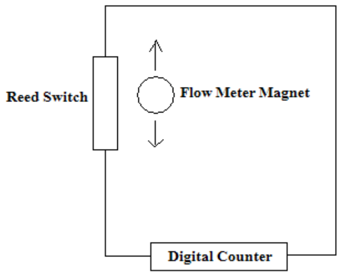


Fig. 3.8 Reed switch Circuit

In the previous research when flow rate exceeds the measuring range was filled in, the flow meter's cup will stop at the middle because gas fill in both side of cup and cannot be released because of gas in other side of cup then the system will stop and cannot continue measure flow rate from that tank.

When the cup stops, the other magnet will be used for make the flow meter's cup move to normal from outside the box. But this method can be used only manually when researcher came to collected data so the gas that flowed during the stop working time cannot be measured.

3.3.2 Temperature Measurement

In the previous research, temperature can only be measured manually using thermometer inserted into each digestion tank.

3.3.3 Methane Concentration Measurement

In the previous research, methane concentration can only be measured manually using digital methane sensor to measure the outlet gas from flow meter before entered the Gas Storage Bag.

3.3.4 Level of Water in Temperature Control Tank

In the previous research, level of water can only be measured manually.

3.3.5 Data Collection

In the previous research, researcher can collected data only when they went to laboratory and can't collect any previous data.

3.3.6 Problem Conclusion

1.) The original measurement and data collection method can only be done manually when the researchers went to laboratory. The system could not collected data in real time because it has no data collector, so the researcher can collect only the current data at the measurement time.

2.) When flow rate in each tank exceeded the measuring range flow meter of that tank will stop working and the flow of gas will not be measured anymore.

3.) When an error occurs, it cannot be resolved until the researcher went to collected data so the gas that was flow in the stop working time cannot be measured and cause an error in data collection.

4.) Without level of water measurement, researcher would not know if the water was being low nor rate of decrease of level of water in temperature control tank.

3.4 Redesigned Measurement Methods

3.4.1 Flow Meter

3.4.1.1 Extend Measuring Range

The original flow meter has low measuring range and cannot use with high flow rate. Redesigning the flow meter to extend the measuring range by installed the addition weight to the cup of flow meter and the level of water in flow meter box, then the volume of gas per turning time was extend and the measuring range was extend too.

3.4.1.2 Redesigned the Counting System

First circuit, two way reed switches were replaced with three way reed switches that send an output data in pulse (on and off) same as reed switches so it can be installed in same position and with old circuits. When the cup with magnet pass, reed switch would let the signal pass to Microcontroller and digital counter as shown in fig 3.9, testing result showed that tis circuit was not worked, only microcontroller can detected a signal because the digital counter can only detected signal from itself.

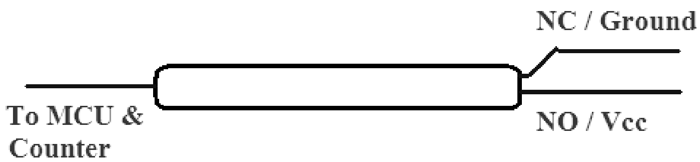


Fig 3.9 1st Design of new reed switch circuit

Second circuit, because microcontroller can detect both signal and no signal but digital counter can only count the input signal so circuit of reed switch was changed to a circuit shown in fig 3.10. When there is no magnetic field, microcontroller should receive signal from reed switch then when there no magnetic field microcontroller should not receive signal from reed switch but digital counter could receive it instead.

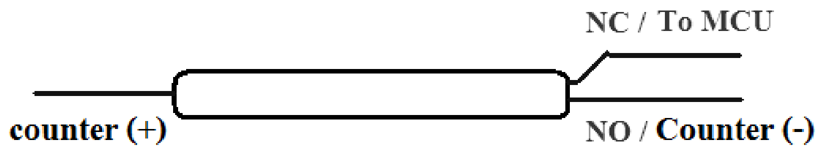


Fig 3.10 2nd Design of new reed switch circuit

Testing result of the second design of new reed switch circuit showed that microcontroller could not detect signal from digital counter because the circuit was not complete but digital counter worked satisfactory.

3.4.1.3 New Reed Switches Circuit

Because the researcher couldn't use same signal for both microcontroller and counter so, two reed switches were installed for each flow meter. 1 from A type reed switch was install for digital counter only and 1 from C type reed switch was install for microcontroller only, the new circuit diagram is shown in Fig 3.11

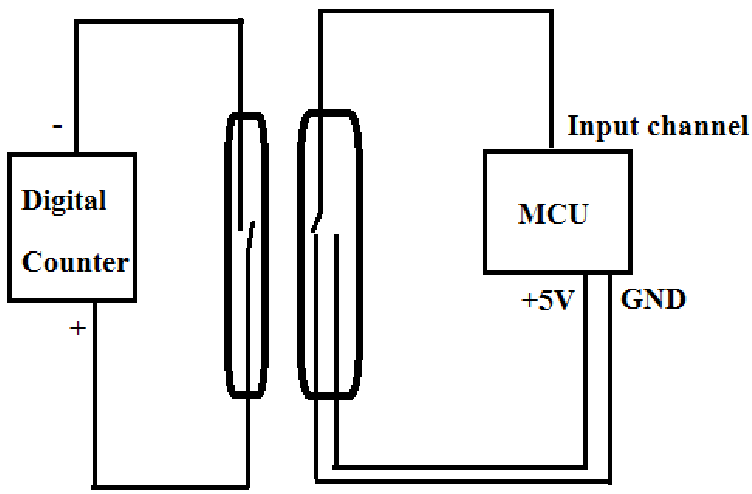


Fig 3.11 New reed switch circuit diagram

Circuit of digital counter worked normally, Circuit of microcontroller was designed to make the microcontroller to receive ground signal instead of nothing when there is no magnetic field to prevented the error from input of microcontroller and receive voltage signal when there is magnetic field and count it to measure the flow count.

3.4.1.4 New Calibration

Same as previous research, syringe was used for calibrated the volume of gas per turning of cup. The air was fed manually into each flow meter. When the cup turned, volume of gas fed into the flow meter for the volume of gas per turning (cm^3) can be read. The result of calibration is shown in Table 3.2 and Table A.2.

Table 3.2: New volume of gas per flow meter turning

No.	Volume of Gas (cm3)	
	Old	New
1	6.5	7.5
2	7	8
3	6	7
4	6	7
5	7	8
6	7.5	8
7	6.5	7.5

3.4.2 Temperature Measurement Using Thermistor

10 kΩ type thermistor (Fig. 3.12) which have standard value of 10 kΩ resistance at 25ºC were used for experiment.

Fig 3.12 10kΩ type thermistor

3.4.2.1 Thermistor Resistance Calibration

For temperature measurement, using seven sets of 10 kΩ type thermistor which have standard value of 10kΩ resistance at 25 ºC. The dry well temperature calibrator (Fig 3.13) which has an error of ±0.2 ºC at 25 ºC room temperature was used for calibration. The standard temperature was set at 0-50 ºC (Fig 3.14) then measured the output resistance value of thermistor for every 5 ºC increment. The result of resistance value of thermistor are shown in Table 3.3 and Fig 3.15.

Fig 3.13: Dry well temperature calibrator

Fig 3.14: Setting standard temperature using dry well temperature calibrator

Table 3.3: Thermistor standard resistance value calibration

Standard Temperature (ºC)	Standard Resistance (kΩ)			
	1	2	3	AVG
0	27.7	27.5	27.67	27.62333
5	22.24	22.27	22.31	22.27333
10	18.03	18.05	18.12	18.06667
15	14.85	14.8	14.78	14.81
20	12.22	12.21	12.1	12.17667
25	10.06	10.05	10.04	10.05
30	8.37	8.36	8.35	8.36
35	7	7	7	7
40	5.88	5.86	5.84	5.86
45	4.92	4.92	4.92	4.92
50	4.16	4.16	4.16	4.16

.

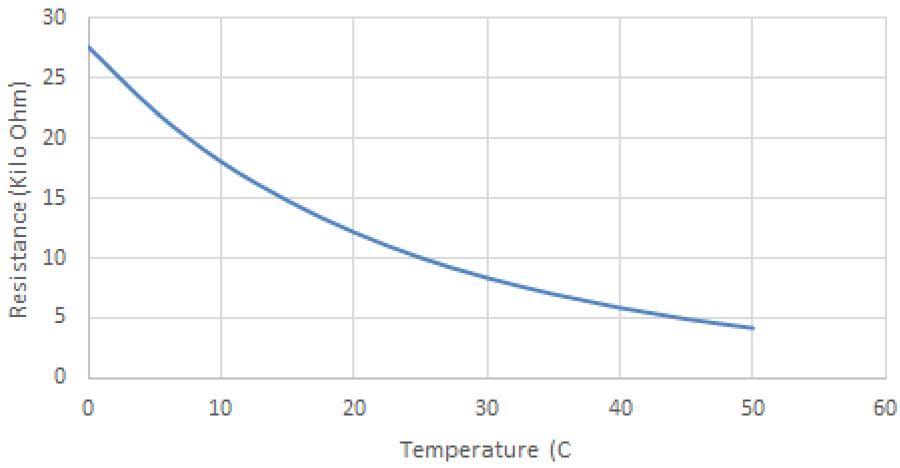


Fig 3.15 Graph of Resistance of thermistor for temperature

Thermistor have standard value of 10kΩ resistance at 25 °C, result at 25 °C standard temperature show that thermistor has an error only 0.05 kΩ

3.4.2.2 Thermistor measuring circuit

For measured output temperature using analog to digital converter of Microcontroller, the circuit should produce an output in voltage value. The measuring circuit is shown in Fig 3.16

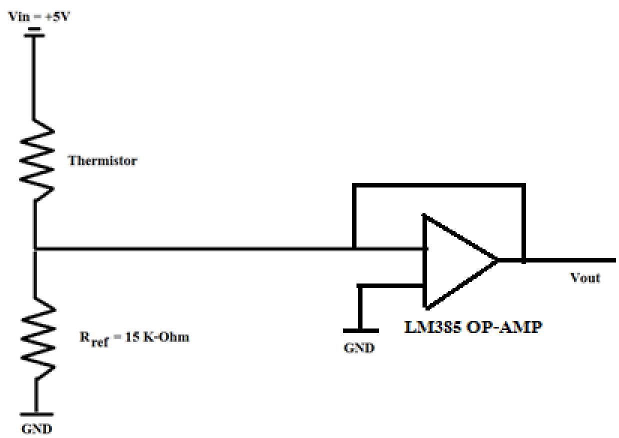


Fig. 3.16 Thermistor circuit diagram

From circuit in Fig. 3.16, the standard output voltage can be calculated by using Equation 3.1 and 3.2

$$V_{STD}(V) = \frac{R_{Ref}}{R_{Ref} + R_{Thermistor}} V_{In} \tag{3.1}$$

T_{STD} Standard temperature set from dry well temperature calibrator

V_{STD} Standard voltage output from calculation

R_{Ref} Reference resistor, this research designed for using a 15 kΩ resistor)

$R_{Thermistor}$ Resistance value of thermistor from Table 3.3

V_{In} Input voltage, this circuit use voltage supply from microcontroller with 5 volt output

In this research equation 3.1 changed to.

$$V_{STD}(V) = \frac{15}{15 + R_{Thermistor}} 5 \tag{3.2}$$

Using equation 3.2, the calculated of standard voltage for each temperature value is show in Table 3.4 and Fig 3.17.

Table 3.4: Standard voltage value from calculation.

T_{STD} (°C)	V_{STD} (V)
0	1.7596
5	2.012162
10	2.268145
15	2.515934
20	2.75972
25	2.994012
30	3.210616
35	3.409091
40	3.595398
45	3.76506
50	3.914405

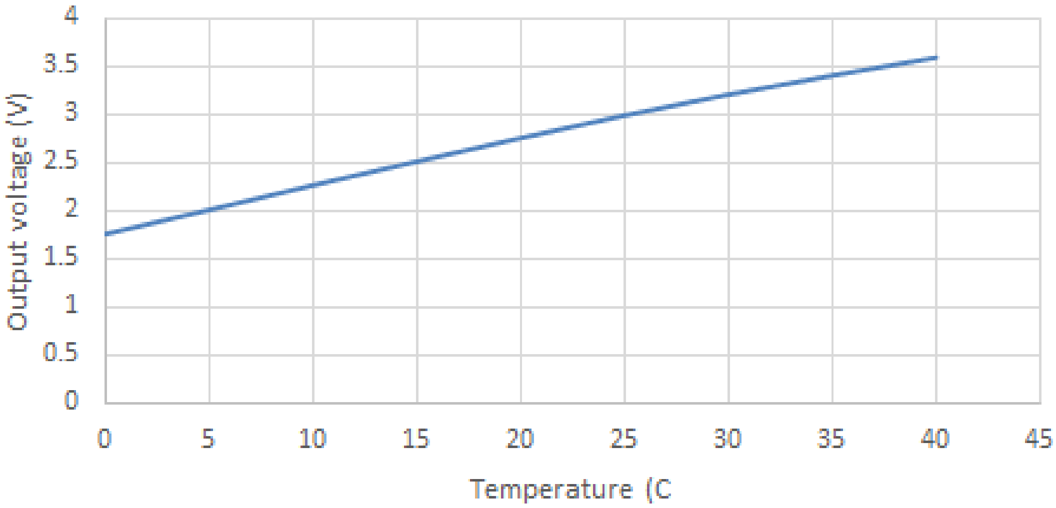


Fig 3.17 Graph of standard voltage of thermistor for temperature

3.4.2.3 Test with Microcontroller

Connected Thermistor circuit to analog to digital channel of microcontroller. The standard temperature was set at 0-50 °C then measured the output voltage value of thermistor for every 5 °C increment. Microcontroller collect and calculated the output voltage and calculate temperature, result of standard temperature compare with microcontroller calculation, the result is shown in table 3.5.

T_{STD} Standard temperature set from dry well temperature calibrator.

T_{MCU} Temperature calculated by microcontroller.

Table 3.5: Temperature calculated by microcontroller using output voltage compared with standard temperature.

T_{STD}	T_{MCU}
0	0.92
5	5.81
10	9.02
15	13.88
20	20.84
25	25.66
30	29.25
35	34.01
40	41.20
45	44.16
50	49.89

From the Table 3.5, average error is 0.90 °C and dry well's error was 0.2 °C. The total error can be calculated by equation 3

e_{total}	Total error
e_{DW}	Error of dry well temperature calibrator
e_{MCU}	Average error of Temperature calculated by microcontroller compare with standard temperature.

$$e_{total} = \sqrt{e_{DW}^2 + e_{MCU}^2} \qquad (3.3)$$

Total error was calculated

$$e_{total} = \sqrt{0.2^2 + 0.9^2} = 0.91\ ^{o}C$$

3.4.4 Level of Water

For safety, distance sensor [4] used for detecting 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 (Fig 3.18) comes with Sharp GP2D12 sensor. Sharp GP2D12 can precisely and reliably read distance from 4cm-30cm. Sharp GP2D12 provides your RCX with capability of measuring distances from an obstacle.

Fig.3.18 Distance sensor

3.4.4.1 Distance Sensor Calibration

Distance sensor was calibrated by using a reflective object placed with the standard distance. For each +1 centimeters increment, measure and collected the output voltage from the sensor using microcontroller for calibration the distance sensor equation. Result of output voltage is shown in Fig 3.19

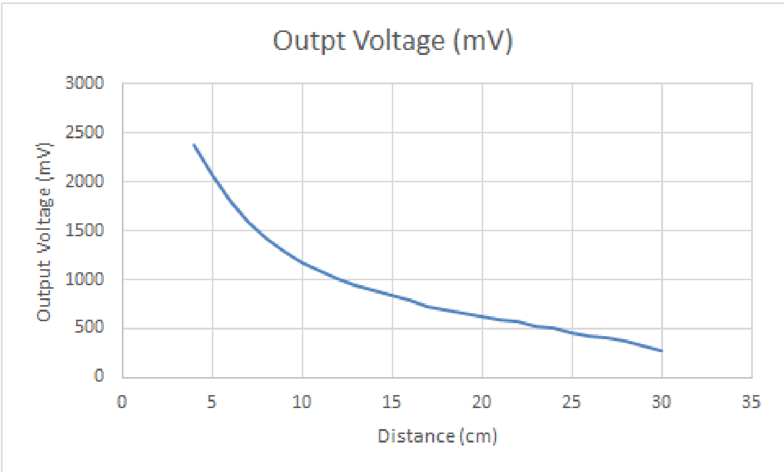


Fig. 3.19 Calibration plot for the distance sensor

From the calibration curve and use the same format as a distance equation from data sheet, new distance equation is shown in equation 3.4.

$$Distance(cm) = \frac{2914}{V_{out(in\ 10\ bits)} + 5} - 1 \quad (3.4)$$

Distance in centimeter

V_{out} Output voltage in 10 bits analog to digital converter format which can calculate from normal voltage value by

$$V_{out(10\ bit)} = \frac{V_{out} \times 1023}{5000} \quad (3.5)$$

3.4.4.2 Distance Sensor Installation

Distance sensor was installed above temperature control tank and there was a reflecting object on the water (Fig 3.20)

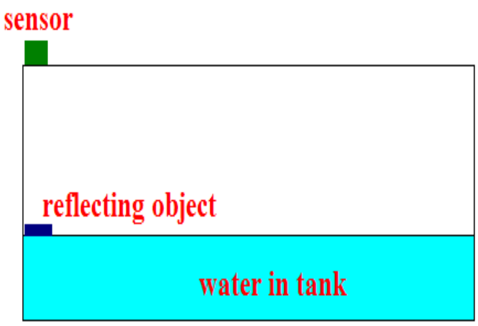


Fig. 3.20 Diagram of distance sensor installation

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

3.5 Microcontroller

PIC18F8722 microcontrollers (Fig 3.21) was use in this research. Microcontroller received signal from reed switches, thermistors methane sensor and distance sensor. For transferring data, the microcontroller was connected to a PC computer by using RS232 serial port.

Fig 3.21 PIC18F8722 Microcontroller with programming board

3.6 Programming

Microcontrollers PIC18F8722 and its programming board with signal ports and programming ports. This research uses C++ language with PIC C Compiler (Fig 3.22) to write and CCS compiler to compile source code for microcontrollers and then use PIC Kit Programmer (Fig 3.23) to load program to microcontroller with ET-PGM PIC USB2.0 (Fig 3.24) using PICkit 2 Programming for loading hex file to microcontroller.

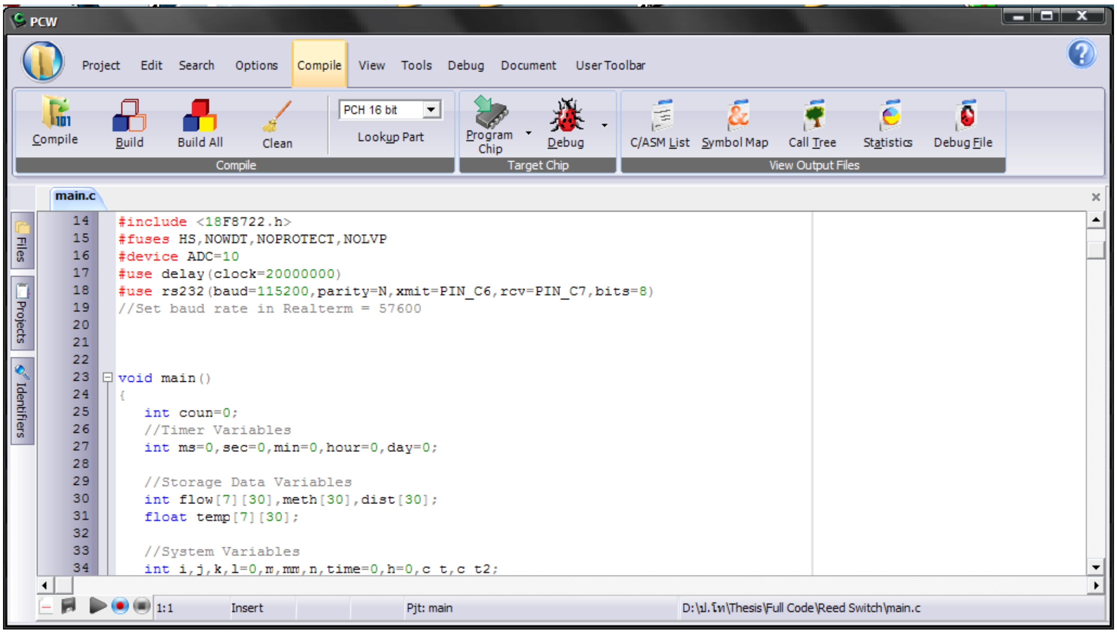


Fig 3.22 PCWHD Program with CCS C Compiler

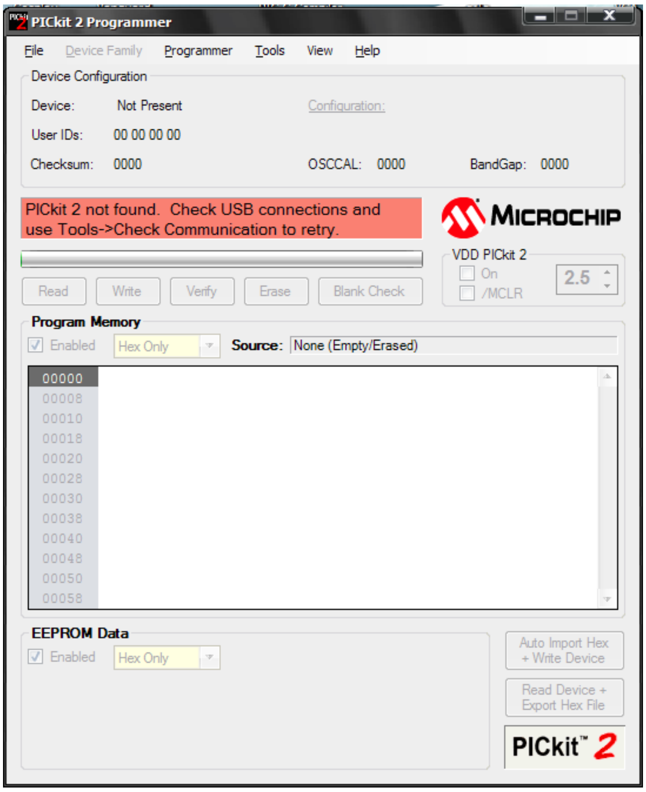


Fig 3.23 PICKit program for code loading to microcontroller

Fig 3.24 Connect microcontroller to computer using ET-PGM PIC USB2.0

3.7 User Interface

3.7.1 User Control Panel

For control the system, five switches were installed for user (Fig. 3.25).

- Switch 1 for show current data in terminal program.
- Switch 2 for read all collected data.
- Switch 3 for reset all data except time and number of data.
- Switch 4 for reset all data to zero.
- Switch 5 for enable or disable RS232 connection.

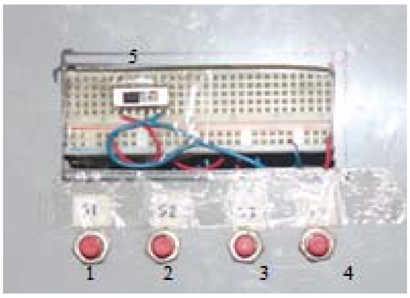


Fig. 3.25 Control switches

3.7.2 Manual Measurement

For flow counter, the digital counter was installed for each flow meter and detected signal by using reed switches for detect a magnet same as microcontroller

For temperature, a thermometer was installed for each digestion tanks

3.8 Input type of Transducers and Ports of Microcontroller Setting

The transducers that produce a pulse input are reed switches and normal switches. The input signal is only on and off. Microcontroller can detect a signal by using normal input-output (I/O) ports, PORTE was use for reed switches and PORTC was used for control switches.

The transducers that produce an analog input are thermistor, methane concentration sensor and distance sensor. All that transducer would change a resistance value of itself and then produce a difference voltage according to measuring value. Microcontroller have to measure and output voltage for calculating. Microcontroller cannot detect a signal by using normal input-output (I/O) ports, it has to use an analog to digital converter (ADC) ports in PORTA and PORTF.

The list of input type and ports for all transducers is shown in Table 3.6.

Table 3.6 Port list for all transducers

<table>
<tr><th>Transducer</th><th>Input Type</th><th colspan="2">Port</th></tr>
<tr><td>Reed switch</td><td>Pulse Input</td><td colspan="2">RE0 – RE6</td></tr>
<tr><td rowspan="7">Thermistor</td><td rowspan="7">Analog Input
(To Analog to digital
Converter / ADC port)</td><td>AN0</td><td>RA0</td></tr>
<tr><td>AN1</td><td>RA1</td></tr>
<tr><td>AN2</td><td>RA2</td></tr>
<tr><td>AN3</td><td>RA3</td></tr>
<tr><td>AN4</td><td>RA5</td></tr>
<tr><td>AN5</td><td>RF0</td></tr>
<tr><td>AN6</td><td>RF1</td></tr>
<tr><td>Distance sensor</td><td>Analog Input
(To ADC port)</td><td>AN8</td><td>RF3</td></tr>
<tr><td>Methane sensor</td><td>Analog Input
(To ADC port)</td><td>AN9</td><td>RF4</td></tr>
<tr><td>Switch</td><td>Pulse input</td><td colspan="2">RC0 – RC4</td></tr>
</table>

3.9 RS232 Connection and Reading Data

For reading data, microcontroller was connected to computer with RS232 serial port and 6 control switches at control box.

3.9.1 Terminal Software for Reading & Collecting Data

For reading current data and saving collected data all terminal could be used for this experiment. This research uses RealTerm Serial Capture Program (Fig 3.26) which can be set many type of display, setting and connection. This program also can save all data on screen automatic without user to copy it himself.

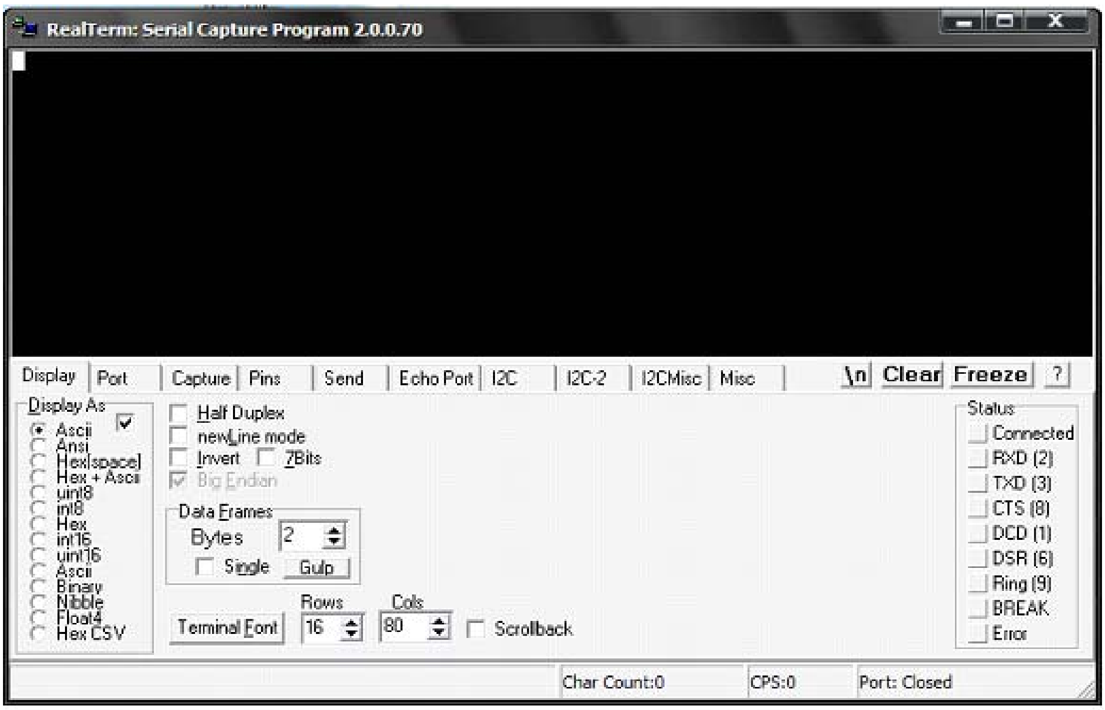


Fig 3.26 Realteam Serial Capture Terminal Program

3.9.2 Instruction of Using Terminal Program

3.9.2.1 Display Setting (Fig 3.27)

- Set Display As to Ansi and uncheck the check box for display correctly
- Set font at Terminal Font
- Set number of Max Rows and Columns and check an enable or disable scroll back

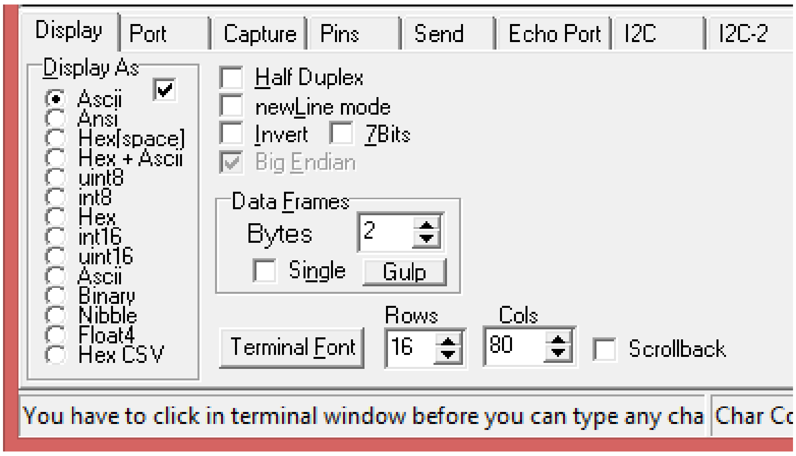


Fig. 3.27 Terminal Program, Display Setting

3.9.2.2 Port Setting (Fig 3.28)

- Set Baud Rate to 57600
- Set Parity to None
- Set Data Bits to 8 Bits
- Set Stop Bits to 1 Bits
- Set Hardware Flow Control to None
- Set Port to port that shown in Device Manager

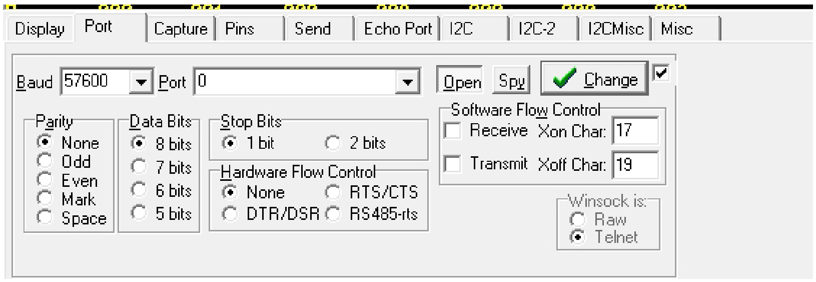


Fig. 3.28 Terminal Program, Port Setting

3.9.2.3 RS232 Serial Port connection

Fig 3.29 and Fig 3.30 show the UCON-232s USB to RS232 Converter and ET-RS232 9 PIN F use for connect microcontroller to computer using USB port

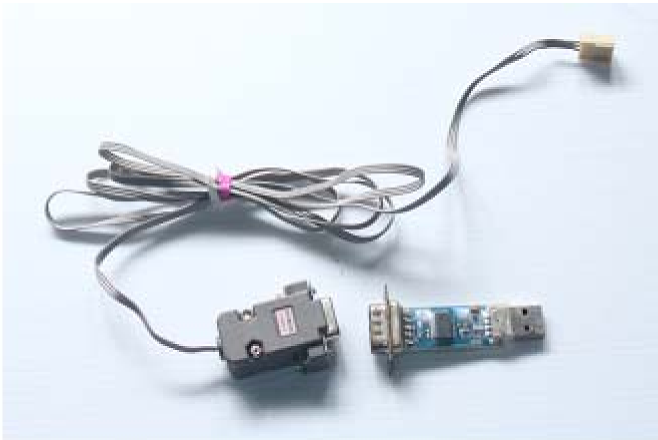


Fig 3.29 UCON-232s USB to RS232 Converter and ET-RS232 9 PIN F

Fig 3.30 Connect Microcontroller to Computer Using RS232 Serial Port

3.9.3 Reading Current Data

After setting program and connect RS232 as detailed in section 3.9.2.1 to 3.9.2.3 then press the Open button in Port setting and press first switch and then the program will show a current data collection consisted of data of

1.) Total time and number of data collected
2.) Flow counter for each tank for last 3 hours or other setting period.
3.) Room or laboratory temperature
4.) Temperature in each tanks
5.) Methane concentration
6.) Distance between distance sensor and reflecting object.

The current data display in software is shown in Fig 3.31 and 3.32

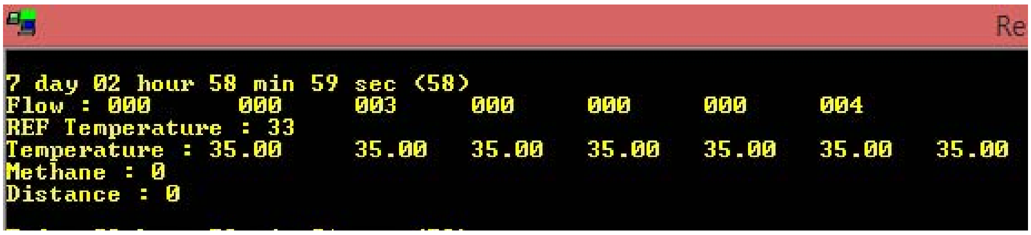


Fig 3.31 Current Data

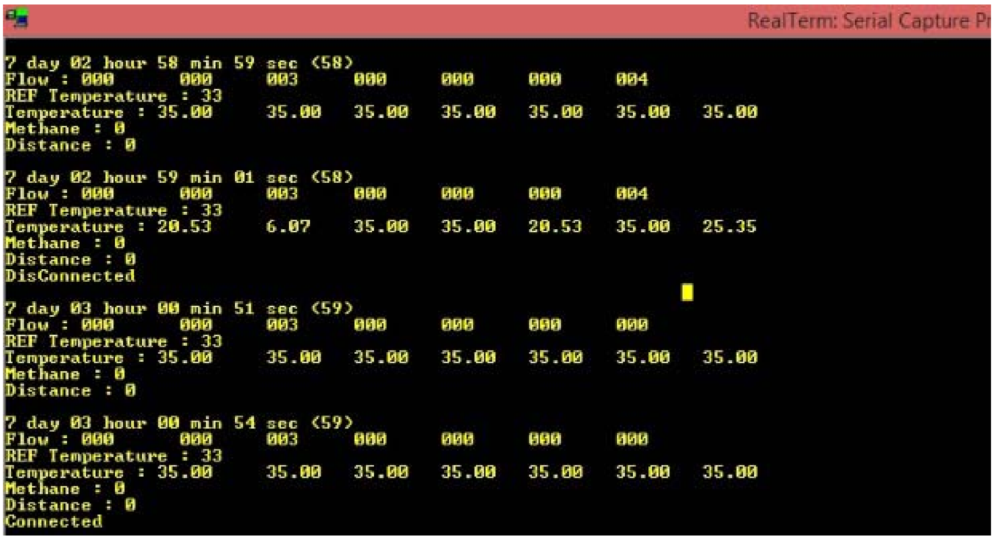


Fig 3.32 Real time Data Reading

3.9.4 Reading All Data

After setting program and connect RS232 as detailed in section 3.9.2.1 to 3.9.2.3 and Open button is enabled then press the second switch and then the program will ask the user to input the number for select which data should the program display then the data shown as show in Fig 3.33, Fig 3.34 and Fig. 3.35.

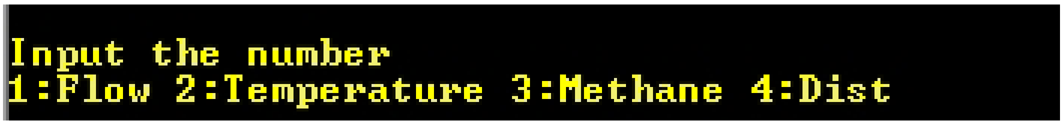
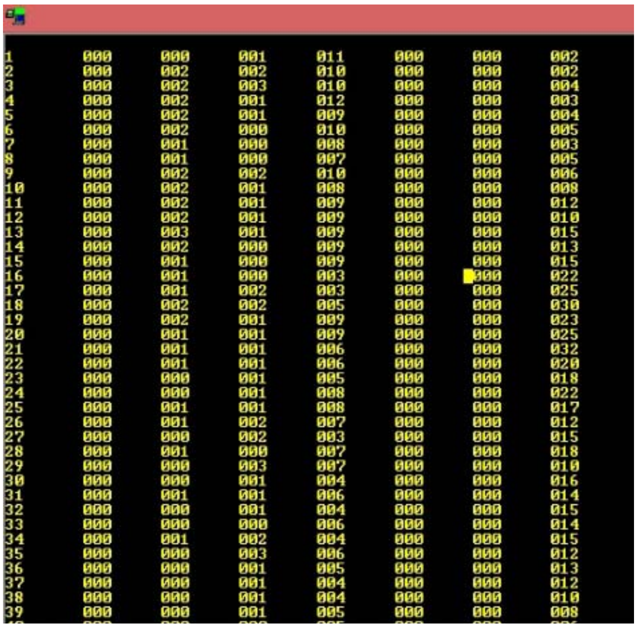


Fig3.33 inputting the number for selected data to be shown



1	000	000	001	011	000	000	002
2	000	002	002	010	000	000	002
3	000	002	003	010	000	000	004
4	000	002	001	012	000	000	003
5	000	002	001	009	000	000	004
6	000	002	000	010	000	000	005
7	000	001	000	008	000	000	003
8	000	001	000	007	000	000	005
9	000	002	002	010	000	000	006
10	000	002	001	008	000	000	008
11	000	002	001	009	000	000	012
12	000	002	001	009	000	000	010
13	000	003	001	009	000	000	015
14	000	002	000	009	000	000	013
15	000	001	000	009	000	000	015
16	000	001	000	003	000	000	022
17	000	001	002	003	000	000	025
18	000	002	002	005	000	000	030
19	000	002	001	009	000	000	023
20	000	001	001	009	000	000	025
21	000	001	001	006	000	000	032
22	000	001	001	006	000	000	020
23	000	000	001	005	000	000	018
24	000	000	001	008	000	000	022
25	000	001	001	008	000	000	017
26	000	001	002	007	000	000	012
27	000	000	002	003	000	000	015
28	000	001	000	007	000	000	018
29	000	000	003	007	000	000	010
30	000	000	001	004	000	000	016
31	000	001	001	006	000	000	014
32	000	000	001	004	000	000	015
33	000	000	000	006	000	000	014
34	000	001	002	004	000	000	015
35	000	000	003	006	000	000	012
36	000	000	001	005	000	000	013
37	000	000	001	004	000	000	012
38	000	000	001	004	000	000	010
39	000	000	001	005	000	000	008

Fig 3.34 Collect Flow Data

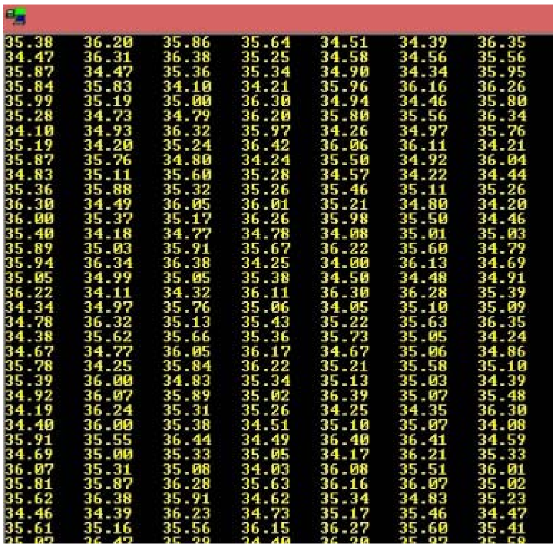


Fig 3.35 Collect Temperature Data

3.9.5 Transfer Data to Text Document

After setting program and connect RS232 as detailed in section 3.9.2.1 to 3.9.2.3, Open button is enabled and in the input number state (from 3.9.4) then open the Capture page (Fig 3.36)

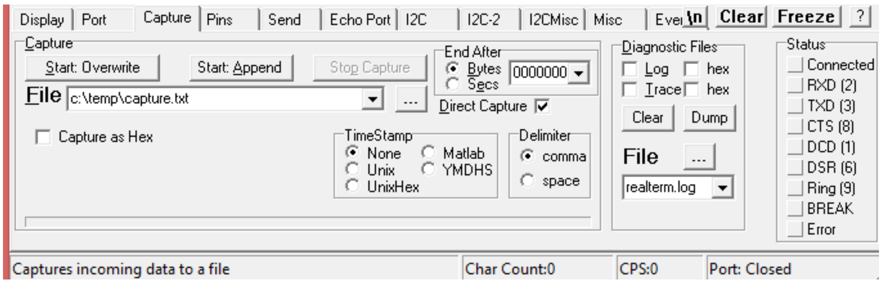


Fig 3.36 Capture page in terminal program

Select File location and file name for data to be saved and then press the Start Overwrite button to start capture the data would display on display screen. In this state the display would stop working and did not show anything anymore but the program was still working normally then click once on the display screen and input the number normally, the data would be saved. Press the Start Overwrite button again to stop capturing data.

3.10 Test the Monitoring System Manually Without Digestion Tank

Before installed the monitoring system in Laboratory-scale digestion system, the system was tested manually for all equipment using the testing program.

1) Reed switches
2) Reed switches with flow meter was tested by feeding normal air into flow meter manually
3) Thermistors
4) Distance Sensor
5) Collecting Data

The methane sensor cannot be tested this part because of not calibrated and not have methane gas.

After testing each part then connected all equipment with Microcontroller and test flow meter manually again to saw the working of Reed switches.

3.11 Experimental Setup

3.11.1 Laboratory Setup

Seven digestion tank were put into a temperature control tank then the gas tube was install for gas produced by the digestion would flow out of digestion tanks (Fig 3.37). Other side of gas tube were inserted in to a flow meters which place on the table (Fig 3.38). The outlet gas tubes from flow meter were inserted into gas container bags

Fig. 3.37 Seven digestion tanks with gas tube

Fig. 3.38 Seven flow meters installation

Thermistors were inserted into each digestion tanks, connected to operational amplifier with gain = 1. Distance sensor was install at the corner of temperature control tank with reflecting object on the surface of water in tank. Then all transducers were connected to microcontroller that place inside the control box (Fig 3.39).

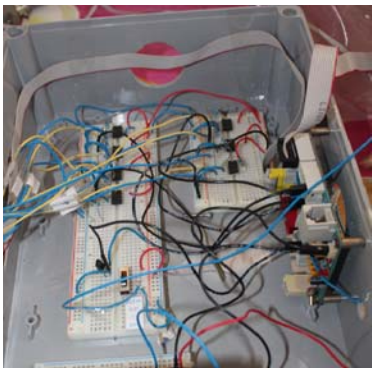


Fig 3.39 Control box

Temperature sensor for heating system was installed in the water in tank to control the pump. Pump would pump the lower than setting temperature water out of tank to heater and feed back into temperature control tank.

Stir blade with control by motor on the cover of digestion tank. The 12V Power supply was used in this research. The timing of stirring was controlled by timer switch (Fig 3.40) which connect to normal 220V and set to activate 15 minutes every 2 hours. It controlled the input power for power supply instead of install power supply directly to 220V to prevent the overload of power supply.

Fig 3.40 15 minutes period analog timer switch

3.11.2 Process of Digestion

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

The system was tested by operating the laboratory scale digester using Napier grass as feedstock. Material was prepared in Inoculums tank before feed in to digestion tank and operated the digestion system. The catalyst was added to the material. After a few days there was some gas produced so it can feed it into the digestion tanks.

Calibrated 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 into main program of first Microcontroller.

3.11.3 Manual Test the System with All Equipment Installed in Laboratory

The system was tested manually for all equipment using the testing program and full program.

1) Reed Switches
2) Reed Switches with Flow Meter was tested by feed normal air into Flow meter manually
3) Reed Swiches, Flow Meter and Digital Counter
4) Thermocouples and OP-AMP
5) Distance Sensor
6) Collecting Data

3.12 Experimental Procedure

3.12.1 Pre-Test the System

The system was tested by operating the laboratory scale digester using papaya and Napier grass as feedstock. Data were monitored and recorded during 2 weeks for pre-test. Monitoring results were observed and compared with manual measurements every 3 days to see that the digestion system and monitoring system worked as planed

.

3.10.2 Full Test the System

After pre-test result showed that the system was working satisfactory the system was tested full experiment by operating the laboratory scale digester using new napier grass that was prepared again same as pre-test. Data were monitored and recorded during thirty days digestion period.

The full test was performed using pineapple (Fig 3.40) as feedstock and use only 3 digestion tanks for one substrate (feedstock). During 30 days of digestion period, monitoring results were observed and compared with manual measurements every 3-7 days

Fig. 3.41 Using pineapple as feed stock

CHAPTER IV
RESULTS AND DISCUSSION

4.1 The Monitoring System

4.1.1 Details of System

A new monitoring system for laboratory scale digestion system was developed and aimed to detect and collect real time signals from transducers including flow meters, methane sensor, and thermistor with operational amplifier and optical distance Sensor.

The monitoring system was tested by operating the digestion system in 2 laboratory sets. The pre-test digestion system consisted of seven sets of 20-Liters digestion tanks using napier grass as a feedstock. The pre-test was aimed to prepare and test the validity of the system. The digestion system is shown in Fig. 4.1 After the pre-test shown, full experiment laboratory test was performed using only 3 digestion tanks for one substrate (feedstock). Full experiment laboratory used pineapple as feedstock.

Fig 4.1 Seven Digestion Tanks in Temperature control Tank

The monitoring system was designed for detecting following data

1) Amount of gas produced from the digestion system

By using a mechanic flow meter (Fig 4.2) contained a water filled with water, flow of biogas was measured using a turning cup separated into two sides and has fixed point at middle of bottom of the box to allow it to move only circular way which trapped the bubble of biogas. The cup would turn when it was filled up with gas.

To detach the number of cup turning, magnet was attached and turning with the cup. Reed switch was attached outside the box. When the cup turns, magnet will pass reed switch and send signal to the digital counter. The number of the cups rotation are collected by counting pulse signal from reed switches.

Fig 4.2 Flow Meter Installed in Laboratory

2) Temperature of Gas in Digestion Tank

For measuring and collect Gas Temperature, thermometers were replaced by 10 kΩ type thermistor in each digestion tank. Microcontroller measured the output voltage from thermistors.

3) Level of Water in Temperature Control Tank

For safety, Distance Sensor used 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 (Fig 4.3) 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.4.3 Distance Sensor

4.1.2 Block Diagram of the Monitoring System

Fig 4.4 shows the block diagram of the monitoring system. The system consisted of the following equipment and transducers with microcontroller's input channels

1. Seven digestion tanks in temperature control tank

2. Gas outlet from the digestion tank was fed into seven flow meters with connected to channel 1 to 7 in control program of microcontroller.

3. Thermistors were inserted into each digestion tanks and connect to the operational amplifier with gain = 1 and then connected to analog to digital converter or channel 8 to 14 in control program of microcontroller.

4. From the 7^{th} flow meter or other one of flow meter or even the combination tube, the outlet gas was fed into a methane concentration sensor connected to analog to digital converter or channel 15 in control program of microcontroller.

5. Distance sensor was installed at the border of temperature control tank and connect to analog to digital converter or channel 16 in control program of microcontroller.

6. Temperature sensor was installed outside the temperature control tank and connect to analog to digital converter or channel 16 in control program of microcontroller.

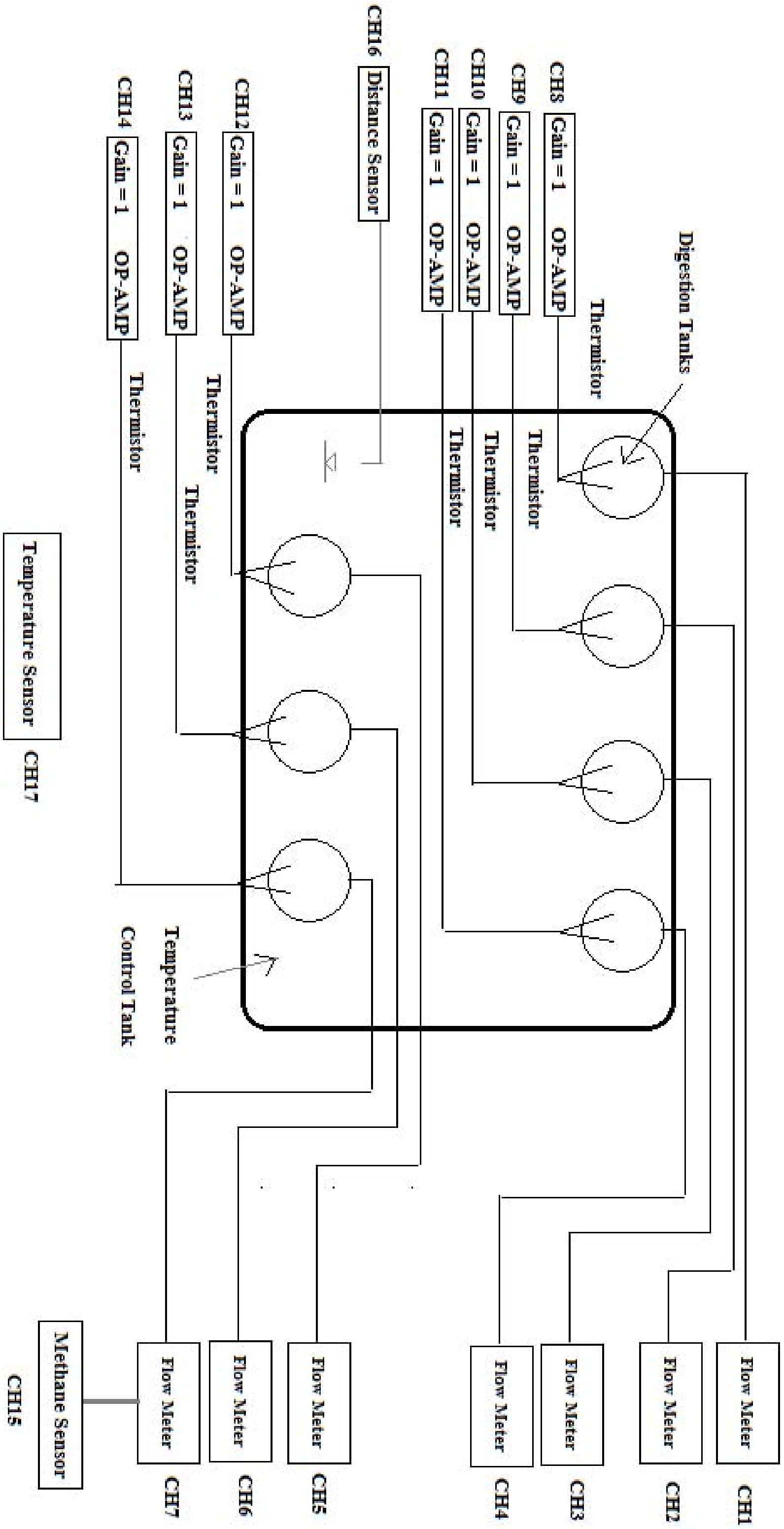


Fig 4.4 Block Diagram of the Monitoring System

4.1.3 Control System and Collecting Data

The monitoring system was controlled by microcontroller PIC18F8722 installed in a control box (Fig 4.5). The microcontroller received signals from reed switches, thermistors, methane sensors and level sensor. For transferring data, the first microcontroller was connected to a PC computer by using RS232 serial port (Fig 4.7)

This research uses C++ language with PIC C Compiler to write and CCS compiler to compile source code

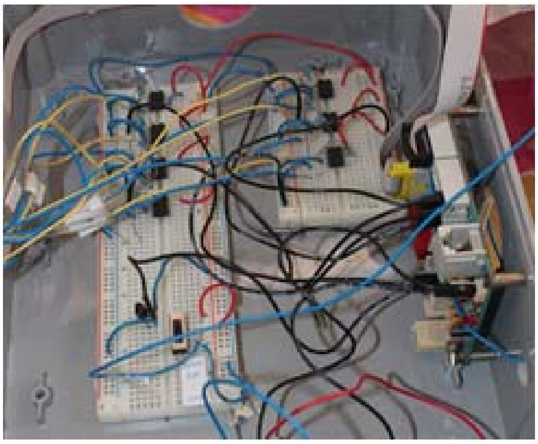


Fig 4.5 Control Box

For reading current data and save collected data, this research uses RealTerm Serial Capture Program is shown in Fig 4.6. Reading data using terminal program is shown in Fig 4.7 and Fig 4.8.

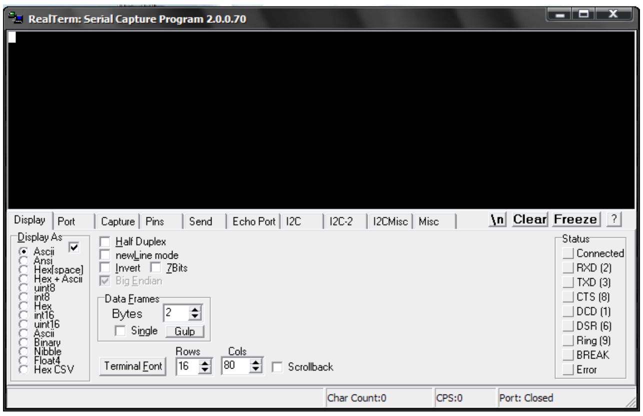


Fig 4.6 RealTerm Serial Capture Program

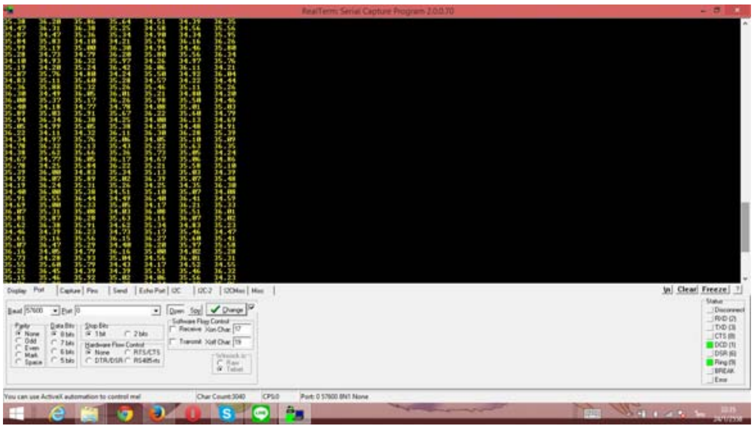


Fig 4.7 Reading temperature data using RealTerm Serial Capture Program

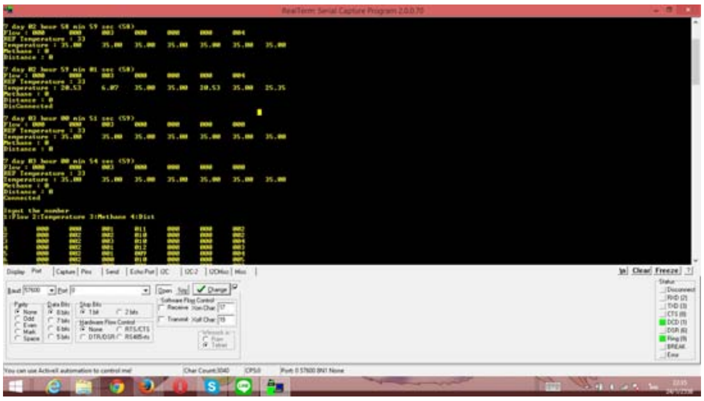


Fig 4.8 Reading current data using RealTerm Serial Capture Program

4.2 Monitoring System Specification

4.2.1 Flow Meter

The boxes of flow meters were filled with water. Flow of biogas which was considered very low flow rate was measured using a turning cup separated into two sides and has fixed point at middle of bottom of the box to allow it to move only circular way which trapped the bubble of biogas. The cup would turn when it was filled up then.

Each Flow Meter has different amount of Gas per turning of cup and was extended the measuring range recalibrate the new volume of gas, result was shown in Table 4.1

Table 4.1 Volume of Gas per turning of cup for each Flow Meter after re-calibration.

Flow Meter	Volume of Gas (cm^3)
1	7
2	7.8
3	6.3
4	7.8
5	6.5
6	6.2
7	7.5

4.2.2 Temperature

For temperature measurement, seven sets of 10 kΩ type thermistor which have standard value of 10kΩ resistance at 25 ^oC were used for experiment. The dry well Temperature calibrator which has an error of ±0.2 ^oC at 25 ^oC room temperature was use for calibration. The standard temperature was test at 0-50^oC and the output resistance value of thermistor for every 5 ^oC increment. The system can interpolated temperature between 0-50^oC using standard voltage shown in table 3.4

4.2.3 Distance Sensor

This research was tested 2 type of distance sensors

1.) GP2D12 infrared distance sensor can measure distance 10 to 80 centimeters from sensor

2.) GP2Y0A21YK0F infrared distance sensor can measure distance 4 to 30 centimeters from sensor

4.2.4 Number of Input Channels

The monitoring system was designed for 22 input channels.

- Seven channels of flow rate
- Seven channels of temperature with operational amplifier
- One channel of temperature sensor
- One channel of methane sensor
- One channel for distance sensor
- Five channels of switches

4.2.5 Memory of microcontroller

Internal memory of PIC18F8722 microcontroller can memory each channel's collected data only 80 times, programming in this research let it memorized data every 3 hours so the system can continue collected data for 10 days.

After transferring data to text document, program allows user to reset the collected data without breaking the system, excluding last two data (last completely collected data and current data), number of data and time counter.

The maximum value of Variable is 255 so the system cannot collected the Total flow count or calculate the total volume of gas to prevent the overflow of variables. Programming in this research let it memorized data every 3 hours so the system can continue collected data for only 31 days.

4.2.6 System Configuration Diagram

P&ID Diagram in Fig 4.9 shows the configuration and installation of all transducers.

TS1	=	Temperature switch
T1-T7	=	Thermistor
Temperature control	=	control the pump
F1-F7	=	Flow meter
P1	=	Pump
ADC	=	Analog to digital converter channels
DAQ	=	Data acquisition

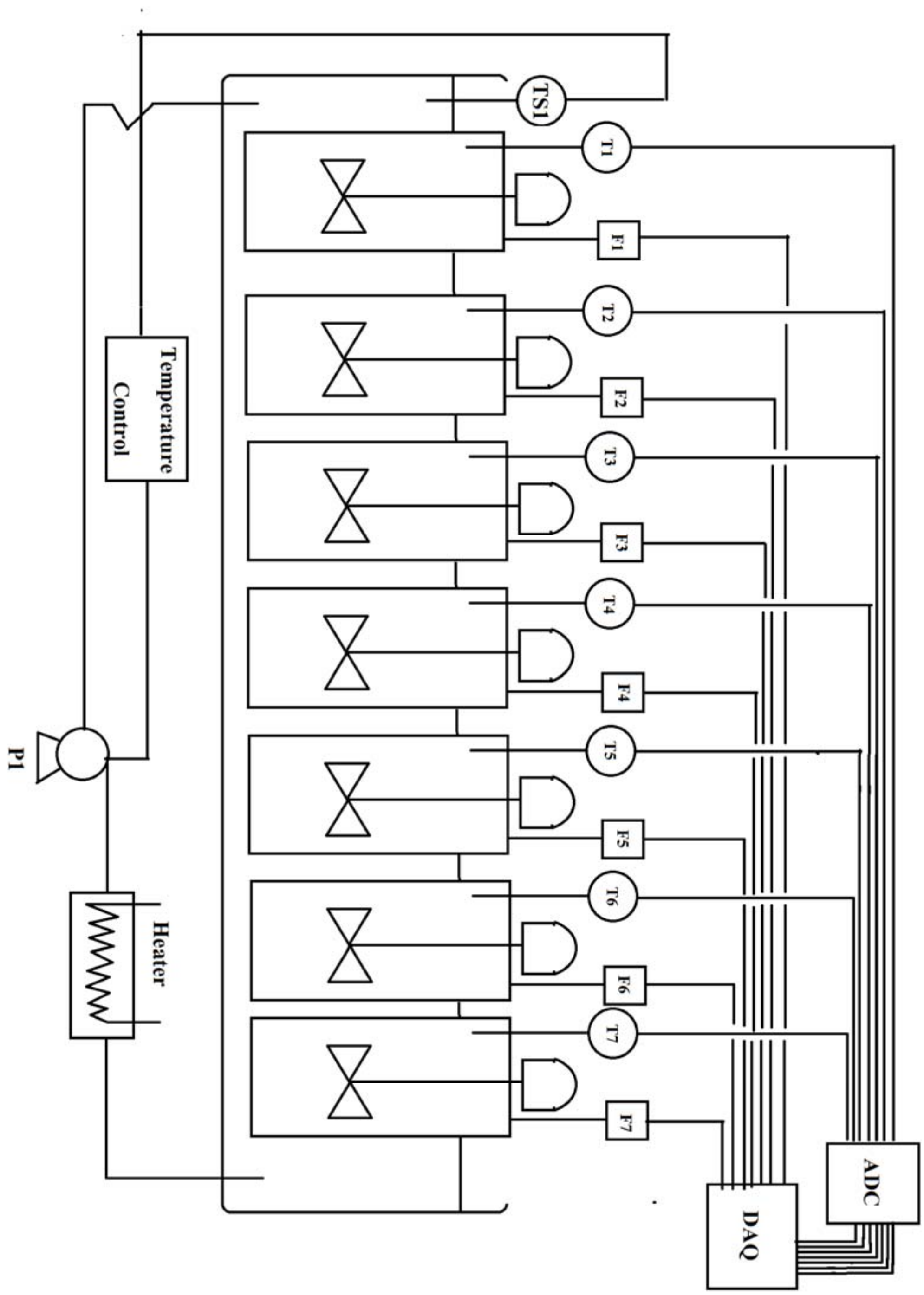


Fig. 4.9 P&ID Diagram of monitoring system

4.2.7 DAQ and Control Diagram

DAQ and control diagram in Fig 4.10 shows the configuration and installation of all control system of all transducers, microcontroller and computer.

T1-T7 Thermistor

F-F7 Flow meter

MS1 Mrthane concentration sensor

DS1 Distance sensor

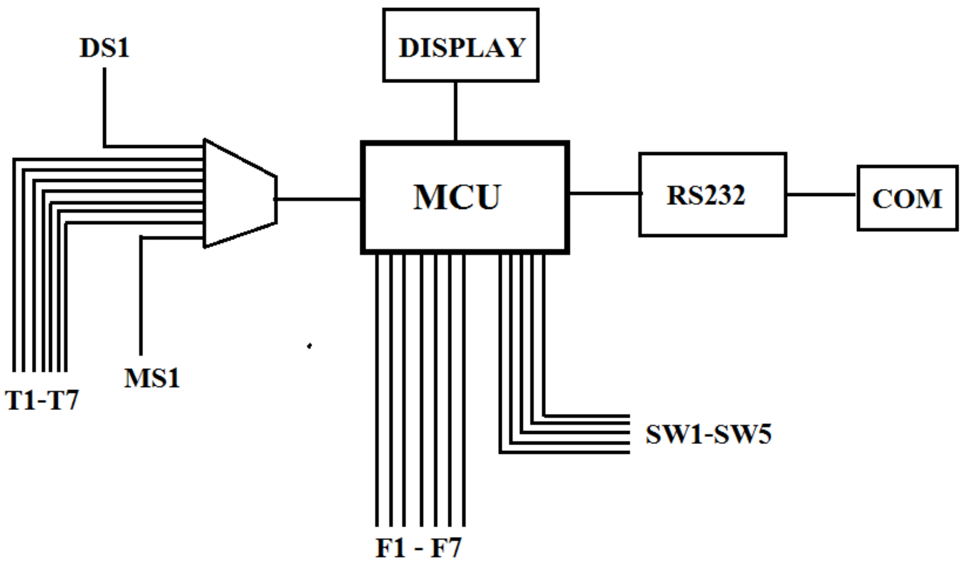


Fig 4.10 DAQ and Control diagram

4.2.8 Circuit diagram

Diagram in Fig 4.11 and Fig. 4.12 show the configuration and installation of circuit of and connecting the user interface, all transducers to microcontroller and computer.

TM	Thermistor Circuit
RS	Reed switch
DS	Distance sensor
MS	Methane concentration sensor
TS	Temperature sensor
S	Switch
PI	Pulse input channels
A2D	Analog to digital converter input channel

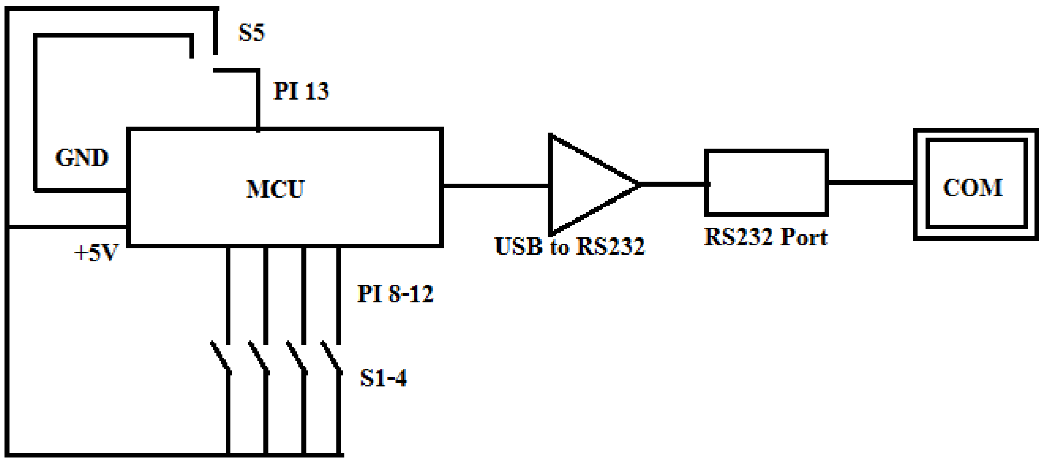


Fig 4.11 Circuit diagram of control switches and user interface

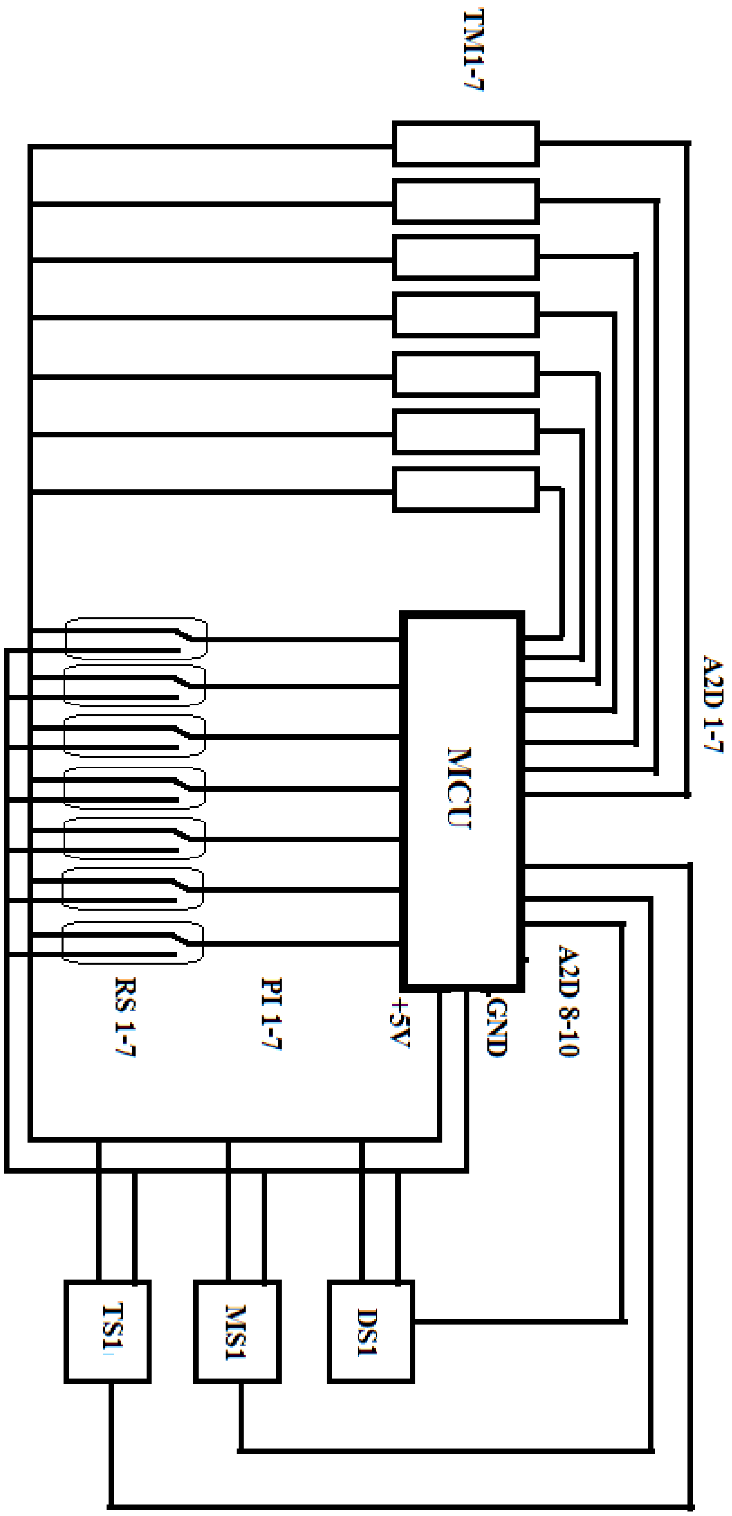


Fig 4.12 Circuit diagram of sensors

4.3 Result of Pre-Test

The pre-test system was aimed to researching and testing a digestion system and monitoring system using 7 set of 20-liters of digestion tanks

For preparing material, mixed the compost manure with water for 15 days, then feed a Napier grass as a feed stock. Amount of napier grass for each digestion tank is shown in Table 4.3. The 3rd tank was not be fed to become a reference tank with testing the gas produce with only manure.

Table 4.3 Weight of napier grass fed in each digestion tank

Tank number	Weight of napier rrass (kg)
1	2
2	3
3	0
4	2
5	3
6	2
7	3

Data were monitored and recorded during 2 weeks for Pre-test. Monitoring results were observed and compared with manual measurements every 3 days to see that the digestion system and monitoring system worked as planning. In the first week of experiment, the digestion system and monitoring system was not worked correctly so after the researcher fixed it, result can only be collected in last 3 days of experiment.

4.3.1 Result of Volume of Gas produced in Pre-test

Volume of gas was measured by using a mechanic flow meter (Fig 4.2) filled with water. Flow of biogas was measured using a turning cup separated in to two sides and has fixed point at middle of bottom of the box to allow it to move only circular way which trapped the bubble of biogas. The cup would turn when it was filled up then. The cup was attached with magnet which moved pass the reed switch then microcontroller detect a signal from reed switch to count the number of rotating cup. The result was compared with digital counters. The result of pre-test is shown in Table C.1 and Fig 4.13

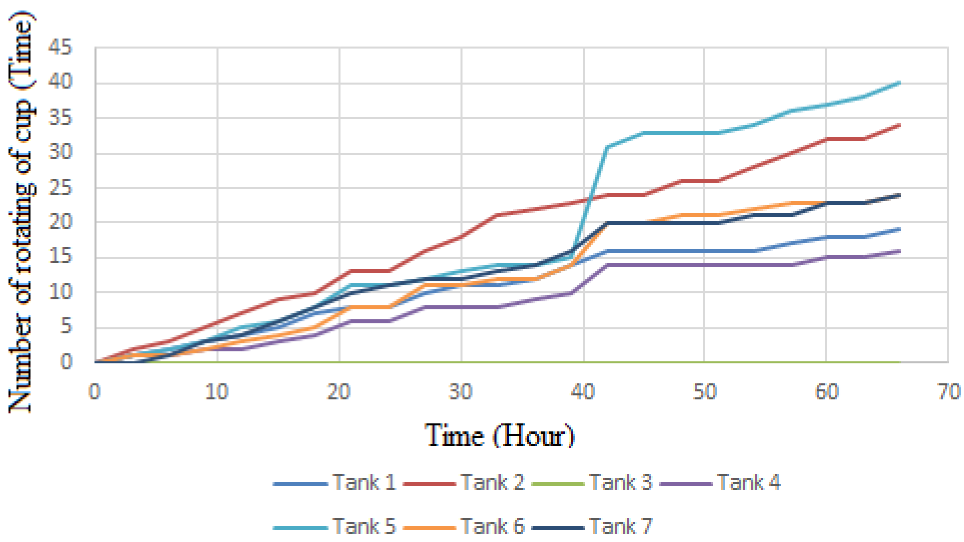


Fig 4.13 Number of rotating of Cup pass the reed switch measured by microcontroller for PRE-Test

4.3.2 Temperature

For measuring and collecting gas temperature, thermometers were replaced by seven 10 kΩ type thermistors in each Digestion Tank. Using LM358N Operational Amplifier with Gain 1 1to manipulate the output voltage for Microcontroller could collect data and calculate the temperature. The result was compared with temperature of water in temperature control tank which controlled around 35 degree Celsius after test that temperature of water is same as gas temperature.

The result of pre-test is showed in Fig 4.14

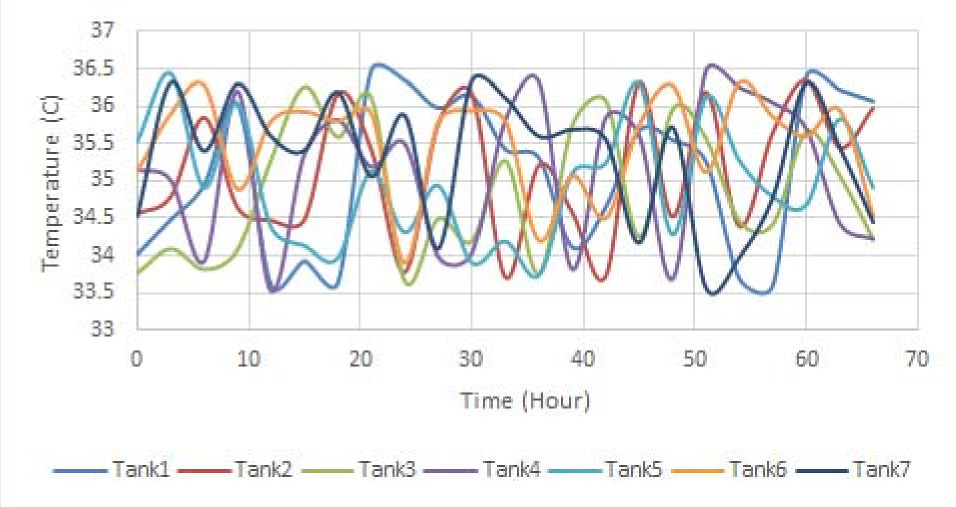


Fig. 4.14 Temperature result in pre-test

4.3.3 Normal gas condition calculation for flow counter from pre-test

From Fig 4.13 and Fig.4.14 the flow counter in normal gas condition (at temperature = 25°c) from pre-test can be calculated by equation 4.1.

$$\frac{P_1 T_1}{V_1} = \frac{P_2 T_2}{V_2} \qquad (4.1)$$

P1 = Room pressure = 1atm

P2 = Pressure in digestion tank = assume that equal to room pressure = 1atm

T_{normal} = Normal temperature = 25°C = 298K

$T_{measure}$ = Temperature in digestion tank in Kelvin

V_{normal} = Volume of gas produce in normal gas condition

$V_{measure}$ = Volume of gas measure from the digestion system

Equation 4.1 is changed to Equation 4.2

$$\frac{1atm \times T_{normal}}{V_{normal}} = \frac{1atm \times T_{measure}}{V_{measure}} \tag{4.2a}$$

$$V_{normal} = \frac{V_{measure} \times T_{normal} = 25}{T_{measure}} \tag{4.2b}$$

The calculated result is shown in Fig 4.15 and Table E.1.

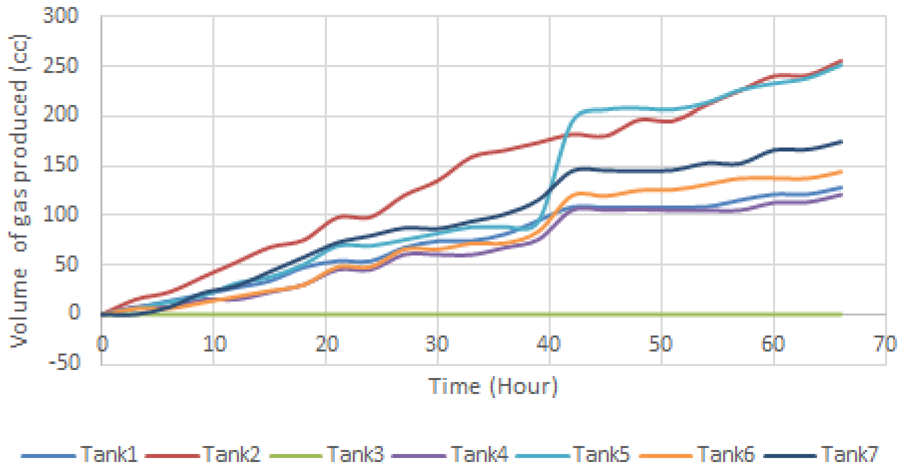


Fig 4.15 Flow counter result in normal gas condition

From the flow counter result of PRE-Test in section 4.3.1 compared with manual test using digital counter and temperature result in section 4.3.2 compare with of water in temperature control tank. The result show that.

1. Flow counting system had no errors

2. Temperature measurement had an error of about ±3 degree Celsius compared with temperature of water in temperature control tank.

3. The optical distance sensor had error of about ±1 centimeters.

4.4 Result of Full-Experiment

The pre-test result shown that the digestion system and monitoring system worked as expected. Full experiment laboratory test was performed using only 3 digestion tanks for one substrate (feedstock) and one reference tank. Full experiment laboratory used pineapple as feedstock. The system operated during 2 weeks digestion period. Monitoring results were observed and compared with manual measurements every 3 hours

4.4.1 Flow Rate of Gas

Same as pre-test Laboratory, volume of gas was measured by using a Mechanic Flow Meter (Fig 4.2), microcontroller detect a signal from reed switch to count the number of rotating cup. Then calculate the flow rate using data from Table 4.1. The result was compared with digital counters. The result of full-test is shown in Fig 4.14 and Table F.1

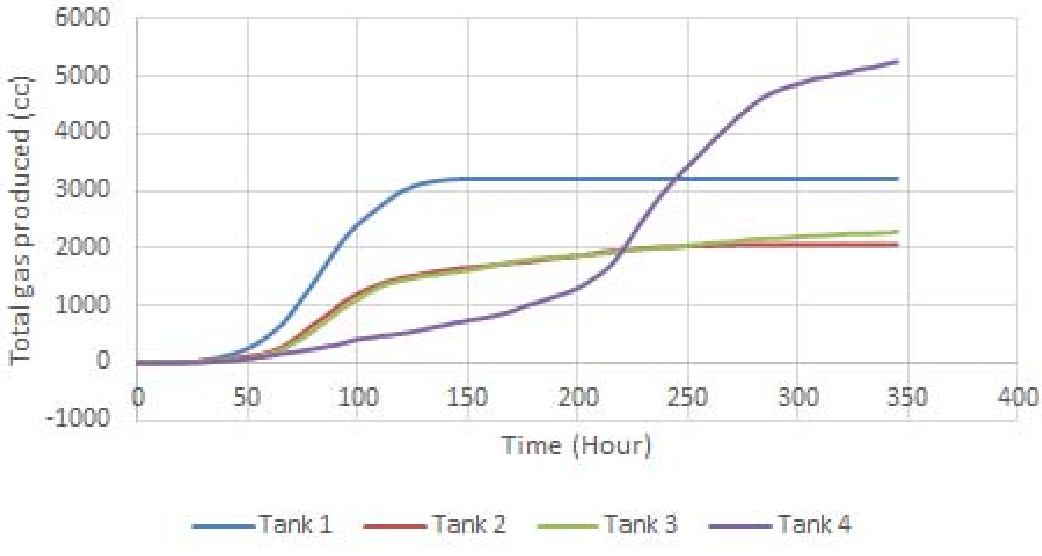


Fig 4.16 Total Gas in Full experiment (cm^3)

4.4.2 Temperature result in Full-Experiment

Same as pre-test, for measuring and collect gas temperature, thermometers were replaced by seven 10 kΩ type thermistors in each digestion tank. Using LM358N operational amplifier with gain 1 to manipulate the output voltage for Microcontroller could collected data and calculated the temperature. The result was compared with temperature of water in temperature control tank which control around 35 degree Celsius after test that temperature of water is same as gas temperature.

The result of Full-Test is shown in Fig 4.17 and Table G.1

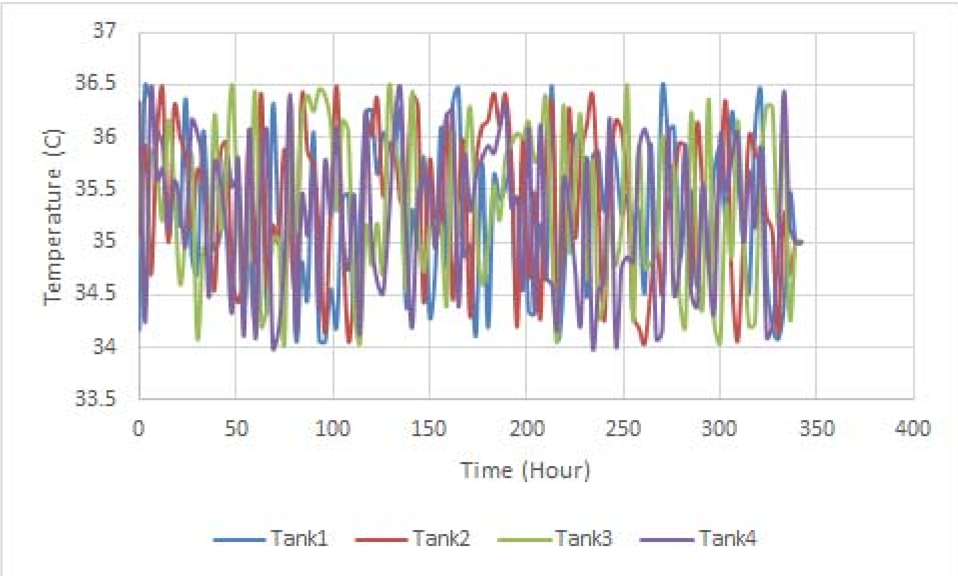


Fig. 4.17 Temperature result in Full-experiment

4.4.3 Normal gas condition calculation for flow counter from Full Experiment result

From Table F.1 and table G.1 the flow counter in normal gas condition (at temperature = 25^{o}c) from pre-test can be calculated by equation 4.1. The calculated result is shown in Fig 4.18 and Table H.1.

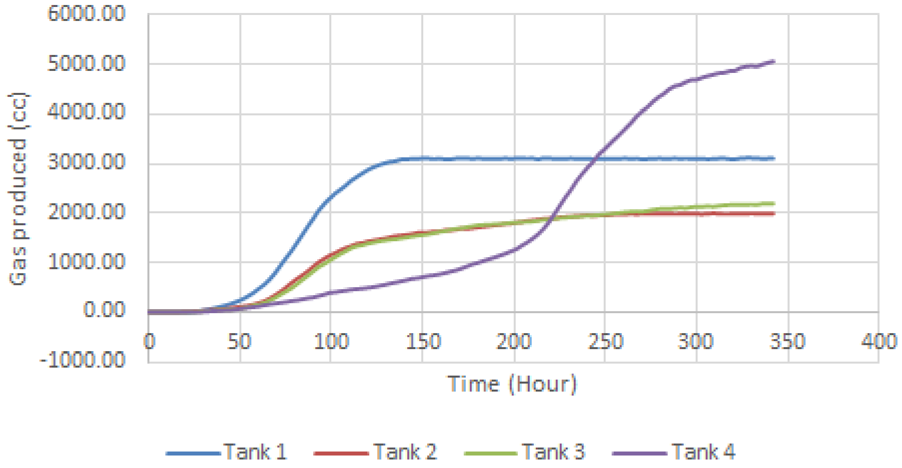


Fig 4.18: Flow counter result in normal gas condition for full experiment

From the result of Pre-Test and Full Experiment compared with manual test using digital counter and temperature of water in temperature control tank. The result show that.

1. Flow counting system had no errors

2. Temperature measurement had an error of about ±3 degree Celsius compare with temperature of water in temperature control tank.

3. The optical distance sensor had error of about ±1 Centimeters.

The monitoring system was able to measure data from different transducers satisfactory.

CHAPTER V
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The old monitoring system had measurement problems due to interruption of flow meter mechanism when the flow rate is high, no sensor to detect water level in tank due to heating system and data had to be collected manually.

A new monitoring system for laboratory scale digestion system was developed and aimed to detect signals from flow and level transducers. The system was able to monitor and record data in real time and can detect very low or very high flow rate of biogas by add the additional weight to the cup of flow meter and re-calibrated with more level of water in flow meter. The main objective was to collect real-time data during digesting period.

The digestion system consisted of seven sets of 20-liters digestion tanks including flow meter, methane sensor, thermistor and optical distance Sensor. System was controlled by PIC18F8722 microcontrollers which programmed using C++ language and reading data in computer using a Terminal Software.

The monitoring system was tested by operating the digestion system in 2 laboratory sets. The first experiment was pre-test using Napier grass as a feedstock.
The test was operated during 2 weeks digestion period. The data was collected data in the last three days of pre-test. The result shown that the digestion system and monitoring system worked as expected. After the pre-test shown full experiment laboratory test was performed using only 3 digestion tanks for one substrate (feedstock). Full experiment laboratory used pineapple as feedstock. The system operated during one month digestion period. The data was collected in daily.

The result showed that flow counting system had no errors, temperature measurement had an error of about ±1.5 degree Celsius. The optical distance sensor had error of about ±1 Centimeters. The monitoring system was able to measure data from different transducers satisfactory.

5.2 Recommendations

5.2.1 Flow Rate

During pre-test, flow meter stopped sometimes, therefore improving the flow meter mechanism should be done to extend the measuring range for collecting higher flow rate of biogas in the future.

5.2.2 Temperature

Operational amplifier had an offset voltage so the output temperature had an error. In this experiment, the temperature in the system was maintained constant at around 35 ^{o}C, therefore the measured data did not show significant errors.

5.2.3 Data Collection and Memory

The set recording data every three hours is too long for very high flow rate, it may cause errors in the result. Therefore, manual observation of counters should be done to confirm the correction of data.

The designed memory of microcontroller was not large enough for long experiment or large amount of data. Therefore an external memory such as memory card should be added for future improvement.

5.2.4 Transferring Data

Data transfer using a Terminal Program is also complicated and confusing. For improvement, new specific program should be done.

5.2.5 Another Future Work

- Monitoring system should be designed to be able to detect more parameters
- Monitoring system should be designed so that the data can be observed real time online.

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APPENDICES

APPENDIX A
FLOW METER CALIBRATION DATA

Table A.1 Flow Meter Calibration Data

Tank Number	Volume of gas (cm^3)							Average (cm^3)
	1	2	3	4	5	6	7	
1	7	7	7.5	6.5	7	7	7	7
2	7.5	7.8	7.5	7.7	8.1	8	8	7.8
3	6	6.4	6.3	6.3	6.2	6.5	6.4	6.3
4	7.8	8	8	7.8	7.5	7.6	7.9	7.8
5	6.5	7	7	6	6.5	6.5	6	6.5
6	6.5	6	6	6.5	6	6	6.5	6.2
7	7.5	7.5	7.7	7.9	7.2	7.6	7.6	7.5

APPENDIX B
DISTANCE SENSOR CALIBRATION

Table B.1 Distance Sensor Calibration Data

Distance (cm)	Output voltage (mV)			Average
	1	2	3	
4	2370	2440	2350	2386.667
5	2110	2080	2060	2083.333
6	1800	1830	1820	1816.667
7	1600	1580	1580	1586.667
8	1430	1410	1430	1423.333
9	1300	1280	1300	1293.333
10	1180	1160	1180	1173.333
11	1070	1090	1110	1090
12	1010	1010	1010	1010
13	940	940	952	944
14	880	896	877	884.3333
15	820	857	838	838.3333
16	790	800	760	783.3333
17	730	740	721	730.3333
18	690	700	687	692.3333
19	670	663	662	665
20	630	625	624	626.3333
21	600	600	580	593.3333
22	570	600	570	580
23	510	541	503	518
24	490	521	495	502
25	460	464	463	462.3333
26	420	443	423	428.6667
27	410	404	405	406.3333
28	370	385	383	379.3333
29	320	324	319	321
30	280	277	281	279.333

APPENDIX C
RESULT OF FLOW COUNT IN PRE-TEST

Table C.1 Number of rotating of Cup pass the reed switch measured by microcontroller for PRE-Test

Day	Hour	Number of rotating of Cup (Time)						
		1	2	3	4	5	6	7
1	0:00:00	0	0	0	0	0	0	0
	3:00:00	1	2	0	1	1	1	0
	6:00:00	2	3	0	1	2	1	1
	9:00:00	3	5	0	2	3	2	3
	12:00:00	4	7	0	2	5	3	4
	15:00:00	5	9	0	3	6	4	6
	18:00:00	7	10	0	4	8	5	8
	21:00:00	8	13	0	6	11	8	10
2	0:00:00	8	13	0	6	11	8	11
	3:00:00	10	16	0	8	12	11	12
	6:00:00	11	18	0	8	13	11	12
	9:00:00	11	21	0	8	14	12	13
	12:00:00	12	22	0	9	14	12	14
	15:00:00	14	23	0	10	15	14	16
	18:00:00	16	24	0	14	31	20	20
	21:00:00	16	24	0	14	33	20	20
3	0:00:00	16	26	0	14	33	21	20
	3:00:00	16	26	0	14	33	21	20
	6:00:00	16	28	0	14	34	22	21
	9:00:00	17	30	0	14	36	23	21
	12:00:00	18	32	0	15	37	23	23
	15:00:00	18	32	0	15	38	23	23
	18:00:00	19	34	0	16	40	24	24

APPENDIX D
RESULT OF TEMPERATURE OF GAS IN PRE-TEST

Table D.1 Temperature of gas measured by microcontroller for PRE-Test

Day	Hour	Tank Number						
		1	2	3	4	5	6	7
1	3:00:00	34.02	34.56	33.77	35.15	35.53	35.13	34.53
	6:00:00	34.48	34.79	34.09	35.01	36.44	35.9	36.32
	9:00:00	34.95	35.85	33.82	33.93	34.91	36.28	35.4
	12:00:00	36.03	34.64	34.08	36.2	36.04	34.89	36.3
	15:00:00	33.61	34.47	35.28	33.53	34.38	35.8	35.6
	18:00:00	33.93	34.48	36.26	35.36	34.13	35.93	35.41
	21:00:00	33.64	36.17	35.59	35.82	33.97	35.8	36.19
2	0:00:00	36.48	35.42	36.12	35.19	35.13	35.91	35.06
	3:00:00	36.35	33.78	33.66	35.5	34.31	33.9	35.88
	6:00:00	35.98	35.76	34.49	33.99	34.94	35.79	34.09
	9:00:00	36.14	36.18	34.19	34.03	33.91	35.94	36.34
	12:00:00	35.42	33.71	35.27	35.82	34.19	35.8	36.11
	15:00:00	35.31	35.21	33.76	36.33	33.74	34.2	35.6
	18:00:00	34.11	34.57	35.75	33.82	35.11	35.07	35.69
	21:00:00	34.65	33.73	36.08	35.85	35.24	34.5	35.56
3	0:00:00	35.68	36.32	34.25	35.61	36.31	35.75	34.17
	3:00:00	35.55	34.52	35.96	33.69	34.28	36.28	35.72
	6:00:00	35.26	36.19	35.57	36.48	36.12	35.12	33.57
	9:00:00	33.69	34.39	34.46	36.25	35.27	36.32	33.98
	12:00:00	33.6	35.65	34.42	36.05	34.79	35.86	34.78
	15:00:00	36.4	36.35	35.66	35.7	34.68	35.6	36.31
	18:00:00	36.22	35.45	35.07	34.43	35.83	35.95	35.45
	21:00:00	36.07	35.98	34.22	34.22	34.91	34.53	34.45

APPENDIX E
RESULT OF FLOW COUNTER IN NORMAL GAS CONDITION IN PRE TEST

Table E.1: Flow counter result in normal gas condition in pre-test (cm^3)

Day	Time	Tank1	Tank2	Tank3	Tank4	Tank5	Tank6	Tank7
1	3:00:00	0	0	0	0	0	0	0
	6:00:00	6.79	15.13	0	7.56	6.24	5.95	0
	9:00:00	13.58	22.54	0	7.56	12.61	5.95	7.27
	12:00:00	20.23	37.75	0	15.05	18.78	12.02	21.67
	15:00:00	27.23	52.88	0	15.13	31.52	17.98	28.9
	18:00:00	33.95	68.01	0	22.62	37.83	23.93	43.50
	21:00:00	47.6	75.19	0	30.10	50.50	29.94	57.82
2	0:00:00	53.9	97.96	0	45.24	69.16	47.86	72.52
	3:00:00	53.97	98.51	0	45.24	69.35	48.17	79.57
	6:00:00	67.48	120.43	0	60.60	75.46	65.84	87.30
	9:00:00	74.2	135.33	0	60.52	82.03	65.78	86.70
	12:00:00	74.41	159.12	0	60.21	88.27	71.79	93.97
	15:00:00	81.2	165.90	0	67.62	88.40	72.16	101.40
	18:00:00	95.06	173.78	0	75.73	94.31	83.94	115.87
	21:00:00	108.5	181.89	0	105.37	194.80	120.15	144.90
3	0:00:00	108.15	180.33	0	105.45	206.63	119.66	145.50
	3:00:00	108.15	196.56	0	106.08	208	125.42	144.82
	6:00:00	108.29	195.46	0	105.14	206.76	125.92	145.80
	9:00:00	108.85	211.69	0	105.22	213.65	131.37	152.92
	12:00:00	115.64	225.88	0	105.30	226.52	137.57	152.47
	15:00:00	121.38	240.47	0	112.94	232.96	137.70	166.20
	18:00:00	121.45	241.17	0	113.41	238.35	137.51	166.65
	21:00:00	128.24	255.76	0	121.05	251.61	144.21	174.45

APPENDIX F
RESULT OF GAS PRUCED IN FULL-TEST

Table F.1 Gas produced in Full-experiment

Day	Hour	Gas produced (cm^3)			
		Tank1	Tank2	Tank4	Tank7
1	0:00:00	0	0	0	0
	3:00:00	0	0	0	0
	6:00:00	0	0	0	0
	9:00:00	0	0	0	0
	12:00:00	0	0	0	0
	15:00:00	0	0	0	0
	18:00:00	0	7.8	0	0
	21:00:00	0	7.8	0	0
2	0:00:00	7	0	0	0
	3:00:00	14	7.8	7.8	0
	6:00:00	21	7.8	7.8	7.5
	9:00:00	21	7.8	7.8	7.5
	12:00:00	21	7.8	7.8	7.5
	15:00:00	28	7.8	15.6	7.5
	18:00:00	28	15.6	0	7.5
	21:00:00	35	15.6	7.8	7.5
3	0:00:00	42	15.6	7.8	15
	3:00:00	49	15.6	15.6	15
	6:00:00	63	15.6	23.4	15
	9:00:00	70	23.4	31.2	15
	12:00:00	84	31.2	23.4	15
	15:00:00	91	39	31.2	22.5
	18:00:00	105	54.6	54.6	22.5
	21:00:00	140	70.2	54.6	15
4	0:00:00	154	78	70.2	15
	3:00:00	154	85.8	62.4	15

	6:00:00	154	93.6	70.2	22.5
	9:00:00	161	85.8	85.8	15
	12:00:00	175	78	93.6	22.5
	15:00:00	175	85.8	85.8	22.5
	18:00:00	168	93.6	93.6	15
	21:00:00	161	93.6	93.6	30
5	0:00:00	133	70.2	62.4	30
	3:00:00	119	70.2	70.2	37.5
	6:00:00	105	54.6	70.2	15
	9:00:00	91	54.6	70.2	15
	12:00:00	91	46.8	62.4	15
	15:00:00	91	39	54.6	22.5
	18:00:00	84	46.8	39	7.5
	21:00:00	84	23.4	23.4	15
6	0:00:00	70	31.2	31.2	15
	3:00:00	49	23.4	23.4	15
	6:00:00	49	15.6	23.4	22.5
	9:00:00	35	23.4	23.4	22.5
	12:00:00	28	23.4	15.6	30
	15:00:00	21	23.4	7.8	22.5
	18:00:00	14	15.6	15.6	22.5
	21:00:00	14	15.6	23.4	22.5
7	0:00:00	7	15.6	15.6	30
	3:00:00	7	15.6	15.6	15
	6:00:00	0	7.8	15.6	22.5
	9:00:00	0	7.8	15.6	22.5
	12:00:00	0	15.6	23.4	15
	15:00:00	0	7.8	23.4	22.5
	18:00:00	0	15.6	23.4	22.5
	21:00:00	0	7.8	23.4	30
8	0:00:00	0	15.6	23.4	30
	3:00:00	0	15.6	15.6	37.5
	6:00:00	0	0	15.6	45
	9:00:00	0	15.6	15.6	45
	12:00:00	0	15.6	23.4	30
	15:00:00	0	15.6	7.8	37.5

	18:00:00	0	15.6	7.8	37.5
	21:00:00	0	15.6	7.8	37.5
9	0:00:00	0	7.8	7.8	37.5
	3:00:00	0	7.8	7.8	37.5
	6:00:00	0	15.6	15.6	45
	9:00:00	0	15.6	7.8	52.5
	12:00:00	0	15.6	7.8	67.5
	15:00:00	0	15.6	7.8	75
	18:00:00	0	23.4	7.8	75
	21:00:00	0	15.6	7.8	90
10	0:00:00	0	7.8	15.6	112.5
	3:00:00	0	7.8	15.6	150
	6:00:00	0	7.8	15.6	165
	9:00:00	0	15.6	15.6	172.5
	12:00:00	0	15.6	7.8	172.5
	15:00:00	0	7.8	7.8	165
	18:00:00	0	7.8	7.8	165
	21:00:00	0	7.8	7.8	150
11	0:00:00	0	0	7.8	135
	3:00:00	0	0	7.8	135
	6:00:00	0	7.8	7.8	127.5
	9:00:00	0	7.8	15.6	112.5
	12:00:00	0	0	15.6	112.5
	15:00:00	0	7.8	0	112.5
	18:00:00	0	0	23.4	120
	21:00:00	0	0	7.8	120
12	0:00:00	0	7.8	7.8	112.5
	3:00:00	0	0	7.8	112.5
	6:00:00	0	0	0	105
	9:00:00	0	7.8	15.6	112.5
	12:00:00	0	0	23.4	90
	15:00:00	0	0	7.8	97.5
	18:00:00	0	0	7.8	90
	21:00:00	0	0	7.8	75
13	0:00:00	0	0	7.8	60
	3:00:00	0	0	0	45

	6:00:00	0	0	7.8	45
	9:00:00	0	0	7.8	37.5
	12:00:00	0	0	7.8	30
	15:00:00	0	0	7.8	37.5
	18:00:00	0	0	7.8	37.5
	21:00:00	0	0	0	30
14	0:00:00	0	0	7.8	15
	3:00:00	0	0	7.8	22.5
	6:00:00	0	0	7.8	22.5
	9:00:00	0	0	7.8	22.5
	12:00:00	0	0	7.8	30
	15:00:00	0	0	0	30
	18:00:00	0	0	0	22.5
	21:00:00	0	0	0	15
15	0:00:00	0	0	7.8	22.5
	3:00:00	0	0	7.8	30
	6:00:00	0	0	0	30

APPENDIX G
RESULT OF TEMPERATURE OF GAS IN FULL-TEST

Table G.1 Temperature of gas in Full Experiment

Day	Hour	Tank Number			
		1	2	3	4
1	3:00:00	34.17	35.07	36.33	36.34
	6:00:00	36.49	35.92	34.43	34.24
	9:00:00	36.33	34.69	35.86	36.46
	12:00:00	36.08	35.98	35.73	35.6
	15:00:00	35.92	36.46	35.21	35.7
	18:00:00	35.05	35	36.16	35.14
	21:00:00	35.51	36.29	35.56	35.58
2	0:00:00	35.18	36.01	34.6	35.38
	3:00:00	36.37	35.8	35.11	34.97
	6:00:00	34.88	35.14	35.83	36.16
	9:00:00	34.7	35.69	34.09	36.04
	12:00:00	36.06	35.55	34.95	35.72
	15:00:00	35.12	35.12	34.88	34.48
	18:00:00	34.93	34.56	36.22	35.76
	21:00:00	35.1	35.87	35.12	35.57
3	0:00:00	35.81	35.95	35.68	35.1
	3:00:00	35.53	34.68	36.5	34.34
	6:00:00	35.61	34.43	35.24	35.81
	9:00:00	34.73	34.68	34.4	34.11
	12:00:00	34.8	36.08	35.13	36.08
	15:00:00	34.28	34.8	36.43	34.09
	18:00:00	36.16	36.42	34.21	35.57
	21:00:00	34.33	34.58	34.39	36.04
4	0:00:00	36.31	35.16	35.04	34
	3:00:00	35.17	35	35.03	34.17
	6:00:00	34.71	35.89	34.04	34.86

	9:00:00	35.99	35.05	36.31	36.4
	12:00:00	34.08	34.58	35.09	34.12
	15:00:00	34.81	36.39	36.16	35.44
	18:00:00	34.47	35.86	36.4	35.06
	21:00:00	36.05	35.73	36.25	35.66
5	0:00:00	34.07	35.1	36.46	34.34
	3:00:00	34.05	34.14	36.4	35.77
	6:00:00	34.55	35.38	36.12	35.25
	9:00:00	34.2	36.49	35.3	36.1
	12:00:00	35.41	35.17	36.16	35.05
	15:00:00	35.45	34.07	36.06	34.74
	18:00:00	34.28	34.45	34.39	35.45
	21:00:00	35.19	34.13	34.04	34.13
6	0:00:00	36.23	36.17	35.15	36.24
	3:00:00	36.26	36.01	34.78	35.03
	6:00:00	35.65	36.37	35.18	34.62
	9:00:00	36.04	35.44	34.73	34.52
	12:00:00	35.9	35.94	36.47	35.23
	15:00:00	35.87	35.9	35.92	36.14
	18:00:00	36.24	35.39	35.64	36.46
	21:00:00	34.39	35.5	34.55	35.11
7	0:00:00	35.3	36.4	36.43	34.19
	3:00:00	34.94	36.3	35.2	35.43
	6:00:00	35.81	34.43	34.72	35.62
	9:00:00	34.3	35.78	35.14	35.59
	12:00:00	34.74	35.18	35.19	34.94
	15:00:00	36.1	35.1	35.15	35.69
	18:00:00	34.75	36.21	34.41	36.21
	21:00:00	36.31	34.47	36.06	36.26
8	0:00:00	36.46	35.44	35.07	34.39
	3:00:00	34.87	35.93	35.66	35.82
	6:00:00	34.97	34.29	36.29	35.3
	9:00:00	34.12	35.75	35.25	35.63
	12:00:00	35.75	36.1	34.6	35.8
	15:00:00	34.19	36.16	34.98	35.92
	18:00:00	35.63	36.42	35.55	35.85

	21:00:00	35.41	36.12	35.21	36.08
9	0:00:00	35.53	36.41	35.81	36.3
	3:00:00	35.7	35.81	35.93	35.33
	6:00:00	34.37	34.2	36.04	35.43
	9:00:00	35.79	36	35.99	34.55
	12:00:00	34.35	34.66	36.15	36.09
	15:00:00	34.32	35.47	35.77	34.35
	18:00:00	35.17	34.27	35.93	36.12
	21:00:00	34.68	35.95	36.37	34.68
10	0:00:00	36.49	36.32	34.94	34.6
	3:00:00	34.13	34.56	34.09	34.19
	6:00:00	34.58	35.01	36.3	35.59
	9:00:00	35.58	36.28	34.91	35.32
	12:00:00	36.03	35.04	35.59	34.74
	15:00:00	35.91	35.84	36.2	34.23
	18:00:00	34.48	36.11	34.65	35.81
	21:00:00	35.81	36.4	35.78	34.02
11	0:00:00	35.87	35.47	34.29	34.54
	3:00:00	35.3	34.25	34.47	34.63
	6:00:00	36.02	35.63	35.21	36.18
	9:00:00	35.79	36.16	34.78	34.04
	12:00:00	35.27	36.06	35.16	34.76
	15:00:00	35.45	35.54	36.49	34.86
	18:00:00	35.17	34.31	34.25	34.81
	21:00:00	35.3	34.19	35.92	35.89
12	0:00:00	34.52	34.04	34.75	36.08
	3:00:00	35.94	34.52	34.8	35.81
	6:00:00	34.87	35.07	34.94	34.08
	9:00:00	36.47	34.5	36.01	34.16
	12:00:00	36.06	35.46	35.43	36.08
	15:00:00	36.1	35.59	35.71	34.52
	18:00:00	34.87	35.95	34.49	34.79
	21:00:00	35.3	35.9	34.21	35.93
13	0:00:00	35.47	34.58	36.23	34.52
	3:00:00	34.58	36.12	34.98	34.39
	6:00:00	35.53	35.5	34.4	35.55

	9:00:00	34.87	34.8	36.37	34.77
	12:00:00	35.69	35.1	34.23	34.36
	15:00:00	35.89	35.63	34.04	36.01
	18:00:00	35.2	36.33	35.35	35.49
	21:00:00	36.24	34.68	34.86	35.8
14	0:00:00	35.64	34.06	36.16	36.03
	3:00:00	35	35	35	35
	6:00:00	34.54	36.02	34.2	35.68
	9:00:00	36.05	35.84	34.23	35.14
	12:00:00	36.44	35.76	35.75	35.89
	15:00:00	34.69	35.24	36.3	34.1
	18:00:00	34.19	35.1	36.29	34.21
	21:00:00	34.08	34.13	35.14	34.9
15	0:00:00	34.39	35.28	36.06	36.44
	3:00:00	35.46	34.7	34.28	35.15
	6:00:00	35	35	35	35
	9:00:00	35	35	35	35

APPENDIX H
RESULT OF FLOW COUNTER IN NORMAL GAS CONDITION IN FULL TEST

Table H.1: Flow counter result in normal gas condition in full-test (cm^3)

Day	Hour	Tank Number (cm^3)			
		1.00	2.00	3.00	4.00
1	3:00:00	0.00	0.00	0.00	0.00
	6:00:00	0.00	0.00	0.00	0.00
	9:00:00	0.00	0.00	0.00	0.00
	12:00:00	0.00	0.00	0.00	0.00
	15:00:00	0.00	0.00	0.00	0.00
	18:00:00	0.00	0.00	0.00	0.00
	21:00:00	0.00	7.52	0.00	0.00
2	0:00:00	0.00	15.04	0.00	0.00
	3:00:00	6.74	15.05	0.00	0.00
	6:00:00	20.33	22.63	7.53	0.00
	9:00:00	40.68	30.12	15.14	7.23
	12:00:00	60.75	37.67	22.64	14.48
	15:00:00	81.24	45.26	30.20	21.81
	18:00:00	108.39	52.90	45.10	28.95
	21:00:00	135.41	67.73	45.26	36.22
3	0:00:00	168.87	82.76	52.71	43.52
	3:00:00	209.59	98.21	60.08	58.18
	6:00:00	256.85	113.41	75.41	72.37
	9:00:00	318.60	128.43	98.30	87.33
	12:00:00	386.30	150.41	128.24	101.24
	15:00:00	468.41	181.24	150.24	116.45
	18:00:00	553.28	217.85	181.59	137.62
	21:00:00	658.39	272.05	234.41	159.11
4	0:00:00	789.05	339.43	286.74	174.72
	3:00:00	940.89	415.07	354.66	189.18
	6:00:00	1091.44	496.65	416.37	203.27
	9:00:00	1235.44	588.55	480.95	223.93

	12:00:00	1399.36	672.58	565.84	240.15
	15:00:00	1565.47	743.77	654.10	260.86
	18:00:00	1736.81	827.83	736.24	282.95
	21:00:00	1889.92	918.53	826.79	296.88
5	0:00:00	2058.35	1010.94	916.36	327.24
	3:00:00	2187.57	1082.21	976.64	354.68
	6:00:00	2299.31	1145.69	1045.20	391.53
	9:00:00	2403.79	1194.16	1115.83	404.92
	12:00:00	2482.29	1252.07	1180.39	420.81
	15:00:00	2569.88	1301.97	1240.94	435.76
	18:00:00	2667.92	1338.16	1300.62	456.49
	21:00:00	2741.26	1384.97	1339.95	465.73
6	0:00:00	2812.99	1398.38	1357.75	477.01
	3:00:00	2880.17	1429.20	1389.60	493.39
	6:00:00	2933.17	1450.07	1410.42	508.58
	9:00:00	2976.72	1469.52	1435.14	530.55
	12:00:00	3011.84	1489.71	1449.60	551.08
	15:00:00	3039.14	1512.48	1467.23	578.38
	18:00:00	3055.74	1537.59	1476.10	599.45
	21:00:00	3087.71	1552.11	1496.44	623.84
7	0:00:00	3092.12	1562.62	1509.89	647.53
	3:00:00	3102.51	1578.16	1531.00	673.91
	6:00:00	3100.53	1602.88	1548.49	687.98
	9:00:00	3115.76	1603.40	1561.47	709.78
	12:00:00	3111.31	1614.06	1576.30	733.05
	15:00:00	3097.62	1629.57	1599.13	745.75
	18:00:00	3111.21	1631.24	1625.67	766.18
	21:00:00	3095.52	1655.59	1639.55	787.74
8	0:00:00	3094.02	1657.92	1667.45	821.61
	3:00:00	3109.99	1670.34	1686.86	846.76
	6:00:00	3108.98	1694.38	1698.45	884.43
	9:00:00	3117.59	1686.37	1719.26	926.94
	12:00:00	3101.13	1699.50	1738.01	969.85
	15:00:00	3116.88	1714.20	1758.51	998.41
	18:00:00	3102.34	1727.79	1762.79	1034.82
	21:00:00	3104.55	1744.50	1772.28	1070.21
9	0:00:00	3103.34	1757.89	1776.36	1105.58

	3:00:00	3101.63	1768.84	1783.20	1145.30
	6:00:00	3115.05	1785.67	1790.08	1181.16
	9:00:00	3100.73	1790.31	1805.42	1228.14
	12:00:00	3115.26	1813.22	1812.00	1272.64
	15:00:00	3115.56	1823.53	1821.76	1345.29
	18:00:00	3106.97	1845.78	1828.34	1409.89
	21:00:00	3111.91	1858.32	1833.25	1489.13
10	0:00:00	3093.72	1871.12	1849.31	1576.71
	3:00:00	3117.49	1889.39	1869.57	1687.95
	6:00:00	3112.93	1894.17	1871.24	1825.14
	9:00:00	3102.84	1893.91	1894.79	1986.22
	12:00:00	3098.32	1916.63	1905.68	2157.00
	15:00:00	3099.52	1926.71	1909.44	2327.90
	18:00:00	3113.94	1932.55	1926.61	2475.21
	21:00:00	3100.53	1938.25	1927.09	2649.79
11	0:00:00	3099.93	1951.63	1944.00	2790.66
	3:00:00	3105.66	1959.38	1950.42	2920.62
	6:00:00	3098.42	1950.62	1953.28	3036.10
	9:00:00	3100.73	1954.79	1963.56	3181.00
	12:00:00	3105.96	1962.95	1976.22	3282.49
	15:00:00	3104.15	1966.26	1982.75	3390.32
	18:00:00	3106.97	1981.69	1997.21	3499.79
	21:00:00	3105.66	1982.46	2008.98	3603.32
12	0:00:00	3113.53	1983.43	2024.17	3716.80
	3:00:00	3099.22	1987.89	2031.40	3828.62
	6:00:00	3109.99	1984.35	2038.02	3959.36
	9:00:00	3093.92	1988.02	2030.96	4060.20
	12:00:00	3098.02	1989.37	2049.86	4143.44
	15:00:00	3097.62	1988.53	2070.58	4251.67
	18:00:00	3109.99	1986.22	2086.36	4342.34
	21:00:00	3105.66	1986.54	2095.83	4413.14
13	0:00:00	3103.95	1995.06	2089.65	4506.05
	3:00:00	3112.93	1985.12	2105.68	4566.12
	6:00:00	3103.34	1989.11	2109.65	4592.42
	9:00:00	3109.99	1993.64	2103.73	4647.63
	12:00:00	3101.73	1991.70	2125.95	4690.18
	15:00:00	3099.72	1988.28	2134.84	4694.07

	18:00:00	3106.66	1983.78	2133.31	4738.21
	21:00:00	3096.22	1994.41	2144.25	4769.64
14	0:00:00	3102.24	1998.44	2135.24	4795.02
	3:00:00	3108.68	1992.34	2150.82	4825.57
	6:00:00	3113.33	1985.77	2163.99	4836.66
	9:00:00	3098.12	1986.92	2171.35	4866.89
	12:00:00	3094.22	1987.44	2168.19	4876.78
	15:00:00	3111.81	1990.79	2171.84	4934.32
	18:00:00	3116.88	1991.70	2171.92	4961.65
	21:00:00	3118.00	1997.99	2180.02	4972.31
15	0:00:00	3114.85	1990.53	2173.53	4962.01
	3:00:00	3104.05	1994.29	2193.69	5004.54
	6:00:00	3108.68	1992.34	2196.11	5036.01
	9:00:00	3108.68	1992.34	2196.11	5065.03

APPENDIX I
CODE OF MICROCONTROLLER

```
/*
Thesis Title : Monitoring System for Laboratory Scale Digestion System

Researcher : Jumphotphong Niyompluek and Kanoksak Eam-o-pas


Author: Jumphotphong Niyompluek

Master degree in Mechanical Engineering

Faculty of Engineering

Mahidol University


Device : PIC18F8722

Compiler : CCS C

*/


#include <18F8722.h>

#fuses HS,NOWDT,NOPROTECT,NOLVP

#use delay(clock=1000000)

#include <lcd.c>

#define TIMER0_INIT_VALUE (65535-(100))


void main()

{


//--------------Set up Timer Interupt---------------

   {

      setup_timer_0(RTCC_INTERNAL|RTCC_DIV_1);
```

```
    // set parameters for TIMER 0
    set_timer0(TIMER0_INIT_VALUE);
    // set initial count value for TIMER 0
    clear_interrupt(INT_TIMER0);

    enable_interrupts(INT_TIMER0);
    // enable TIMER0 interrupt
    enable_interrupts(INT_TIMER1);
    // enable TIMER1 interrupt
    enable_interrupts(GLOBAL);
  }

//----------------Setup ADC--------------------
  setup_adc_ports(AN0_TO_AN8 | VSS_VDD);
  setup_adc(ADC_CLOCK_INTERNAL);
  setup_adc(ADC_CLOCK_DIV_32);

//------------Setup I/O Ports---------------
  set_tris_c( 0b11111110 ); // Pin RC0 is output, the rest is input. (Switches and Debug)
  set_tris_d( 0b11111111 ); // Port D is all input (Reed Switches)

//---------------Variables------------------
  {
    //System Variables
    int state = 0;
    int i,j,k,l,m,n;
    int lockreed[7],lockswitch;

    //Display and storage Variables
```

```
    int flow[7][30],temp[7][30],methane[30];
    int showflow[7],showtemp[7],showmeth,showdist;
    int count,number,dist, timeset, timer, lcd;

    //ADC Variable
    int ref_volt,ref_temp,tc_ref_v,read_v;

    // Set voltage of Thermocouple at 0-100C (Gain = 100 | R1 = 10ohm , R2 = 1K.ohm)
    long std_volt[11] = {3240,2987,2731,2484,2240,2005,1789,1590,1404,1234,1085};
    // Set voltage of Distance Sensor (4-30 cm)
    int dist_v[27] =
    {5000,5000,5000,2386,2083,1816,1586,1423,1293,1173,  //1-10 cm
    1090,1010,944,884,838,783,730,692,665,626,   //11-20 cm
    593,580,518,502,462,428,406,379,321,279 };   //21-30 cm
  }

  lcd_init() ;


//========================================================================
//================== Main Program =====================================
//========================================================================
  while(1)
  {
      //Timer Set
      if(state == 0)
      {
        if(input(PIN_C0)&&lockswitch==0)
        {
```

```
    timeset +=5;
    lockswitch==1;
  }
  if(input(PIN_C1)&&lockswitch==0)
  {
    timeset +=60;
    lockswitch==1;
  }
  if(input(PIN_C2)&&lockswitch==0)
  {
    timeset = 0;
    lockswitch==1;
  }
  if(input(PIN_C3)&&lockswitch==0)
  {
    set_hour = timeset/60;
    set_min = timeset%60;

    state = 1;
  }

  if(lockswitch==1)
  {
    if(!input(PIN_C0)&&!input(PIN_C1)&&!input(PIN_C2)&&!input(PIN_C3)
    {
      lockswitch==0;
    }
  }
```

```
      //LCD Display
      lcd_gotoxy(1,1);
      lcd_putc("\fTime Set\n");
      //lcd_putc("%d Minutes",timeset);
      printf(lcd_putc,"%d Minutes",timeset);

      //=================================================================
    }

//End                                          of                                          State
0================================================================

    if(state == 1)
    {
//------------Switches Control------------------------------

      if(input(PIN_C0)&&lockswitch==0)
      {
        lcd += 1;
        if(lcd==6)
        {
          lcd = 1;
        }
        lockswitch = 1;
      }
      if(input(PIN_C1)&&lockswitch==0)
      {
        lcd -= 1;
        if(lcd==0)
```

```
  {
    lcd = 6;
  }
  lockswitch = 1;
}
if(input(PIN_C2)&&lockswitch==0)
{
// Data send to SD Card
  lockswitch = 1;
}
if(input(PIN_C3)&&lockswitch==0)
{
// All Reset
  //Reset flow
  for(k=0;k=6;k++)
  {
    //Replace First measurement Last insteed
    showflow[k][0] = showflow[k][number];
    for(l=1;l=30)
    {
       //Reset measurement no. 2-30
       showflow[k][l] = 0;
    }
  }

  //Reset temp
  for(k=0;k=6;k++)
  {
    //Replace First measurement Last insteed
```

```
        showtemp[k][0] = showtemp[k][number];
        for(l=1;l=30)
        {
            //Reset measurement no. 2-30
            showtemp[k][l] = 0;
        }
    }

    //Reset Methane
    for(k=0;k=3;k++)
    {
        //Replace First measurement Last insteed
        showmeth[k][0] = showmeth[k][number];
        for(l=1;l=30)
        {
            //Reset measurement no. 2-30
            showmeth[k][l] = 0;
        }
    }

    number=0;
    lockswitch = 1;
  }

  if(lockswitch==1)
  {
    if(!input(PIN_C0)&&!input(PIN_C1)&&!input(PIN_C2)&&!input(PIN_C3)
    {
      lockswitch==0;
```

```
    }
  }

//--------------LCD Display Control----------------

  if(lcd == 1)
  {
    lcd_gotoxy(1,1);
    printf(lcd_putc,"Time %2d : %2d : %2d\n");
    printf(lcd_putc,"Count : %3d");
  }
  if(lcd == 2)
  {
    lcd_gotoxy(1,1);
    lcd_putc("\fFlow 1-4\n");
    printf(lcd_putc,"%3d %3d %3d %3d",showflow[0],showflow[1],showflow[2],showflow[3]);
  }
  if(lcd == 3)
  {
    lcd_gotoxy(1,1);
    lcd_putc("\fFlow 5-7\n");
    printf(lcd_putc,"%3d %3d %3d ",showflow[4],showflow[5],showflow[6]);
  }
  if(lcd == 4)
  {
    lcd_gotoxy(1,1);
    lcd_putc("\fTemp 1-4\n");
    printf(lcd_putc,"%3d %3d %3d %3d",showtemp[0],showtemp[1],showtemp[2]
,showtemp[3]);
```

```
        }
        if(lcd == 5)
        {
           lcd_gotoxy(1,1);
           lcd_putc("\fTemp 5-7\n");
           printf(lcd_putc,"%3d %3d %3d",showtemp[4],showtemp[5],showtemp[6]);
        }
        if(lcd == 6)
        {
           lcd_gotoxy(1,1);
           lcd_putc("\fMethane\n");
           printf(lcd_putc,"%3d %3d %3d",showmeth[0],showmeth[1],showmeth[2]);
        }

//------------Reed Switches----------------------------
        // 1st Reed Switches
        if(lockreed[0]==0)
        {
          if(input(PIN_D0))
          {
             showflow[0] += 1;
          }
        }
        else
        {
          if(!input(PIN_D0))
          {
             lockreed[0]==0;
          }
```

```
}

// 2nd Reed Switches
if(lockreed[1]==0)
{
  if(input(PIN_D1))
  {
    showflow[1] += 1;
  }
}
else
{
  if(!input(PIN_D1))
  {
    lockreed[1]==0;
  }
}

// 3rd Reed Switches
if(lockreed[2]==0)
{
  if(input(PIN_D2))
  {
    showflow[2] += 1;
  }
}
else
{
  if(!input(PIN_D2))
```

```
  {
    lockreed[2]==0;
  }
}
// 4th Reed Switches
if(lockreed[3]==0)
{
  if(input(PIN_D3))
  {
    showflow[3] += 1;
  }
}
else
{
  if(!input(PIN_D3))
  {
    lockreed[3]==0;
  }
}
// 5th Reed Switches
if(lockreed[4]==0)
{
  if(input(PIN_D4))
  {
    showflow[4] += 1;
  }
}
else
{
```

```
  if(!input(PIN_D4))
  {
    lockreed[4]==0;
  }
}

// 6th Reed Switches
if(lockreed[5]==0)
{
  if(input(PIN_D5))
  {
    showflow[5] += 1;
  }
}
else
{
  if(!input(PIN_D5))
  {
    lockreed[5]==0;
  }
}

// 7th Reed Switches
if(lockreed[6]==0)
{
  if(input(PIN_D6))
  {
    showflow[6] += 1;
  }
```

```
}
else
{
  if(!input(PIN_D6))
  {
    lockreed[6]==0;
  }
}

//-----------Thermocouple-------------------------------

    //Reference Temperature
    //read ref_volt and convert to ref_temp

    //??????????????????

    //convert ref_temp to tc_ref_volt
    for(i=0;i=101;i++)
    {
      if(ref_temp == i)
      {
        tc_ref_volt = tc_volt[i];
        i=101;
      }
    }

    // Read Voltage from Thermistor

    for(i=0;i=6;i++)
```

```
        {
          //Read Voltage from each Thermocouple
input_volt = read_adc();
    input_volt *= 5000/1023;
    printf("Volt : %f \n\r",input_volt);
    if(input_volt >= std_volt[0])  temp = 0;
    else
    {
      for(i=1;i<=10;i++)
      {
        if(input_volt<std_volt[i-1]&&input_volt>std_volt[i])
        {
          n_temp=i;
          break;
        }
      }
      temp = i*5;
      temp += ((std_volt[i-1]-input_volt)/(std_volt[i-1]-std_volt[i]))*5;
      temp -=4;

    }
    temp /= 100;
    c_temp += temp;
    j++;
    if(j==100)
    {
      printf("Volt : %4f \n\r",input_volt);
      printf("Temp : %.2f \n\r",c_temp);
      j=0;
```

```
    c_temp = 0;
  }
//----------Distance Sensor--------------------------------
      set_adc_channel(7);
      read_v = read_adc();
      for(i=3;i=30;i++)
  {
    if(read_v > dist_v[i] && read_v < dist_v[i+1]
    {
      //dist = i;
      //Interpolation
      dist = i + ((read_v - dist_v[i-1])/(dist_v[i+1] - dist_v[i-1]));
      i=30;
    }
  }

//----------Methane Sensor---------------------------------


//----------Safty System Control


//----------Timer Control-------------------------------
      if(time_hr == set_hr&&timer_min = set_min)
      {
         write_sd = 1;
         time_hr = 0;
         time_min = 0;
         time_sec=0;
```

```
        }

//----------SD Card Control----------------------------
        if(write_sd == 1)
        {



        }

//=========================================================
      } // End of State = 1
  } //End of Infinity Loop
}
//=============================================================
//===========================Timer Interupt============================
//========================================================================

#INT_TIMER0
void TIMER0_isr( void )
{
  timer0_flag ^= 1;
  // toggle the flag for Timer 0
  time_sec +=1;
  if(time_sec==60)
  {
    time_min++;
    time_sec = 0;
  }
  if(time_min==60)
```

```
  {
    time_hr++;
    time_min = 0;
  }
  set_timer0(TIMER0_INIT_VALUE);
  // reset TIMER0 to its initial value
}
```

BIOGRAPHY

NAME	Jumphotphong Niyompluek
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