WOLKITE UNIVERSITY

College of Engineering and Technology

Department of Electrical and Computer Engineering

DESIGN AND CONTROL OF PH LEVEL IN WASTEWATER USING FUZZY LOGIC CONTROLLER

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DECLARATION

We, the undersigned, declare that this project, "Fuzzy logic controller based PH control of wastewater plant, is our own work. This work has not been submitted earlier either to this university or to any other institute for the partial fulfillment of the requirement of a course of study. All the sources of the materials used by our work are properly referred.

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It is approved that this final-year project report has been written in compliance with the formatting rules laid down by the department of the university. This project has been submitted for examination with my approval as a university advisor.

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ABSTRACT

The demand for application of advanced control strategies for process industries is increasing rapidly due to complex nature of industrial processes. The demand also increases to achieve improvement of the product quality and environmental factors. One such example of complex process is the pH neutralization process. This work presents the process to simulate the control system of pH level by adding acid or base (alkali) into a process tank in a wastewater system to maintain the pH level to neutral value, which is pH 7. The controller should be designed in such a way that neutral output of the system is obtained.

The pH neutralization process is highly nonlinear and has time varying characteristics where gain changes by several order. Hence controlling the value of pH is considered to be difficult and depends on nonlinear control techniques. Classic PID (proportional-integral-derivative) controllers are the most popular control system present in industrial plants although they are not suitable for applications in non-linear systems. On the other hand, fuzzy logic properly deals with system non-linearity and uncertainties where frequent changes at the operation point and disturbances occur. So our work is done based on fuzzy logic controller. The system is developed in Simulink/MatLab® software. It emulates a real plant through the use of the fuzzy inference toolbox of this software. The results are presented and lead to conclude that the fuzzy system is appropriated to systems with non-linear characteristics like pH regulation in waste water treatments.

Key words: PH neutralization, non-linear system, fuzzy logic controller, Simulink/MatLab®.

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ACRONYMS

CSTR	continuously stirred tank reactor
FIS	fuzzy inference system
FLC	fuzzy logic controller
GUI	graphical user interface
HCL	hydrochloric acid
NaOH	sodium hydroxide
PH	partial hydrogen ion concentration
PI	proportional-plus-integral controller
PID	proportional-integral-derivative controller
PLC	programmable logic controller

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CHAPTER ONE

1. Introduction

1.1 Background

Nearly all process plants generate a wastewater effluent that must be neutralized prior to discharge or reuse. Therefore, pH control is needed in just about every process plant, and yet a large percentage of pH loops perform poorly. Results are lesser product quality, environmental pollution, and material waste. Examples of areas where pH control processes are in extensive use are water treatment plants, many chemical processes, metal-finishing operations, production of pharmaceuticals and biological processes. With ever increasing demands to improve plant efficiency and tighter regulations in environmental protection, effective and continuous pH control is extremely advantageous.

Wastewater neutralization plays an important part in a wastewater treatment process. It provides the optimum environment for microorganism activity between pH 6.5 and 7.5{1}, and the right water discharge to the public sewage as mandated by the Department of Environment of between pH 5 and 9 (Environmental Quality Act, 1974) {2}. Wastewater of pH below 4.5 and above 9 may greatly reduce the activity of the microorganisms which treat the water and may not support their life at all {3}.

For a number of years, Hydrogen chloride (HCL) acid was used in wastewater treatment facilities to control alkalinity. It’s a product that works, but it also has many potential problems. HCL acid can be difficult to apply and control. Correcting the pH of alkaline waste water is usually required either for discharge to sewer, in preparation to further biological, physical/chemical treatment or direct discharge to the environment. Strong acids such as hydrochloric acid have traditionally been used to neutralize alkaline waste streams prior to discharge {4}.

1.1. Statement of the problem

It has been reported in literature that researchers have been trying for ages to control the pH with a tuned classical PID controller tuned for a certain characteristics, it becomes completely un-tuned for the next. As the process to be controlled is highly nonlinear, the usual PID-type controller is not able to control these systems adequately. To overcome this problem, we (here at the electrical engineering Department University of Wolkite) have engaged in finding a solution to the problem. One of the options possible is the use of fuzzy logic based PH control action. Based on prior knowledge of the process, the pH neutralization process is divided into several fuzzy regions such as high-flow rate, medium-flow rate and low-flow rate. Then, a fuzzy logic controller is designed using random variable of pH value as input, giving adequate performance in all regions. And the second problem is that uncontrolled PH level in wastewater led to diverse environmental effect when discharged, in order to solve this problem we should take a control action.

1.2 Objective of the project

1.2.1 General objective

The main objective of this project is to design and control of fuzzy logic based PH control of waste water.

1.2.2 Specific objective of the project

- ✓ To simulate a design that represents this project.
- ✓ To design the model of this project.
- ✓ To study about PH of water in order to take control action.
- ✓ To validate the result from simulation (by MATLAB).
- ✓ To investigate the performance of fuzzy controller in control of PH.
- ✓ To develop good knowledge on intelligent controller

1.3 Significance of the study

By using fuzzy logic based controller we can control the PH of liquid/solution. This gives a great and successful controlling action that compensates its difficult nonlinear characteristics and also prevents pollution of environment and in turn offers safe environment for living and non-living things if the controlled solution discharges to the environment.

This provides

- ✓ To achieve improvement of the product quality
- ✓ Environmental safety
- ✓ Agricultural productivity
- ✓ Health safety
- ✓ Good economic growth
- ✓ Industries can reduce unnecessary price by recycling and using it.

1.4 Scope of the project

This project is all about how to design the controller and simulate it using MATLAB. The PH of the liquid/solution in the container will be detected by the sensors, and it will be considered as a feed-back and then the feed-back value is compared with that of the desired or set point and after comparing, the value (error) is sent to the fuzzy controller. The basic control principle of the liquid/solution system is to maintain the liquid/solution PH in the container at a desired set point value when there is inflow of into container and outflow liquid/solution out of the container by neutralization process.

1.5 Outline of the project

The thesis consists of six chapters.

Chapter 1- This chapter introduces background information relevant to the thesis. Includes overview background, problem statement, objective, significance, scope and outline.

Chapter 2- explains about the literatures that we are revised and used for the project completion.

Chapter 3- This chapter presents two aspects of the work concerning system modeling. The first part discusses the methodology used and development of the pH concepts used in this investigation. The second part of this chapter explains system block diagram, material description and model of the system.

Chapter 4- This chapter starts with an overview of the formulation of the overall control structure and overall system design which shows matlab Simulink.

Chapter 5- is all about the project result and discussion.

Chapter 6- describes the conclusion and recommendation of the project.

CHAPTER TWO

2. Literature Review

The qualitative determination of pH value for food materials is done by tasting through human sensory organs. These some are noticed to be acidic and some alkaline. With modern pH electrodes these taste sensations can be measured in exact figures. The pH helps manufacture a product with defined attributes, produce a product at low cost, and prevent damage to environment, materials, and humans. The quality, purity and quantity of the product depend on the pH. In the last few years the measurement of pH has gained a wide importance. In the control and regulation of chemical and biological processes, it has become indispensable to monitor the pH values. In order to measure pH value, a measuring electrode (pH electrode) and a reference electrode are needed. In many cases, a combination electrode, housing both measuring and reference elements, is used.

Manoj et al [4] reported the development of fuzzy based control system for pH control and also to minimize the defects and the human negligence with the help of MATLAB. Unlike the other automated systems programmed using microcontrollers and PLC's, MATLAB serves the purpose of easy programming and has high flexibility. The smaller change in pH will lead to tedious effects in the process. The control of the pH process is also non-linear in nature and maintaining the pH value in the process is difficult for the desired transient response. In order to reduce such problems fuzzy based system was designed and was efficient than conventional integral controllers.

Gayatri K Palnitkar[6] reported that fuzzy controller, whose ability to handle non-linearity is well known, suggests better approach to control the pH. In her paper pH neutralization model is developed in MATLAB/Simulink. First, a conventional PI controller was designed and its performance was tested for various set points on neutralization curve. Its limitation in controlling nonlinear process like pH is highlighted. Further, a fuzzy logic controller was designed and its ability to control nonlinear process was presented using simulation results. The results clearly indicate superiority of fuzzy controller over conventional PI controller in dealing with nonlinear systems.

Marcílio de Paiva Onofre Filho et al.,[15] reported the design, implementation, and performance evaluation of a fuzzy controller for pH regulation in a stirred tank reactor. The controller is designed to perform pH neutralization of industrial plants, mainly in units found in oil refineries where it is strongly required to mitigate uncertainties and nonlinearities. Classic PID (proportional-integral derivative) controllers are the most popular control system present in industrial plants although they are not suitable for applications in non-linear systems. On the other hand, fuzzy logic properly deals with system non-linearities and uncertainties where, occur frequent changes at the operation point and disturbances. On account of their low complexity, the fuzzy controller requires little computational effort and may be applied to commercial solutions based on microprocessors, microcontrollers and PLC with good performance. In addition, it adjusts the changes in pH regulating process, avoiding or reducing the need for re-tuning to maintain the desired performance. The system is developed in Simulink/MatLab software. It emulates a real plant through the use of the fuzzy inference toolbox of this software. The results are presented and lead to conclude that the fuzzy system is appropriate to systems with non-linear characteristics like in pH regulation.

McAvoy and his fellow researchers (McAvoy, Hsu, & Lowenthals 1972) presented a paper on a rigorous and generally applicable method of deriving dynamic equations for pH neutralization in Continuous Stirred Tank Reactors (CSTRs). This paper and the associated model has been used as a platform for many subsequent investigations, such as those of Gus tafsson & Waller, Henson & Seborg and Wright & Kravaris and formed the basis for their attempts to introduce new and improved forms of pH control, especially in the area of adaptive control.

T.K Gustafsson and K.V Waller have produced several interesting papers concerning modelling and control of the pH neutralization process and a number of these have been reviewed and cited by others as providing good reference material. In 1982 (Gustafsson 1982) introduced a new concept concerning the averaging pH value of a mixture of solutions.

The research group of Henson & Seborg (Henson & Seborg 1994) is another group that has published work on adaptive nonlinear control applied to a pH neutralization process. That publication (Henson & Seborg 1994) is now recognised as an important paper and point of reference in the field of pH control. The group implemented the controller and evaluated its performance on a bench scale pH neutralization system in order to gain additional insight in terms of the practical application.

There are many published papers that discuss pH control in the context of this type of application(e.g.(Mahuli, Russell Rhinehart, & Riggs 1993;Paraskevas & Lekkas 1997)). In general, in this case, the purpose of the chemical plant is to neutralise the waste product solution (which may arise as a result of some manufacturing process) before discharging it to the environment. In such cases the control of the pH value to a certain environmental and legislative standard is very important (Rudolfs 1953).

2.1 History of pH values

Acidic and basic are two boundaries that describe chemicals, just like hot and cold are two extremes that describe temperature. Mixing acids and bases can cancel out their extreme effects; much like mixing hot and cold water can even out the water temperature. A substance that is neither acidic nor basic is neutral.

2.2 PH definition

PH is really a measure of the relative amount of free hydrogen and hydroxyl ions in the water. The pH of a solution measures the degree of acidity or alkalinity relative to the ionization of water sample. Pure water dissociates to yield 10-7 M of [H+] and [OH-] at 25 ºC; thus, the pH of water is neutral i.e. 7.

PH water = - log [H+] = - log 10-7 = 7

Most pH readings range from 0 to 14. Solutions with a higher [H+] than water (pH less than 7) are acidic; solutions with a lower [H+] than water (pH greater than 7) are basic or alkaline.

2.3 The Neutralization System

Neutralization is a chemical reaction, also called a water forming reaction, in which an acid and a base or alkali (soluble base) react and produce a salt and water (H2O). In other words, it can be said that neutralization is the combination of hydrogen ions H+ and hydroxide ions OH− (or oxide ions O2−) to form water molecule H2O. In the process, a salt is formed [9].

The neutralization systems to be controlled are illustrated in Figure 3.2. Figure 3.2 is a closed loop system, which contains a mix tank, an acid tank and a base tank. The mix tank contains the wastewater to be processed. As we know, most of the wastewater is acidic or basic which are not beneficial to the environment. Therefore, the aim of this system is to neutralize it by adding acid or base from another tank depends on its pH value sensed by the pH meter (sensor) in the mix tank. If the reading of the pH meter shows pH value which is less than 7, then it is acidic and certain amount of base will be pumped into the mix tank from the base tank. On the other hand, if the reading of the pH meter shows pH value which is more than 7, then it is basic and certain amount of acid will be pumped into the mix tank from the acid tank.

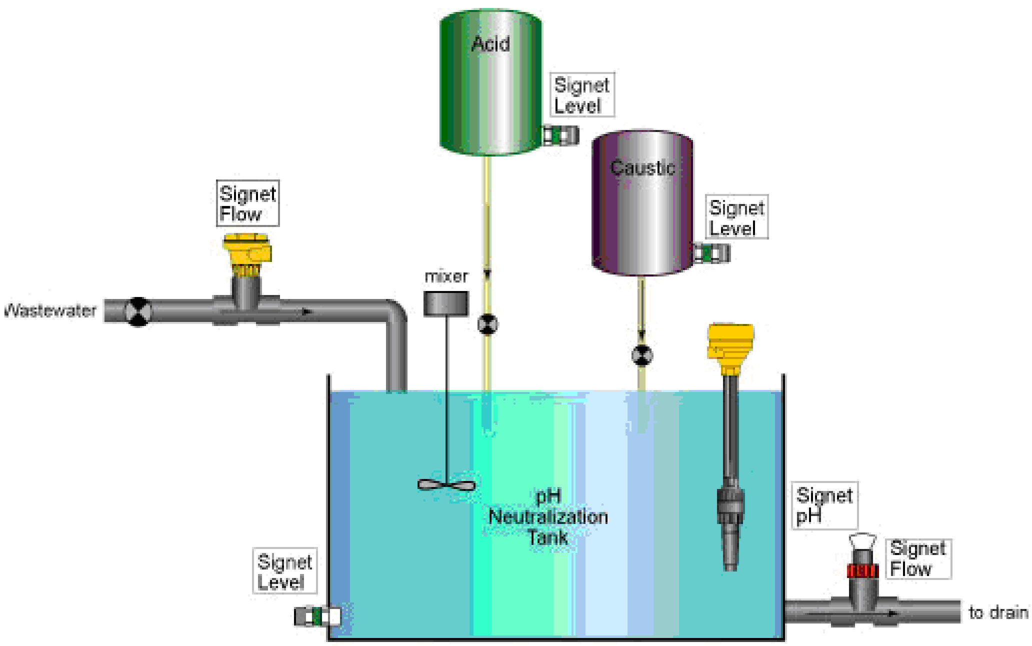


Figure 2.1 reactor tank

2.3.1 The Reactor Tank

The reactor tank is very crucial in this research as this is where the neutralization reaction process takes place and where the output measurements are taken. (AG 120) are installed near the acid feed stream inlet. The main purpose of this agitator is to mix both solutions completely and homogeneously. In addition to that, it will also accelerate the neutralization reaction process. The agitator produces some turbulence in the tank in order to mix the solution satisfactorily. The pH value from the online pH meter is also relatively consistent, indicating that the agitator works adequately and its turbulence does not adversely affect the measured signals.

The outlets for the acid and alkaline streams as they flow into the tank are separately placed far apart. In practice, both solutions will take some time to travel and merge before the neutralization reaction takes place. Theoretically, if both inlet streams are close to each other some of the delays will be eliminated but there will inevitably be further lags or time delays before the concentration in the whole tank reaches a steady uniform level following a change of an input. Thus this arrangement introduces additional dynamic behavior in the neutralization reaction, especially in terms of reaction lags and transport time delays. Most models described in the literature (e.g (Gustafsson & Waller 1983a; Henson & Seborg 1994; McAvoy, Hsu, & Lowenthals 1972; Mwembeshi, Kent, & Salhi 2001)) do not include pure time delays as the models are based on laboratory scale equipment where delays are much smaller, possibly due to more efficient mixing. As a result, the development of the pH neutralization plant model was found to be more challenging than originally expected.

2.4 Overview of pH control

In general pH control methods can be divided into three main categories. The first category is an open loop type of control scheme in which the control valve opening is kept at certain positions for specific time durations. A specific pH value in the reactor tank is not really the main concern. Normally this type of control approach is used for start-up and shutdown of a process or at an initial or pre-process stage within a multistage neutralization process in which at the later stages of the process involve a feedback controller to control the pH value to a specific value or within a range of values.

The second category is the most popular and commonly used approach and is based on feedback control principles. Unlike the open loop control approach, this type of control scheme involves a direct relationship between the control valve opening and the pH value in the process. The general idea is that when the pH value is higher than the desired value the control valve opening is decreased. Conversely, if it is lower than the set point then the control valve opening is increased. This control approach is also known as a corrective control approach. This is because the control action will take place once there is a discrepancy between the process variable and the required set point. There are many types of feedback control schemes that have been published and discussed by previous researchers. The most widely used type of controller for this feedback control approach is the Proportional, Integral and Derivative (PID) type of controller together with the closely associated variations on this control algorithm involving Proportional control (P) or Proportional plus Integral control (PI).

The third control method that is widely used in this type of application is feed forward control. In this control approach the controller will compensate for any measured disturbance before it affects the process (i.e. the pH value in the case of this application). In order to implement this control approach it will normally be necessary to make more measurements on the process. In the case of a pH process the disturbances could arise from unexpected changes in the concentrations of both solutions as well as changes in the flow rates for the two streams. Thus, with a properly designed feed forward scheme, if a disturbance occurs the controller will react before the pH value in the reactor tank is significantly affected. Based on this principle this feed forward control approach is also known as a form of preventive control. The preventive control approach is very much faster than the corrective control approach. Often, in an ideal case, a controller will involve a combination of corrective control and preventive control. It is unusual to have a controller which involves only feed forward control. This is because the feedback control scheme will handle or react to any unknown or unmeasured disturbances (which are unmanageable by means of feed forward control alone). At the same time the feed forward control scheme will react faster to any measured disturbance before it affects the process.

CHAPTER THREE

3. Methodology and System Description

3.1 Methodology

1. Gather all necessary data and information needed for the design of the system.
2. Reviewing related literatures
3. Studying and selection of materials
4. Designing the system using software
5. Result evaluating and analysis

3.2 Block Diagram

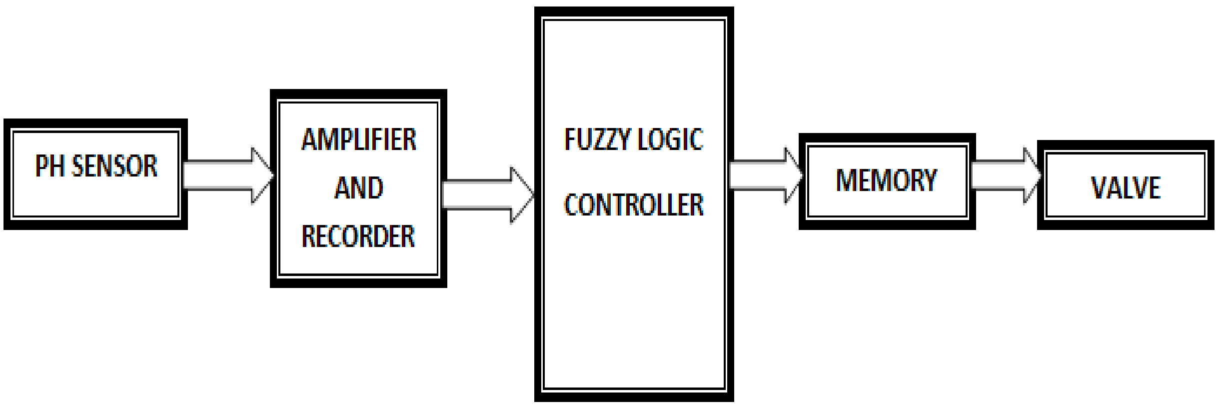


figure 3. 1 block diagram of the project

As shown in the above figure of block diagram the system the system uses ph sensor as an input and this ph sensor reads the ph of wastewater in the tank. After the reading the ph amplified and recorded and given as an input to the fuzzy controller. Then the fuzzy controller will perform its task based on the rule bass on it. Then it’s saved and the command will be transferred to the valve in order to open or close the valve to neutralize the system and operate to the optimum ph value.

3.3 working principle of the system

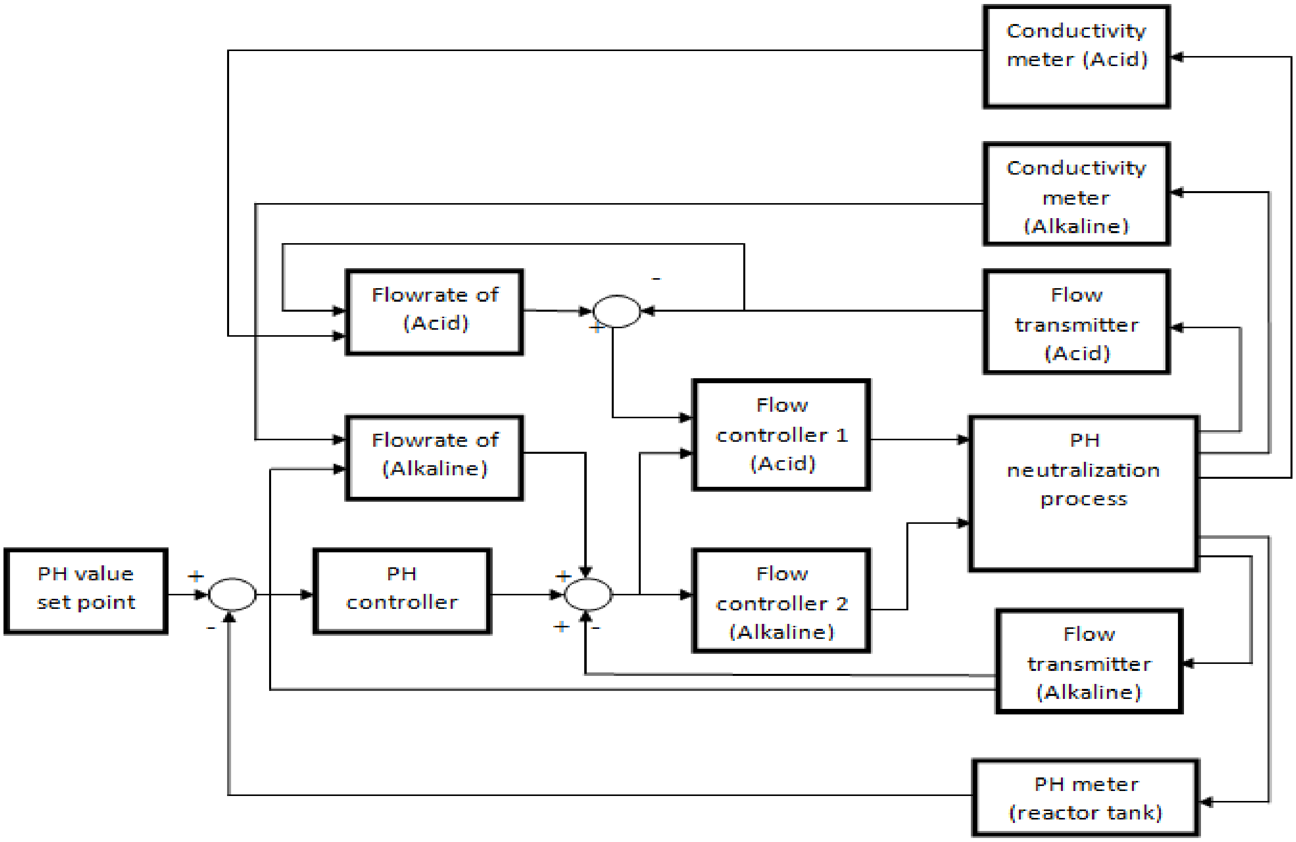


Figure 3.2 working principle of the system

Here there is detail information about the system. There is a sensor that senses system ph and transfers data to the controller. There is a needed data on the controller that contains all parameters as a membership function then it compares the feed data to that of membership category to match to the specific group. Then it compares to the set point of neutralized or neutral state, which is 7. Then after wards it produces error and that error fed to the system again, but it is not the only input for the system. There is also another input that is change in error produced by the difference of previous output and current ph output. Then the system starts to perform its task by reading inputs and match to the rule bases. Then the valve will respond to the parameters and the flow rate is controlled by the flow controllers.

3.4 flow chart of the system

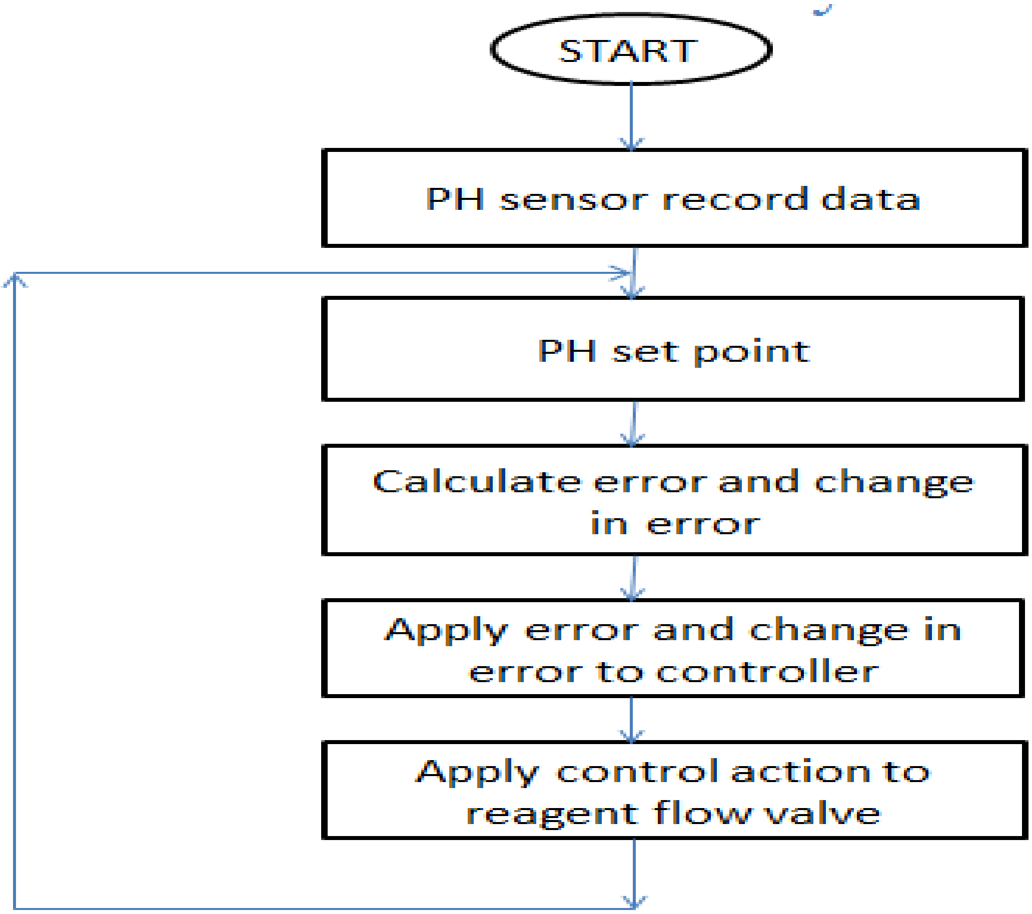


Figure 3.3 flow chart of the system

3.5 Component description

There are five main process variables that will determine the behavior of the pH neutralization process for this plant. As given in the table below (i.e. Table 3.1), the instrumentation that provides the main required process variables from the plant involves one pH meter, two flow meters and two conductivity meters. These three main measuring instruments are crucial for the control strategy.

The pH meter provides the main feedback of the process variable to the controller whereas the flow meters and conductivity meters can be used to provide inputs that indicate whether or not the system can be controlled. Therefore the accuracy and reliability of these instruments are also important in order to ensure that the performance of the controller is satisfactory and consistent.

Table 3.1 main process variables with their instrumentation

No	Process variable	Instrument
1	PH value from the reactor tank	PH Meter
2	Concentration in acid tank	Conductivity Meter
3	Concentration in alkaline tank	Conductivity Meter
4	Flowrate for acid stream	Flowmeter
5	Flowrate for alkaline stream	Flowmeter

3.5.1 pH Meters

The pH meter provides the main feedback of the process variable to the controller. The pH meter can be divided into two parts. The first part is the process electrode, which acts as a sensor. This electrode will measure the electrical potential (i.e. in mV), which is developed across the surface of a sensing membrane. The second part is the controller, the main function of which is to convert the measured electrical potential signal into a pH value according to the Nernstian Slope.

The meter is normally installed in waste water treatment plants, and in chemical and food processing industries as well as neutralization process plants. As mentioned earlier, the primary objective of this pH neutralization process is to control or maintain the pH value in the reactor tank to a desired value. Thus this pH meter will provide an important feedback signal for the controller.[15]

3.5.1.1 pH Measurement

Measuring pH involves comparing the potential of solutions with unknown [H+] to a known reference potential. PH meters convert the voltage ratio between a reference half-cell and a sensing half-cell to pH values. In acidic or alkaline solutions, the voltage on the outer membrane surface changes proportionally to changes in [H+]. The pH meter detects the change in potential and determines [H+] of the unknown by the Nernst equation:

$$E = E_o + (2.3RT)/nF \log \{\text{unknown } [H^+]/\text{internal } [H^+]\} \quad (3.1)$$

Where:

E = total potential difference (measured in mV);

Eo = reference potential;

R = gas constant;

T =temperature in Kelvin;

n = number of electrons;

F = Faraday's constant;

[H+] = hydrogen ion concentration.

The measurement range for the pH meter is set to pH values in the range 0 to 14 and the corresponding output range for the meter is 4 to 20mA. The pH meter has been calibrated with three standard buffer solutions (of pH values 4, 7 and 9). The readings from this meter have been compared and verified with readings from a laboratory pH meter that acts as a primary standard and the results are satisfactory and acceptable. The pH meter needs to be re-calibrated from time to time and the measuring probe cleaned in order to ensure its reliability and accuracy.

3.5.2 Conductivity Meters

The conductivity meters used to provide inputs that indicate whether or not the system can be controlled. The meter also has two parts: the process electrode and the controller. The main function in each case is similar to the functions within the pH meter. The process electrode measures the density of ions in the aqueous solution in the form of an electrical current. Normally the range of the generated electrical current is very small. The controller displays the measured current using suitable basic units of measurement, which are milliSiemens/cm (mS/cm) and microSiemens/cm (μS/cm).

The conductivity value relates to the concentration value of an aqueous solution and a different solution will involve a different relationship. The main factor was to be able to achieve a linear relationship between the conductivity and the concentration of the solution. In addition to that, other factors also had to be considered such as the safety of the plant and the cost of the experiments. After considering all factors the best concentration values for hydrochloric acid and sodium hydroxide range from 0.01M to 0.1M.

Based on the tests carried out on the meter the relationship between conductivity and concentration for the two solutions are as follows:-[15]

i. Hydrochloric Acid

$$\text{Concentrat ion value} = \frac{\text{Conductivity value}}{287.88}$$

ii. Sodium Hydroxide

$$\text{Concentrat ion value} = \frac{\text{Conductivity value}}{210.43}$$

As mentioned above, there are two conductivity meters. One meter is installed at the acid tank and the other at the alkaline tank. Both these tanks were cleaned during the refurbishment and recalibration work on the plant. This was to ensure that the tanks were free from any contamination and thus would not lead to the occurrence of any unwanted reactions. Concentrated hydrochloric acid and sodium hydroxide are used to prepare the solutions at the required concentrations. During the preparation process each solution is stirred manually with a special rod in order to ensure that the solution is uniformly mixed.

The measurement range for the conductivity meter is between 0mS and 200mS, which correspond to an output range for the meter from 4 to 20mA. The meter has also been calibrated with standard buffer solutions that have conductivity 1413mS and 12.88mS.

3.5.3 Flow meters

There are two magnetic flow meters for the system one is for acidic and another is for base. These flow meters or flow transmitters will provide flow rate indications for the acid stream (FT120) and for the alkaline stream (FT121). A magnetic flow meter is suitable for wastewater or other dirty fluid applications as there is no direct contact between the fluids being measured and the measuring parts or elements. The operating principle of a magnetic flow meter is based on Faraday's law of electromagnetic induction. The fluid acts as a conductor and the induced potential is proportional to the average flow velocity which is perpendicular to the flux lines. The magnetic flow meter can also be considered as divided in two parts. The first part is a sensor in which the magnetic field is normally mounted along the pipeline. The second part is the transducer. This is where all the conversions of the measured variable into a desired form in terms of the electrical signal take place. The operating range for FT 120 is 0-300L/h and as for FT121 is between 0-350L/h. Again the output range for these meters is 4-20mA. There was no need for adjustment or recalibration of these meters as they were found, from initial tests, to serve the intended purpose perfectly.[15]

3.5.4 Control Valves

In a process control application control valves represent an important form of final element that will determine the performance of a controller. In general there are three types of control valve characteristics, which determine the relationship between the control valve opening and the actual stream flow rate as shown in Figure 3.6 (Spirax-Sarco Limited 2007). The first type of control valve characteristic is termed linear opening, the second type is called quick opening and the third type is called an equal percentage type of valve. In general terms the physical shape of the plug and the seat arrangement of the control valve lead to differences in valve opening and thus to the different control valve characteristics. Thus the actual setting of the trim (i.e. the shape of the plug and seat arrangement) of each control valve is unique as it also depends on the process involved.[7]

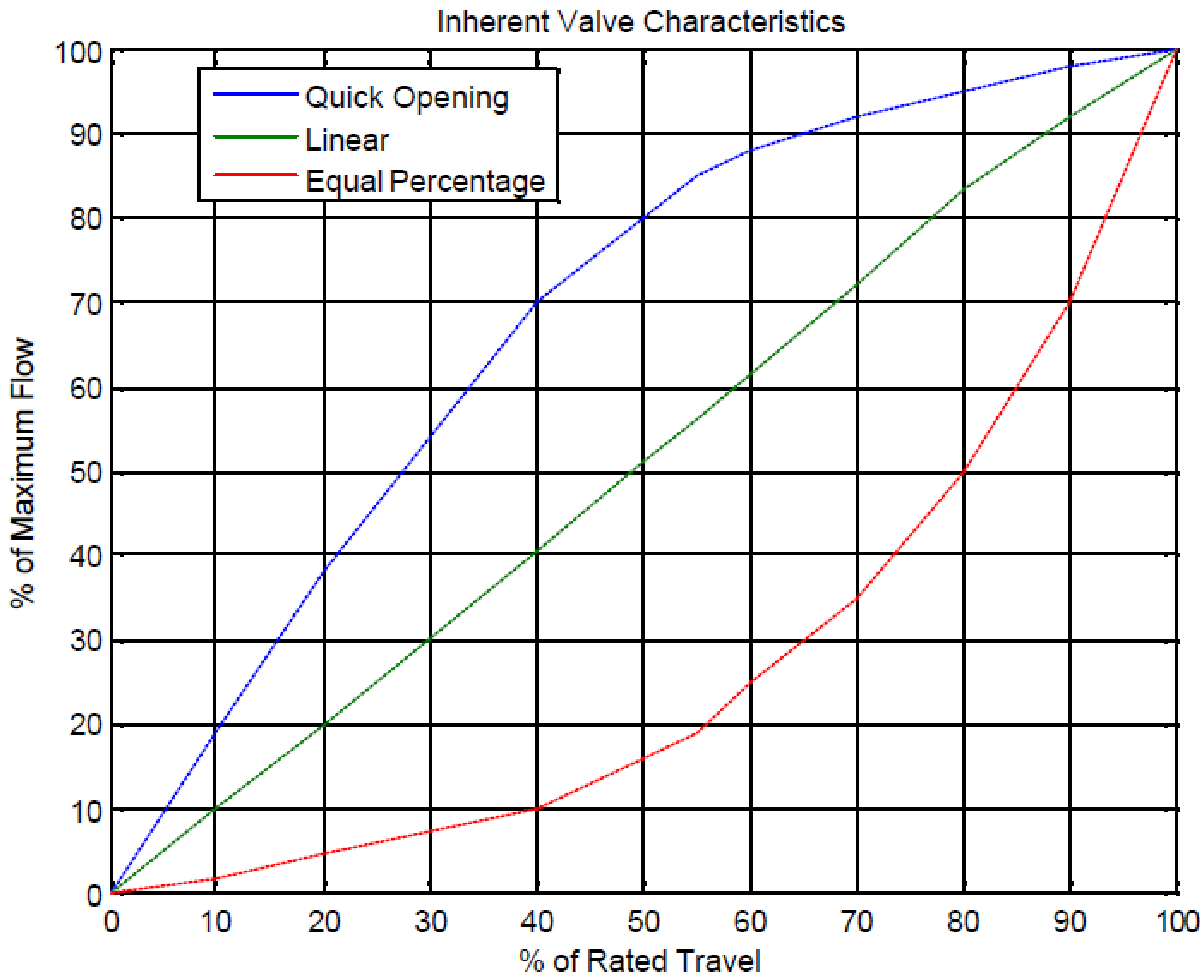


Figure 3.4 Typical characteristic of a control valve [7]

However any given control valve is likely to have a form and characteristics broadly similar to one of these three types shown in the figure. As for the linear opening type, this form of control valve is generally required for applications in which the differential pressure drop across the control valve is relatively constant over the valve travel range. This type of situation commonly arises for control of liquid level and flow.

As shown in the figure, the quick opening characteristic valve exhibits a rapid increase in flow rate as the valve opens even with a small change of opening. The movement of this type of valve can be extremely small relative to small changes in the controller output thus the valve has an inherently high range of operability. The typical application for this type of control valve is a frequent on-off service and this type of characteristic is also useful for processes where immediate large flow rate is required.

As mentioned above, the third type of control valve is the equal percentage characteristic valve. The trim for this type of control valve has been designed so that each increment in the control valve opening will lead to an increase of the flow rate by a certain percentage of the previous flow. In general, the response for the equal percentage type of control valve is much slower or less sensitive compared to the fast opening type. This type of control valve is normally being used in processes where large changes in the pressure drop are expected. The type of control valve is also common in temperature and pressure control applications. As shown in the figure the "upscale" curve was obtained when the percentage of opening was initially at 0% opening and the valve opening was continuously increased upwards until the valve was fully open (i.e. 100% opening).

The "down scale" curve was obtained when the initial control valve opening was at 100% and the percentage of control valve opening was steadily decreased until the control valve was fully closed. This exercise also allowed investigation of the hysteresis error.

As shown in Figure 3.7, there is clear evidence of leakage at the control valve CV121 since there should be zero flow when the control valve has a 0% opening and the results indicate that there is still a measured flow of approximately 20L/h under these conditions.

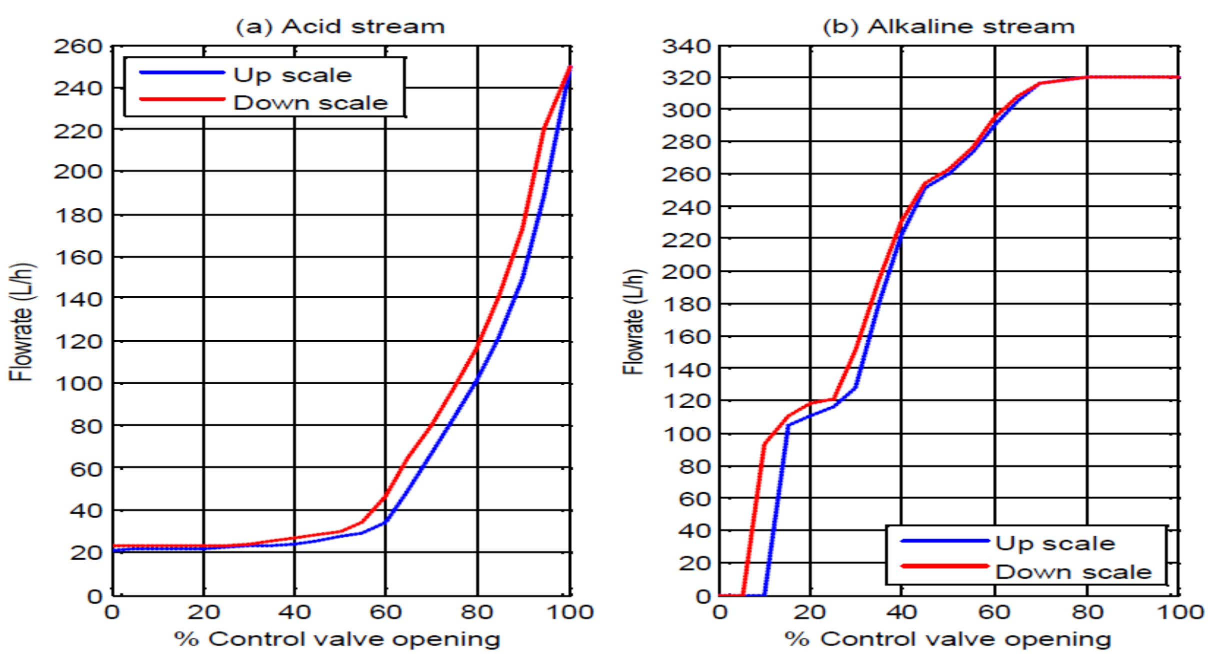


Figure 3.5 Control valve characteristics [7]

The characteristic of the control valve CV121 can be divided into three different responses as described in the Table 3.2. The responses for the first part of the range can be termed as "Low Gain Factor". This is when the control valve opening is in the range from 0% to 60% and provides a flowrate for the acid stream of approximately 20L/h to 40L/h. The second response is called a "Moderate Gain Factor" response and the corresponding range of the control valve opening is between 60% and 80%. This range will give a much greater variation of flow rate (from 40L/h to 120L/h). Within this part of the range the relationship between the control valve movement and the flow rate is more predictable and linear compared with the first range of control valve response. The last column in Table 3.2 shows the effective gain factor obtained by linearizing the response over the specific range. As an example for the case of the moderate gain factor (referring to second- last column), the effective gain factor is calculated as follows:-

$$Effective\ Gain\ Factor = \frac{[Maximum\ Range - Minimum\ Range]_{Flowrate}}{[Maximum\ Range - Minimum\ range]_{\%controlvalveopening}}$$

$$= \frac{[120-40]L/h}{[80-60]}$$

$$= 4L/h$$

Table 3.2 Categories of control valve responses [7]

Range		Control Valve Gain factor	Effective Gain Factor (L/h)
Control valve Opening (%)	Flowrate(L/h)		
CV121			
0-60	20-40	Low	0.33
60-80	40-120	Moderate	4
80-100	120-240	High	6
CV122			
5-10	0-100	High	20
10-60	100-300	Moderate	4
60-80	300-320	Low	1

As shown in the table a 1% change of the control valve movement will provide a 4L/h change in the flow rate in this part of the operating range. The third range is from an 80% to 100% opening and is termed a "High Gain Factor" response range. It should be noted that this third part of the range involves the same amount of control valve movement or variation as the second part (i.e. 20%). However, the fast response range will provide an even wider range of acid stream flow, from 120L/h to the maximum flow rate which is approximately 240L/h. As shown the slope of the fast response part of the range is much steeper. Thus it shows that a small movement of control valve opening will result in a large change of flow rate. Therefore the Suitable range for the experiment ranges from 60% to 80% opening that is in the moderate response range.

For the control valve CV122 the response is an inverse form of the response of control valve CV121. The first 5% of the control opening provides 0L/h of alkaline flow. In order to provide 0-100L/h of flow rate the control valve opening needs to be controlled between 5% and 10%. This suggests that it is very difficult to manage the control valve movement since a 1% change of opening can produce a change of flow rate of the order of 20L/h.

As shown in Figure 3.7 for control valve CV122 the flow rate of the alkaline stream will reach 300L/h when the control valve opening is at 60%. This gives a 50% variation of control valve movement which can produce a flow rate in the range 100L/h to 300L/h. As given in Table 3.2, for this part of the range, there is a change of approximately 4L/h for every 1% opening of the control valve movement. Therefore, this is a sensible operating range for experimental work on pH neutralization process.

3.5.5 Reagents (Acids and Bases)

As described in the Arrhenius theory, an acid is a substance that ionizes in water to give hydrogen ions (H+) whereas a base is a substance that ionizes in water to give hydroxyl ions (OH-). The charge balance equations for acid and base reactions with water are given in Equation (3.1) and Equation (3.2) respectively. As shown in these equations, the hydrogen ion is actually a mere proton. Thus, based on the Bronsted-Lowry theory, an acid is described as a substance that can donate a proton and a base is a substance that can accept a proton.

$$\mathrm{HA} + \mathrm{H_2O} \leftrightarrow \mathrm{H_3O^+} + \mathrm{A^-} \tag{3.1}$$

$$\mathrm{B} + \mathrm{H_2O} \leftrightarrow \mathrm{HB^+} + \mathrm{OH^-} \tag{3.2}$$

Acids and bases can be categorized as monoprotic or polyprotic (i.e. diprotic, triprotic, etc.). This depends on the number of hydrogen ions or hydroxide ions that the substance has. To explain further, phosphoric acid (H3PO4) may used as a convenient example. This acid is considered as a triprotic acid. This substance ionizes in three different stages since it has three hydrogen ions to donate, as shown in Equations (3.3), (3.4) and (3.5). Each stage has a different value of dissociation constant which describes the attributes or characteristic of the substance.

$$H_3PO_4 \leftrightarrow H^+ + H_2PO_4^- \quad (3.3)$$

$$H_2\,PO_4^- \leftrightarrow H^+ + HPO_4^{2-} \quad (3.4)$$

$$HPO_4^{2-} \leftrightarrow H^+ + PO_4^{3-} \quad (3.5)$$

The dissociation constant also describes the strength of the acids and bases. A large value of dissociation constant for an acid indicates that it is a strong acid that is able to donate or ionize all protons in water. On the other hand, a small value of dissociation constant for an acid shows that it is a weak acid and it dissociates partially.

$$K_{a1} = \frac{[H^+][H_2PO_4^-]}{[H_3PO_4]} \quad (3.6)$$

$$K_{a2} = \frac{[H^+][HPO_4^{2-}]}{[H_2PO_4^-]} \quad (3.7)$$

$$K_{a3} = \frac{[H^+][HPO_4^{3-}]}{HPO_4^-} \quad (3.8)$$

The acid-base neutralization reaction involves a chemical reaction in which hydrogen ions and hydroxide ions are neutralized or combined with each other to form water (H2O) while the other ions involved remain unchanged.

As an example, Equation (3.9) shows the acid-base neutralization reaction between hydrochloric acid and sodium hydroxide.

$$H^+ + Cl^- + Na^+ + OH^- \rightarrow H_2O + Na^+ + Cl^- \quad (3.9)$$

In this example hydrogen and hydroxide ions combined together to form water and the mixed solution will also contain some salts.

A titration curve is normally used to describe the characteristic of the acid-base neutralization reaction. This curve is able to provide useful and important information about the reaction, such as the equilibrium point, the type of acid and base involved (strong or weak, and whether monoprotic or polyprotic) as well as the total volumes or amounts of the substances involved at the end point of the titration process. The titration curve can also show the level of complexity of the acid-base neutralization process, especially in terms of the nonlinearity and the time varying nature of the process.

As an example, Figure 3.8 shows the typical pattern of a titration curve for a monoprotic acid and a polyprotic acid (hydrochloric and phosphoric acids respectively). As shown clearly in the figure, the behavior of the neutralization process is highly nonlinear. The figure shows an S shaped curve in which the slope of the curve differs from one type of acid to another. The titration curve also depends on the concentration and composition of the acid and base involved in the reaction process. Thus it shows that the process gain can vary significantly and this creates an important challenge for pH control applications. The S-shaped curve also shows that the most sensitive point on the curve is in the region where the pH value is 7. At this point we should expect a significant change in output for a very small change of input. Thus this operating point involves difficult conditions for open-loop experimentation and for control.

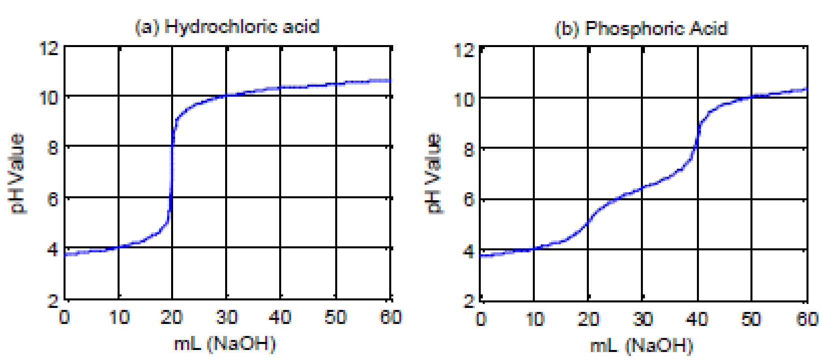


Figure 3.6 Typical titration curves for monoprotic acid (left) and polyprotic Acid (right)[7]

The concentration of hydrogen and hydroxide ions determines whether the mixed solution is acidic or alkaline. The mixed solution becomes an acidic solution when the concentration of hydrogen ions is greater than the concentration of hydroxide ions. The opposite is true for the case of a mixed solution that is alkaline. However, if the concentration of both ions is the same then the mixed solution has reached a condition called a neutral solution. As described in (Christian 2004a), the concentration of H+ and OH- in an aqueous solution can vary over an extremely wide range (normally between 10-14M and 1M). Thus it is very convenient to measure the acidity of the solution by using the logarithm of the concentration of hydrogen ions,(log H+), rather than the concentration itself (H+). This concept of pH scaling for measuring the acidity of a substance was introduced by Sørenso in 1909 (Bates 1973;Christian 2004a;Mattock & Taylor 1961).

$$\mathrm{PH} = -\log_{10}[\mathrm{H}^{+}] \qquad (3.10)$$

Based on this concept and Equation (3.10), the scale for measuring the acidity of a solution is between 0 and 14. At 25^{o}C, if the pH value is below 7 the mixed solution has a higher concentration of hydrogen ions and thus the solution is acidic. If the pH value is 7 it shows that the mixed solution is neutral and if the pH value is more than7, it indicates that the solution is alkaline.

3.5.5.1 Chemical reaction

- ✓ HCl(acid) + NaOH(base) ==> H_2O + NaCl
  which are dissociated into ions:
  $H^+ + Cl^- + Na^+ + OH^-$ ==> $H_2O + Na^+ + Cl^-$
- ✓ i.e. Na^+ and Cl^- are unaffected.
- ✓ pH = inverse log of the concentration (activity) of free H^+ , or pH = -log [H^+]
- ✓ Water dissociates into H^+ and OH^- ;
- ✓ the dissociation constant is: $K_{water} = [H^+] [OH^-] = 10^{-14}$
- ✓ So there has to be 10^{-7} moles each of H^+ and OH^- in a kilogram of neutral solution at standard temperature of 25°C. One mole is 6.023 x 10^{23} atoms (or molecules) and H_2O has a molecular weight of 18 grams per mole. One kilogram of water has about 1000/18 = 55.6 moles of water or about 3.35 x 10^{25} atoms of oxygen and about twice that number (6.7 x 10^{25} atoms) of H^+ (the amount of free H^+ or free OH^- is relatively small compared to the amount of undissociated H_2O).
- ✓ pH ranges at 25°C from 0 to 14; pH < 7 = acidic solution; pH > 7 = basic solution. If HCl or another acid is added then pH decreases; if NaOH or another base is added then pH increases.

- ✓ pH increases as carbonic acid (a weak acid) dissociates: When carbon dioxide combines with water, such as what happens in the atmosphere when fossil fuels are burned, carbonic acid is formed: $H_2O + CO_2 ==> H_2CO_3$. Free H^+ are made available during successive dissociations:
- ✓ $H_2CO_3 ==> H^+ + HCO^{3-}$ carbonic acid to bicarbonate, occurs at pH ~6.4
- ✓ $HCO_3 ==> H^+ + CO_3^{2-}$ bicarbonate to carbonate, occurs at pH ~10.3

Remember, free H^+ is available only when acidic, or when pH < ~7. The dissociation of bicarbonate to carbonate occurs when there is too much OH^- in the system and H^+ is "released" to balance out the base.

✓ Dissolved Cations and Anions in Water

Cations = electron donors, positively charged: Na^+, K^+, Mg^{++}, Ca^{++} , Fe^{++} or Fe^{+++} , Mn^{++} , Al^{+++}

Anions = electron acceptors, neg. charged: Cl^- , F^- , I^- , Br^- , SO_4^{--} , CO_3^{--} , HCO_3^- , NO_3^{--} , NO_2^-

Metals = act like cations mostly: Cu, Zn, Pb, Co, Ni, Cr, As, Se, Mo, etc.

✓ Water Analyses - Need to have cation-anion balance

Millequivalent (MEQ) = mole equivalent charge or anion or cation, measure of total charge due to the ion in question dissolved in the solution. Start with concentration, divide by mole wt., multiply by charge: XX mg/L / MW x CHG = MEQ

Example: NaCl in solution, Na = 50 mg/L (50 ppm): 50/23 x 1 = 2.17 MEQ

Cl = 77 mg/L (77 ppm): 77/35.5 x -1 = -2.17 MEQ

So, if the total cation and anion MEQ’s are not balanced, some error exists in the analysis

3.5.6 Software tool

3.5.6.1 Matlab

MATLAB, which stands for MATrix Laboratory is a very powerful software package tool for solving various types of problems in mathematics, science and engineering. It has a very extensive library of predefined programs or functions designed to help engineers and scientists to solve their problems in a faster and less painful way, having over 40 toolboxes for different subjects of study. A toolbox of a particular subject contains mainly the functions or programs required to solve problems related to the subject.

MATLAB- is software package for high performance numerical computations and visualization. It provides an interactive environment with hundreds of built in functions for technical computations, graphics and animation. Best of all, it also provides easy extensible with its own high level programming language. [4-6]

3.5.6.2 Fuzzy controller

Conventional control approaches are not convenient to solve the complex issues in this highly nonlinear system. Fuzzy logic is a form of probabilistic logic or many-valued logic; it deals with approximate reasoning rather than fixed and exact. Fuzzy logic is a part of artificial intelligence or machine learning which interprets a human's actions. Fuzzy models interpret the human actions and are also called intelligent systems.

A fuzzy set is an extension of a crisp set. Crisp sets allow only full membership or no membership at all, whereas fuzzy sets allow partial membership. Fuzzy sets represent commonsense linguistic labels like slow, fast, small, large, heavy, low, medium, high, tall, etc. A membership function is essentially a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. Various types of membership functions are used, including triangular, trapezoidal, generalized bell shaped, Gaussian curves, polynomial curves, and sigmoid functions.

A fuzzy inference system (FIS) essentially defines a nonlinear mapping of the input data vector into a scalar output, using fuzzy rules. The mapping process involves input/output membership functions, FL operators, fuzzy if–then rules, aggregation of output sets, and defuzzification. A general model of a fuzzy inference system (FIS) is shown in Figure 3.9. The FIS maps crisp inputs into crisp outputs. It can be seen from the figure that the FIS contains four components: the fuzzifier, inference engine, rule base, and defuzzifier. The rule base contains linguistic rules that are provided by experts. It is also possible to extract rules from numeric data. Once the rules have been established, the FIS can be viewed as a system that maps an input vector to an output vector. The fuzzifier maps input numbers into corresponding fuzzy memberships. This is required in order to activate rules that are in terms of linguistic variables. The fuzzifier takes input values and determines the degree to which they belong to each of the fuzzy sets via membership functions.

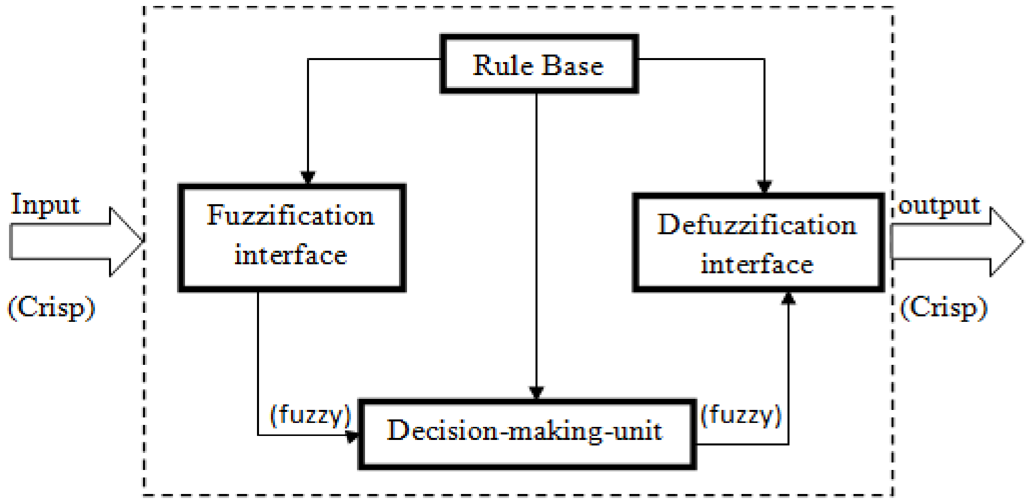


Figure 3.7 Fuzzy logic system

The inference engine defines mapping from input fuzzy sets into output fuzzy sets. The defuzzifier maps output fuzzy sets into a crisp number. Given a fuzzy set that encompasses a range of output values, the defuzzifier returns one number, thereby moving from a fuzzy set to a crisp number. Several methods for defuzzification are used in practice, including the centroid, maximum, mean of maxima, height, and modified height defuzzifier. The fuzzy logic controller (FLC) acts as a part of the control system just like in conventional control systems.

3.5.6.2.1 Benefits of Fuzzy Logic

The main advantages of fuzzy logic control over conventional control are as follows:

- ✓ Fuzzy logic has the ability of controlling nonlinear processes. This control is achieved by formalizing the expertise of an operator who has prolonged experience in handling and tuning the process or a designer who has vast engineering knowledge in the specific area of process control engineering.
- ✓ For processes which do not have precise mathematical method are difficult to control by classical control method. Fuzzy logic provides simple solution for model development of such processes.

- ✓ Fuzzy logic is capable of producing accurate and reliable solution from imprecise or vague information. Hence fuzzy logic is able to resemble human decision making process.
- ✓ Fuzzy logic uses linguistic approach which is easy to interpret than complex mathematical form of description. Hence fuzzy logic system is relatively easy and implementation is straight forward [10].

3.6 Dynamic modeling of pH Neutralization Process

The dynamic model of pH neutralization process involves material balances on selective ions, equilibrium constants and electro neutrality equations. Based on principle of material balances the process mixing dynamics may be described as follows:

$$V\frac{dxa}{dt} = F_a C_a - (F_a + F_b)xa \quad (3.11)$$

$$V\frac{dxb}{dt} = F_b C_b - (F_a + F_b)xb \quad (3.12)$$

Where V is the maximum volume of the CSTR (L); Ca, Fa is the concentration (mol/L) and flow rate (L/s) of titration stream A; Cb, Fb is the concentration (mol/L) and flow rate(L/s) of process stream B; Fa +Fb is the flow rate of effluent stream; Xa is the concentration of acid component (chloride ion, Cl^-) in the effluent stream; Xb is the concentration of base component (sodium ion, Na^+) in the effluent stream.

Mathematical Equation for pH is

$$PH = -log_{10}[H^+]$$

For neutralization of strong acid (HCL) with strong base (NaOH)

$$HCL + NaOH \rightarrow H_2O + NaCL$$

$$H^+ + OH^- \rightarrow H_2O$$

For, Qa = Flow of acid

Qb = Flow of base

V = Volume of fluid inside

$$V\frac{d}{dt}[Na^{+}] = [Na^{+}_{in}] * [Q_b] - [Na^{+}] * [Q_{out}]$$

$$[Na^{+}] + [H^{+}] = [Cl^{-}] + [OH^{-}]$$

$$[H^{+}][OH^{-}] = K_w = 10^{-14}$$

Relationship expressed in difference of ionic concentration X:

X = [OH-] – [H+]

X= [Na+] – [Cl-]

$$[H^{+}] = \left(\frac{x}{2}\right) * (\sqrt{1 + \frac{4*kw}{x^{\wedge}2}} - 1) \quad \text{if X>0} \quad (3.12)$$

$$[H^{+}] = -\left(\frac{x}{2}\right) * (\sqrt{1 + \frac{4*kw}{x^{\wedge}2}} - 1) \quad \text{if X<0} \quad (3.13)$$

$$[H^{+}] = \sqrt{kw} \quad \text{if X=0} \quad (3.14)$$

From the definition of $PH = -log_{10}[H^{+}]$, the well-known pH titration curve for a strong acid-strong base is given by following equation:

$$[PH] = -log_{10}\left(\frac{x}{2} + \sqrt{\frac{x^2}{4} + K_W}\right) \quad (3.15)$$

Where $x = (x_a - x_b)$

The SIMULINK implementation of dynamic pH neutralization process model is shown below.

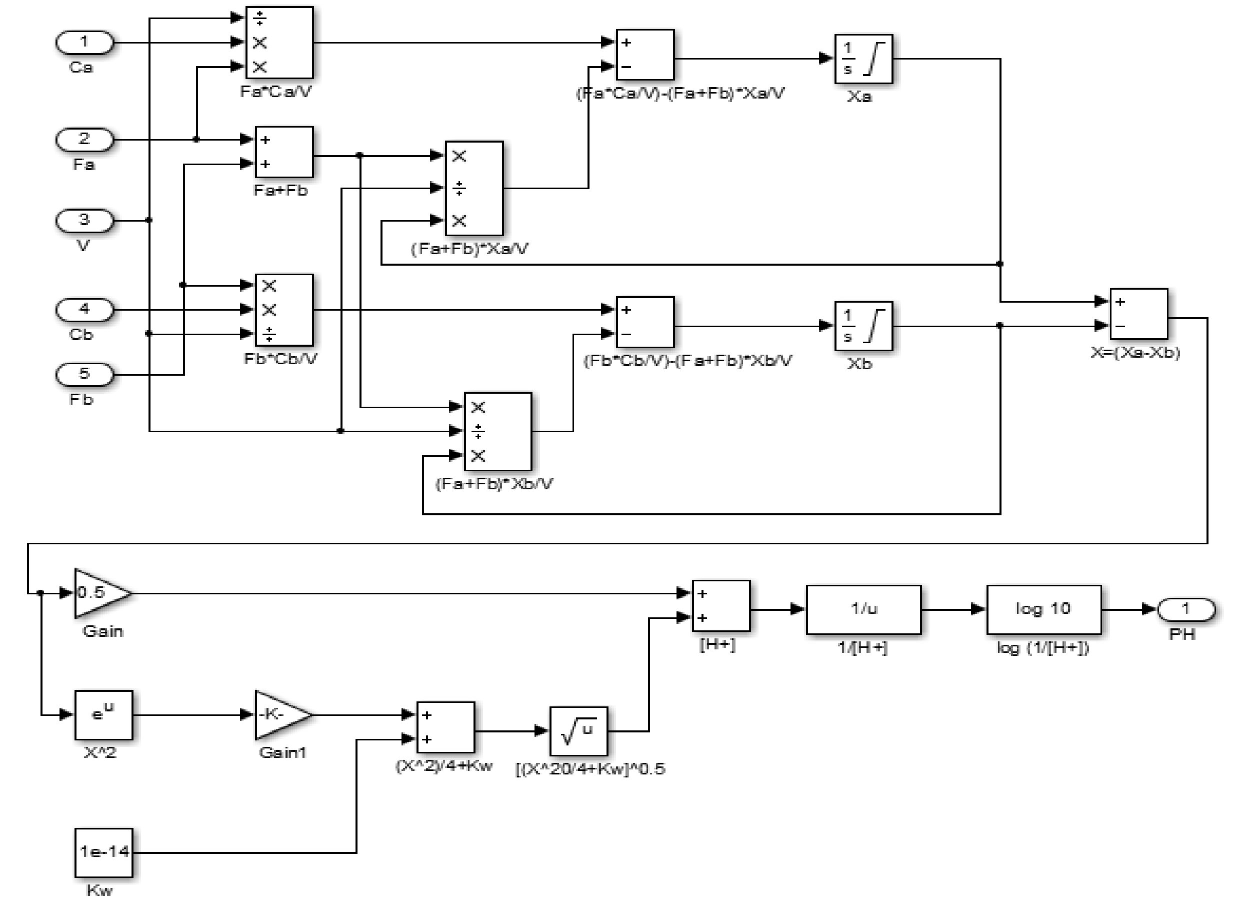


Figure 3.8 Dynamic model of pH neutralization process

CHAPTER FOUR

4. System Design

As described before system design is based on the right modeling of the plant and the chosen controller. So our first task is designing mathematical model for the plant as we done in the previous chapter. Now our second task is designing the controller in order to design the overall system.

4.1 Design of the Fuzzy Logic Controller

The proposed fuzzy logic based controller for pH neutralization process is based on Mamdani fuzzy inference system (FIS), most commonly used fuzzy methodology [10]. Fuzzy inference system consists of an input stage, a processing stage, and an output stage [11]. The input stage maps the inputs to the appropriate membership functions and degree of membership. The processing stage invokes appropriate rules and generates a result for each, then combines the results of the rules. Finally the output stage converts the combined results back into a crisp control output value.The first step in the developing the PH fuzzy logic controller is to select the variables that well be important in choosing an effective control action. The variables are known as the conditions or the antecedent variables. Two condition variables are readily identified as being important in the PH control system. The rules presented for the proposed system use the two following

1. $Error\ (E) = PH_{set} - PH$
2. $change\ in\ error(\Delta E) = \frac{dE}{dt}$

condition variables:

Where *PHset* is the desired fixed set point for the PH system, which is 7. ΔE is the rate of change of error. Once the condition variables have been chosen, the second step is to choose the action or the consequent variables. In our system identifying the output variables is straight forward task. There are two things the controller can adjust to alter the state of ph control system, either the input flow rate *Qi* (adjustment of the pump or the electronic valve) or the output flow rate *Qo* (adjustment of the electronic valve), which can be increasing or decreasing by adjusting the valve. The task of our controller is to adjust the input electronic valve according to desired set value. Next is to defined the linguistic terms used to described these linguistic variables i.e. fuzzy sets for each variables. These fuzzy sets are written to describe the conditions variables E and ΔE action variable input Qi. When more linguistic terms are used to describe conditions or antecedent variables more rules are needed by fuzzy logic controller.

4.1.1 The FIS Editor

We have defined two Inputs for the Fuzzy Controller. One is $Error\ (E)$ of the ph system in the tank and the other one is $change\ in\ error(\Delta E)$ of neutralization system in the Tank. Both these Inputs are applied to the Rule Editor [6]. According to the Rules written in the Rule Editor the controller takes the action and governs the opening of the Valve which is the Output of the controller and is denoted by “acidic valve” and “basic valve”. It may be shown as:

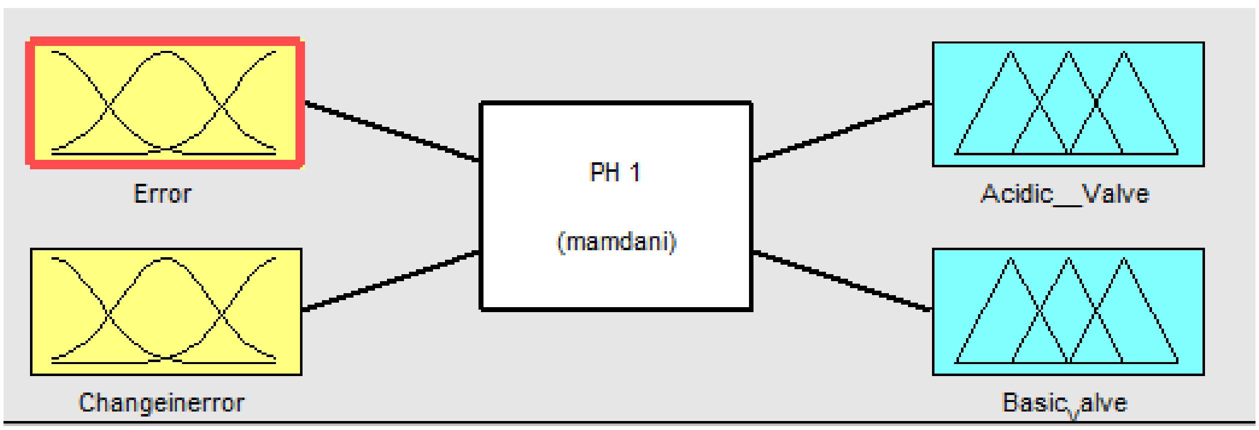


Figure 4.1 Mamdani type Fuzzy Controller

4.1.2 The Membership Function Editor

The Membership Function Editor shares some features with the FIS Editor. In fact, all of the five basic GUI tools have similar menu options, status lines, and **Help** and **Close** buttons. The Membership Function Editor is the tool that lets you display and edits all of the membership functions associated with all of the input and output variables for the entire fuzzy inference system.

[System]

Name='PH 1'

Type='mamdani'

Version=2.0

NumInputs=2

NumOutputs=2

NumRules=117

AndMethod='min'

OrMethod='max'

ImpMethod='min'

AggMethod='max'

DefuzzMethod='centroid'

4.1.2.1 Fuzzy Set characterizing the Input

A. Error (range= -7 to 7)

Fuzzy variable	MF used	crisp input range
MF1='ULB'	trimf	[-7 -6 -5]
MF2='ELB'	trimf	[-6 -5 -4]
MF3='VLB'	trimf	[-5 -4 -3]
MF4='LLB'	trimf	[-4 -3 -2]
MF5='MB'	trimf	[-3 -2 -1]
MF6='LB'	trimf	[-2 -1 0]
MF7='N'	trimf	[-1 0 1]
MF8='ELA'	trimf	[4 5 6]
MF9='VLA'	trimf	[3 4 5]
MF10='MA'	trimf	[1 2 3]
MF11='LAA'	trimf	[2 3 4]
MF12='LA'	trimf	[0 1 2]
MF13='ULA'	trimf	[5 6 7]

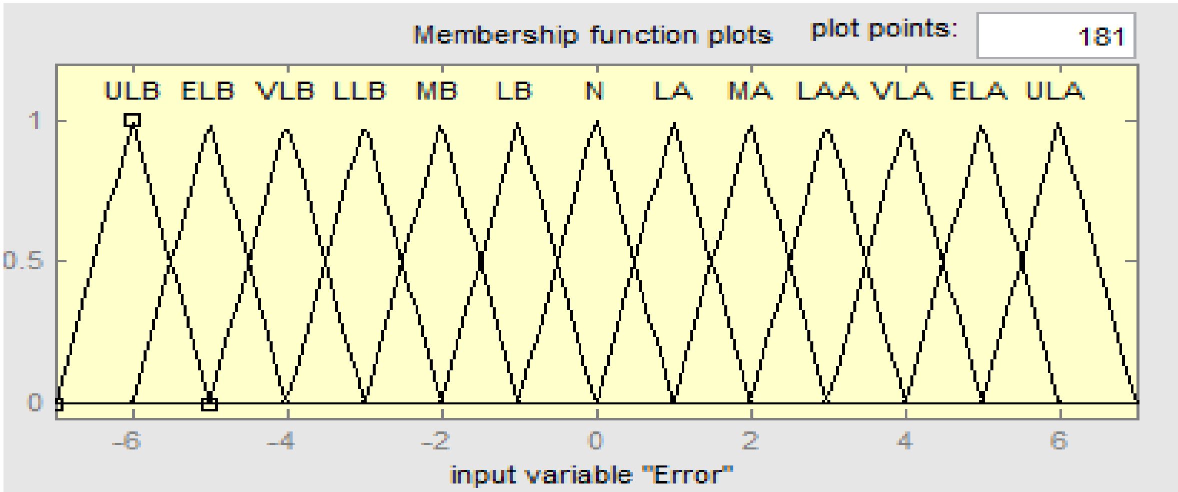


Figure 4.2 Membership function Fuzzy set characterizing Input 1

B. change in error (range= -0.5 to 0.5)

Fuzzy variable	MF used	crisp input range
MF1='VLB'	trimf	[-0.5 -0.4 -0.3]
MF2='LLB'	trimf	[-0.4 -0.3 -0.2]
MF3='MB'	trimf	[-0.3 -0.2 -0.1]
MF4='LB'	trimf	[-0.2 -0.1 0]
MF5='N'	trimf	[-0.1 0 0.1]
MF6='LA'	trimf	[0 0.1 0.2]
MF7='MA'	trimf	[0.1 0.2 0.3]
MF8='LAA'	trimf	[0.2 0.3 0.4]
MF9='VLA'	trimf	[0.3 0.4 0.5]

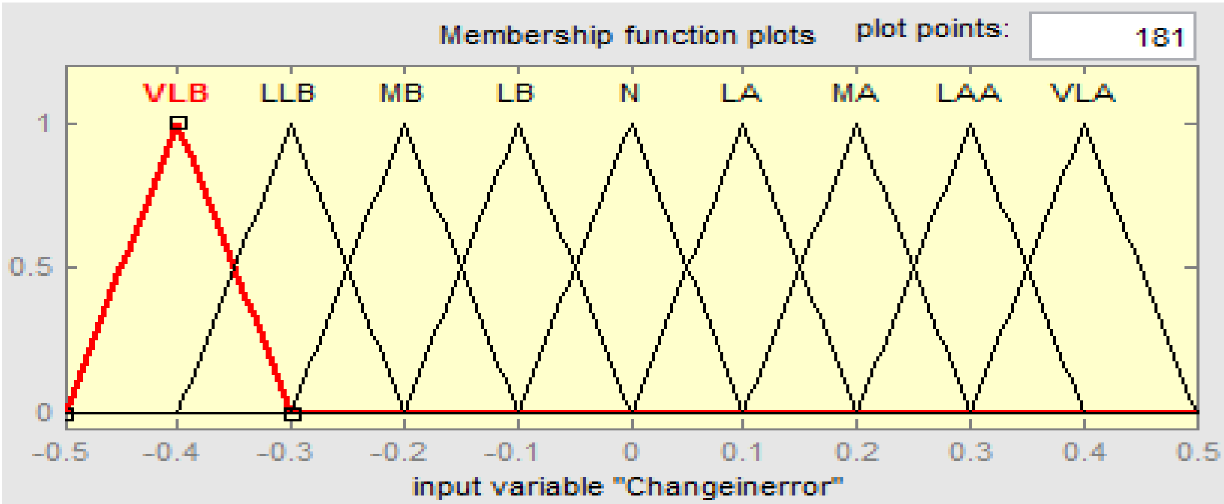


Figure 4.3 Membership function Fuzzy Set Characterizing input 2

4.1.2.2 Fuzzy Set Characterizing the Output:

A. Acidic valve (range= 0 to 5)

Fuzzy Variable	MF used	Crisp Input Range
MF1='fC'	trimf	[0 1 2]
MF2='Q.open'	trimf	[1 2 3]
MF3='M.open'	trimf	[2 3 4]
MF4='3Q.open'	trimf	[3 4 5]

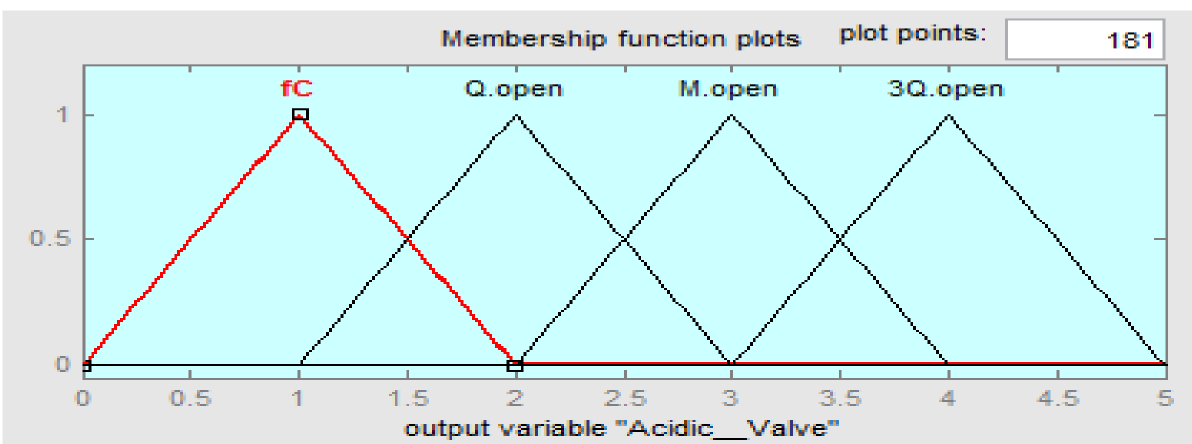


Figure 4.4 Triangular membership function output

B. Basic valve (range= 0 to 5)

Fuzzy Variable	MF used	Crisp Input range
MF1='fC'	trimf	[0 1 2]
MF2='Q.open'	trimf	[1 2 3]
MF3='M.open'	trimf	[2 3 4]
MF4='3Q.open'	trimf	[3 4 5]

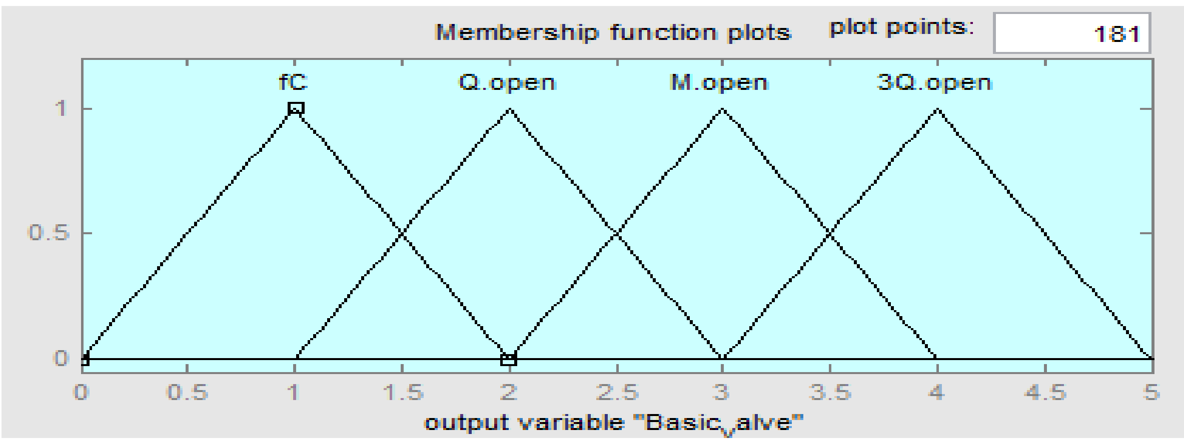


Figure 4.5 Triangular membership function output

4.1.3 The Rule Editor:

Constructing rules using the graphical Rule Editor interface is fairly self-evident. Based on the descriptions of the input and output variables defined with the FIS Editor, the Rule Editor allows you to construct the rule statements automatically,

Table 4.1 Rule base formulation

ΔE / E	VLB	LLB	MB	LB	N	LA	MA	LLA	VLA
ULB	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,M.o
ELB	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,Q.o
VLB	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,M.o	FC
LLB	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,M.o	A,M.o	FC	B,M.o
MB	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,M.o	A,Q.o	FC	B,M.o	B,3Q.o
LB	A,3Q.o	A,3Q.o	A,M.o	A,M.o	A,Q.o	FC	B,Q.o	B,M.o	B,3Q.o
N	A,3Q.o	A,3Q.o	A,M.o	A,Q.o	FC	B,Q.o	B,Q.o	B,M.o	B,3Q.o
LA	A,3Q.o	A,3Q.o	A,Q.o	FC	B,Q.o	B,M.o	B,M.o	B,3Q.o	B,3Q.o
MA	A,3Q.o	A,M.o	FC	B,Q.o	B,Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o
LLA	A,M.o	FC	B,M.o	B,M.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o
VLA	FC	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o
ELA	B,Q.o	B,M.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o
ULA	B,M.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o

4.1.4 Rule viewer

It is a figural diagram for each rule that is done on the rule base system. It shows all the input and output combinations and anyone can see the input and output relations in it.

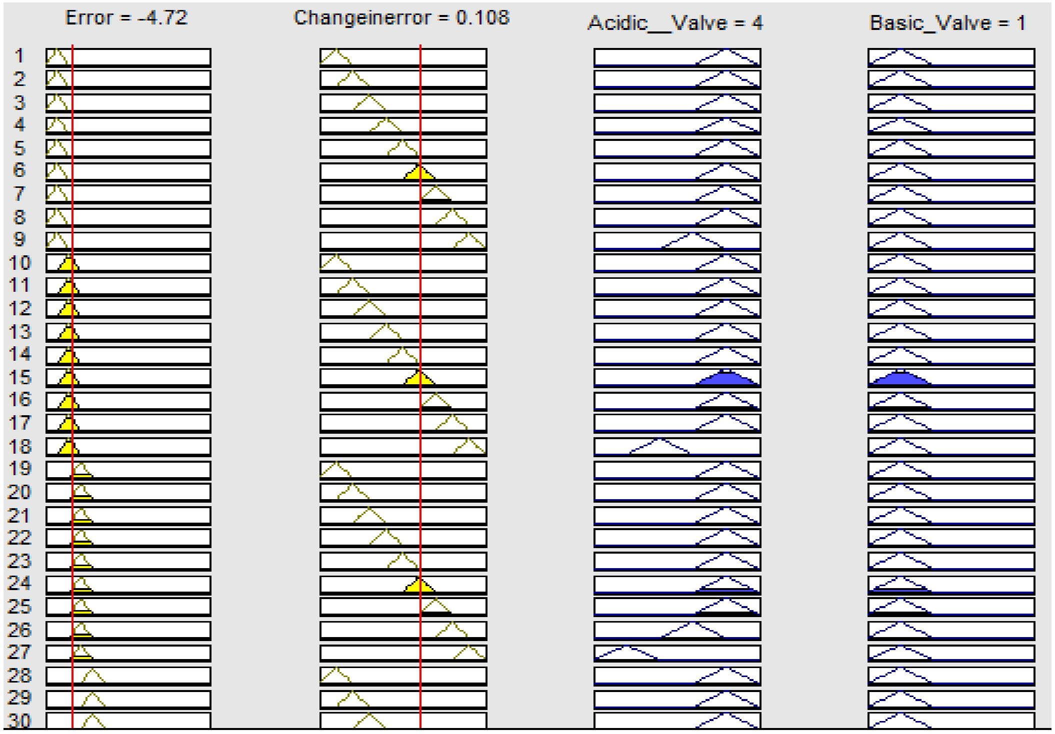
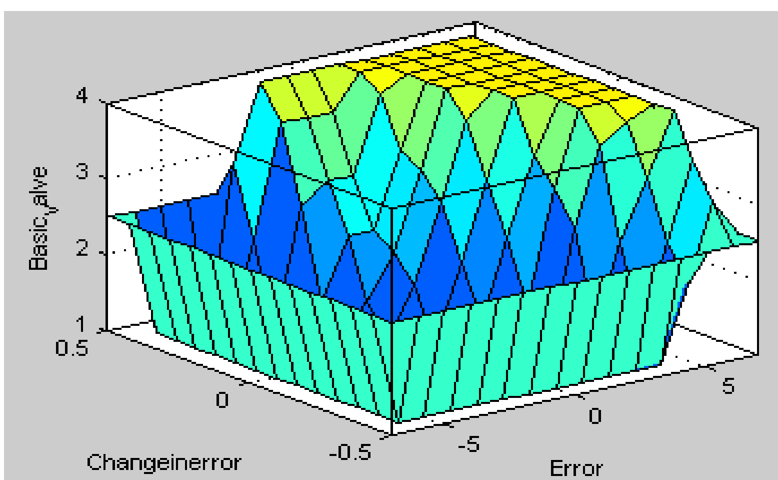


Figure 4.6 rule viewer

4.1.5 Surface viewer

The Surface Viewer, invoked using surfview('a'), is a GUI tool that lets you examine the output surface of a FIS stored in a file, a.fis, for any one or two inputs. Because it does not alter the fuzzy system or its associated FIS structure in any way, Surface Viewer is a read-only editor.

(a)



(b)

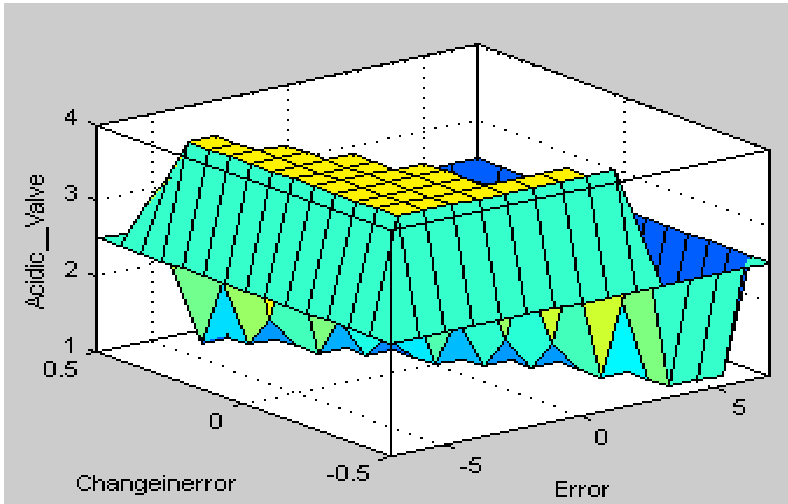


Figure 4.7 (a) shows surface viewer of basic valve and (b) shows surface viewer of acidic valve

4.2 Overall matlab Simulink design of the system

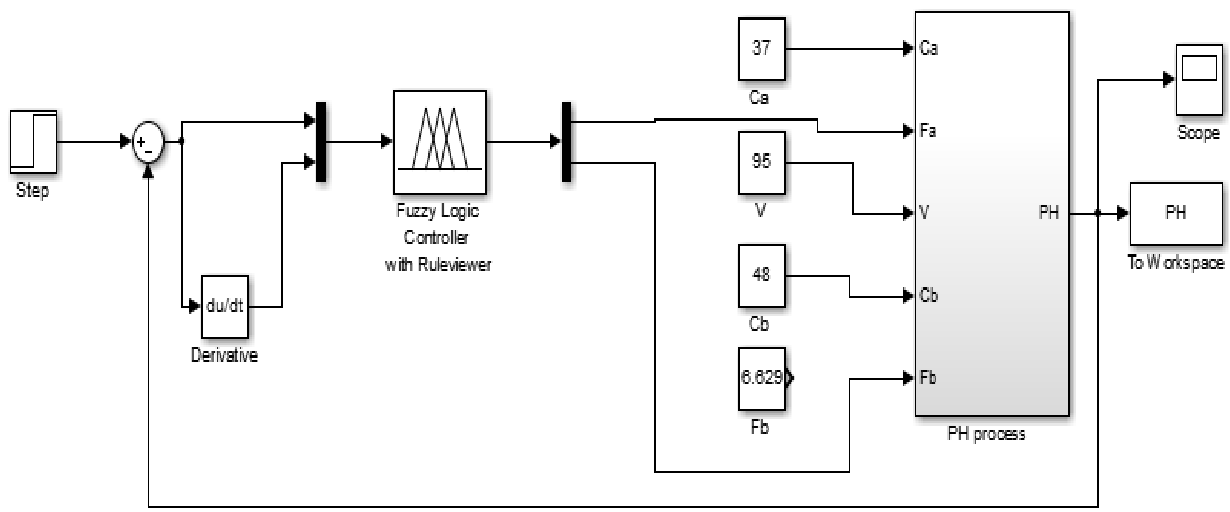


Figure 4.8 overall matlab Simulink design of the system

And there is a ph process Simulink design for the overall matlab Simulink as a sub system that operates mathematical operations due the input ports that are fed to the system.

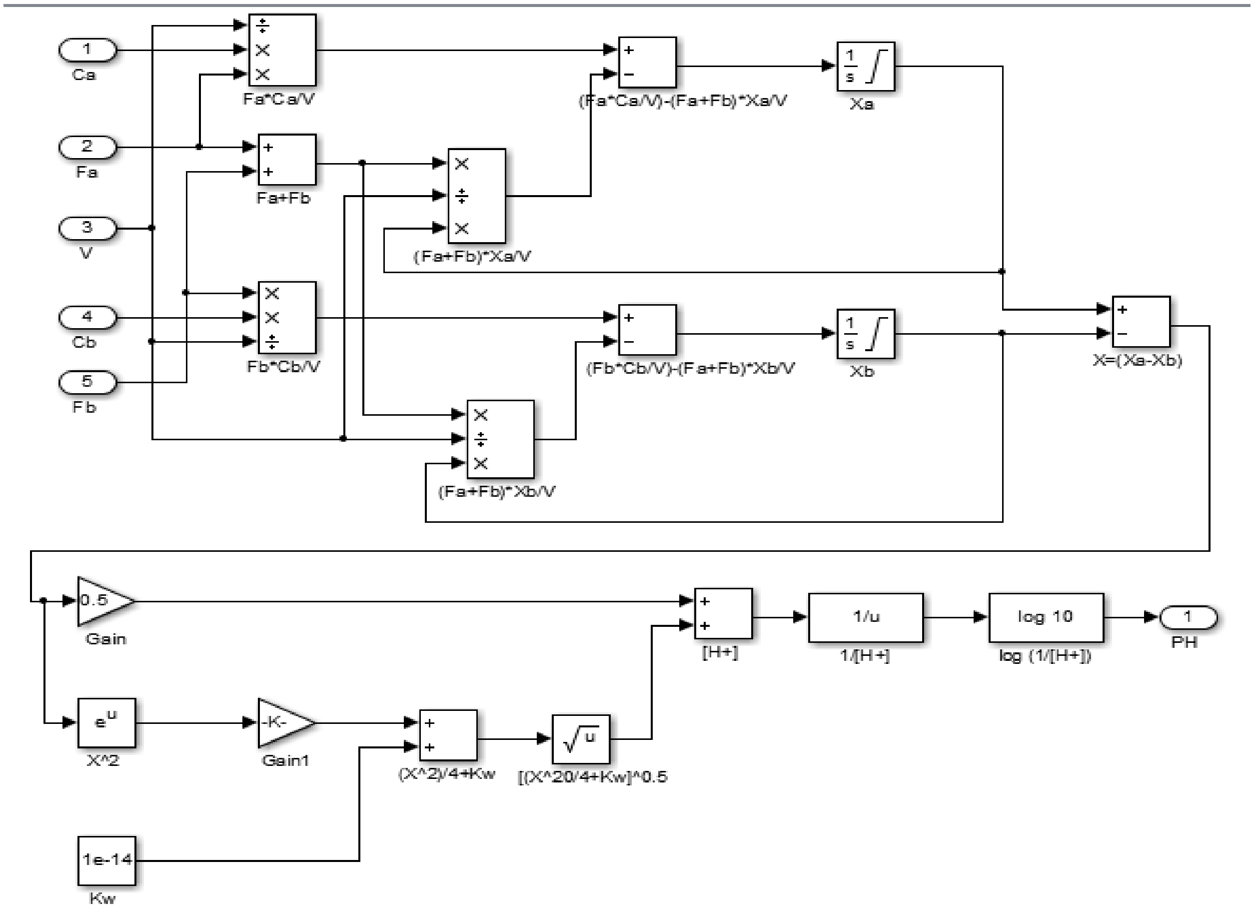


Figure 4.9 model of dynamic ph process

As shown in the above matlab Simulink we use a step input source to drive the system. Then the output reading of the PH value feed backed to the system and compared to that of the set point. Then the fuzzy logic controller makes decision based on the rule bases on it. Then it sends output command to the actuator in order to open or close the valves. Afterward the valves will adjust their degree of openness or closeness based on the transferred rule base. There is a memory function block used for saving previous data/output. The ph process performs its task based on the subsystem function on it. It have 5 inputs that are concentration of acid Ca, flow rate of acid Fa, volume of wastewater in tank V, concentration of base Cb and flow rate of base Fb. After the calculation of those parameters the logarithmic equation calculates the equivalent output and the PH meter detects it to recirculate the process.

UNIT FIVE

5. Result and Discussion

5.1 Simulation result

Response of PH level control to neutralization in wastewater treatment plant using Fuzzy Logic Controller.

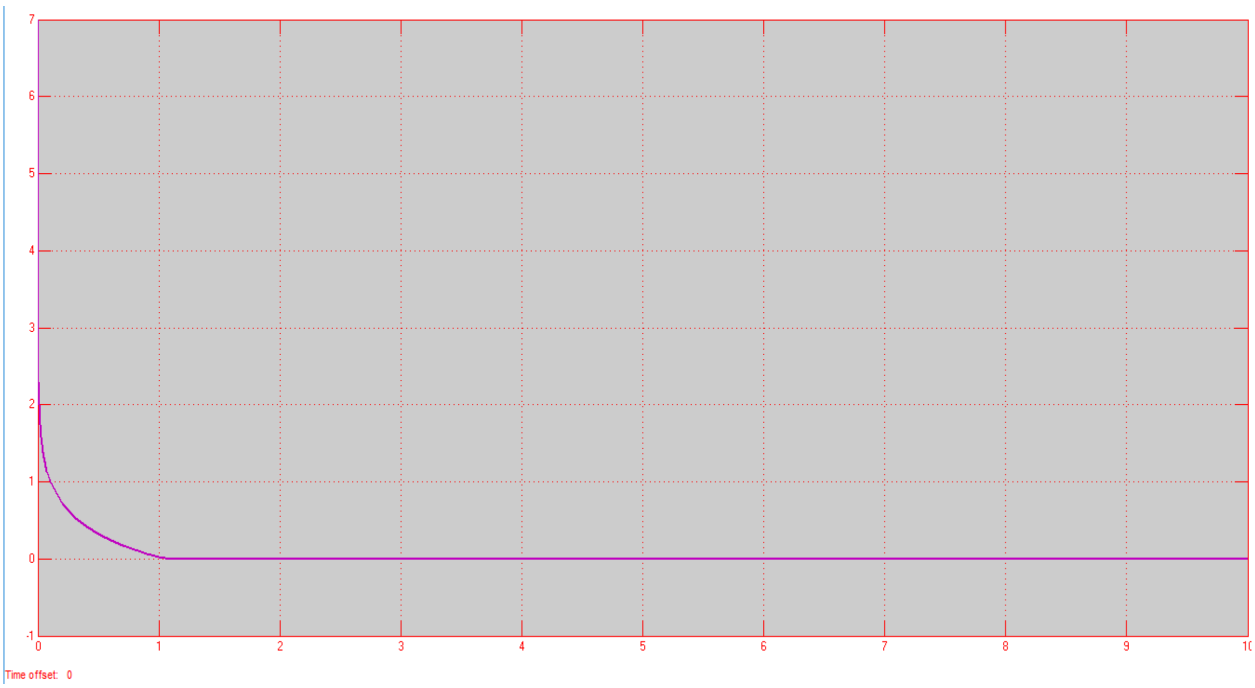


Figure 5.1 shows fuzzy logic controller response for acidic state.

This graph shows that the solution/wastewater in the tanker is acidic solution so the controller responds to open basic valve and add basic NaOH solution to neutralize the system.

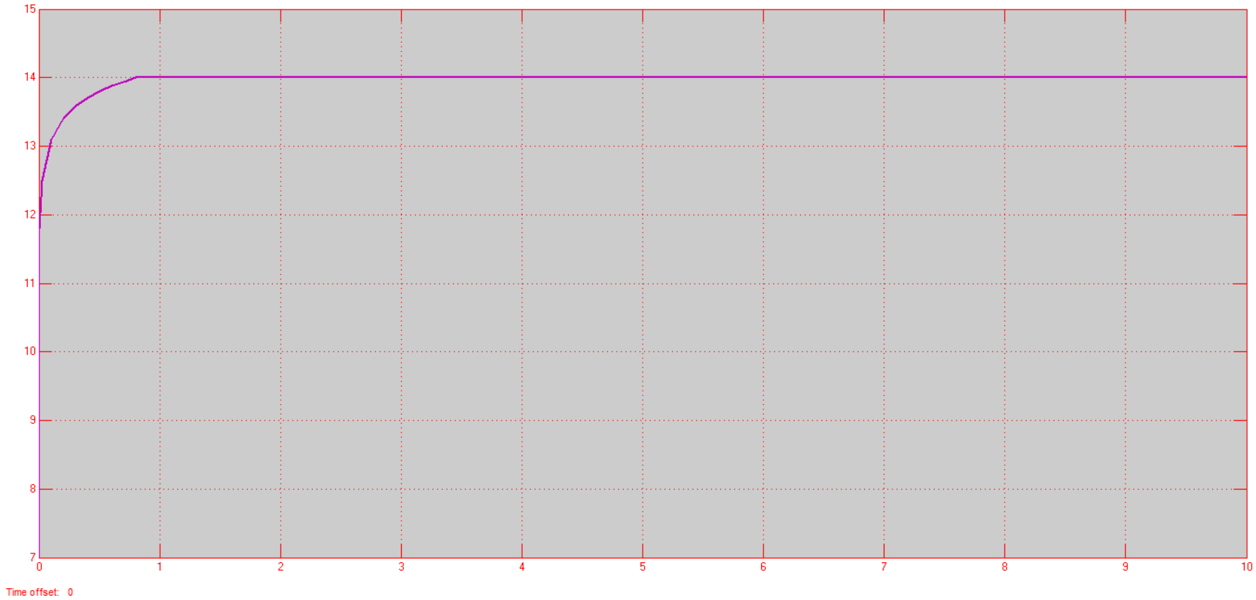


Figure 5.2 shows fuzzy logic controller response for basic state.

This graph shows that the solution/wastewater in the tanker is basic solution so the controller responds to open acidic valve and add acidic HCL solution to neutralize the system.

So finally when we operate to control both flow rates at the same time we get the following response. The graph shows the constant value which is the neutralized value 7, which cancels out the acidic and basic state and go on the normal condition.

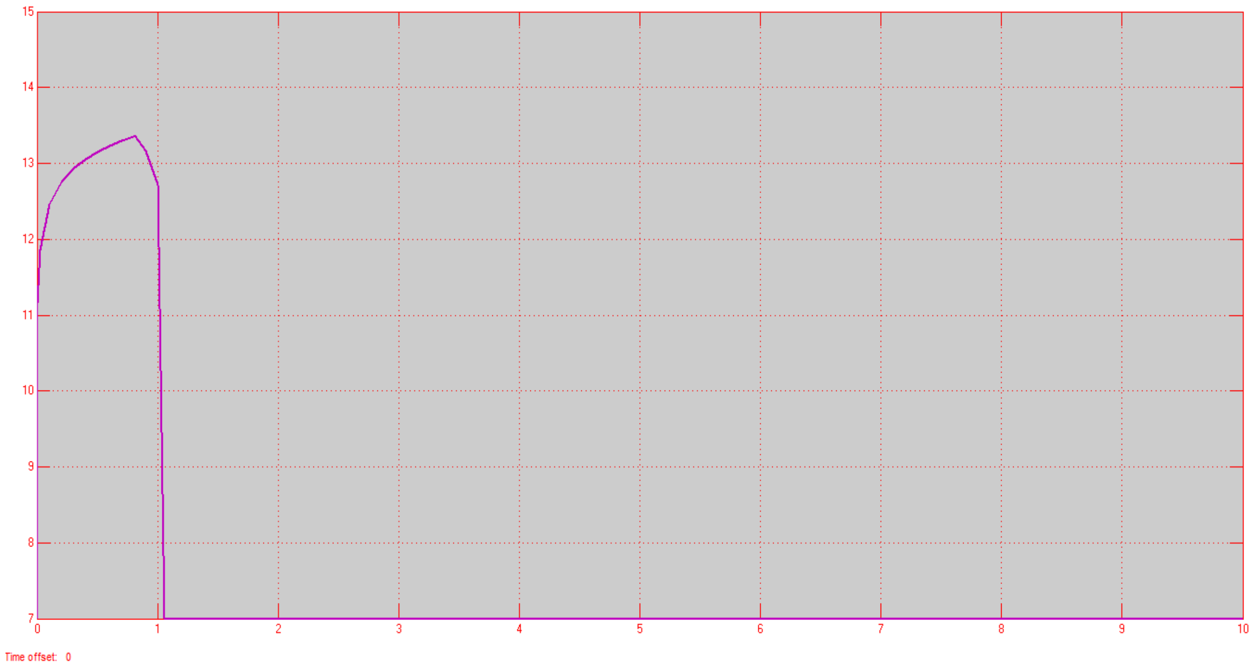


Figure 5.3 shows fuzzy logic controller response for both controlled states (neutralization)

As shown above when we control both the flow rates of acid and base the system rises to its critical value and then starts to settle to its neutralized value which is 7.

5.2. Discussion

As expected, FLC provide good performance in terms of oscillations and overshoot in the absence of a prediction mechanism. The FLC algorithm adapts quickly to longer time delays and provides a stable response than that of other controllers. As we have seen the results from the past researches based on PID controller there is high overshoot and steady state error. To strictly limit the overshoot, using Fuzzy Control can achieve great control effect. Comparing to other control systems fuzzy systems indicated that the fuzzy logic controller significantly reduced overshoot and steady state error. So we can conclude that fuzzy logic controller is an effective controller, especially for the non-linear dynamic systems its appropriate selection.

CHAPTER SIX

6. Conclusion and Recommendation

6.1 Conclusion

This paper reviews the use of fuzzy logic in pH Neutralization process. The pH neutralization process is considered as highly nonlinear and time varying process, hence cannot be controlled efficiently using conventional controllers. Fuzzy logic controller is capable of providing optimized solution for such processes. Unlike the other automated systems programmed using microcontrollers and PLC's, MATLAB serves the purpose of easy programming and has high flexibility. Fuzzy Logic provides a completely different, unorthodox way to approach a control problem. This method focuses on what the system should do rather than trying to understand how it works. One can concentrate on solving the problem rather trying to model the system mathematically, if that is even possible. This almost invariably leads to quicker, cheaper solutions.

As described in the first chapter of this thesis, there were two primary objectives of this research. The first was to develop a dynamic nonlinear pH neutralization process model, based on chemical principles that can represent the specific pH neutralization plant. The second goal for this research was to design and develop advanced controller, based possibly on a Fuzzy Logic Control approach, involving use of an appropriate controller structure. Generally, both the main objectives have been achieved. The developed model of the pH neutralization process is capable of providing dynamic responses.

6.2 Recommendation

As mentioned from the beginning of the thesis, this project involves an acid-base reaction process between hydrochloric acid and Sodium Hydroxide. Thus, an investigation on how different types of acid and alkaline would react and behave with this control approach has to be a further recommendation for future work. Another recommendation would be the certain outside changes can be fed to the controller so it can also maintain the pH accurately.

Further investigations of other methods based on the Tagaki-Sugeno approach would also be useful. It would be interesting to find out the differences in terms of control performance, stability, robustness possible with this approach, as well as the implementation issues that arise. More combination of MATLAB and embedded coding can be done to ensure that the system becomes fully automated and intelligent to the core. This work can be extended to design of neuro fuzzy logic controller which will be more effective.

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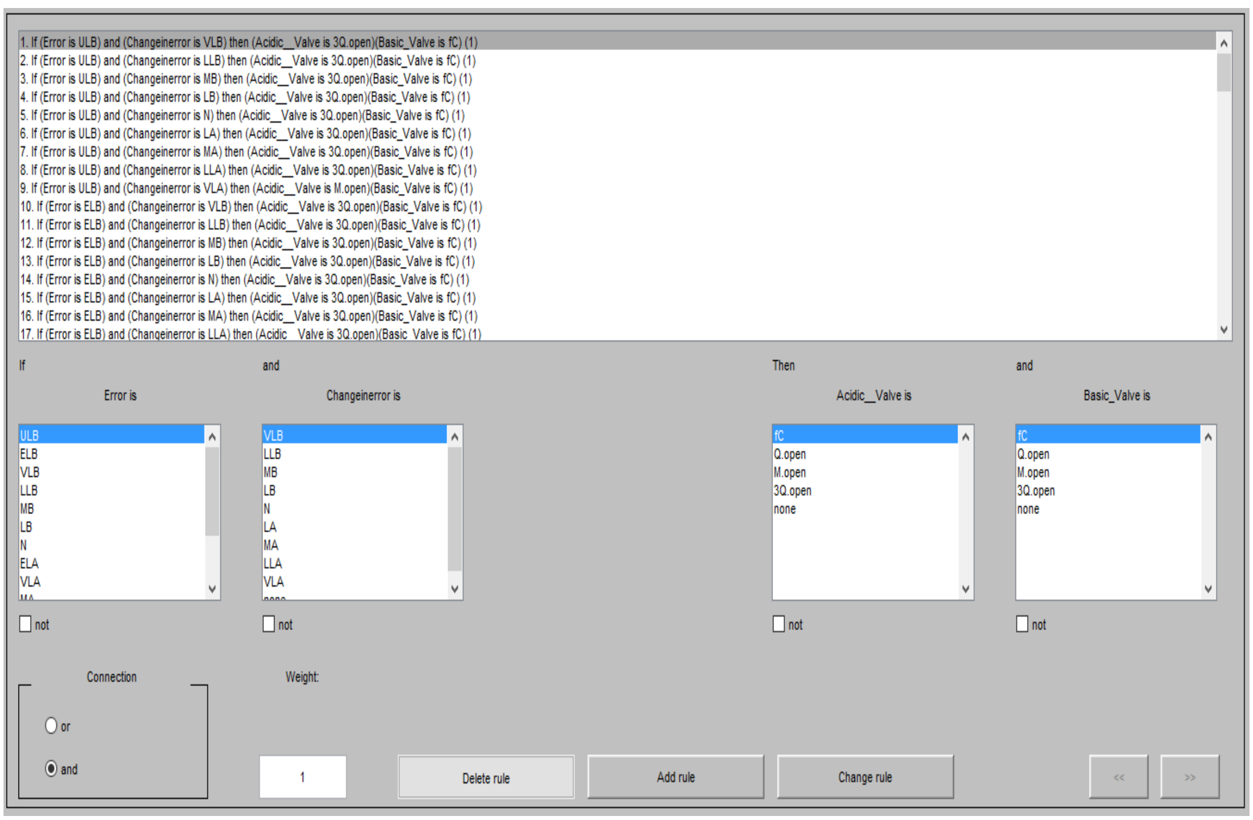
APPENDIX

Appendix I-Table of the Rule Base Formulation

ΔE / E	VLB	LLB	MB	LB	N	LA	MA	LLA	VLA
ULB	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,M.o
ELB	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,Q.o
VLB	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,M.o	FC
LLB	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,M.o	A,M.o	FC	B,M.o
MB	A,3Q.o	A,3Q.o	A,3Q.o	A,3Q.o	A,M.o	A,Q.o	FC	B,M.o	B,3Q.o
LB	A,3Q.o	A,3Q.o	A,M.o	A,M.o	A,Q.o	FC	B,Q.o	B,M.o	B,3Q.o
N	A,3Q.o	A,3Q.o	A,M.o	A,Q.o	FC	B,Q.o	B,Q.o	B,M.o	B,3Q.o
LA	A,3Q.o	A,3Q.o	A,Q.o	FC	B,Q.o	B,M.o	B,M.o	B,3Q.o	B,3Q.o
MA	A,3Q.o	A,M.o	FC	B,Q.o	B,Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o
LLA	A,M.o	FC	B,M.o	B,M.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o
VLA	FC	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o
ELA	B,Q.o	B,M.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o
ULA	B,M.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o	B,3Q.o



Appendix II- Overall Simulink Design and sub system