UNIVERSITI PUTRA MALAYSIA

CONTROL OF pH LEVEL USING FUZZY CONTROLLER

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Master of Science

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By

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The idea of constructing this project is 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. Environment has been ruined by lots of development especially at the industrial area. For that reason, it is important that the wastage is been taking care of as a preventative measure before things get worse. The control system of pH level in this project is done by using LabVIEW which is graphical programming environment software with the addition of fuzzy logic controller of MATLAB. Block diagram of the whole system is constructed in LabVIEW and the calculation of the amount of acid and alkali to be added to the process tank to maintain its pH level at neutral (pH = 7) is done by fuzzy logic controller. Control of pH in mix tank depends on the flow rate which could be manually control by several valves which enable either acid or base to be pumped in. The control development has been designed in LabVIEW block diagram and the Graphical User Interface (GUI) has been created in the LabVIEW front panel. The result of experiment could be easily controlled and several results could be compared to obtain the best neutralization system. Further use of this project could also help the process of drinking water system. Since human has been contaminated by a lot of sickness and it is founded that alkaline water is good for human, therefore this project also could be use to control the alkalinity of water instead of neutralization.

Abstrak tesis ini dibentangkan kepada Senat Universiti Putra Malaysia untuk memenuhi keperluan bagi pengajian Sarjana Sains

KAWALAN TAHAP pH MENGGUNAKAN PENGAWAL LOGIK FUZZI

Oleh

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Pengerusi : Samsul Bahari b. Mohd Noor, PhD

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Tujuan thesis ini adalah untuk merekabentuk satu sistem kawalan tahap pH dengan menambah asid atau alkali untuk mengekalkan tahap keneutralan dalam tangki sistem sisa cecair dari kilang. Alam sekitar telah dimusnahkan oleh pelbagai pembangunan terutama di kawasan perindustrian. Oleh itu, adalah langkah berjaga-jaga perlu diambil untuk memelihara alam sekitar. Program menggunakan LabVIEW digandingkan dengan kawalan logik fuzzy MATLAB telah digunakan untuk sistem kawalan tahap pH dalam tesis ini. Gambarajah blok keseluruhan sistem ini telah direka dengan menggunakan LabVIEW dan pengiraan isipadu asid dan alkali yang diperlukan untuk mengekalkan tahap keneutralan (pH=7) pula direka menggunakan sistem kawalan logik fuzzy.

Kawalan pH dalam tangki campuran perlu mengambil kira faktor nisbah aliran cecair di mana ia boleh dikawal secara manual oleh beberapa injap. Rekabentuk sistem kawalan ini dibuat dengan menggunakan gambarajah blok dan sistem antaramuka pengguna grafik telah direka pada panel hadapan LabVIEW. Hasil eksperimen dapat dikawal dan dibandingkan untuk mencapai sistem peneutralan yang terbaik dan berkesan. Projek ini juga boleh membantu pemprosesan air minuman dengan mengawal kealkalian.

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A very great gratitude to my supervisor, Dr. Samsul Bahari Mohd Noor and Dr. Hamiruce Marhaban for all the effort and guidance in helping me to complete my Masters of Science project. Other than that, I would like to express my thanks to my parents, boyfriend and friends who always support me mentally and physically. There are a lot of commitments that I am responsible of especially in my current work as a lecturer in Tar College. Doing masters as part time studies is not easy if we cannot manage the time between studies and work. I truly thank UPM for providing all the necessary facilities when ever I need it. May all this hard work be as a stepping stone for a brighter future.

This thesis submitted to the Senate of University Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Masters. The members of the Supervisory Committee are as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

ILANUR MUHAINI BT MOHD NOOR

Date : 3rd July 2009

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CHAPTER 1

1.1 Introduction

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. A control of pH process is highly nonlinear. The pH value versus the reagent flow has a logarithmic relationship. Away from neutrality, the process gain is relatively small. Near neutrality where pH=7, the process gain can be a few thousand times higher.

1.2 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 (H_2O). In other words, it can be said that neutralization is the combination of hydrogen ions H^+ and hydroxide ions OH^- (or oxide ions O^{2-}) to form water molecule H_2O. In the process, a salt is formed[9].

The neutralization systems to be controlled are illustrated in Figure 1.2. Figure 1.2 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.

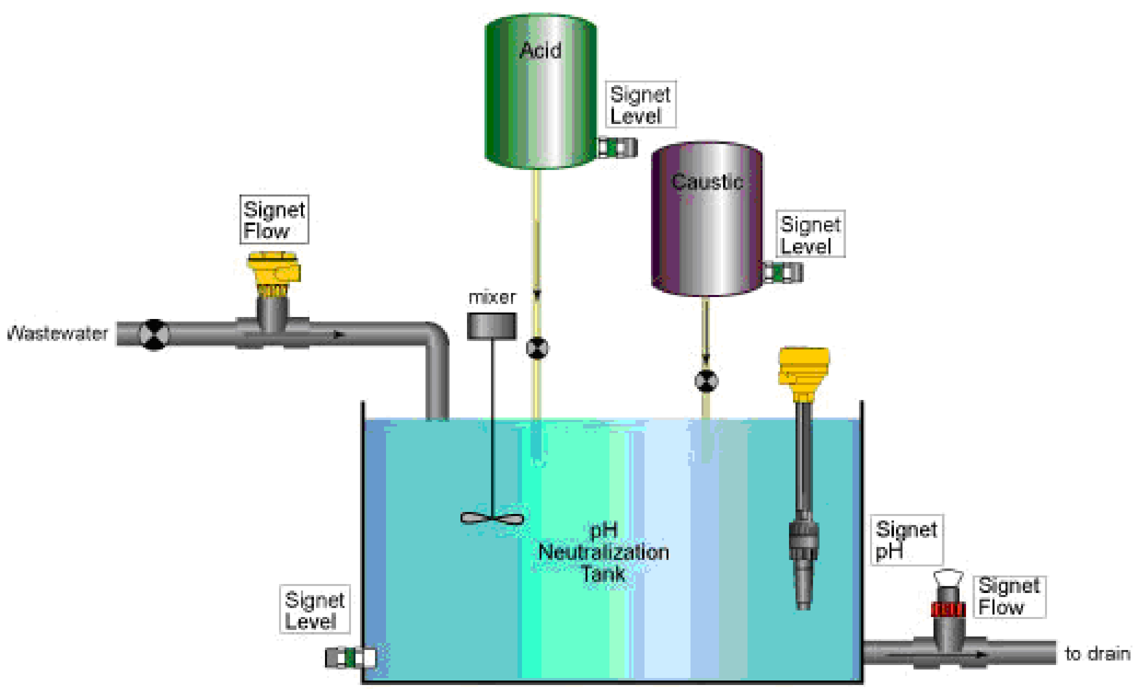

Figure 1.2: The PH neutralization plant showing mainly the mix tank with acid and caustic (base) tank supplied to it

1.3 Problem Statement

As the process to be controlled is highly nonlinear, the usual PI-type fuzzy controller is not able to control these systems adequately. To solve this problem, 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.

One of the most critical problems in practical engineering design and implementation applications is the total cost and time constraint. Industrial control projects also are restricted by financial limitations especially in hardware. However economizing the project usually causes the quality is being degraded. Software control methods like fuzzy controllers are more efficient because it could be controlled without effecting hardware in the plant. Not only that, the whole system could be altered without difficulty in case of any addition or deduction of inputs and outputs in the process plant. Unlike mathematical models simulation, fuzzy controllers only need few rules and suitable membership function which saves hassle time if one is not dedicated in developing the mathematical model. This projects also being designed using LabVIEW programming which is a graphical programming. Only a small number of calculations on flow rate of the acid and base need to be added with C programming in the block diagram module of LabVIEW.

In compare with the conventional controllers, fuzzy controllers have a high ability to control nonlinear, time–invariant, time-delayed and complex processes. But unlike the conventional controllers, the procedures of fuzzy control algorithm involve the powerful software and big volume of memory to implement.

Fuzzification, fuzzy inference and defuzzification call for strong software programming as shown in Figure 1.3. The heart of fuzzy controller is rule base that expresses the control laws in a human expert natural language basis. The number of rules is determined based on the number of fuzzy subsets (membership functions) for each fuzzy input/output variable. When the number of fuzzy subsets and consequently the number of fuzzy rules is bigger the approximation of control surface is more accurate, smooth and robust. On the other hand fuzzy rules should be stored in a memory space and big number of rules needs large memory space and long program cycle time. The design, tuning and implementation of fuzzy controllers are complex and time consuming, too. Therefore new simple algorithms are necessary to simplify the design procedure of fuzzy logic controller.

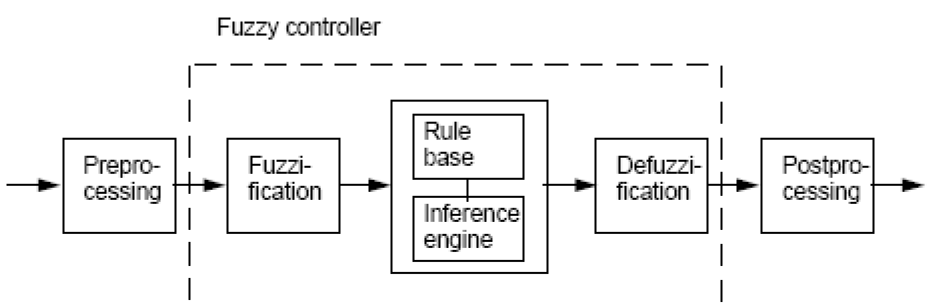

Figure 1.3: Block Diagram of a Fuzzy Controller

1.4 Objectives and Project Interests

- To design and implement fuzzy controller to obtain a neutral pH for the wastewater treatment plant using LabVIEW software.

- To simulate the pH level of mix tank with randomly sensed pH values and analyzes non-linear system.

1.5 Outline of the Thesis and Contributions

The thesis consists of five chapters. The first chapter is Introduction and includes overview background, problem statement, and outline of the project. The main idea of the project is to control the flow rate of acid liquid and alkali liquid into the mix tank to maintain the mix tank at neutral pH which is 7. The manner in which the flow rate is quantified depends on whether the quantity flowing is a solid, liquid or gas. For solid, it is appropriate to measure the rate of mass flow, whereas in the case of liquid and gases, flow is usually measured in terms of the volume flow rate. Chapter two explains about the Fuzzy Logic Controllers in MATLAB software. Mamdani-type fuzzy controllers is chosen for this project since it is more suitable with the non-linear system compared to Sugeno-type. Fuzzy Logic is a model for an alternative design methodology which can be applied in developing both linear and non-linear systems for embedded control. By using fuzzy logic, designers can realize lower development costs, superior features, and better end product performance. Chapter three includes the method of using LabVIEW software which is virtual programming software that compromise of Front Panel and Block Diagram of the system. LabVIEW programs are called virtual instruments, or VIs, because their appearance and operation imitate physical instruments, such as oscilloscopes and multimeters. LabVIEW contains a comprehensive set of tools for acquiring, analyzing, and storing data, as well as tools to help troubleshoot the codes. Chapter four will discuss about the results of simulation, plotted graph and rule views.

Finally, the thesis is concluded in Chapter five. The capabilities and limitations of the proposed methods are presented. Furthermore, some perspectives for future work are suggested.

The whole process in designing the whole project is illustrated in the flow chart of Figure 1.4. After sensed the wastewater pH value in the mix tank, the system will calculate the concentration (M) based on the pH value. If the pH value is 7, then no acid or base will be pumped into the mix tank but if it is less or more than 7, then it will calculate again the concentration value so that a specific amount of acid or base will be added.

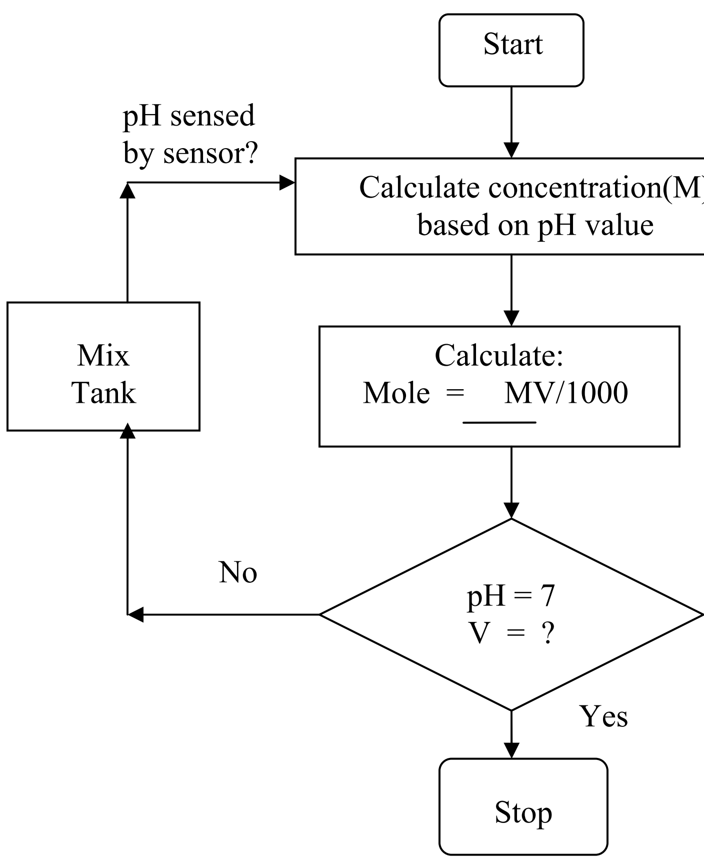

Figure 1.4 : Flow chart of designing the whole project

1.6 The Scope of Work

The scope of the thesis is to design and simulate a pH controller for a wastewater tank using MATLAB Fuzzy Toolbox and LabVIEW Control Development. LabVIEW is a kind of programming language, which allows us to connect to the external world through a data acquisition (DAQ) card, and make changes to this external environment.

LabVIEW uses function blocks instead of written code to do this. The DAQ card connects from the computer to the external world we wish to control. LabVIEW provides the graphical user interface (GUI) in the front panel and graphical programming base in the block diagram section. These features include a menu which could call the Fuzzy logic controller (MATLAB) as the controller of the whole system and provide the ease in integration; LabVIEW has the ability to execute MATLAB m-files.

The proposed methods are applicable to nonlinear processes, time invariant and time-delayed processes.

CHAPTER 2 : LITERATURE REVIEW

2.1 Related research works review

A number of approaches have been proposed in the literature in recent years to solve pH control problems. In both nonlinear and linear control techniques, researches have been proposed and proved on neutralization processes. *Ranganath Muthu and Elamin El Kanzi, 2003* [86] designed the combination of proportional plus integral controller (PI) controller and fuzzy logic controller (FLC) for a simulation highly non-linear of pH neutralization process. The paper compares the performance between PI and FLC. The author also compares the regulatory response of the influent flow and servo response during the neutralization process. It is shown in this paper that the FLC shows better regulatory as well as servo response than the PI controller. The linear techniques paper are based on using multiple linear models evaluated at several working points, for example, the multimodel control approach proposed by *Nyström et al. (1998)* [87]. Using this technique, the controller is designed based on linear quadratic (LQ) technique and then the procedure is combined with two gain scheduling methods, which enables work to be done over a wide range of operating points. A scheduling-gain multimodel LQ controller can be proposed by designing an optimal linear controller for multimodel plant representation (in which models have their stationary gains scaled to the same value). A similar technique has been proposed by *Galan et al. (2000)* [88] , using robust control based on a multi-linear model. The proposed methods try to identify the regions and then to decompose the complex system domain, to calculate an optimal controller. It must be pointed out that a multi-model scheme can be classified as robust only in the sense of accommodating a wider range of plant operation. However, it does not require detuning in closed loop performance, as required by regular model based schemes.

Another example is in *Toivonen et al. (2003)* [89], where velocity-based linearized models are proposed to modify the internal model control applied to designing scheduled controllers. The authors applied the proposed method to a strongly nonlinear pH neutralization process, describing the relation between variable changes, without the necessity of a well-defined stationary gain. By modifying the IMC structure, this method can eliminate the steady state offsets.

Although linear controllers are simple to implement, nonlinear controllers give better performance, due to the inherent nonlinear behavior of the pH process. Nonlinear controllers have been proposed by *Narayanan et al. (1998)* [90], using three process variables (difference in hydrogen and hydroxyl ion concentrations, hydrogen ion concentration, and pH process) and an internal model control strategy with a nonlinear adaptive model. Nonlinear controllers have also been studied by *Yoon et al. (2002)* [91], proposing back stepping techniques to handle a wide class of uncertain systems and avoid unwanted cancellations of favourable nonlinearities.

There are also researchers interested in studying pH control using predictive control techniques. For example, *Gomm et al. (1996)* [92], proposed the use of a neural predictive strategy to study the in-line pH process. They used a nonlinear autoregressive exogenous (NARX) model structure for the proposed approach, which was used on-line to predict future process responses. *Norquay et al. (1998)* [93], have also studied the use of both static nonlinear elements and linear dynamic elements of the SISO Wiener Model. The authors studied several methods to calculate the predictions: polynomial methods, autoregressive models with exogenous inputs (ARX) and step-response models to represent the linear dynamic element.

Although all these techniques have been proved successfully on real plants, the main difficulty is still the necessity of developing a model that adequately represents the pH process in any operating condition. To solve this problem, this paper discusses a technique based on fuzzy control to design pH controllers without the necessity of any plant model.

Babuska et al. (2002) [94], have proposed a fuzzy self-tuning PI controller for a pH control in a fermentation system, where the essential idea is to tune the controller PI gains on-line by means of a parameter that results from a fuzzy inference mechanism.

Most fuzzy controllers use control error (e) and change in the control error (Δe) as controller inputs. As it is a fuzzy controller, it does not need a mathematical model of the system to control the pH levels.

2.2 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.

2.2.1 Definition

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.

2.2.2 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:

$$E = E_o + (2.3RT)/nF \log \{unknown [H+]/internal [H+]\}$$ ………(Equation1)

where:

E = total potential difference (measured in mV);

E_o = reference potential;

R = gas constant;

T =temperature in Kelvin;

n = number of electrons;

F = Faraday's constant;

[H+] = hydrogen ion concentration.

2.2.4 pH Temperature Compensation

The pH of any solution is a function of its temperature. Voltage output from the electrode changes linearly in relationship to changes in pH, and the temperature of the solution determines the slope of the graph. One pH unit corresponds to 59.16 mV at 25 °C, the standard voltage and temperature to which all calibrations are referenced. The electrode voltage decreases to 54.20 mV/pH unit at 0.0 °C and increases to 74.04 mV/pH unit at 100.0 °C.

Since pH values are temperature dependent, pH applications require some form of temperature compensation to ensure standardized pH values. Meters and controllers with automatic temperature compensation (ATC) receive a continuous signal from a temperature element and automatically correct the pH value based on the temperature of the solution. Manual temperature compensation requires the user to enter the temperature of the solution in order to correct pH readings for temperature. ATC is considered to be more practical for most pH applications.

2.2.5 pH System

A successful pH reading is dependent upon all components of the system being operational. Problems with any one of the three which are electrode, meter or buffer will yield poor readings.