UNIVERSITY OF GÄVLE

Automatic Control for a Gas System Using PIC Microcontroller

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Abstract

In many processes it is important to have automatic control in the modern life. For example, PLC systems are using for machine control, water pressure and flow are able to be controlled by DDC program, even a car can be driven by computer. In this article, author will turn our focus on the control system for fermentation tank. The fermentation tank that produces methane is considered as clean and recycle energy source. It is widely used in house, electronic power machine and vehicle around the world. However, its reaction temperature and output concentration control are usually hard to detect without automation system. In this study, the problem is focused to combine fermentation tank and automatic control system in laboratory testing.

In this paper, author will be able to use PIC (Peripheral Interface Controller) microcontroller to solve this problem and automatically control the methane tank output methane gas with certain concentration, which could be used as energy source. The temperature and concentration sensors that are chosen as input data of the controller and corresponding algorithm were performed on the PIC. They will be used to realize the composition and thermal state measurement. With those information, the valves of material and water control can be controlled in methane tank.

Limited by the experiment equipment and methane reaction tank system, the controller was just tested in the laboratory environment instead of practical application. The test result shows that the controller has its capability to automatically control the stable output of methane gas. In the test, water and material valves are controlled automatically open or close after monitoring temperature and concentration information of the gas in the tank.

Key words: methane, PIC, automatic control

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1 Introduction

This chapter gives the background of methane tank system, control system, the purpose, research questions and the limitation of this study. The limitation is the most important in this thesis. Its content run through this whole thesis and affects the end result.

1.1 Background

It is important to have an automatic control in many process for modern life. For instance, PLC systems are using for machine control, water pressure and flow is able to be controlled by DDC program, even a car can be driven by computer. Control system has more than 200 years in its development history. The first automatic control device is the Watt fly-ball governor which was invented by James Watt in 1767. In addition, Watt is the inventor of steam engine. After that, control system keeps an important role in people life. In 1909, Henry Ford propose an idea of production lines for motor cars. It extremely raises the efficiency in the manufacture process [1]. Automatic control is widely used in the World War II, it has been used in autopilot for aircraft, machine tools, chemical process and voltage at electric power plants [2]. Until now, it makes human beings be free from repetitive and boring works that can be efficiently finished simply. For example, control system of automatic room heating can keep a comfortable temperature for what users want, and the users do not need to pay any attention to it. Such as a personal computer, people can use it to play game, finish work quickly and so on. Actually, each device of computer has its own control system, the operation system (likes WINDOWS) provides a plant to do interaction in these control systems and it also builds an environment to use software. Control system exists everywhere in human beings' living and industry.

In China, methane tank system was widely used in the countryside. In 1995, the Chinese government launched projects to construct household biogas digesters in the rural areas. The government has spent a large sum of money in these projects [3]. Chinese people usually use crop stubble, animal waste and human excrement to ferment into methane for domestic application. Based on a research in 2006, over 1200 million tons of crop stubble and manure could be used for the generation of biogas in China [4]. But Chinese technology was in a backward situation in 20th century. China could not build electrical network for the whole country. The application of biogas digesters help to lower the dependence on fossil fuels for the country's energy management [5]. Even today most of the people in China are still using methane to generate power. The reason why methane tank system is popular in the rural areas in China is that it is a kind of greatly perfect clean, cheap and convenient energy power. The family energy consumption structure has been improved through constructing biogas digesters in rural areas [6]. The Chinese government has achieved impressive results through several decades of study and construction in the field of biogas production. Right now, more than 38.51 million household digesters have been built in rural areas [7]. The development of the household digester in the rural areas has the great assistance to better the rural environment and the Chinese biogas industry [8] [9].

It is reported that rural household biogas utilization is a vital component of renewable energy construction in China [10]. In the modern times, there are many countries that have also begun to use biogas in transport. Such as: Iran, Pakistan, Argentina, Brazil and India [11]. For example, in Sweden there is a biogas-powered train, named *Biogast åget Amanda*, has been in service in Sweden since 2005 [12]. In addition, there are some biogas buses working in Link öping of Sweden. In 2007, an estimated 12,000 vehicles were being fuelled with upgraded biogas worldwide, mostly in Europe [13].

From the above, methane is a type of useful gas. And it becomes increasingly popular in the whole world. However, methane has a fatal shortcoming. The disadvantage is that the methane is a kind of combustible gas. It is very unstable if the volume ratio is between 5%-15% [14]. In addition, the biogas digester is an efficient energy provider. In the biogas digester, it includes other several kinds of gases, such as carbon dioxide, nitrogen, hydrogen and so on. Normally, the methane occupies 50% to 75% [15]. Therefore, internal environment of biogas digester is complex and unstable. To control the output of gas in the right concentration is very important and necessary. In total areas of China, people know about the use of methane, but there are not cheap and convenient electronic products that help farmers to control the use of methane gas. This thesis designs an electronic system to make inside situation of digester stable by PIC-microcontroller.

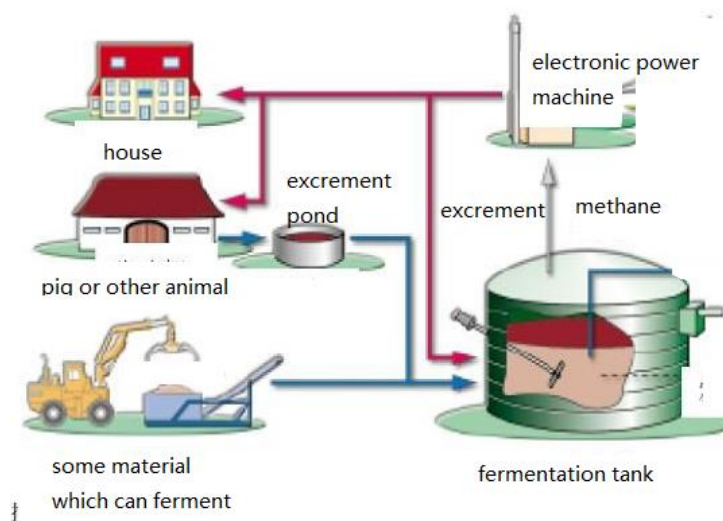The Chinese biogas system and biogas digester structure are shown in Fig. 1.
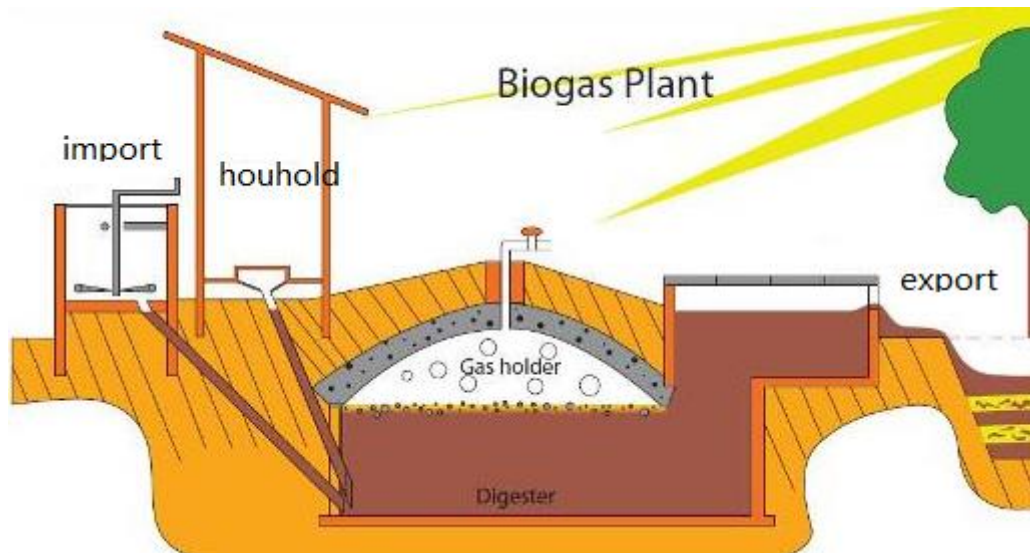

Figure 1: Chinese Methane System

Figure 2: Simple Sketch of Household Biogas Plant

Fig. 1 presents the whole fermentation tank system in china. It shows that the all fermentation material is coming from excrement of human daily life. It is a kind of renewable energy. The fermentation material is very easy to get; and it do not need anything else. After methane gas has been fully burned, it only produces the power, water and carbon dioxide. That is why it is a cheap, clean and convenient energy. In Fig. 2, it has presented the basic structure of fermentation tank is presented.

According to Figs. of 1 and 2, they show that there are three primary ports in the tank. Two of them are for input of the excrement and fermentable material. Another one is for output of the methane. These three ports decide the primal design for this thesis.

1.2   *Purpose and Research Questions*

The aim of this thesis was to build a control system for biogas digester, using following devices: PIC16f690 microcontroller, MQ-2 gas sensor and AD590 temperature sensor to monitor the temperature and gas concentration in the laboratory test that can be used in a system sort in China. By this way, the tank can output safe concentration gas and work in a comfortable environment. The methane is unstable in air if its volume ratio is between5 %-15 % [14]. So, the gas export of biogas digester will turn on when the concentration is more than 20.8%. Then, the control system of the biogas digester will decrease the temperature when it is over 25 degrees Celsius, since the best ferment action temperature for methane gas is between 15 to 25 degrees [16].

There were two challenges in the beginning process. First, it has to choose a suitable gas sensor and temperature sensor which has the necessary detection range. In the original system, methane occupies 50%-70% in the biogas digester [15]. Also, it is very unstable if the volume ratio is into 5%-15% [14]. Therefore the detection range of the gas sensor should arrive to at least 20.8%. And it is better for the gas sensor to have a high level detection range. Then, this control system will monitor internal situation well. As the choice of temperature sensor, most of temperature sensors can detect 15-25 degrees Celsius. The temperature will not be able to be very high or low in the biogas digester. Then for accuracy of detection, range should be as narrow as possible. Second, the

methane gas is a kind of dangerous gas and very difficult to find. Alcohol was used to substitute methane to test the controller.

1.3 Limitation

The study has several limitations on sensors and test gas.

First, it is restricted by the purchase of methane and experimental materials that are substituted by alcohol in a simulated operation in the research. Even the methane tank, such as construction of methane gas chamber was hard to be built. Therefore it was difficult to build the complete system. Thus a potential control system was proposed in this study with the microcontroller to monitor the temperature and gas concentration. Different measured data is illustrated in the research to narrow the tolerance of substitution in experiment. So, in the research, the temperature sensor and gas sensor are respectively used in each different environment.

Second, the standard gas, like methane gas, is too difficult to find for this research thus the research used a simple method to keep gas sensor in a closed and stable surrounding.

Third, the detection range of gas sensor is not enough.

Fourth, author did not find any suitable valves. Instead of that, the author used a LED light, instead of valves. The detail will be introduced in Chapters 3.

2 Theory

This chapter mainly introduces the control system, the devices, the basic structure of methane tank control system, the information of sensors entire wire connection based on the PIC microcontroller. Therefore, it provides the basic theory of this study for readers. Next chapter will explain the whole process and test based on these specific theory knowledge.

2.1 Control System

In the previous part, it has introduced how general and important control system is. In the following, it will illustrates what the control system is. "*Control system are systems that are used to maintain a desired result or value. In addition, A system can be define as arrangement of parts within some boundary which work together to provide some form of output from a specified input or inputs*" [1]. It is a common sense that driving a car needs a good driver, so the driver is a control system in this car. A system has been illustrated by a simple figure on the below:
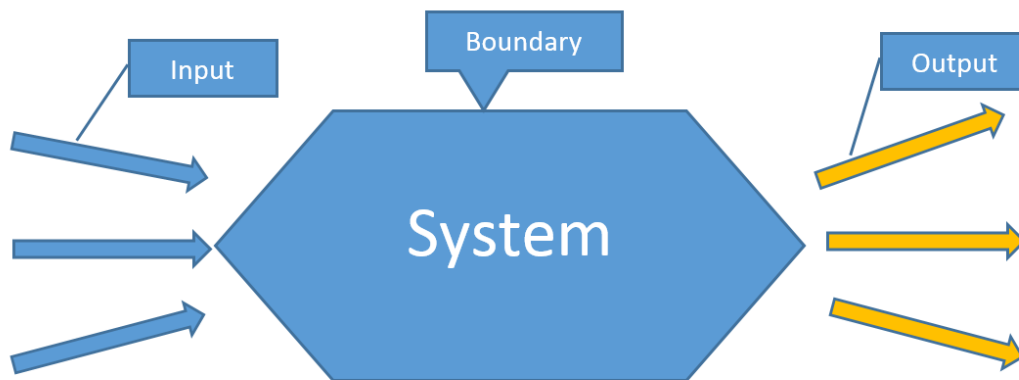

Figure 3: illustration of system

 Typically, control system is divided by two main types: open-loop and close-loop. The distinction in these two types is that the close-loop control system includes feedback path. That means output signal of close-loop control system will effect input signal, but open-loop will not. For example in the previous about automatic room heating, the control system always keeps room comfortable temperature by what users want. The control system can keeps hot when its temperature is lower than a critical value or stop heating when the room temperature is higher. The heating (output) effects the input signal of control system. Therefore this control system is belong to close-loop type. If the turning on/off for heating only depends on voltage, it is an open-loop type control system.
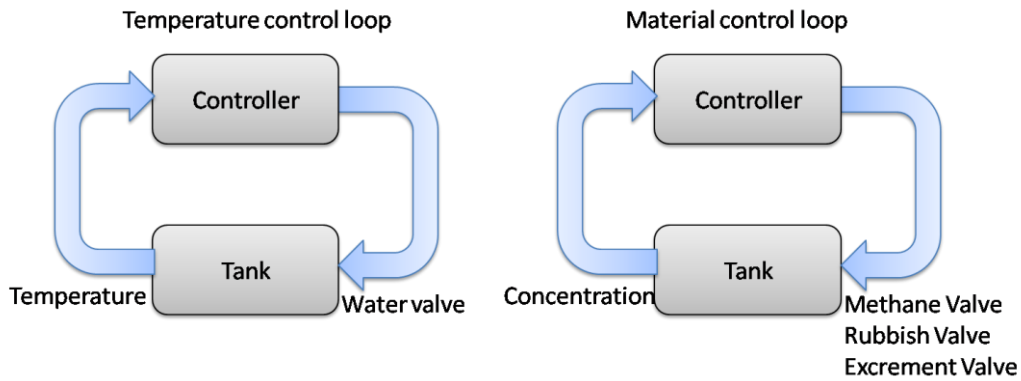
Figure 4: Two closed control loop in the fermentation tank system

In this study, there are two control close-loops in methane system. One is temperature control loop, this loop is to stable the gas temperature which maintain the methane reaction. Temperature is acquired by using temperature sensor. Water valve is controlled according to the acquired temperature data. The other loop is material control loop, this loop is to stable the source that maintain the methane reaction. Gas concentration is acquired by using gas concentration sensor. The three valves (Methane valve, rubbish valve and excrement valve) are controlled according to the acquired concentration data. The research of this two process will descript in chapter three.

2.2   Sensors

2.2.1   MQ-2 Gas Sensor

This research uses MQ-2 Semiconductor Sensor as gas sensor [17]. In Fig. 5, is shown that alcohol and methane have almost same sensitivity characteristics. In addition, the alcohol fluid is very simple to find and be controlled. MQ2 as specialized for alcohol detection is much preferred to be adopted in the research.

In design experiment, the PIC16F690 microcontroller was chosen to take the role of ADC (Analog-to-Digital Converter). The output voltage of gas sensor is an analog value which can not be used and shown on in the LCD screen directly. Therefore, as for the analog value converter to digital value, the PIC16F690 microcontroller and MQ-2 gas sensor are needed to connect. The circuit and sensitivity characteristics have shown in Fig. 5 and 7:
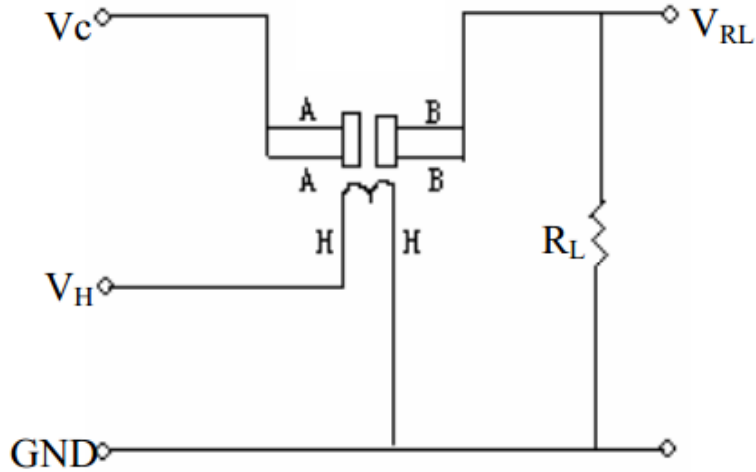
Figure 5: Circuit of MQ-2[17]

Circuit	Loop Voltage	V_c	≤24V DC
	Heater Voltage	V_H	5.0V±0.2V ACorDC
	Load Resistance	R_L	Adjustable
Character	Heater Resistance	R_H	31Ω±3Ω（Room Tem.）
	Heater consumption	P_H	≤900mW
	Sensing Resistance	R_s	2KΩ-20KΩ(in 2000ppm C_3H_8)
	Sensitivity	S	Rs(in air)/Rs(1000ppm isobutane)≥5
	Slope	α	≤0.6($R_{5000ppm}$/$R_{3000ppm}$ CH_4)

Figure 6: Datasheet of MQ-2 Gas Sensor [17]

In the process, R_L of Fig. 6 is selected and equal to 1kΩ due to the R_L is an adjustable resistance from datasheet. It will not be selected by a specific value, but used to calculate the ideal V_{RL} (output voltage) of the gas sensor. By the datasheet, the output voltage does not show that V_{RL} is a stable value. The V_{RL} depends on the value of R_L, supply voltage and internal resistance of gas sensor. Then in the Fig. 6, the range of R_S (internal resistance) is 2kΩ-20kΩ. For the output voltage value, it can be got more accurate, the range of output voltage should be much bigger. The details will be presented in section 3.1.1.
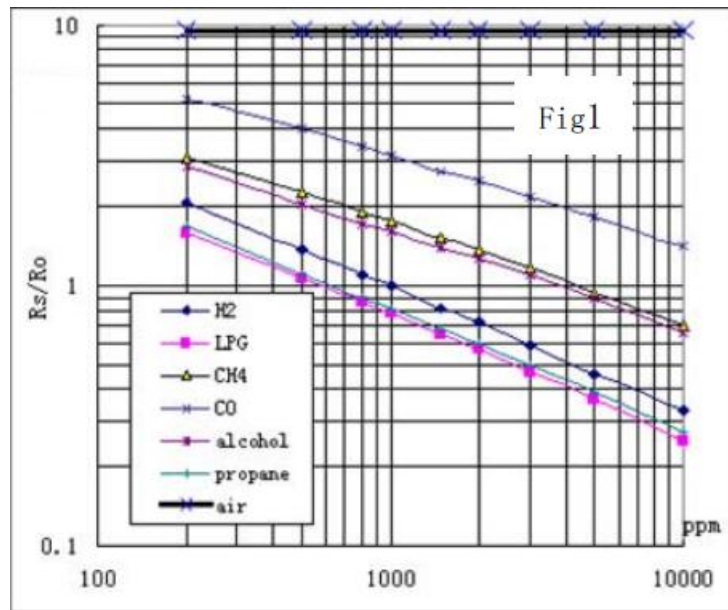
Figure 7: Sensitivity Characteristics of MQ-2 [17]

In the Fig. 7, with a common unit, the concentration named 'PPM' (parts per million). So, 10000PPM is 1%. Rs/Ro is the internal resistance ratio value of gas sensor and would change linearly as gas concentration change. In addition, the range of sensor is 10000PPM. However, the ideal detection concentration should be more than 30%. The same type of gas sensor with the range of more than 30% share the same gas concentration characteristic in this gas sensor. Thus, this sensor is able to be used in the experiment to test the controller. This is the reason for the third limitation. The PPM unit can also be written by 1 mg/l.

2.2.2 Temperature Sensor

This research uses AD590LH as temperature sensor to collect values of the temperature sensor, the PIC16F690 microcontroller is via the ADC (analog-to-digital converter). The circuit has shown in Fig. 8.

Figure 8: Circuit of temperature measurement [18]
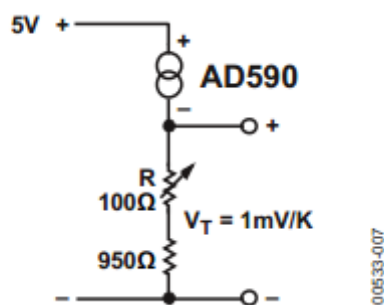
According to Fig. 8, the output voltage is equal to the temperature in Kelvin as 1mV/K. The value of temperature in Kelvin scale = (273.15+value of temperature in Celsius degrees) K. In this design, the temperature inside the tank should be less than 25℃. Therefore, the output voltage should be less than 298.15 mV. Otherwise the PIC16F690 will activate the pump to move water.

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2.3   Microcontroller

Microcontroller is a chip that combine the microprocessor with one or more other components. These components contains memory, ADC (Analog-to-Digital Converter), DAC (Digital-to-Analog Converter), parallel I/O interface, serial I/O interface, timers and counters.

The microprocessor responses to arithmetically operate the binary data which likes a CPU in a computer. However, its speed, general purpose registers, memory addressing and instruction set are very low compare with a CPU. Therefore, it can be illustrated as a low level CPU.

The memory is used for storing the data, programming instruction and results. It also provides these information to other units. So that the microcontroller can be processed by pre-write instruction without computer or any other devices.

The ADC and DAC can do convert signal between analog signal and digital. The analog signal usually is a voltage number in a range. Such as a temperature sensor, it can converts the temperature value to a specific voltage value. Then, this voltage value can be converted to digital value as binary via ADC. In addition, the parallel I/O interface and serial I/O interface supply one or more ports for connecting sensors on the microcontroller.

The timers and counters of microcontroller provide a specific frequency. This frequency determines how process speed in this programmer.

In this study, the PIC16F690 microcontroller has been chosen to control sensors for building an automatic control system, which includes all components previous.
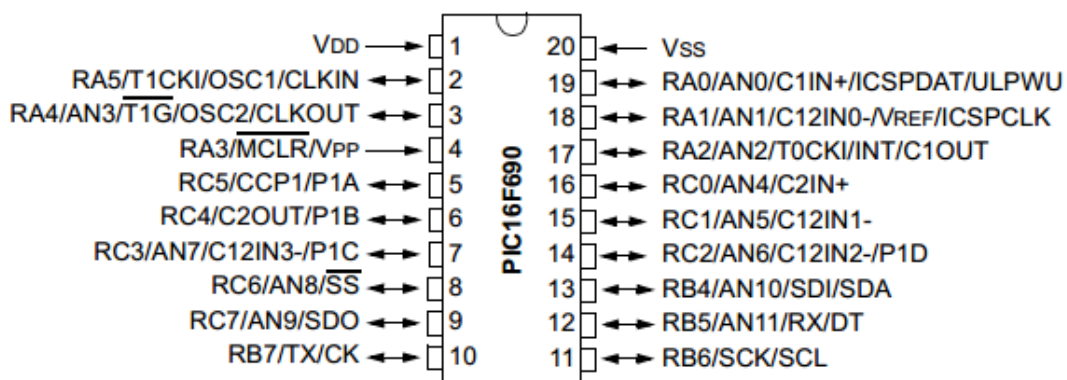
2.4   PIC Microcontroller

Figure 9: The functions of pins in PIC16f690 microcontroller [18]

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The PIC series microcontroller are invented by MICROCHIP Company. In this study, the PIC16f690 microcontroller has been chosen and used in the methane tank control system. In addition, the PIC16f690 microcontroller should be first installed with software: MPLAB_X for control connection.

The whole PIC16f690 microcontroller contains a PICKIT programming board and a chip board. The PICKIT programming board is used for providing the supply voltage, as a bridge between computer and microcontroller. It also help microcontroller to store instructions. The chip board is applied to load PIC16f690 microcontroller chip and supply ports for external devices.

The PIC16f690 microcontroller has 20 pins. In the Fig. 9, there are many abbreviation words in the side of each pin. The R_{SS} (pin 20) is ground pin. The R_{DD} (pin 1) is supply voltage pin and it should be provided 5V DC voltage usually. The abbreviation words after RAX, RBX and RCX (the X means the number) are the functions that can be offered from these pins. The ANX means that this pin can apply to ADC or DAC function. Because sensors only can output the analog signal and only the digital signal can be programmed in the microcontroller. Therefore, the function of ANX (the X means the number) pins will be often used in processes of this study. These previous pins' functions will all be used in this study and the processes detail of connection will be introduced in chapter 3.

2.5   System of Tank

According to Fig. 1 and 2, there are three primary ports in the tank. Two of them are for input of the excrement and fermentable material. Another one is for the output of methane. Now if decreasing the temperature, it should be used to control the system temperature. After the analysis and combination with purpose, the basic theory structure of the tank is shown in Fig. 10.
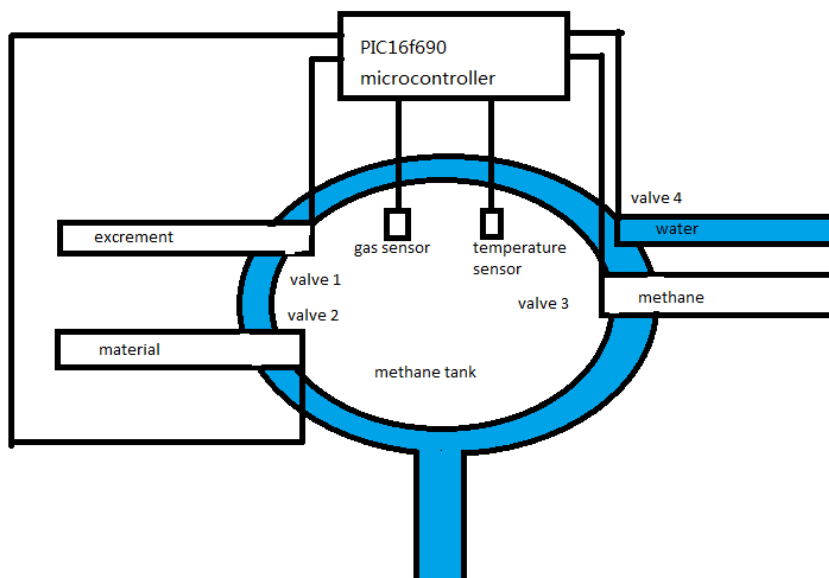
Figure 10: Basic Structure of Methane Tank

In this design, it does not need to pay too much attention to the structure of the fermentation tank and the method to generate methane gas. Because the purpose is to makes an electronic control system for monitoring gas concentration and temperature control in the laboratory. Therefore the tank structure and the generation method are not necessary to be introduced in this thesis.

As showed in Fig. 10, what the relationship between the control system and biogas digester is explained. Ideally, valve 3 will be opened when the gas concentration has arrived to more than 15%. Methane gas is unstable if the concentration is in the range of 5%~15% which is dangerous [14]. However in this design, the gas concentration at least has to be more than 30% for safety.

About the valve 1 and valve 2 in the original control system, they are used for the input of fermentation material when concentration of the methane gas becomes very low. However in this thesis, it should not be needed to use real material and excrement to produce methane. The method of generating methane gas will not be discussed. A bottle is used to

The valve 4 is used for controlling the temperature, i.e., when the temperature is above 25 degrees Celsius. The controller will automatically open the valve to introduce water into the tank to reduce the temperature, since the best ferment reaction temperature for methane gas is between from 15 to 25 degrees [16].

The tank for methane ferment reaction is replaced with a bottle, since the tank is not available in this work. To test the gas sensor, the alcohol is used instead of methane and a new method is used to adjust the MQ-2 gas sensor. The detailed information will be introduced in Chapter 3.

In Fig. 11, flow charts are showing how the sensors work.
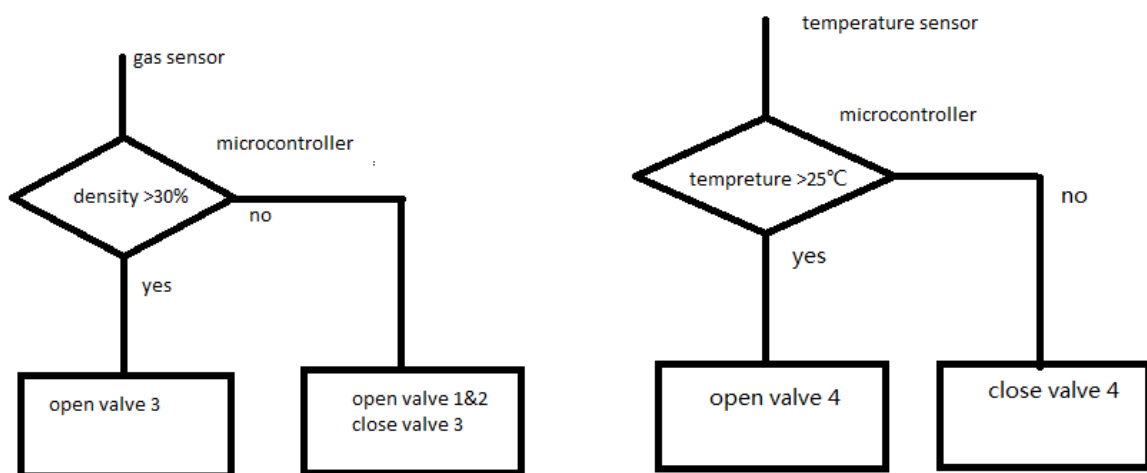
Figure 11: Flow charts of sensors

3 Process and Results
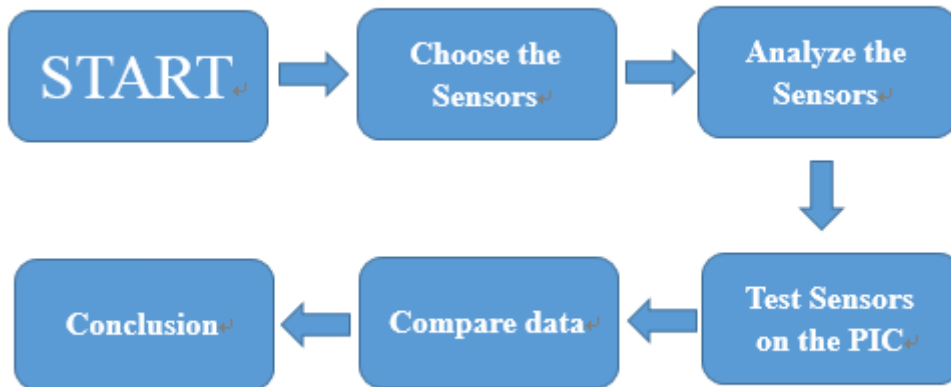
Figure 12：Process flow chart of sensors

The Fig.12 shows the whole process in this study. This chapter will explain the process of analysis, testing and compare data about sensors. Depending on the theory information in the chapter 2, we will analyse them and record the data of laboratory testing. After that, the ideal and measured data will be compare.

Before process and results are described, Section 1.3 should be review again. In first limitation, it is restricted not to build a real system for this research. The temperature sensor and gas sensor respectively are used in each different environment. In process, just putting AD590 temperature sensor in the warm water will detect the temperature and putting MQ-2 gas sensor in an almost closed glass pot will also detect the concentration.

In the second and third limitations, there are no standard concentration gas and no enough range of gas sensor. In this research, it uses alcohol fluid instead of methane gas. And the range of MQ-2 cannot be changed.

In the fourth limitation, no valves are used. For this reason, this research use LED lights instead of valves. The details are presented below.

3.1 Total Wire Connection of Design
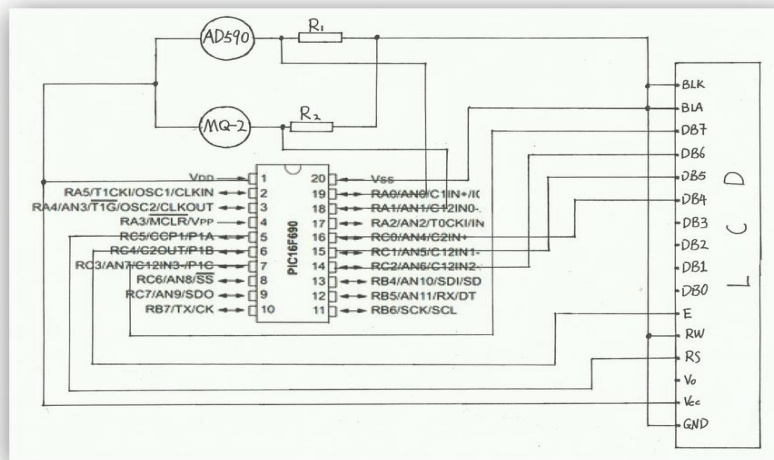
Figure 13: The connection of sensors and LCD all

The Fig. 13 all connections of sensors and LCD to the PIC16F690 microcontroller are shown. And it shows all of the pins in the PIC16F690 microcontroller. The V_{DD} (pin 1) is supply voltage pin and it had been measured in next sections. The V_{SS} (pin 20) is ground pin. So, the gas sensor, temperature sensor, and LCD screen supply voltage, were provided by V_{DD}. And all these three devices should be connected to V_{SS} to consist a complete circuit. Furthermore according to Fig. 13, there are some pins marked AN1, AN2 or AN8. These pins are analog pins. As previous paragraph shows, analog pins can be used to realize ADC functions. So, RA0 (pin 19) and RA1 (pin 18) have been chosen to monitor temperature sensor and gas sensor [19].

In the Fig. 11, flow charts of the AD590LH temperature sensor and the MQ-2 gas sensor are shown. It means if the temperature and concentration are over a value, then the PIC16F690 microcontroller will output a high level voltage signal. And this signal will control the pump or valves to adjust the environment inside tank. The signal output ports are selected as RB5 (pin 12) and RB4 (pin 13). These two ports are digital pins and can output a high-level voltage signal. When the temperature is more than 25 degrees Celsius, the RB4 will output a high-level signal. When the gas concentration is more than 30%, the RB5 will output a high-level signal. The Fig. 11 will be shown in the section 2.5.

In this experiment, the concentration critical value has been changed to 3000PPM (0.3%) since the full scale detection range of MQ-2 is only 10000PPM (1%).

In practical application, the controller could be used for automatic control for methane only if the sensor with range of 1% be changed to sensor with range of 30%. The high range sensor and low range sensor share same characteristic and could be changed. The reason why author does not use sensor of 30% is that high range sensor could only test methane, CO2, H2 and so on .these could not be acquired in funding range, thus author choose low range sensor for test purpose.

3.2   Process of Gas Sensor

3.2.1   Analysis of MQ-2 Gas Sensor in Ideal Situation

According to Fig. 5, the circuit can be simplified. This is shown in Fig. 14.
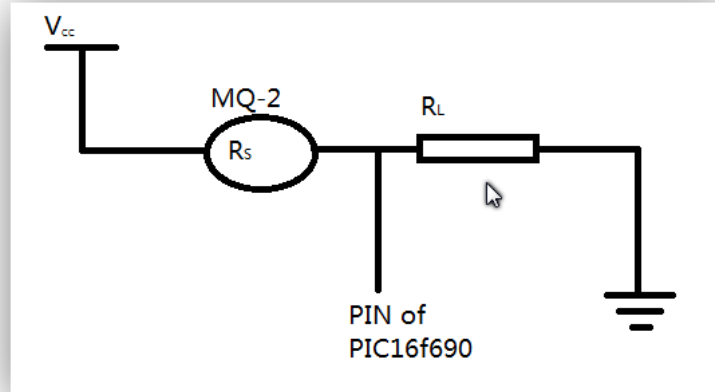
Figure 14: Basic Circuit of MQ-2

From Fig. 14, R_L resistor and R_S resistor assemble a series circuit. The formula of R_S can be deduced as:

$$\frac{R_L}{R_L+R_S} = \frac{V_{RL}}{V_{CC}} \tag{3.1}$$

Where R_S is sensing resistance, R_L is loading resistance, V_{RL} is loading voltage and V_C is supply voltage.

After reformulating eq. 2.1, value of V_{RL} and R_S can be found as:

$$V_{RL} = \frac{V_{CC}*R_L}{R_L+R_S} \tag{3.2}$$

and

$$R_S = \left(\frac{V_{CC}}{V_{RL}} - 1\right) * R_L \tag{3.3}$$

Author chooses 1k ohm resistor as RL resistor. According to Fig. 7, alcohol can be used to substitute for methane, since their sensitivity characteristics are similar. Table 1 is showing the MQ-2 sensitivity for alcohol.

Table 1: Alcohol sensitivity characteristics rate data of MQ-2

Concentration (ppm)	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
R_S/R_O	2	1.6	1.4	1.2	1	0.9	0.8	0.76	0.7	0.68	0.65

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In this thesis, temperature sensor and gas sensor supply voltages are provided by the PIC16F690 microcontroller. The V_{CC} after be measured in PIC16F690 microcontroller, it equal to 4.75Volt. Therefore these two have a constant value.

According to Fig. 6, the R_S is the sensing resistance of the gas sensor and it has a range. According to the handbook of MQ-2 gas sensor, R_S is defined as the resistance in different gases and different concentration [17]. As a result, the R_S can be understood as a variable resistor and its resistance will be changed depending on gases type and concentration.

According to the handbook of the MQ-2 gas sensor, the R_O of Fig. 7 is the sensing resistance in 1000 PPM Hydrogen [17]. And in the Fig. 7, is shown that the resistance of R_O is equal to R_S when R_O/R_S is equal to 1:1. Therefore, R_O is equal to R_S when the gas sensor is kept in 1000 PPM Hydrogen environment.

In order to get the R_S value from Table 1, Ro should be calibrated before. Because the ratio of R_S and Ro stable in the clean air, this make it very convenient calibrate the Ro in this environment.

Then the calibration equation is also Eq. 3.3, and the feed in parameter is descript as following:
- The output voltage (V_{RL}) has been measured in clean air and is equal to 0.05 V.
- Loading voltage (R_L) was selected to 1 kΩ.
- Supply voltage (V_{CC}) was measured to 4.75 V.

Then according to eq. 3.3, R_S can calculated to 94 kΩ in clean air. Since R_S/R_O equals 9.5 in clean air, R_O becomes 9.89 kΩ.

Because the value of Ro is constant values of Rs are given in Table 2 for different concentration. Finally, the output voltage of the gas sensor, V_{RL}, can be calculated with eq. 2.2. The V_{RL}, R_L, and V_{CC} have shown in the previous paragraph. The result is shown in Table 2.

Table 2: Output voltage and R_S value of MQ-2 in the different alcohol concentration

Concent ration (ppm)	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	1000 0
R_S /R_O	2	1.6	1.4	1.2	1	0.9	0.8	0.76	0.7	0.68	0.65
R_S (Ω)	19780	15824	13846	11868	9890	8901	7912	7516	6923	6725	6428
V_{RL} (mV)	229	282	320	369	436	480	533	558	600	615	639

The Tab.2 could be illustrated in Fig.15, the relation would be used as to detect the VS alcohol concentration.
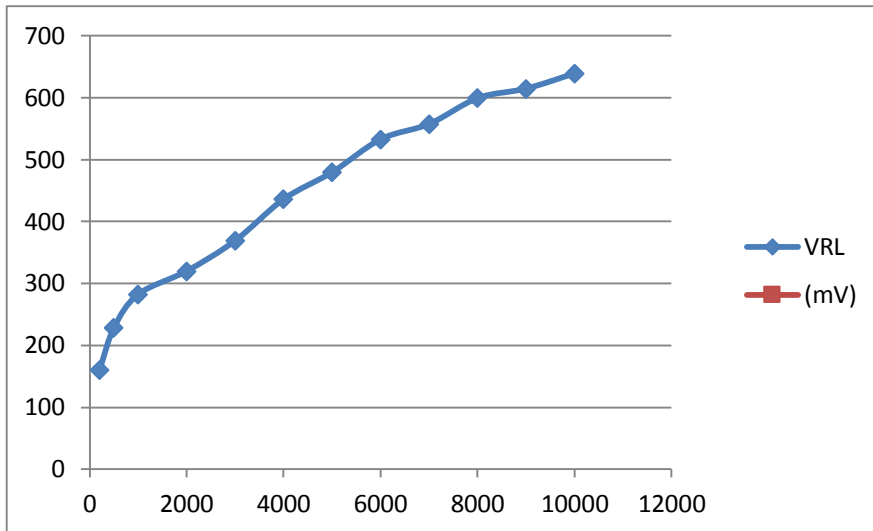
Figure 15: Output voltage VS alcohol concentration

3.2.2   Testing of MQ-2 Gas Sensor in laboratory

The whole process steps of testing gas sensor should be introduced first. The all steps are shown in Fig. 16.
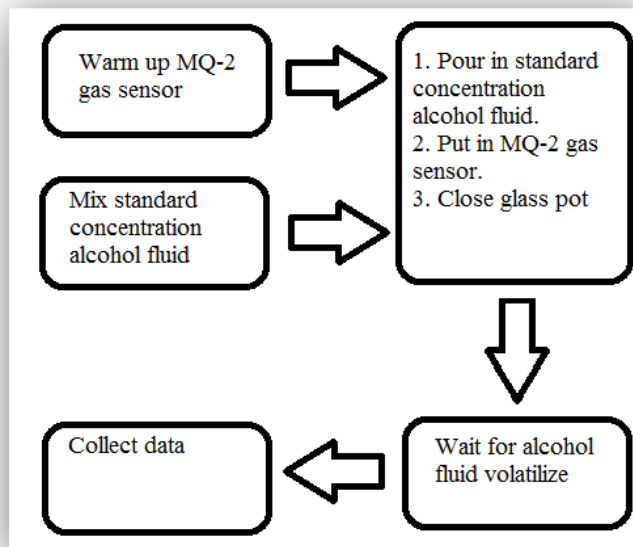
Figure 16: Steps of MQ-2 Gas Sensor Process

The five steps in Fig. 16 are introduced in the paragraphs above.

3.2.2.1   Warm Up MQ-2 Gas Sensor

This part is the first step in the process and it is about heating time of MQ-2 gas sensor. The MQ-2 gas sensor needs a long heat-up time before first using. In practical, the best output voltage is achieved after the sensor was warmed up more than ten days. In the

data of Table 2, the ideal output voltage of MQ-2 gas sensor in different concentration of alcohol is shown. As shown in Table 3, there are many different output between 2 days, 7 days and 10 days. The heat-up time undisputedly determines the accuracy of the output.

Table 3: MQ-2 gas sensor output voltage VS heat-up time

Concentration (PPM)	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
Ideal V_{RL} (mV)	229	282	320	369	436	480	533	558	600	615	639
Practical V_{RL} (mV) 2 days	330	510	728	900	1050	1150	1200	1220	1290	1340	1430
Practical V_{RL} (mV) 7 days	230	200	311	350	454	494	520	570	615	645	665
Practical V_{RL} (mV) 10 days	201	223	311	365	445	470	519	569	590	620	650

In the Table 3, the output voltage becomes to idealized state after 10 days. It means the heat-up time before first using is very important.

Figure 17: Output voltage VS concentration in different heat-time

Fig. 17 show that the sensor could describe the real V_{RL} only after 7 day's warm up. The date acquired after 2 day's warm up is way above ideal V_{RL} and after 7 day's warm up, sensor's character become stable and it does not need warm up any more.

3.2.2.2 Mix Standard Concentration of Alcohol Fluid

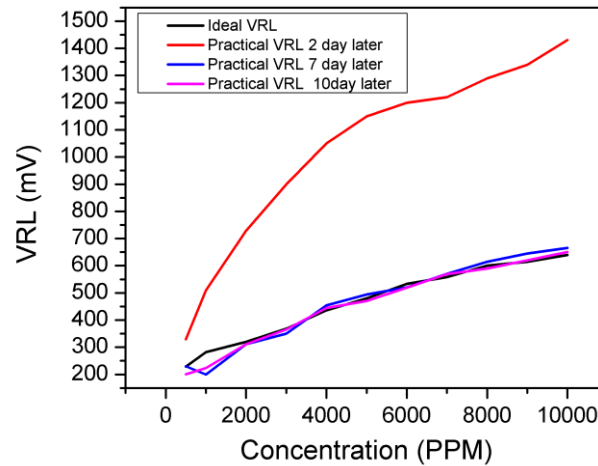This part of the gas sensor process is mixing the standard concentration of alcohol fluid. In Chapter 2 was shown on that unit PPM also can presented as mg/l. Therefore the mixing method just needs to get out the mass of pure alcohol and use clean water to mix fluid until one liter. In this process, 60% ethanol concentration fluid has been used as primary alcohol fluid. As common knowledge, the density, mass and volume calculation can be done in the following way:

$$M = D * V \qquad (3.4)$$

Where M is mass, D is density and V is volume.

Eq. 3.4 is working in the pure fluid. But as the previous paragraph shows, a 60% ethanol concentration fluid is chosen as primary fluid. Therefore, the volume should multiply the concentration of primary fluid.

$$M = D * V * C \qquad (3.5)$$

Where M is mass of alcohol in standard concentration fluid, D is density of pure alcohol, V is volume of primary fluid and C is concentration of primary fluid.

After reformulating eq. 3.5, the value of V can be found as:

$$V = \frac{M}{C*D} \qquad (3.6)$$

In this step, 1 liter 10000 PPM standard concentration of alcohol fluid is mixed. According to eq. 3.4, the purpose is to get 1 liter 10000 PPM standard fluid and 10000 PPM equal to 10000 mg/l. therefore, there are 10000 mg pure alcohol in the fluid. The mixing process has shown on below:

- The mass of pure alcohol is 10000 mg.
- The density of ethanol is 789 mg/ml at 20 degrees Celsius.
- The concentration of primary alcohol fluid is 60%.

Putting these three conditions in eq. 3.6, V equals to 21.1 ml. So, mix 21.1 ml with clean water until the whole volume reaches 1 liter. Now, there is a 1 liter 10000 PPM standard concentration of alcohol fluid mixed. This fluid includes 10000 mg pure alcohol and it follows that 10000 PPM equal to 10000 mg/l.

3.2.2.3 Put the Standard Fluid and Gas Sensor in the Glass pot.

Figure 18: The glass pot which used to adjust the MQ-2 sensor

The gas sensor testing method in this research is to use an almost closed glass pot to create a closed and stable measurement environment. Moreover, it also must provide a space for the gas sensor. In Fig. 18, the pot volume is 220 ml. The chosen fluid volume in this research is 100 ml.

3.2.2.4   Wait for Fluid Volatilize

Ideally, the alcohol fluid will volatilize in the remaining area. The remaining area will contain a standard concentration of gas if the standard concentration of alcohol fluid is as much as possible after a relatively long time.

In the research, the output voltage will be almost stable after 50 minutes, which could be shown in Fig.19. In Table 4, the output voltage increase depends on time when concentration is less than 4000 PPM. It is possible the gas sensor in the low concentration. The alcohol of fluid is not easy to be volatilized. However, the increasing or decreasing is not important.

Table 4: MQ-2 gas sensor output voltage by different measurement time

Concentration (PPM)	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
V_{RL} at 2 min (mV)	100	160	254	330	419	518	538	613	767	720	882
V_{RL} at 5 min (mV)	150	178	265	335	432	512	523	605	712	690	780
V_{RL} at 20 min (mV)	190	197	285	345	438	423	520	590	650	640	690
V_{RL} at 30 min (mV)	201	212	302	350	443	435	519	585	603	631	665
V_{RL} at 50 min (mV)	201	223	311	365	445	470	519	569	590	620	650
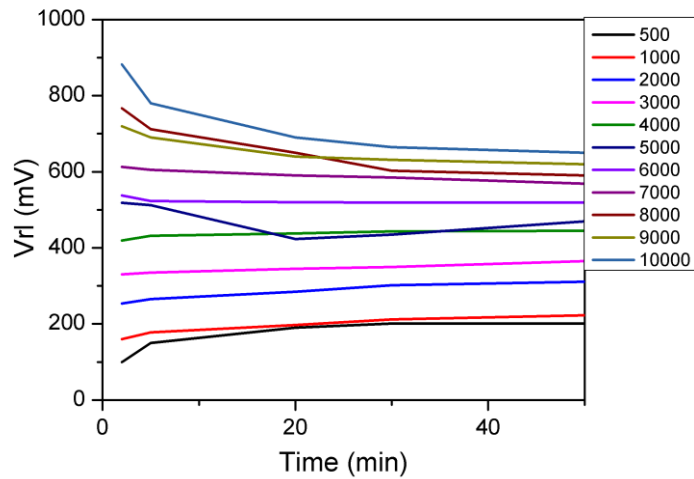
Figure 19: Output voltage VS time in different concentration

3.2.2.5　　　　Collect Data

Follow the steps above, the practical data of the gas sensor output voltage is shown in Table 5.

Table 5: Output voltage of MQ-2 in the different concentration alcohol fluid

Concentration (PPM)	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
Ideal V_{RL} (mV)	229	282	320	369	436	480	533	558	600	615	639
Practical V_{RL} (mV)	201	223	311	365	445	470	519	569	590	620	650
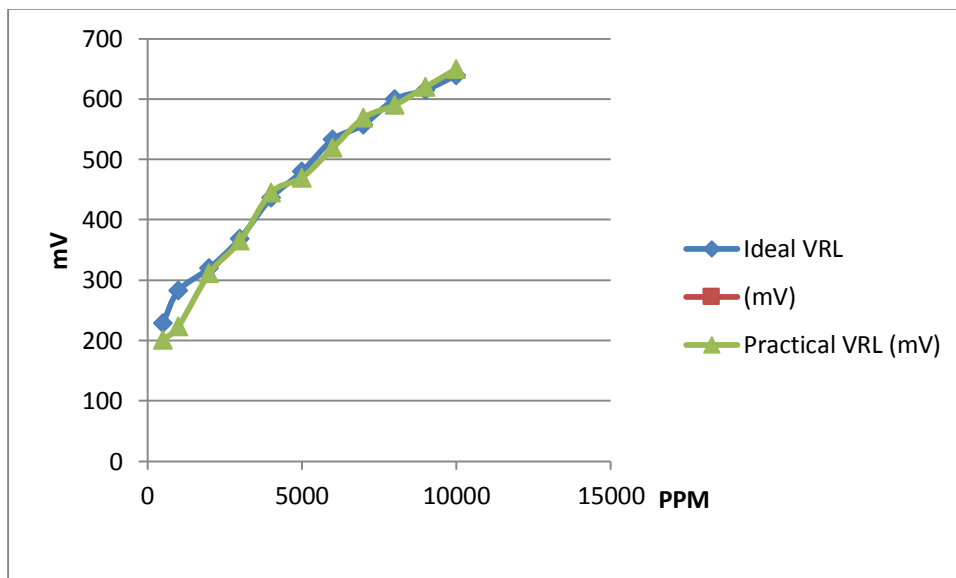
Figure 20: Data comparison between ideal and practical output voltage

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According to Fig. 20, since the lines of ideal and practical are very close, the sensor in the controller could measure gas concentration correctly.

3.3   Process of Temperature Sensor

TheAD590LH temperature sensor as described above is for detecting the temperature inside the tank. It is connected with the PIC16F690 microcontroller. When the temperature inside the tank is over 25 degrees Celsius, the sensor detects it and the microcontroller outputs a signal to the pump for decrease the temperature.

In Fig. 8, it shows that the loading resistor is consisted by two different resistors. One of them is a stable resistor and the other is an adjustable resistor. The selection range of the adjustable resistor is 100 Ω. Therefore, the process of temperature sensor is choosing a suitable resistor for adjustable sensor.

In the process, there is digital thermometer used for the AD590LH adjustment. The steps are shown below:
- Firstly, a vacuum cup should be used with a cover to keep the temperature for a few minutes.
- Pour some hot water into vacuum cup.
- Put the digital thermometer and AD590LH in the vacuum cup, and lid the cover.
- Compare the data of the digital thermometer and AD590LH. Then, adjust the resistor until the AD590LH outputs the correct voltage. The output voltage of the AD590LH should follow the rulers of Kelvin unit.
- Pour a little of cold water into vacuum cup. And repeat the step 4 to check the adjustable resistor.

3.4   3.4 Result

This chapter will focuses on how to use the final data of MQ-2 gas sensor. Before introduce the method, the reason should be presented first.
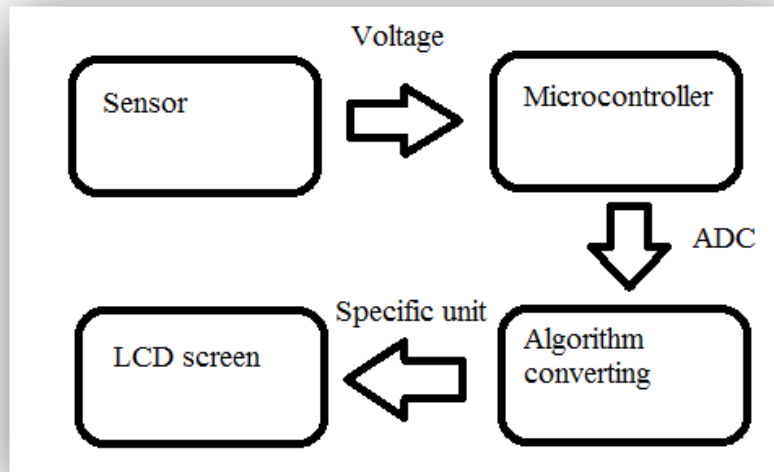
Figure 21: Whole Process of Microcontroller

The Fig.21 has shown on the whole process about microcontroller. In the previous chapters, they have talked the process from block 'Sensor' to block 'Algorithm converting'. This process means the output voltage of sensor should be change to digital value via to ADC (analog-to-digital-converter). However, this is not the end. These digital values should be reformulated as a result of what in the specific unit.

In the gas sensor, user does not want to know how many output voltage is outputted by sensor. The user only want to know what the gas concentration is. Such as, the analog value will be changed to digital value as 100 if the gas sensor output 100 mV in 200 PPM. If the steps without 'Algorithm converting' step, the number 100 will show on the LCD screen directly. In addition, if the steps within 'Algorithm converting' step, the number 200 will show on the LCD screen. The step of converter number from 100 to 200 named poly-fit.

In the table 2, it has presented the practical output voltage of MQ-2 gas sensor in different concentration. In this part, the data should be inversed due to the process of poly-fit is converter the number of output voltage to concentration. And the process of table 2 is converter the concentration to output voltage. The pictures have shown on below:
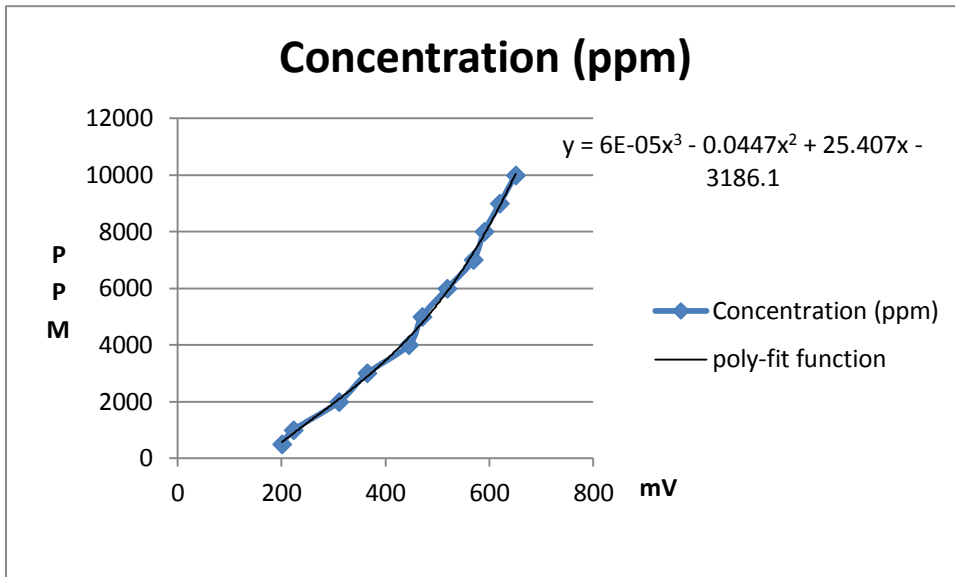
Figure 22: concentration depend by practical output voltage

According to the Fig. 22, the poly-fit function has shown on in the picture. The black line is the poly-fit function. There are little difference between the blue line and poly-fit line. Because the output voltage data cannot be constituted a perfectly function. If want to get a poly-fit line what can be more close the practical data. It can use a more high level polynomial function to solve this problem. In the ideal, high power polynomial function is better than low power. However, the PIC16F690 microcontroller's arithmetic speed is too low to calculate the results on time. Therefore, it is not a suited function in this thesis.

In this part, author uses the Excel to get the poly-fit function. The function has shown on below:

$$y = 6 * 10^{-5}x^3 - 0.0447x^2 + 25.407x - 3186.1 \qquad (3.7)$$

Where X is value of gas sensor's output voltage and Y is the concentration in different gas sensor output voltage.

4 Discussion

This chapter would discuss what has been done in this paper in macroscopic and what could be done to improve this work in the future.

Also, since controller in this paper is only tested in the experiment instead of application, there should be some modification before it could be used in application.

4.1 Controller system construction.

The controller system in this paper include two input: gas concentration sensor and gas temperature sensor, and four output: water valve output, excrement valve output, rubbish valve output, methane valve output. With this two input and four output, two closed control loop is formed as material loop and water temperature loop.

This construction could meet the fundamental demand of automatic control of methane producing, however, the system could not detect whether there is still rubbish and excrement at the input port. That means the gas would get out from rubbish or excrement port if there is no rubbish or excrement at the port, and the controller does not know this. Thus, two more sensors like pressure sensors should be located before the rubbish and excrement input pot to detect whether there is still material to feed the tank. This information could be display on the LCD screen showing whether the controller is at good condition and whether the system is at good condition.

4.2 Sensor selection

The sensor should be changed to a methane sensor from an alcohol sensor, when this controller is used practical application. Methane sensor share the same character with alcohol sensor, which could be applied only after the same calibration procedure with alcohol sensor.

The calibration procedure include: 1. Choose R_L; 2 Calibrate the relation between the gas concentration and output voltage; 3. Code the relation to the program.

In the R_L selection, the $R_L = \sqrt{a * b}$, in which, a is the maximum value of Rs and b is the minimum value of Rs. This equation could be acquired as following.

In order to get the maximum of range of output voltage, the voltage range could illustrated as:

$$Range = \frac{V_{CC} * R_L}{R_L + a} - \frac{V_{CC} * R_L}{R_L + b}$$

Same to

$$Range = \frac{V_{CC} * R_L}{(R_L + a) * (R_L + b)} * (b - a)$$

At the point where gradient of range is zero, the range will peak at the maximum value.

$$\frac{\partial Range}{\partial R_L} = V_{CC} \frac{-R_L^2 + a * b}{(R_L + a) * (R_L + b)}$$

$$\frac{\partial Range}{\partial R_L} = 0$$

Then

$$-R_L^2 + a * b = 0$$

And the selection equation of $R_L = \sqrt{a * b}$ could be acquired, the user could choose resistor near $R_L = \sqrt{a * b}$.

4.3   Controller application

When this controller is applied to the practical situation, following issues should be done:

First. Add two more pressure sensors before excrement valve and rubbish vale to detect whether there is material before the port and program another display function for LCD screen to illustrate whether the controller is working properly. The algorithm could be design as if there is pressure before port then the valve after the port could be open, otherwise, open the other one. If both port is not available, then display some information on LCD screen to notice the user that there is something wrong with the system.

Second. Change the sensor to methane gas sensor and calibrate the sensor as discussed before. The cost of methane gas sensor should be much more expensive then the alcohol gas sensor.

Third. The valve output driver should be changed to corresponding driver of valve that used in application. The algorithm could be same as what has been described before, since the commonly used valve need similar driver signal but just with higher drive current or voltage.

5 Conclusion

This thesis is divided by four main chapters. They are introduction, theory, process and discussion. In the introduction chapter, it has interpreted why author is interesting in this topic and what are the functions in methane controller system. This methane gas is become more and more popular in the whole world because the methane gas is a kind of clean, cheap and convenient power. In the chapter 1, the pictures of methane tank structure help author to design what kind of functions control system should have.

The chapter theory has talked about the output voltage of gas sensor and temperature sensor in the ideal situation. These ideal data will compare with practical data in the chapter three. Thus these ideal can decide how the practical does. In the deduce process, the output voltage of gas sensor has little complex to understand. So, author writes process more detail and clean.

The chapter process and result has explained what to do and how to do. In this chapter, author uses any methods to remedy the several limitations of thesis. Such as, using the glass pot instead for methane tank and using alcohol to similar standard concentration methane gas. Finally, author gets the perfect result. It also proves the methods which author used is working.

The chapter discussion has described how to use the output voltage data in the PIC16F690 microcontroller. And finally, thesis finished the whole process from measure the data of gas sensor's output voltage to converter these value to concentration on the screen.

The difficult points are capturing the several limitations in this thesis. Such as: no methane tank and methane gas. These limitations affect the design and process in the whole thesis. Fortunately, author uses glass pot and alcohol fluid to solve these problems. And some practical data is very close expected data.

To conclude, biogas is a crucial component of both the rural new energy development and sustainable development in China. The biogas digesters save more energy resources because of higher heat efficiency when comparing with coal-based or firewood-based energy consumption [20]. It is reported that the utilization rate of the biogas potential is only 19% [21]. It is suggested by the Chinese scientists that household digesters should be continued promoted in the rural areas [7]. Hence, more research needs to be carried out in this field.

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Appendix A

The coding in appendix A run at the PIC hardware and the function is
to displace the gas temperature value and gas concentration value on
the LCD.

```
#include <pic.h>
#include "lcd.h"
/*****************************************/
// Prototypes
/*****************************************/
voidinit_display(void);
voidprint_data(char data);
voidprint_instr(char instr);
void E(void);
void delay(void);
voidlong_delay(void);


/*****************************************/
// Definitions (this is not variables!)
/*****************************************/
#define CLEAR 0x01
#define ADDRESS 0x80
/*****************************************/
// Function that initiates the display
/*****************************************/
voidinit_display(void)
{
        // See the datasheet flow chart for the procedure below
        // This part initiates the LCD in 4-bit mode...
        long_delay();
        long_delay();
        PORTC=0x03;
        E();
        PORTC=0x03;
        E();
        PORTC=0x03;
        E();
        PORTC=0x02;
        E();

        // Set LCD properties...
        print_instr(0x28);   // 2: Dual line (even though it is
single line)
        print_instr(0x0C);   // 3: Display on, cursor, blink
        print_instr(CLEAR);  // 4: Clear
        print_instr(0x06);   // 5: Entry mode set

// LCD is now initialized...
}

/*****************************************/
// Print chars to LCD with 4-bit method
/*****************************************/
voidprint_data(char data)
{
```

```c
        PORTC = (data>>4) & 0x0F;
        RC5=1; // RS
        E();

        PORTC = data & 0x0F;
        RC5=1; // RS
        E();
}

/*****************************************/
// Print instruction to LCD with 4-bit method
/*****************************************/
voidprint_instr(char instr)
{
        PORTC = (instr>> 4) & 0x0F;
        E();
        PORTC = instr& 0x0F;
        E();
}

/*****************************************/
// Toggle E to execute command/instruction
/*****************************************/
void E(void)
{
        //         delay();
        RC4=0;
        delay();
        RC4=1;
        delay();
        RC4=0;
        delay();
}

/*****************************************/
// Just a short delay
/*****************************************/
void delay(void)
{
        unsigned int del;
        for(del=0;del<700;del++);
}

/*****************************************/
// Just a long delay, used at init...
/*****************************************/
voidlong_delay(void)
{
        unsigned long j;
        for(j=0;j<100000;j++);
}
```

Appendix B

The coding in appendix B run at the PIC hardware and the function is to transform the voltage value to gas temperature and gas concentration.

```
/*
@ This is PIC MCU ADC Test
@ /lcd.h/ This is LCD Fun word
@ MCU Type 16F690 have 12changer 10bit
*/
#include <pic.h>
#include <math.h>
#include "lcd.h"


__CONFIG(FOSC_INTRCCLK & WDTE_OFF & PWRTE_ON & MCLRE_OFF & CP_OFF & CPD_OFF);


#define     AD590_CH    0
#define     MQ2_CH                  1

unsignedint g_vol;
unsigned char dis_buf[10];


signed short temp;
unsignedint mq2;
/*
*/
void gpio_init(void)
{
            ANSEL=3;

            PORTA = 0x03;
            TRISA = 0x03;
            WPUA = 0x00;
            IOCA = 0x00;
            PORTC = 0x00;
            TRISC = 0x00;
            PORTB = 0x00;
            TRISB = 0x00;
}
//
voidADC_calc(unsigned char ch)
{
            unsigned long l_tmp;
            unsignedintw_m;
            unsignedintw_adc=0;
            unsigned char i;

            ADCON1 = 0x50;
            ADCON0 = ch<<2;
```

36

```c
                ADCON0 |= 0x80;
                ADCON0 |= 0x01;

                for(i=0; i<8; i++){
                        ADCON0 |= 1<<1;/*set GO for 1*/
                        while(ADCON0 & (1<<1));
                        w_m = (ADRESH<<8)|ADRESL;
                        w_adc += w_m;
                }
                ADCON0 = 0x00;
                w_adc /= 8;/* 平均法 */
                l_tmp = w_adc;
                g_vol = (l_tmp*4750)/1024;
}
/*@n:0~65535 for nop
*/
voidCPU_wait(unsigned int n)
{
                while(n--);
}
/*
@x:0~15;
@y:0~1;
@*str Length Max 16 Byte
*/
voidLCD_str(char x, char y, const char *s)
{
                if(y==0)
                {
                        x+=0x80;
                }
                else
                {
                        x+=0xC0;
                }
                print_instr(x);
                while(*s!='\0')
                {
                        print_data(*s);
                        s++;
                }
}
/*@Display value*/
void display(void)
{
                if(temp<0){//如果是负的温度
                        temp = -temp;
                        dis_buf[0] = '-';
                        dis_buf[1] = (temp/100%10)+'0';
                        dis_buf[2] = (temp/10%10)+'0';
                        dis_buf[3] = (temp%10)+'0';
```

```
                                     dis_buf[4] = 'C';
                                     dis_buf[5] = '\0';//结束符
                      }else{
                                     dis_buf[0] = '+';
                                     dis_buf[1] = (temp/100%10)+'0';
                                     dis_buf[2] = (temp/10%10)+'0';
                                     dis_buf[3] = (temp%10)+'0';
                                     dis_buf[4] = 'C';
                                     dis_buf[5] = '\0';
                      }
                      LCD_str(0,0,"Temp=");
                      LCD_str(5,0,dis_buf);

dis_buf[0] = (mq2/10000%10)+'0';
                      dis_buf[1] = (mq2/1000%10)+'0';
                      dis_buf[2] = (mq2/100%10)+'0';
                      dis_buf[3] = (mq2/10%10)+'0';
                      dis_buf[4] = (mq2%10)+'0';
                      dis_buf[5] = '\0';
                      LCD_str(0,1,"MQ-2=");
                      LCD_str(5,1,dis_buf);
LCD_str(10,1,"PPM");
}
/*@Main Code
*/
void main(void)
{


          gpio_init();
          init_display();

          while(1)
          {
                      CPU_wait(50000);
                      ADC_calc(AD590_CH);
                      temp = g_vol - 100;
          CPU_wait(50000);
                      ADC_calc(MQ2_CH);
      mq2=0.0176*g_vol*g_vol+2.3026*g_vol-227.37;
                      display();

                      RB4 = temp > 27;
      RB5 = mq2 >3000;
          }
}
```

Ci