AN AQUATIC QUALITY AUTOMATION SYSTEM (AQAS)

By

CHE KU 'ADLAN CHE KU SALIM

FINAL YEAR PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
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CERTIFICATION OF APPROVAL

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5723

A project dissertation submitted to the
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JUNE 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

CHE KU 'ADLAN BIN CHE KU SALIM

ABSTRACT

An Aquatic Quality Automation System (AQAS) is a system designed to monitor and control the water quality. This system usually installed at the wastewater treatment plant. Raw waters, such as water from river usually have a low pH value, which can be group as acid. This system is trying to neutralize the pH value as to make the pH value as close to 7 as possible. In this project, a controller for this system will be designed. The controller will be designed to monitor and control the pH of the liquid in a Continuous Stirred Tank Reactor (CSTR). pH control system is well-known as a difficult process due to the non-linearity of the titration curve of the pH itself.

In this project, a good controller will be designed to overcome the non-linearity of the pH control system. pH value can varies significantly during neutralization process. The controller designed must be set up at a typical specification and able to react accordingly to the changes in pH during the whole process. PID controller will be designed for this project. SIMULINK software will be use in this project to aid in the controller design stage.

It is concluded that using the PID controller can actually be use for pH control system. The SIMULINK software is a great help during the designing and simulation stage as to optimize the PID controller.

ACKNOWLEDGEMENT

First and foremost I would like to thank God Almighty for being my strength in times of needs and my place of comfort. With God, all things are possible.

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ABBREVIATIONS AND NOMENCLATURES

AQAS	Aquatic Quality Automation System
CSTR	Continuous Stirred Tank Reactor
PID	Proportional, Integral, Derivative
CaCO3	Calcium Carbonate
KMnO4	Potassium Permanganate
HCl	Hydrochloric Acid
NaOH	Sodium Hydroxide
ODE	Ordinary Differential Equation
FODT	First Order with Dead Time

CHAPTER 1:

INTRODUCTION

1.1 Background of Study

This Aquatic Quality Automation System (AQAS) is designed to monitor and control the water/liquid quality, inside the installed area. For this project, pH is chosen as the variable to be controlled. This system usually used in industry, especially in wastewater treatment plant. At wastewater treatment plant, the water is being treated before released to the river or distributed to the neighbourhood and one of the treatments is pH neutralization process. Let us take an example of one company that deals with water treatment process. Water from the river (raw water) is being pumped into the tank and pH value of the water is checked. Usually, the pH of the water is far below 7, means that it is acidic. In the first tank, they will add a reagent called chalk to increase the pH value. The chemical name for this chalk is Calcium Carbonate ($CaCO3$). Basically, adding this $CaCO3$ will boost up the pH value slightly higher than 7, in the range of 7.5 to 8.5. The neutralization process does not end here. After the raw water is added with the $CaCO3$ in the first tank, it will be transferred to the second tank. In this second tank, the water will be added with another reagent called Potassium Permanganate ($KMn04$). This reagent is added in order to adjust the colour of the water. In addition to colour adjustment, this $KMn04$ will reduce the pH of the water. At the end of this process, the water will have pH ranged from 6.5 to 7.5, which can be considered as neutral. In both tanks, mixers are installed to make sure the water is well-stirred.

The problem occurred in this company is that the controller is not working well. This is due to the pH of the raw water varies significantly. The controller at the plant does not have the ability to react to such great variation of the pH of the raw water. Currently practice at the plant is that, every morning, the technicians will have to manually check the pH of the raw water using the pH sensor. Then, the valve for the CaCO3 will be opened depending on the pH of the raw water. The lower the pH of the raw water, the bigger the opening will be. Another problem is that, the pH sensor installed to sense the pH of the raw water will be covered by slugs and mud for a certain amount of time. If the raw water is murky, the pH sensor will be covered by mud faster.

This problem is not encountered by this company alone. The pH neutralization process is well-known as a difficult process due to highly non-linear characteristics of the pH itself. The concentrations and flows of the liquids involved in the process are one of factors that need to be taken into consideration. In case of the liquids involved in the neutralization process has low concentration; it cannot be neutralized using the reagent. Liquids with low concentration will have difficulties to change their pH. This phenomenon is called *buffering* [1].

In this project, a good controller is to be designed. The proposed solution is to use PID controller. SIMULINK software will be used in simulation stage to make sure the design is the best chosen. The major concern is to prove that PI controller can actually be used for this pH neutralization process.

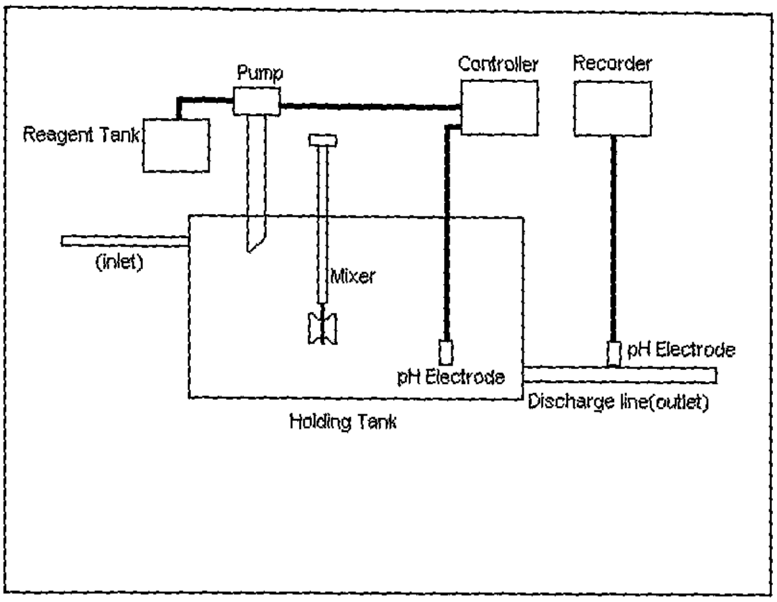

Figure 1: Basic Illustration of the AQAS

In this system, basically there will be two inputs, one mixer, one controller, and one output, as shown in Figure 1. The first input is liquid with pH value ranged from 14 to 8. In other words, the first input will be liquid that is not neutral. The second input will be the reagent added to the tank in order to neutralize the pH of the first input. The mixer is installed inside the holding tank. The function of this mixer is to stir the liquid to make sure that the liquids inside the tank is well-stirred. The output is liquid coming out from the holding tank, and the desired pH for the liquid is as close to 7 as possible.

1.2 Problem Statement

For the pH neutralization process, PID controller will be designed to control the process with certain limitations and assumptions. The most preferred controller is PI controller. The performance of the PI controller will be tested throughout this project.

1.3 Objectives and Scope of Study

The objective of this project is to design a good controller that can be used in the pH neutralization process.

The scopes of study for this project are:

- To study the pH neutralization process.
- To obtain the mathematical model for pH neutralization process and run simulations based on the model.
- To run experiments for pH neutralization process in Process Control & Instrumentation Laboratory (23-00-06). PI controller will be tested during the experiments.
- Make the comparison between the results of simulations and the experiments.

CHAPTER 2:

LITERATURE REVIEW

2.1 Aquatic concept

Aquatic is something that is related to water. This project involves some sort of liquids, which are acid and bases. Bases, having pH value greater than 7 will be the first input into the tank. To neutralize the bases, acid which has pH value lower than 7 will be used as the reagent. The concern is to make sure that the pH value of the final product is as close to 7 as possible.

2.2 Quality concept

Quality means the degree of excellence of something. In this project, the word quality is necessary since the desired output is a liquid with pH value close to 7. Liquids having pH value less than 7 are considered acid, and liquids with pH value greater than 7 are considered as base. Liquids with pH value approximately 7 are considered as water. Liquids with pH value of 7 are in neutral state. Unlike acid and base, liquids with neutral state bring no harm to environments. They are not hazardous and corrosive like most of the acids and bases do. Considering this matter, the word quality fits well for this project.

2.3 Automation system

When the word automation system is used, it means that to automatically control a process. Usually, in automation system, there will be the usage of a network to interconnect sensors, controllers, operator terminals and actuators. In this project, there will be the usage of sensors and controller. Also, the system designed in this project is meant to automatically control the neutralization process.

2.4 Concept of pH

pH is actually the measurement of the acidity or alkalinity of a liquid that contains a proportion of water [1]. To define the pH

$$pH = - Log_{10}H^+$$

where H^+ is hydrogen ion concentration, gram moles/liter.

Liquids with pH below than 7 are called acid while liquids with pH value higher than 7 are called alkalis or bases. From the equation above, it is noted that H^+ is the hydrogen ion concentration therefore; the measurement of pH is the measurement of the dissociation of the acid or alkali molecules into ions. For some acids, they dissociate readily and produce high concentrations of hydrogen ions. These kinds of acids are called strong acids. This also applies to bases.

2.5 pH Neutralization

As mentioned before, pH neutralization process is a very non-linear process. This is shown in Figure 2.

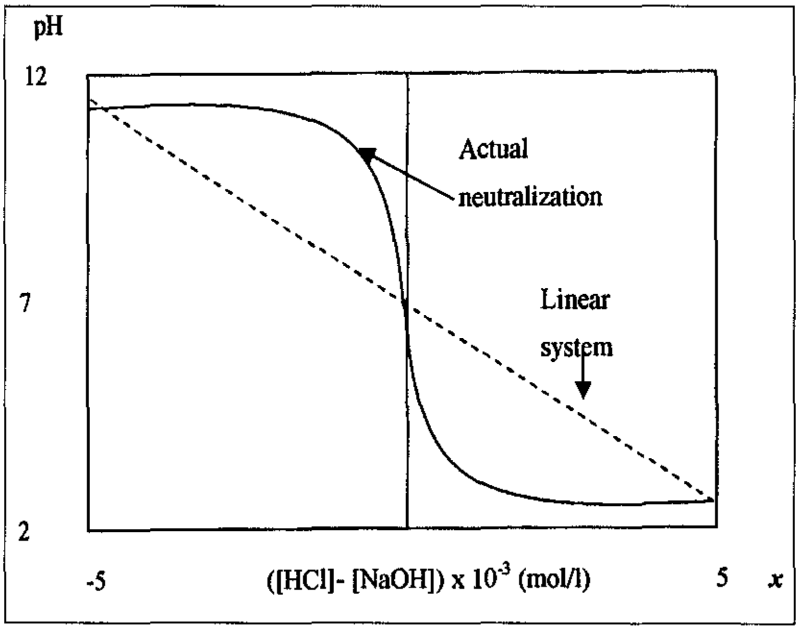

Figure 2: Titration Curve for pH Neutralization Process

Here is presented the chemistry point of views that explain the non linearity behaviour of pH neutralization process as per explained by Astrom [2], pH is a measure of the concentration or more precisely the activity of hydrogen ions ($[H^+]$) is a solution. It is defined as:

$$pH = -\log[H^+] \qquad (1)$$

However, the formula is not totally correct since $[H^+]$ has the dimension of concentration which is measured in the unit M = mol/l. the modified formula is:

$$pH = -\log[H^+]f_H \quad f_H = \text{constant with dimension l/mol.} \qquad (2)$$

But, the first formula is universally accepted in most chemistry textbooks. Water molecules are dissociated (split up into hydrogen and hydroxyl ions) according to the formula:

$$H_2O \Leftrightarrow H^+ + OH^- \qquad (3)$$

In chemical equilibrium, the concentration of hydrogen ion H^+ (or rather $H3O^+$) and hydroxyl ions are given by the formula:

$$\frac{[H^+][OH^-]}{[H_2O]} = cons\tan t \qquad (4)$$

Only a small fraction of the water molecules are split up into ions. The water activity is practically unity, and we get:

$$[H^+][OH^-] = K_w \qquad (5)$$

The equilibrium constant $\boldsymbol{K_w}$ has the value 10^{-14} $[(mol/l)^2]$ at 25°C.

So, where the non linearity come from?

It is good to describe the process with an example. Let's take a look on the neutralization process pf m_A mol hydrochloric acid, HCl by m_B mol of sodium hydroxide NaOH in a water solution. The reaction takes places as follows:

$$HCl + NaOH \Leftrightarrow H^+ + OH^- + Na^+ + Cl^- \qquad (6)$$

Let's the total volume be V. the concentration of chloride ions is then:

$$[Cl^-] = x_A = m_A / V \qquad (7)$$

And the concentration of sodium ions is given by:

$$[Na^+] = x_B = m_B / V \tag{8}$$

because the acid and base are completely ionized. Since the number of positive ions equals to the number of negative ions, it follows that:

$$x_A + [OH^-] = x_B + [H^+] \tag{9}$$

the concentration of hydroxyl ions can be related to the hydrogen ion concentration by Equation 5:

$$x = x_B - x_A = [OH^-] - [H^+] = \frac{K_w}{[H^+]} = 10^{pH-14} - 10^{-pH} \tag{10}$$

Solving for [H+] gives:

$$[H^+] = \sqrt{x^2 / 4 + K_w} - x/2 \tag{11}$$

$$[OH^-] = \sqrt{x^2 / 4 + K_w} - x/2 \tag{12}$$

This gives:

$$pH = f(x) = [H^+] = \sqrt{x^2 / 4 + K_w} - x/2 \tag{13}$$

Equation 13 proves the nonlinearity of the pH neutralization process with the curve as shown in Figure 2.

2.6 Mathematical model of pH neutralization process

The model used for this project is from McAvoy et al [3].

$$V\frac{dx_a}{dt} = F_a C_a - (F_a + F_b)x_a \tag{14}$$

$$V\frac{dx_b}{dt} = F_b C_b - (F_a + F_b)x_b \tag{15}$$

where,

x_a, x_b = concentration of non-reacting acid and base solution in the mixing tank (mol/litre)

C_a, C_b = concentration of influent and neutralizing agent (mol/litre)

F_a, F_b = flow rate of influent and reagent (litre/sec)

From this model, an Ordinary Differential Equation (ODE) has been made:

$$\frac{dx_a}{dt} = \frac{F_a C_a}{V} - \frac{(F_a + F_b)x_a}{V} \tag{16}$$

$$\frac{dx_b}{dt} = \frac{F_b B_b}{V} - \frac{(F_a + F_b)x_b}{V} \tag{17}$$

To build the equivalent MATLAB SIMULINK block, the ODE has to be represented in state-space or matrix form.

$$\begin{bmatrix} \hat{x}_a \\ \hat{x}_b \end{bmatrix} = \begin{bmatrix} -(F_a + F_b)/V & 0 \\ 0 & -(F_a + F_b)/V \end{bmatrix} \begin{bmatrix} \hat{x}_a \\ \hat{x}_b \end{bmatrix} + \begin{bmatrix} F_a C_a / V \\ F_b C_b / V \end{bmatrix} u(t) \tag{18}$$

Then, from the ODE, block diagram for the model is built.

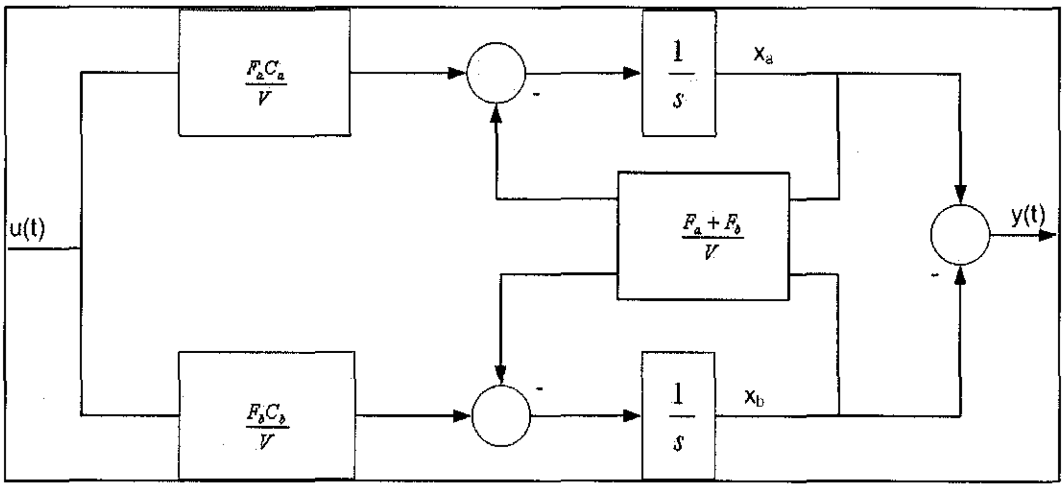

Figure 3: ODE Block Diagram

2.7 Empirical model

There is another method to identify the neutralization process, which is the empirical modeling. This method is basically designed for process control. Empirical model means that the data are taken through the experiments, rather than theories or ideas. The model is developed based on the relationship between selected input and output variables.

For the empirical model, it is usually designed for typical process control, which means it does not have the ability to compensate with other process. Since the project only concern about the pH, and not other process, this method can be used to identify the neutralization process.

In empirical modeling, model is determined by making small changes to the input variable. The small change to the input must be sufficiently enough to make the output changes. If the change to the input is larger, it may disturb the process by adding some an unnecessary noise to the process. The resulting response is used to determine the model. The procedure for empirical modeling is shown in Figure 4.

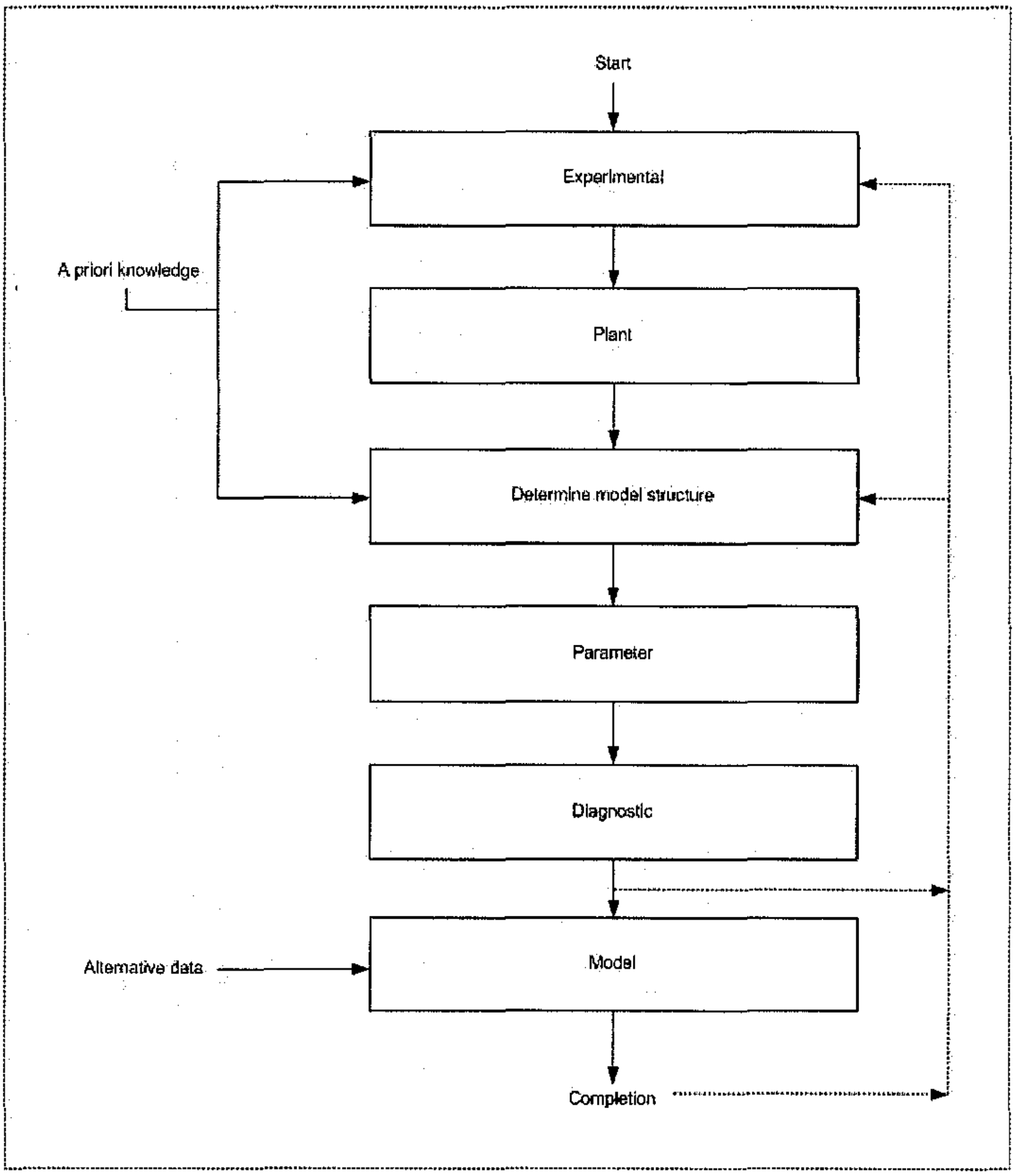

Figure 4: Procedure for empirical transfer function model identification

There are two methods to identify the empirical modeling, which are the statistical method and process reaction curve method [4].

Process reaction curve method is the easiest one as compared to the statistical method and most widely used for identifying dynamics models. The process reaction curve method consists of four actions, which are:

1. Allow the process to reach steady state.
2. Introduce a single step change in the input variable.
3. Collect he input and output response data until the process again reaches steady state.
4. Perform the graphical process reaction curve calculations.

The model is based on a First Order with Dead Time (FODT) model. The model is shown is Equation 19 below.

$$\frac{Y(s)}{X(s)} = \frac{K_c e^{-\theta s}}{\tau s + 1} \qquad (19)$$

There are two graphical approaches to determine the process parameter is process reaction curve method. The first technique is introduced by Ziegler-Nichols. The calculation involves in this technique in shown in Figure 5.

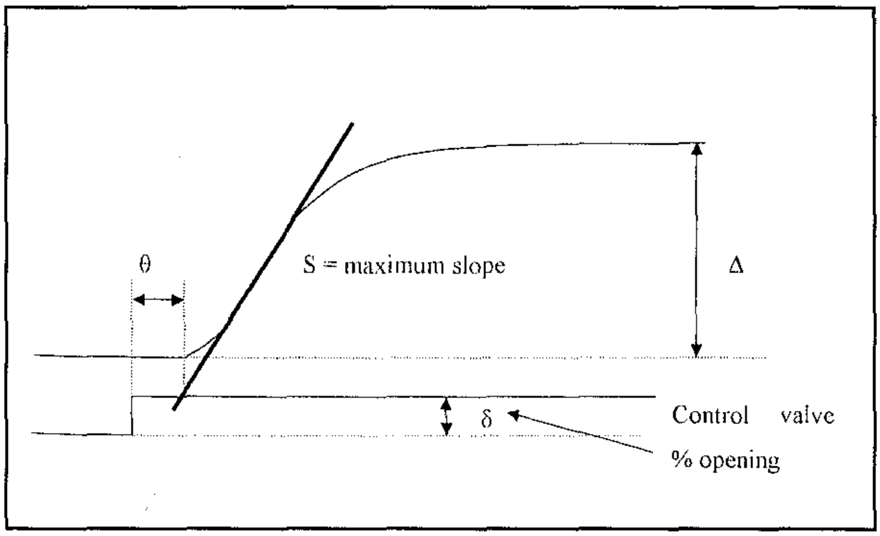

Figure 5: Process reaction curve for Method I

The equations used to calculate the parameter are:

$$K_c = \frac{\Delta}{\delta} \tag{20}$$

$$\tau = \frac{\Delta}{S} \tag{21}$$

θ = interception of maximum slope with initial value (as shown in Figure 5).

For method II, the graphical calculations are as shown in Figure 6.

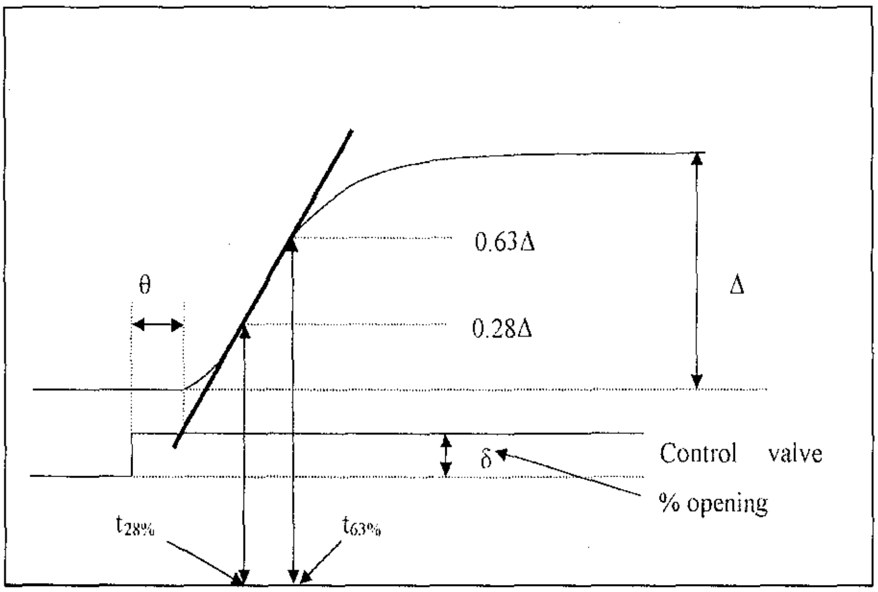

Figure 6: Process reaction curve for Method II

To calculate the process parameter, use the equations below:

K_c is similar to equation 20

$$\tau = 1.5(t_{63\%} - t_{28\%}) \tag{22}$$

$$\theta = t_{63\%} - \tau \tag{23}$$

Method II is preferred since there is difficulty to determine the slope of the curve in method I, especially when the signal has high frequency noise. Due to the difficulty, Method I typically has larger errors in parameter estimates.

2.8 System Topology

There are several types of system available for the pH neutralization process [5]. Below are two of the topologies to be taken into consideration for this project. They are:

2.8.1 Batch Processing

For the batch processing system, it has a discontinuous input, one mixer, one controller, and one output. This system uses ON/OFF relay controller for "batch" processing. Batch means the liquid is processed one by one. Discontinuous input means that the input is not allow to flow freely into the system. At start, the input is allowed to flow into the tank. When the liquid level inside the tank reached specified level, the input stop flowing as there the valve is closed. The mixing process start after the valve for the input is closed. As for the controller, it consists of pH electrode or pH sensor. It also is connected to the valve that is controlling the reagent to be added to the liquid inside the tank. As the mixing process start, the pH sensor will sense the pH level of the liquid inside the tank and send the signal to the controller. The controller will then analyze the signal before sending another signal to open the valve for the reagent. The valve for the reagent will be open until the pH of the liquid inside the tank is neutralized.

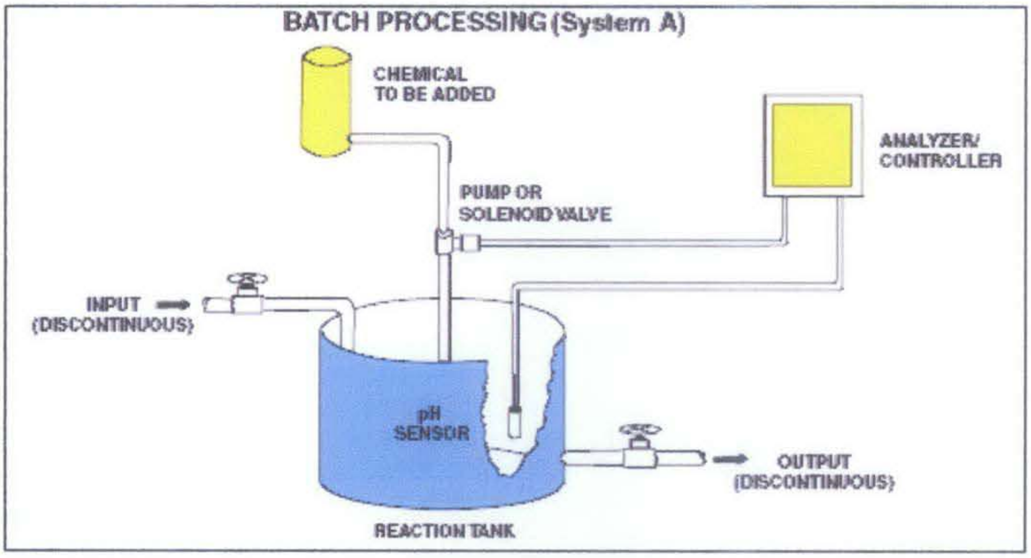

Figure 7: Batch Processing

Discontinuous output carries the same meaning as discontinuous input before. The output will not be flowing out if the tank freely. The valve for the output will be open after the liquid inside the tank is neutralized. After one cycle, this system will repeat the same thing over and over until the input reach its end.

In this batch processing system, it will require some sort of level sensing as to know when the tank is full or empty. This level sensing is a must because the mixing process and the neutralization process will not start if the input valve is not closed. There will be some delay between adding reagent and sensing the resulting pH of the liquid. It all depends on the mixing process. The faster the mixing process, the less delay/ or overshoot is obtained for this system.

For this first system, it has one advantage. That is, it does not easily handle a continuous flowing process.

2.8.2 Continuous with Tank

This second system has similar figure as the first system. The only difference between them is that this system will have continuous input and output instead of discontinuous. There will be no valve installed at the input and the output of this system. With this continuous process cycle, an ON/OFF relay controller is not enough. The ON/OFF relay controller with latching or deadband is required for this system. The deadband will hold the final control element for a longer time than without deadband. Having this deadband, there will be no rapid cycling required and the operation can be smooth.

Unlike the first system, this second system will require no level sensing. But, in this system, a really good mixing is important. The mixer design should be undersized. As for this system, it can be fairly accurate, but in general it does not produce smooth output. The pH of the output tends to cycle between levels.

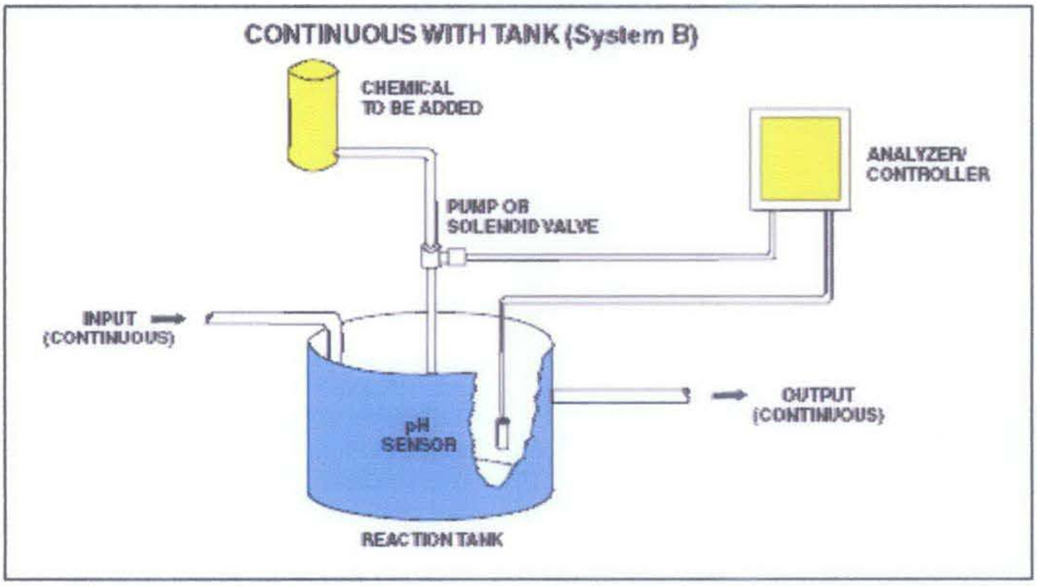

Figure 8: Continuous with Tank Processing

2.9 PID Controller

PID controller will be used in this project. PID stands for Proportional (P), Integral (I), and Derivative (D). Each of these variables will have different effect on the controller.

- Proportional (P)

  P will provide the corrective measurement to the error. It is proportional to the error occurred at the output. The larger the output, the larger the value of K_c generated. This mode does not completely remove the effects of disturbances [4].

- Integral (I)

  The main function of this integral action is to make sure that the process output agrees with the set point in steady state. With proportional control, there is normally a control error in steady state. With integral action, a small positive error will always lead to an increasing control signal, and a negative error will give a decreasing control signal no matter how small the error is [6]. This mode will adjust the manipulated variable until the magnitude of the error is reduced to zero [4].

- Derivative (D)

  The purpose of the derivative action is to improve the closed-loop stability [6]. This mode is known as predictive mode. When the controlled variable is constant, this mode will do nothing to the manipulated variable. When there are changes in controlled variable, this derivative mode will adjusts the manipulated variable proportional to the rate of change of the controlled variable [4].

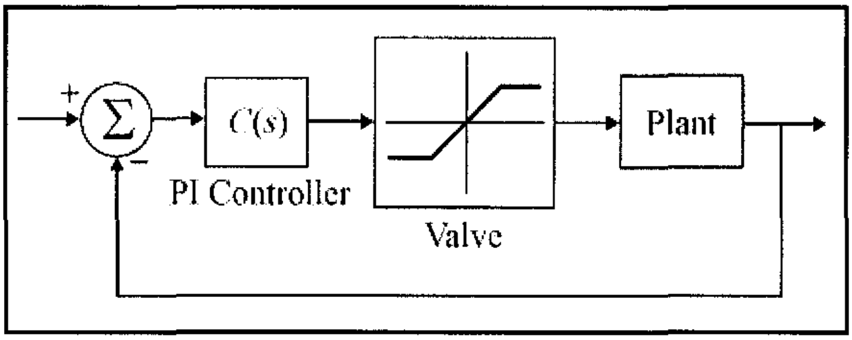

Figure 9: Block Diagram of a Simple PI Controller

CHAPTER 3:

METHODOLOGY/PROJECT WORK

3.1 Flowchat

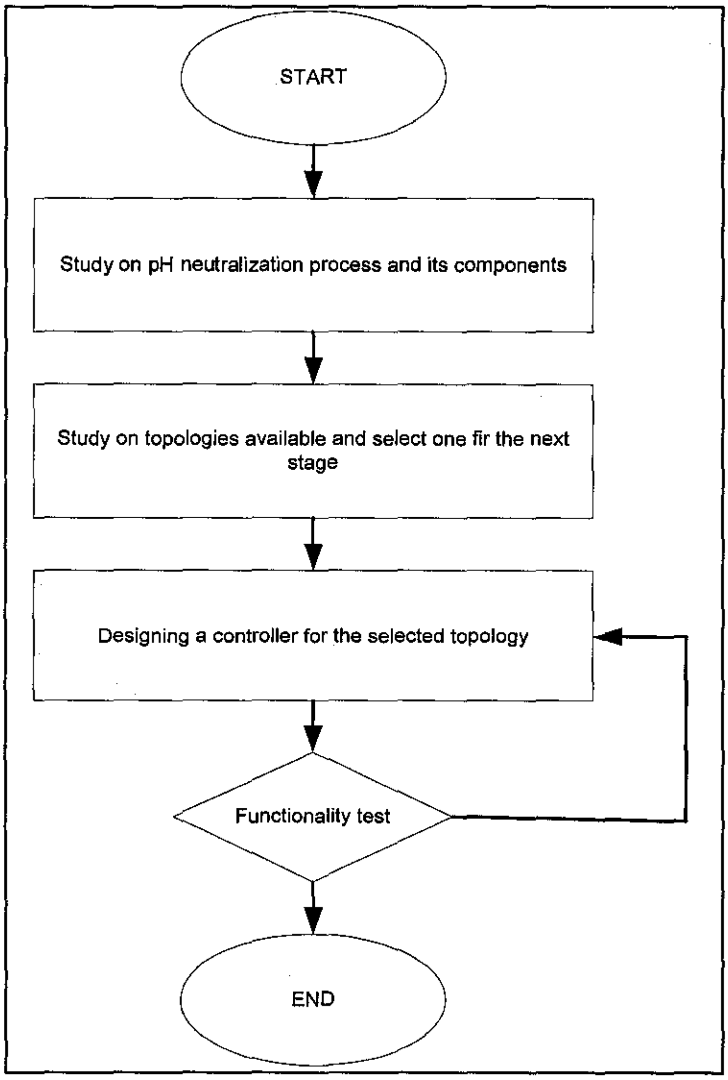

Figure 10: Flowchart

3.2 Description of the AQAS

There will be two inputs, one output, one mixer, pH sensors and a controller involved in this system. The first input will be liquid with pH value varies from 14 to 8. The second input will be a reagent that will neutralize the first input in a holding tank. A mixer is needed to stir the inputs in the holding tank, to make sure the neutralization process goes smoothly. pH sensors will be installed at two different locations to sense the pH of the liquid. The first pH sensor will be installed in the mixing tank, and the other one will be installed at the output of the holding tank. A controller is the major concern here. The pH sensors will be connected to the controller. For the first pH sensor, it will send signal to the controller to report the pH value inside the mixing tank. Then, the controller will control the valve for the second input. The lower the pH value of the first input, the opening of the valve will be larger. The second pH sensor is used to record the pH value of the output.

3.3 Data Generation

In this project, the data will be generated using software called SIMULINK. SIMULINK® is an environment for multidomain simulation and Model-Based Design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that let you design, simulate, implement, and test a variety of time-varying systems, including communications, controls, signal processing, video processing, and image processing [7]. As mentioned before, the software called SIMULINK will be used in the simulation stage. The parameters for the PID controller, Kc, Ti, and Td will be obtained using either "try and error method" or Ziegler-Nichols' Method" [6]:

- Using try and error method. Using this method, experimental values will be selected and the behaviour of the feedback system is observed. The parameters are then modified until desired behaviour is obtained.
- Develop a mathematical model that describes the behaviour of the process. Parameters of the controller are then determined using some method for control design. Ziegler-Nichols' method will be the reference for this option. There are two basic method designed by Ziegler and Nichols which are Step Response Method and Frequency Response Method.

3.4 Computer Simulation

Several simulations have been done using the SIMULINK software. During the first simulation, all P, PI and PID controllers have been tested. Equations from Ziegler-Nichols Open-Loop Tuning correlations have been used during the simulations. The first step is to determine the value of K_p, which is the gain of the system. The equation is:

$$K_p = \frac{output}{input}$$
$$= 0.35$$

The value of the dead time, θ and time taken to reach 63% of the set point, T are chosen. θ is set to be 0.5 minute and T is 2.5 minutes. Then, the value of K_c, T_i, and T_d of the PID controller is calculated using table from Ziegler-Nichols method.

Table 1: Ziegler-Nichols Open-Loop Tuning Correlations

Controller	**K_c**	**T_i**	**T_d**
P-only	$(1/K_p) / (T/\theta)$	-	-
PI	$(0.9/K_p)(T/\theta)$	3.3θ	-
PID	$(1.2/K_p)(T/\theta)$	2.0θ	0.5θ

After all of those values obtained, the simulation can be run. The next step is to observe the entire responses from the three controllers above. So far, the initial pH inside the holding tank is set to be 1. The set point, or the final output is set to be 7, and the pH of the reagent is 14.

For the next simulation, the mathematical model obtained earlier will be used. From the block diagram of the mathematical model shown earlier, SIMULINK block diagram has been built. The blocks are as follows:

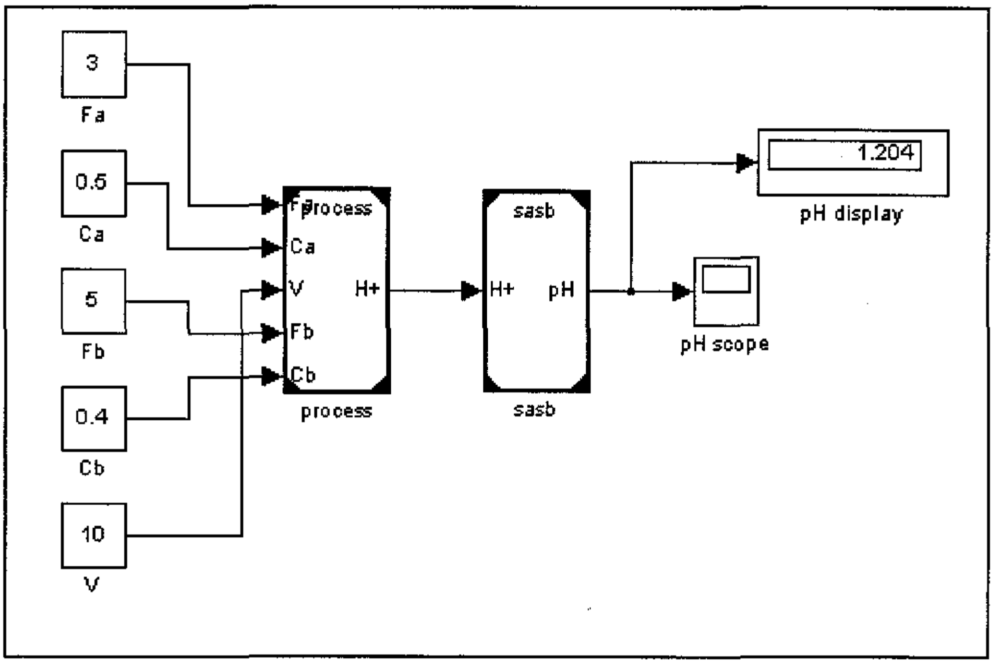

Figure 11: SIMULINK block diagram for mathematical model

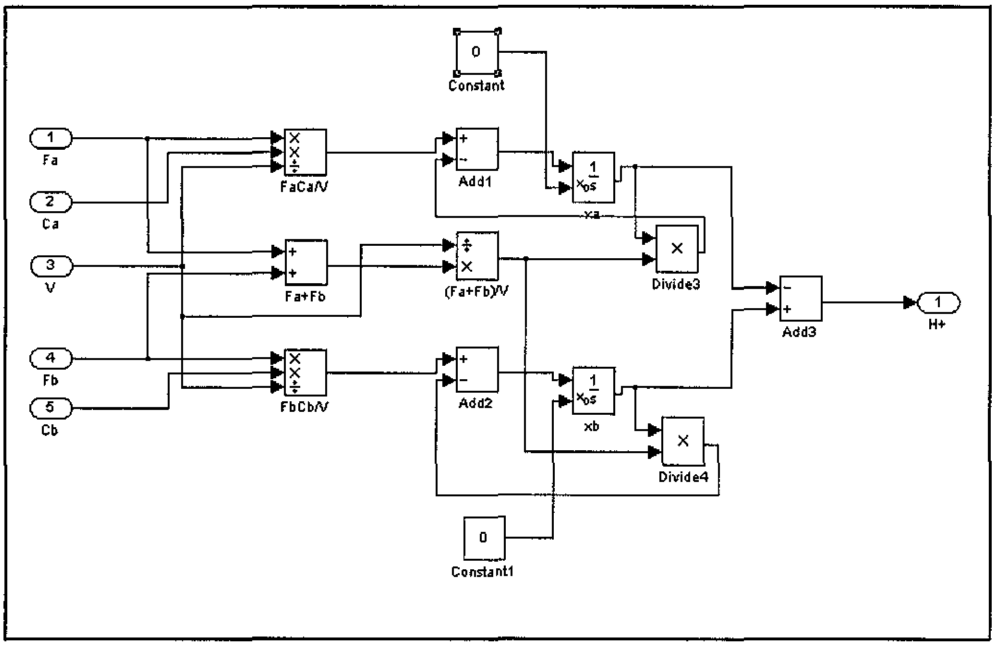

Figure 12: SIMULINK sub-module for process

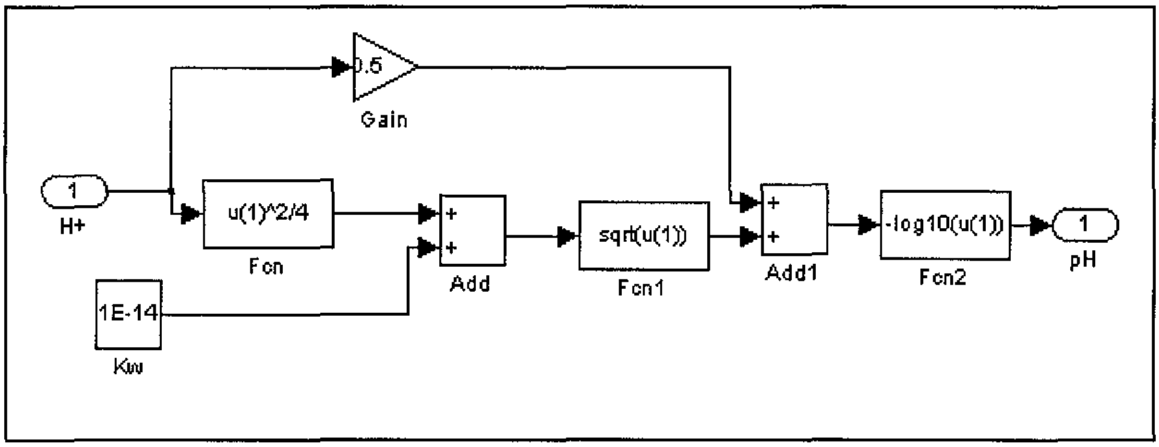

Figure 13: SIMULINK sub-module for sasb

3.5 Empirical Model

For the empirical model, experiments have been conducted in Process Control & Instrumentation Laboratory (23-00-06). The physical representation of the pH neutralization process in the lab is shown in Figure 13.

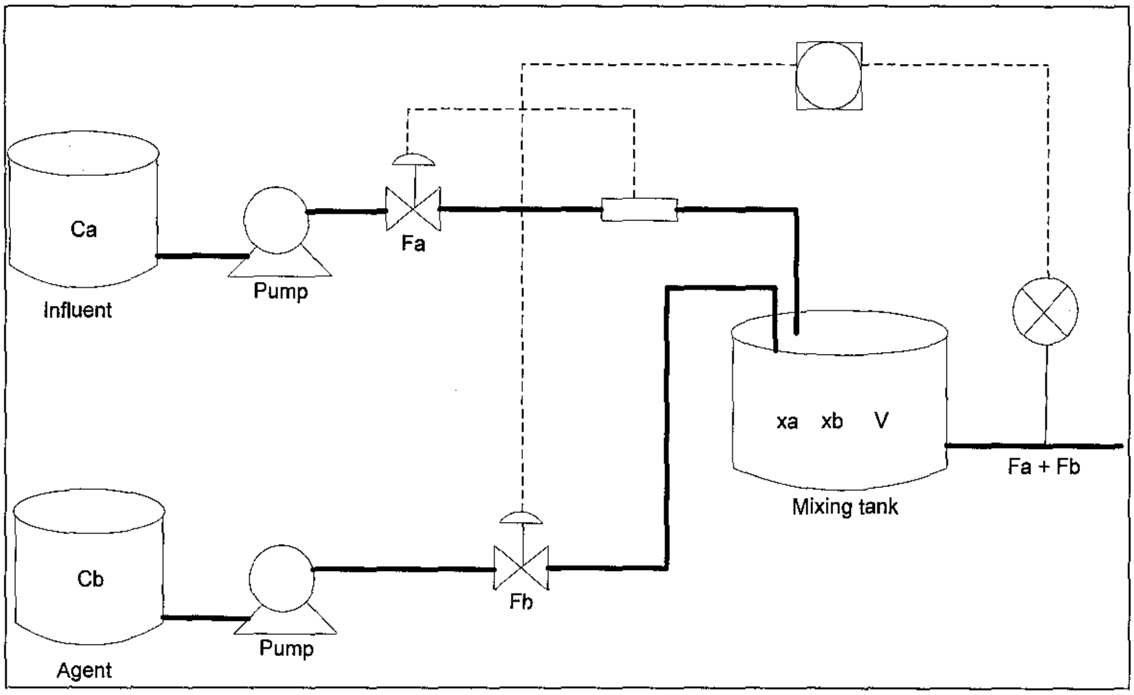

Figure 14: Physical representation of the pH neutralization process

The procedure for the empirical model is as attached in Appendix 1.

CHAPTER 4:

RESULT AND DISCUSSION

From the calculations that have been done before for the first simulation, the value for K_p is 0.35. With the value of the dead time, $\theta = 0.5$ minute and T value is 2.5 minute, the values for the K_c, T_i, and T_d are obtained as follows:

Table 2: Values for PID controller parameters using Ziegler-Nichols method

Controller	K_c	T_i	T_d
P-only	14.29	-	-
PI	12.86	1.65	-
PID	17.14	1	1.25

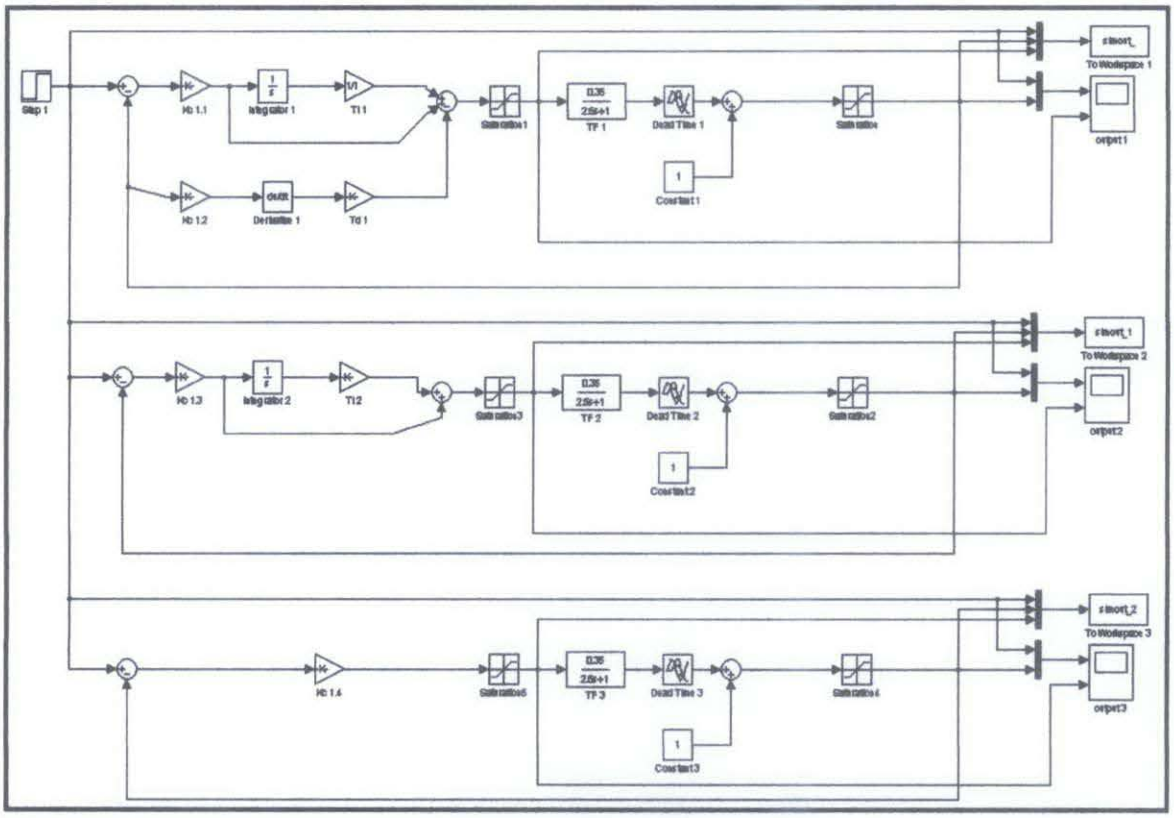

Figure 15: P, PI, and PID controller

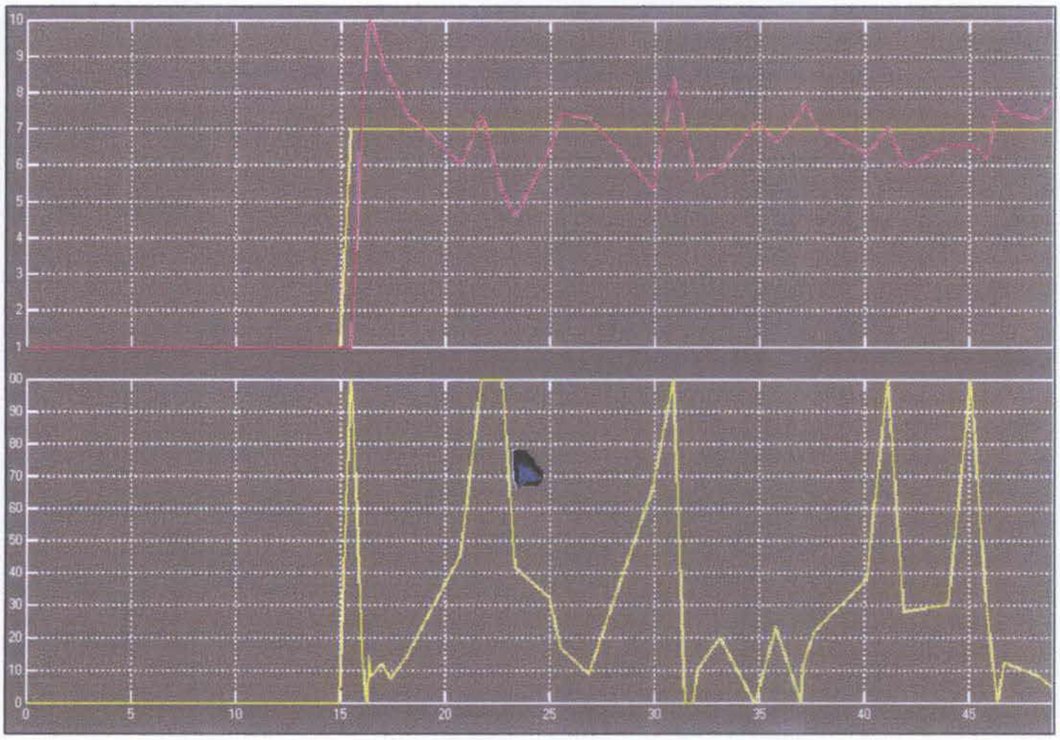

Figure 16: Response for PID controller

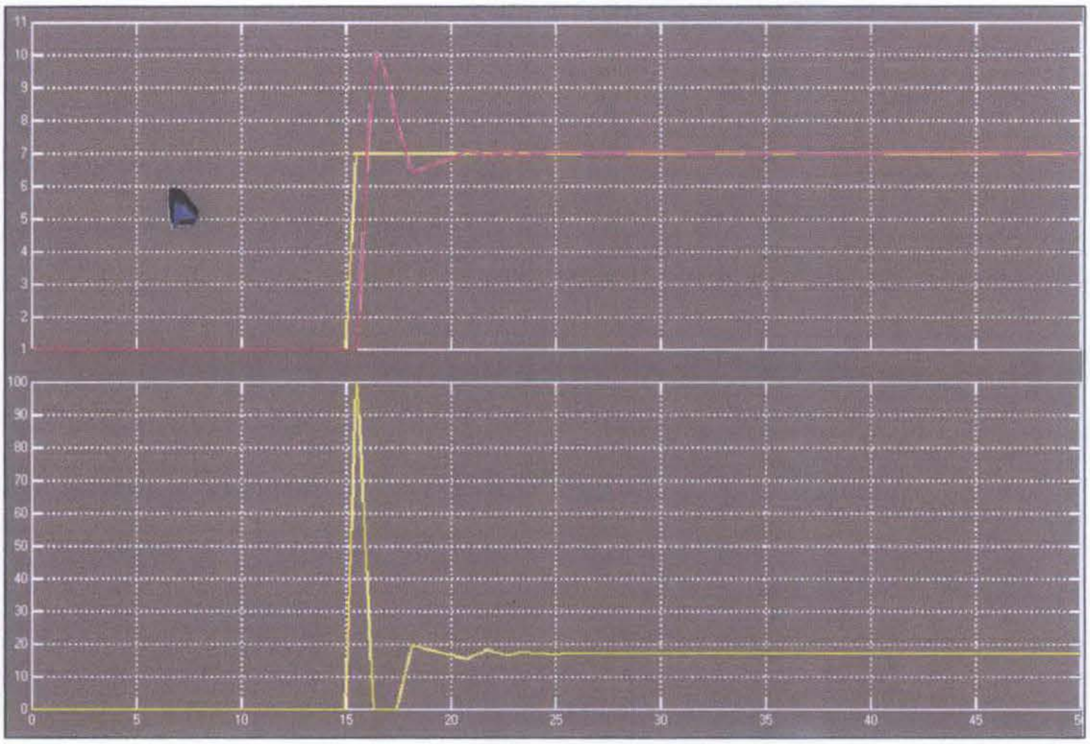

Figure 17: Response for PI controller

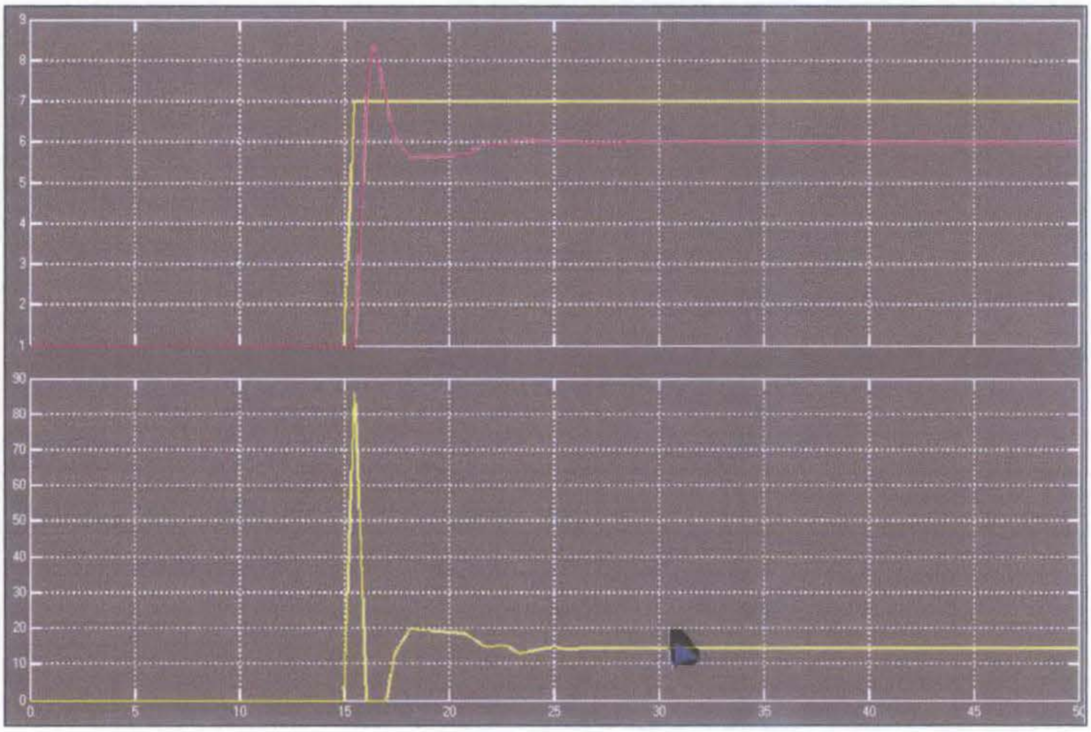

Figure 18: Response for P controller

In Figure 16, 17, and 18, the upper graphs are the responses for set point (yellow), while the purple curves show the controlled variable responses. Y-axis is the value of pH while x-axis is time in second. The lower graphs show the manipulated variables responses. Y-axis is the percentage of the valve opening and x-axis is time in second.

Based on these responses, it showed that P controller can give a smooth response, but in the same time, it will have a big offset. Using the PI controller, the response will give a bigger overshoot than the P controller, but the offset is removed from the response. The final value is equal to the desired value. For the PID controller, it seems that the response is not stable. So, the best controller based on this simulation is the PI controller.

The simulation result for the mathematical model is as follow:

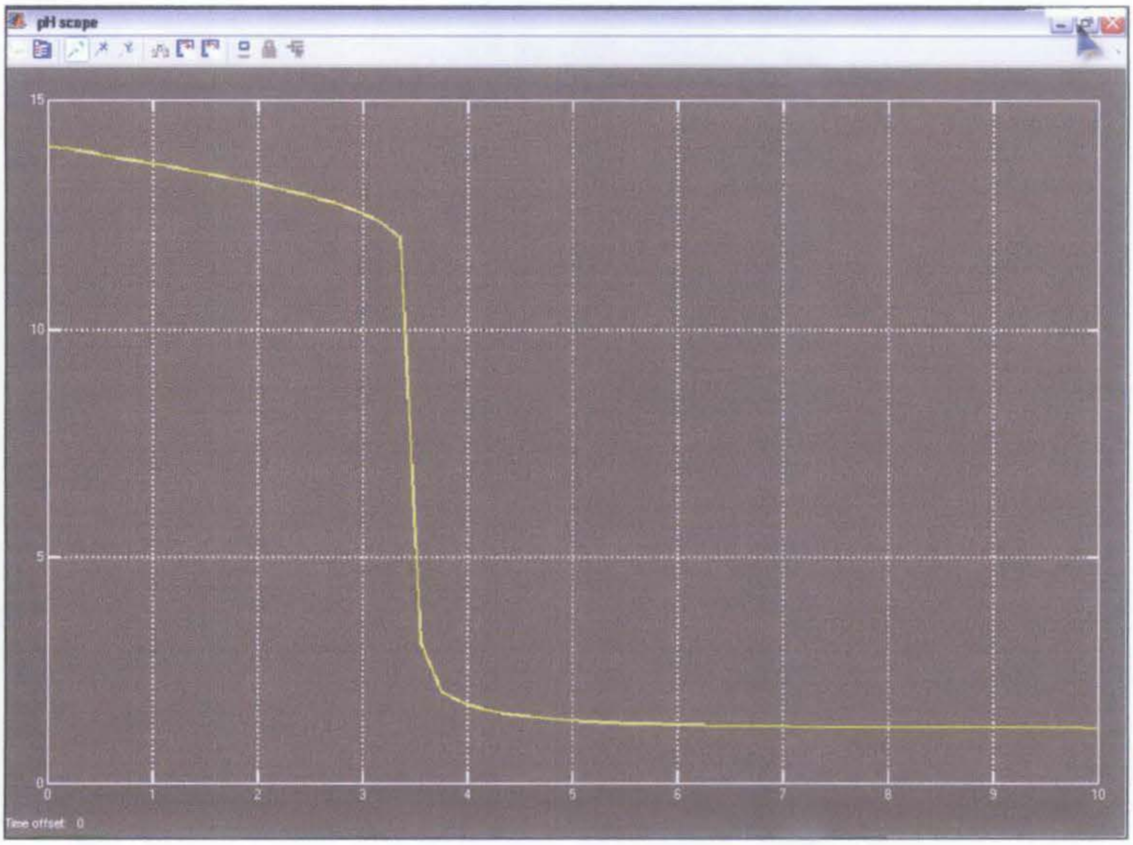

Figure 19: pH curve from the mathematical model

$F_a = 3$

$C_a = 0.5$

$F_b = 5$

$C_b = 0.4$

$V = 10$

The curve in Figure 18 shows an uncontrolled pH neutralization process. The pH value goes down from 14 to 1. The response is not as desired since the objective is to make the pH value as close to 7 as possible. As to control the process, all the parameters are kept constant except for the value for the flow of the second input, F_b. The initial value of pH will be set, and then the flow F_b will be adjusted so that the final value of pH is 7. The flow of F_b will be controlled using PI controller.

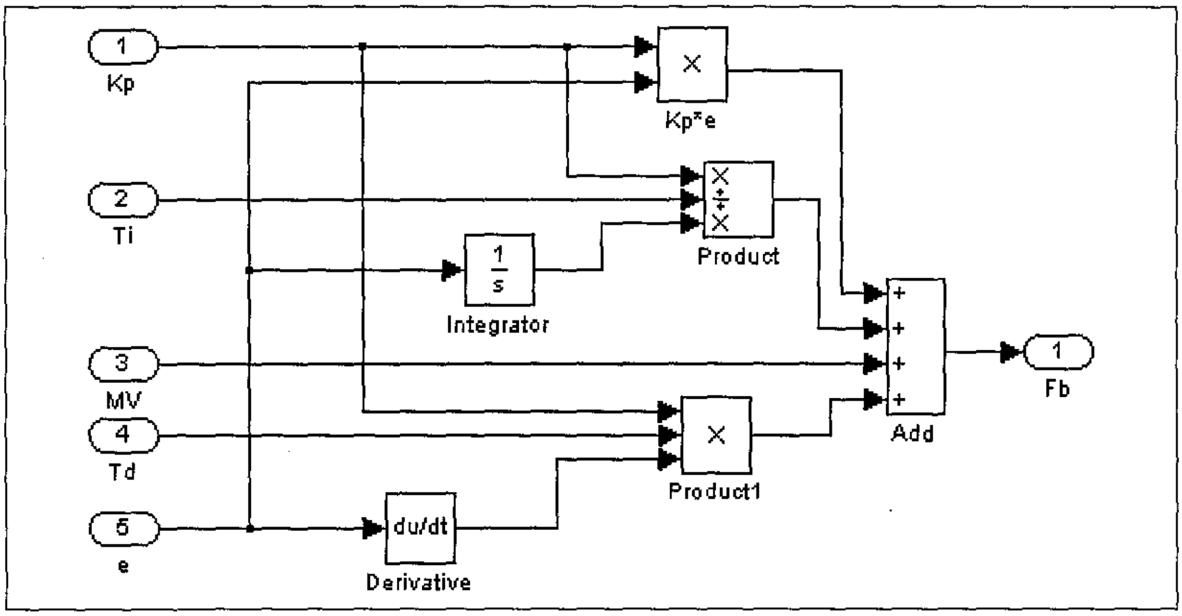

Figure 20: PID block built in SIMULINK

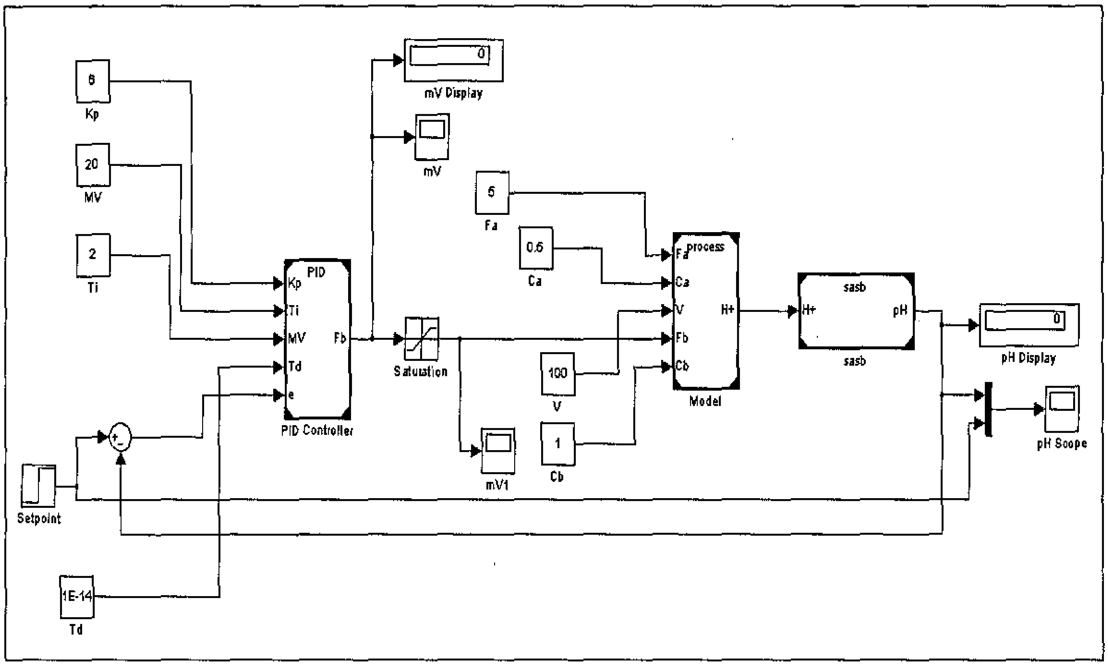

Figure 21: Block diagram of the mathematical model with PID controller

Table 3: Simulation result for mathematical model

pH	**F_b**
14	125
13	95
12	75
11	60
10	50
9	35
8	15

After the simulations are finished, the experimental works have been done. In the experiment, the PI controller also has been used to control the process. The responses for the experiments are as shown in figures 22, 23, 24, 25, 26, 27 and 28 below. The upper graphs show the responses of the controlled variable and the lower graphs shows the responses of the manipulated variables (valve). For the upper graphs, the y-axis shows the flow rates of the second input, which are the reagent. For the lower graphs, the y-axis shows the percentage of valve opening for the reagent. The conversion is as follows:

$$FCV = \frac{u(t)}{100} \times 4 + 1 \qquad (24)$$

The x-axis for all those graphs indicates the time in second. The summary of the result are shown in Table 4.

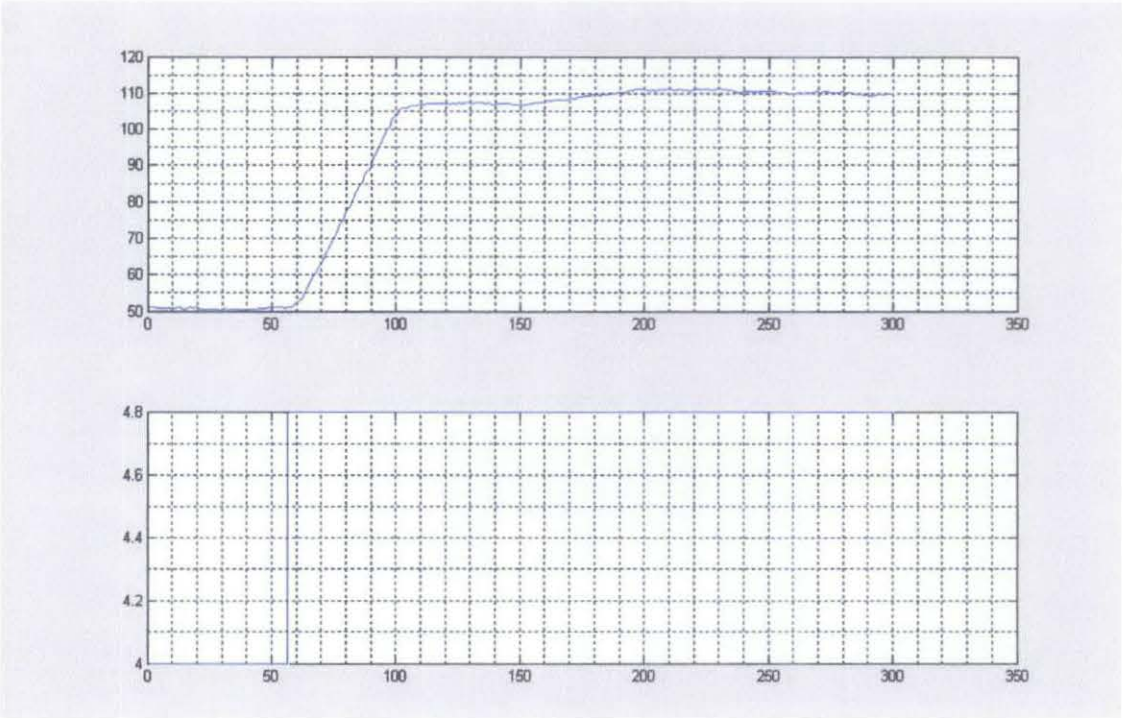

Figure 22: Response when initial value of pH = 14

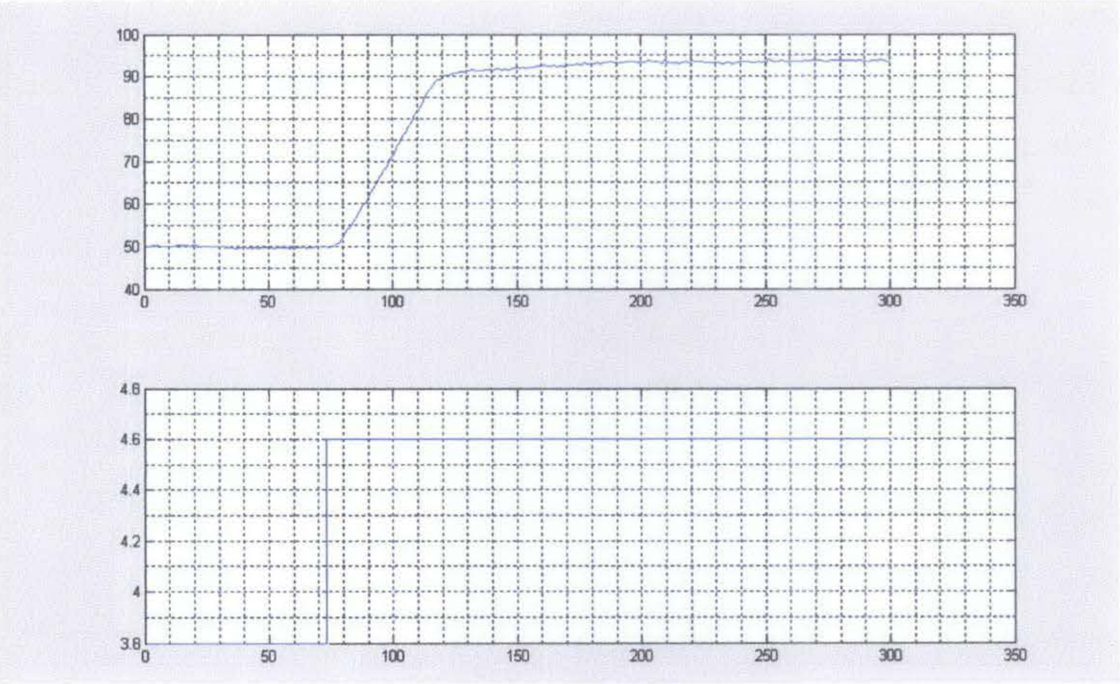

Figure 23: Response when initial value of pH = 13

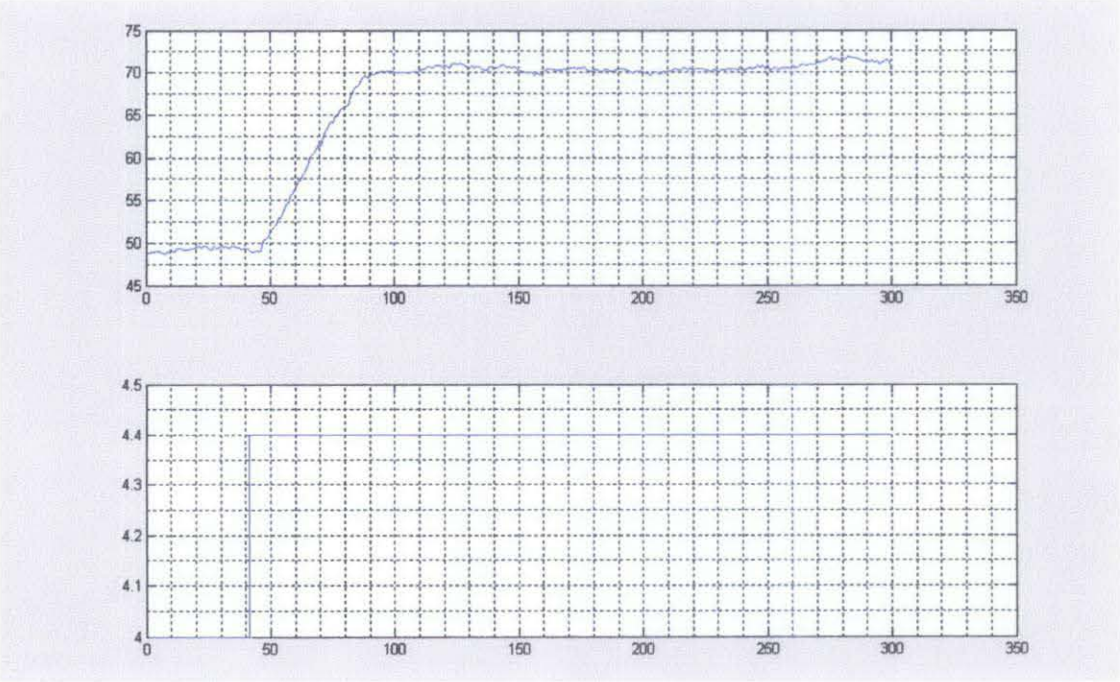

Figure 24: Response when initial value of pH = 12

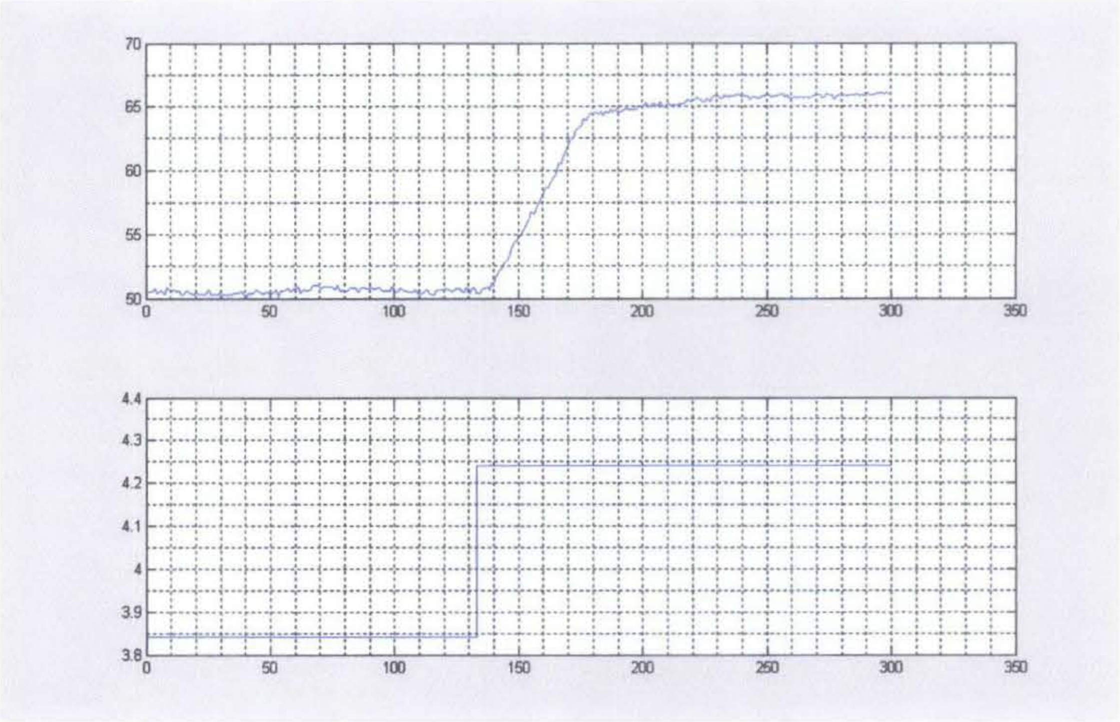

Figure 25: Response when initial value of pH = 11

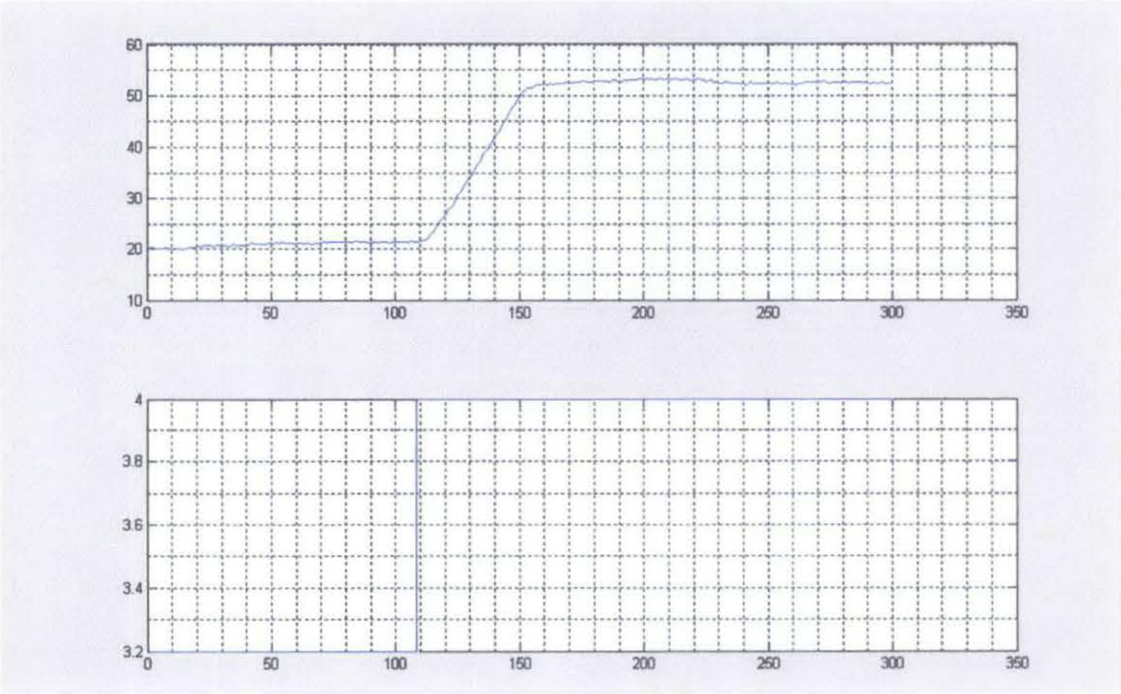

Figure 26: Response when initial value of pH = 10

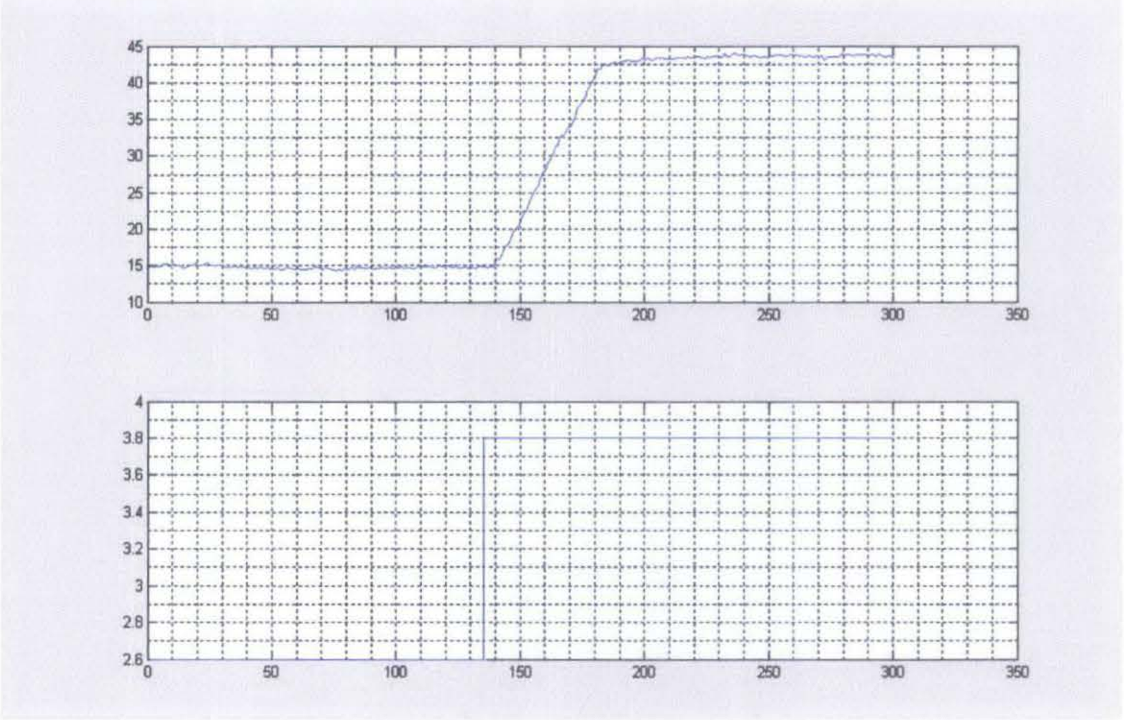

Figure 27: Response when initial value of pH = 9

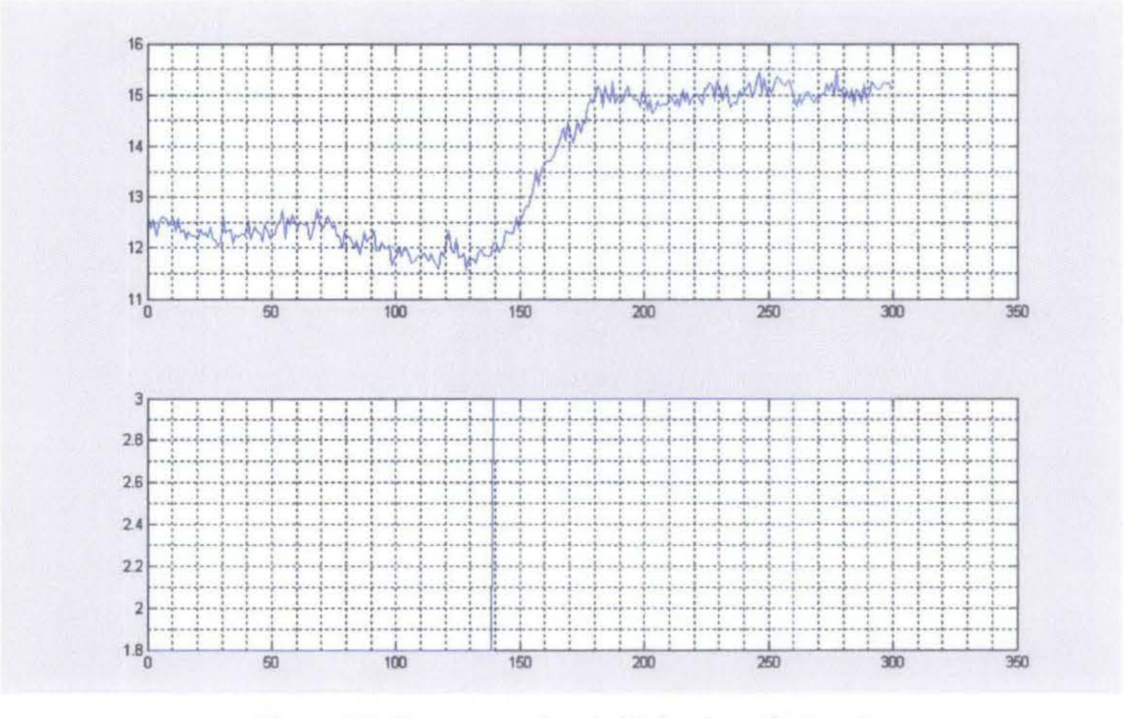

Figure 28: Response when initial value of pH = 8

Table 4: Experimental results

pH	**F_b**
14	110
13	90
12	70
11	65
10	55
9	40
8	15

Table 5: Comparison between simulation and experimental results

pH	F_b (Simulation)	F_b (Experiment)
14	125	110
13	95	90
12	75	70
11	60	65
10	50	55
9	35	40
8	15	15

The result from the simulations and the experiments shows that PI controller can actually be used in pH neutralization process. Although there are some difference between result from simulations and experiments, it may due to human error while handling equipments in the lab.

CHAPTER 5:

CONCLUSION AND RECOMMENDATION

Based on the result from the simulations, it is proved that PI controller is best chosen for this project. PI controller will give the best response compared to the other two controllers, P and PID.

From the mathematical model, the pH curve is obtained. With PI controller block diagram connected to the initial mathematical model block diagram, the pH neutralization process is controlled as the final value of the pH is reduced to 7. The performance of PI controller in pH neutralization process also been tested physically in the lab during the experiments. With the obtained results, it is certain that the PI controller can actually be used in pH neutralization process.

At the end of this project, the quality of the liquid is controlled since the pH of the liquid is reaching the desired state, which is 7. As said before, liquids with pH value of 7 are in neutral state, and do not bring any harms to the environment. The objective of this project is achieved as the proposed PI controller is able to control the pH neutralization process.

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APPENDIX 1

PH CONTROL IN A CSTR

OBJETIVE OF THE EXPERIMENT:

1. To study the pH control pilot plant and prepare a P & I diagram.
2. To tune a liquid flow control loop by ultimate gain method.
3. To tune a pH control loop by the process reaction curve method.
4. To study the closed loop characteristic of the pH control loop of the CSTR.

INTRODUCTION AND THEORY

pH is defined as $\log_{10}H+$ and is a measure of the acidity or alkalinity of a liquid. The pH scale is from 1 to 14, with 7 as the pH of neutral water. A value of the pH lower than 7 designate as acidic solution. pH control is important for many chemical processing applications and in pollution control.

In the present experiment the acid flow is under PID flow control while the CSTR pH is controlled by a PID loop controlling the alkaline flow. The loop will be tuned by the ultimate gain method. The pH control loop will be tuned by the process reaction curve method.

PROCEDURE

The experiment has the following three parts:

1. Tuning flow loop in the acid flow path.
2. Tuning pH control loop.
3. Operating closed loop pH control.

Start-up

1. Switch on power to the Local Control Panel.
2. Turn the selector to DCS to run the experiment under DCS control. Set it to local if the experiment to be run under local control by using multi loop controller only.
3. Switch on the main air supply compressor at the compressor room. Wait for the compressor to stop before starting any experiment. This is to ensure that the main instrument air supply to the system is sufficient before running any experiment.
4. Switch on the DCS server and clients. The entire system is to start-up automatically. When prompted, key in your user name and password to log in. Consult the supervisor for the correct user name and password.

Preparation of Acidic process stream

1. Fill the acid storage tank with water (up to ½ tank).
2. Use the manual pump provided for acid to pump about 10% of the acid solution into the storage acid tank. Caution: Always add acid to water. Do not add water to the acid.
3. Stir the final solution to ensure homogeneity.

Preparation of Alkaline process stream

1. Fill the alkaline storage tank with water (up to ½ tank).
2. Use the manual pump provided for alkaline to pump about 30% of the alkaline solution into the alkaline storage tank. Caution: Always add alkaline to water. Do not add water to alkaline.
3. Stir the final solution to ensure homogeneity.

Start-Up

STEP	ACTION	REMARKS
1	Ensure that all Utility Service are ready (i.e. Switch on Power Supply to Control Panel and Switch on Air Supply Systems to the Pilot Plant.	
2	At the Local Control Panel, turn the selector switch to 'DCS'.	
3	Fill the vessel VE100 with water until it is about to half full.	
4	Ensure that the DCS is ready (i.e. it is communicating properly with the control panel).	
5	At the computer and the 'Chemical Processing Over-View' display, click on the button [PID FIC 120].	Display for 'Experiment 1 – Simple PID flow Control (FIC120)' will appear.
6	From the WS/PNL select combo-box, choose DCS. This will transfer control of the pilot plant to the DCS.	Click on drop down box and select 'DCS'.
7	From the Control select combo-box, choose FIC120.	
8	At the Controller Faceplate (FIC120) set the controller to MANUAL mode.	Click on drop down box and select 'MANUAL'.
9	Close the control valve FCV120 manually (0%) i.e a) Setting Control Mode to 'MANUAL' then b) At the MV data entry field, key in 0 and press [ENTER]	Same operation to Open/Close other control valve manually.
10	Adjust the Hand Valves at the Pilot Plant as follows: Open Hand Valve HV103 Open Hand Valve HV102	Hand valves to be Open/Closed Fully.

Table 1: Preparation and Start-Up

STEP	ACTION	REMARKS
1	At the FIC120 Controller Faceplate, set the P, I and D parameters as follows: - Gain (K_p) = 2.0 - Integral time (I) = 9999 - Derivative time (D) = 0.0	Before setting any variables, click on 'OPER' icon (on lower right side) and type 'MNGR'.
2	Adjust the Controller Set Point (SP) to $0.1 m^3/h$.	Set SP = 100.
3	Set the Controller Manual Mode and open the Control Valve FCV120 by 86%.	Set Controller Manipulated Variable, (MV) = 86%.
4	Start the Pump P100 via DCS.	Click on drop down box and select 'ON'.
5	Slowly adjust the Control Valve FCV120 to bring the Process Variable (PV) to almost equal to the SP.	Adjust MV.
6	Observe the PV from the Trend Window and wait until it has stabilized to a constant value.	
7	Set the Controller to AUTO mode.	
8	Wait for the PV to stabilize.	
9	Make a small step change to SP (e.g. increase the set point by 10% i.e. to 110).	
10	Observe the PV from the Trend Window. If the PV response is not oscillatory, adjust the control Gain (K_p) value until it become oscillatory.	Set controller to MANUAL mode, adjust SP and MV to initial values and doubles the K_p value. Repeat Step 7, 8, and 9.
11	If the PV response is oscillatory, observe whether the magnitude of PV is increasing or decreasing. If it is increasing, reduce the controller gain by 1.5 times. If it is decreasing, increase the controller gain by 2 times. Aim to obtain an oscillatory response with almost constant amplitude.	
12	When constant amplitude oscillation is achieved, allow at least 3 oscillation cycles to be recorded and freeze the trend window.	
13	Print out the PV response curve.	Print in colour.
14	Stops pump P100 and set the controller FIC120 to MANUAL mode.	
15	Using the printed graph obtained from section above, measure and tabulates the relevant values as required. K_u is the ultimate gain of the controller gain (the controller gain at which constant amplitude oscillation is acquired). T_u is the ultimate amplitude oscillation of PV.	Refer table 3
16	Based on the equations for Closed Loop	Refer table 3

	Tuning for PI, calculate the required controller tuning parameters.	
17	Key in the calculated tuning parameters at the FIC120 controller faceplate.	Set $K_p = K_c$ and Integral = T_i

Table 2: Closed Loop Tuning Method for Flow Control Loop

Measurement	Test 1	Test 2	Test 3	Average
Ultimate Controller Gain, K_u				
Time for 3 Oscillation periods or more (minute)				
Calculations:				
Ultimate Period, T_u (time taken for one Oscillation period) (minute)				
Tuning Parameters:				
Gain, K_c				
Integral Time, T_I (minute/repeat)				
Derivative Time, T_D (minute/repeat)				

Table 3: Tabulation of Results – Results for Closed Loop Tuning

pH Control

STEP	ACTION	REMARKS
1	Ensure that all Utility Services are ready (i.e. Switch on Power Supply to Control Panel and Switch on Air Supply Systems to the Pilot Plant.	
2	Adjust the Hand Valves at the Pilot Plant as follows: Open Hand Valve HV103 Open Hand Valve HV102 Open Hand Valve HV112 Open Hand Valve HV113	Hand valves to be Open/Closed Fully
3	At the Local Control Panel, turn the selector switch to 'DCS'	
4	Ensure that the DCS is ready (i.e. It is communicating properly with the control panel).	
5	At the computer and the 'Chemical Processing Over-View' display, click on the button 'PID AIC 122].	Display for 'Experiment 1 – Simple PID pH Control (AIC 122)' will appear.
6	From the WS/PNL, select combo-	Click on drop down box and select

	box, choose DCS. This will transfer control of the pilot plant to the DCS.	'DCS'
7	From the Control select combo-box, choose pH AIC 122.	
8	At the FIC120 Controller Faceplate: - Set the controller to AUTO mode. - Set its output to 100% (fully open). - Set its P, I, and D values.	Set MV = 100, K_p, I and D accordingly.
9	Open HV 100 and HV 110 to fill vessel VE100 and VE110 with water until each of them is about ¼ full.	
10	Close HV110 when the water level at VE110 is ¼ full.	
11	When the water level at VE100 is about ¼ full, start pump P100 via DCS to fill the reaction vessel VE120. Continue to fill VE100.	
12	When the water level at the reaction vessel VE120 is above its agitator blades, stops pump P100.	
13	Close HV 100 when the water level at VE100 is ¼ full.	
14	At the vessel VE100, use the hand pump provided to add concentrated sulphuric acid in to it [Note: do not add water into concentrated acid instead add acid into water]. Observe the reading of the conductivity meter. Stop adding acid when the conductivity of the solution is approximately 100 micron-Siemen.	The students are advised to wear eye protection goggle and rubber gloves when dealing with acid solution.
15	At the vessel VE110, use the hand pump provided to add concentrated caustic soda {Sodium hydroxide} solution into it. Observe the reading of the conductivity meter. Stop adding when the conductivity of the solution is approximately 100 micron-Siemen.	The students are advised to wear eye protection goggle and rubber gloves when dealing with alkaline solution.
16	At the AIC122 Controller Faceplate, set the controller to MANUAL mode.	Click on drop down box and select 'MANUAL'
17	Close the Control Valve pHCV12 manually (0% open)	pHCV12 is the same Control Valve as FCV121.
18	Ensure that all tanks are properly	

	covered.	

Table 4: Preparation for pH Control

STEP	ACTION	REMARKS
1	Start agitator AG120 via DCS	
2	At the FIC120 Controller Faceplate: - Adjust the Controller Set Point to 0.05 m^3/h	SP = 50
3	Start pump P100 via DCS	

Table 5: Start-Up

STEP	ACTION	REMARKS
1	At the AIC 122 Controller Faceplate, manually Oen Control Valve pHCV122 to 10%.	Set MV = 10
2	Starts pump P100 via the computer.	Click on drop down box and select 'ON'
3	Observe the pH curve from the Trend Window and wait until it has stabilized.	
4	Adjust the output of controller AIC122 to obtain a stable pH value (AT122) between 6.5 and 7.5.	Set SP = 7
5	At the Controller Faceplate (AIC122), make a Step change of between 10 to 20% to the control valve FCV121 manually.	Set SP = 7.7 Adjust controller MV
6	Observe the pH curve (AT122) from the Trend Window and wait until it has stabilized to a new constant value and freeze the trend window.	This is the process Reaction curve
7	Print out the pH trend curve.	Print in color
8	Stop both pumps P100 and P101, and the agitator AG120 via DCS. Then set the controllers FIC120 and FIC121 to MANUAL mode.	

Table 6: Process Identification for pH Control Loop

STEP	ACTION	REMARKS
1	Compare the process value curve with a set of expected process Reaction Curve provided.	
2	Identify the process response with the corresponding Reaction Curve.	
3	Make several measurements as per the Reaction Curve chart.	Refer to table 8
4	Sketch a Block Diagram to represent the process and describe the characteristic if this process.	Dead time, Capacity/Rate of Rise, Time Constant, Noise.
5	Using the printed graph obtained from section above (process analysis), measure and tabulate the relevant values required. Refer to table	Note: dB_u, and dM are changes from 1st stable output to the 2nd.
6	Based on the equations for Open Loop Tuning, calculate the required controller tuning parameters.	
7	At the AIC122 controller faceplate, key in the calculated controller tuning parameters.	

Table 7: Result Analysis for pH Control Loop

Type of Model	Time constant, T_1	Time constant, T_2	Decay time, τ
First Order			
First Order with decay time			
Second order			
Second order with decay time			

Table 8: CSTR Model

Measurement	Test 1	Test 2	Test 3	Average
Change in Manipulated Variable, dM				
Change in Ultimate Value, dB_u				
Slope, S				
Apparent Dead Time, T_d				

Calculations:				
Apparent Time Constant, T = dB_u / S				
Steady State Process Gain, Kp = dB_u / dM				
R = T_d / T				
Tuning Parameters:				
Gain, K_c				
Integral Time, T_I (minutes/repeat)				
Derivative Time, T_D (minutes/repeat)				

Table 9: Results for Open Loop Tuning

pH Control Performance

STEP	ACTION	REMARKS
1	Repeat the Start-up procedure for this experiment.	
2	At the AIC122 Controller Faceplate: - Set the controller to MANUAL mode. - Set its output to 10% Set its P, I, and D values obtained in the previous experiment.	
3	Starts pump P110 via the computer.	
4	Set both the Controller (FIC120 and AIC122) to AUTO mode.	
5	Wait for the Process Value (PV) of FIC120 and AIC122 to stabilize.	
6	Make a small step change to the Set Point of FIC120 Controller of between 10 to 20%.	
7	Observe the Process Value (PV) of the pH controller AIC122 from the Trend Window and look for some typical response characteristic. Refer to guidelines.	Refer Siborg (1989).
8	Capture the importance process response and print out the trend curve.	Print in color.
9	Stop both the pumps P100 and	

	P110 and the agitator AG120 via the computer, then set the controllers FIC120 and AIC122 to MANUAL mode.	

Table 10: Control Loop Performance Test for pH Control Loop

STEP	ACTION	REMARKS
1	Using the printed graph obtained from section above (process analysis), measure and tabulate the relevant values as required.	Refer Table Siborg (1989)
2	Describe the characteristic of the process response.	
3	Discuss the functions of each controller tuning parameters; P, I and D.	
4	Suggest any improvement to the process control loop and its total error.	

Table 11: Tabulate and Analysis Results

Characteristic	Test 1	Test 2	Test 3	Average
Initial value of SV				
Final value of SV				
ΔS				
Gain				
Rise Time				
Overshoot				
Decay ratio				
Period				
Response Time				

Table 12: Closed Loop Response