# STUDY OF FUZZY LOGIC CONTROLLER AND ITS APPLICATION TO PH NEUTRALIZATION PLANT

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Abstract - ***The need to regulate the pH value within a specific level and limit arises from environmental legislative and quality standards. The pH control poses some interesting challenges in the area of process control. The inherent nonlinearity of the pH process often renders conventional control difficult. This paper demonstrated that fuzzy controller, whose ability to handle non-linearity is well known, suggests better approach to control the pH. In this paper pH neutralization model is developed in MATLAB/Simulink. First, a conventional PI controller is designed and its performance is tested for various set points on neutralization curve. Its limitation in controlling nonlinear process like pH is highlighted. Further, a fuzzy logic controller is designed and its ability to control nonlinear process is presented using simulation results. The results clearly indicate superiority of fuzzy controller over conventional PI controller in dealing with nonlinear systems.***

***Key Words:*** *Nonlinear control; pH neutralization; Fuzzy Logic Control.*

## 1. INTRODUCTION

Studies on pH neutralization control in process engineering have increased in last few decades. pH control systems were developed and used successfully on various applications of pH neutralization process plants in many industries such as chemical processes, biotechnological industries, waste water treatment plants, sugar industries, food and beverages and pharmaceuticals. The main problem in pH process control is highly non-linear dynamic characteristics of the process. In order to achieve better performance of pH neutralization process control, non-linear response of the system must be taken into consideration.

The excessive nonlinearity of the pH process makes control by conventional linear PI controller difficult. The fuzzy controller uses three different membership functions for three linear regions of a standard pH-base titration curve. These three functions provide three different control gains and thus the fuzzy controller works as a varying gain controller compensating against the nonlinear behavior of the pH titration process. For simulation purpose, we have used MATLAB-Simulink based empirical model of the pH titration curve. This simulation assumes that the acid flow is constant and base flow is manipulated in order to control the pH. While showing the benefits of fuzzy approach for pH control, this thesis also highlights limitations of the conventional PID control.

## 2. OVERVIEW OF pH PROCESS

pH pilot plant consists of a reactor tank. The acid stream (HCL) and the base stream (NaOH) are introduced into the reactor tank. The pH transmitter sends pH value to the pH controller. The pH controller then based on the set point, manipulates the base flow using a linear control valve. The acid flow is maintained constant and not manipulated. The out flow is kept constant during the process.

The set up for the process is as shown below in the figure.

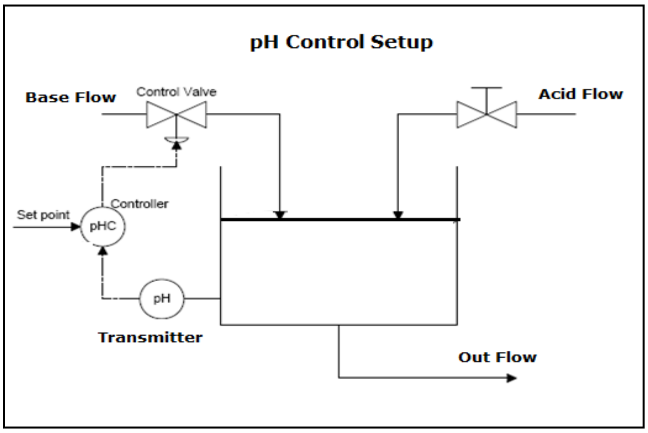


**Fig. 1.**Overview of pH Neutralization Plant

The steady state values of the acid and base flow are assumed to be 15 volumetric units. The outlet flow is maintained at a constant value of 5 units of flow in order to keep storage volume of this tank at 100 volumetric units.

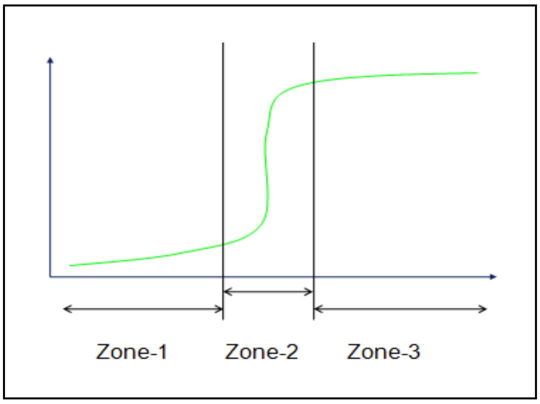


**Fig. 2.** Titration Curve for pH

### 3.MATHAMATICAL MODEL FOR MATHAMATICAL pH NEUTRALIZATION PROCESS

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 in CSTR

Qb = Flow of base in CSTR

V = Volume of fluid inside CSTR

$$v\frac{d}{dt}[Cl^-] = [Cl^-_{in}] * [Q_a] - [Cl^-] * [Q_{out}]$$

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

$$[Na^+] + [H^+] = [Cl^-] + [OH^-] \quad (5)$$

$$[H^+][OH^-] = K_\omega = 10^{-14}$$

Relationship expressed in difference of ionic concentration X:

$$X = [OH-] - [H+]$$

$$X = [Na+] - [Cl-]$$

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

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

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

### 4. CONTROL STATEGIES FOR NEUTRALIZATION PLANT

The pH neutralization process was simulated and controlled using two approaches as discussed below using MATLAB Simulink.

### 4.1) pH Neutralization using PI controller MATLAB

Simulation representation of the PI controller for the pH neutralization pilot plant is as shown below. pH is affected by the variation in base flow, where acid flow is kept constant. According to disturbance of flow of base, pH should give the output as set point.

A PI controller was designed and implemented for the pH neutralization model. The acid solution is neutralized by the base flow entering the reactor tank manipulated by a linear flow control valve. This control valve is manipulated by a PI controller, which receives the pH set point and pH measured value. This controller has reverse action and it is implemented through individual blocks of the Simulink. To avoid saturation of the integral action, saturation block is added at the output side. The Simulink model of the closed loop system is as shown in fig below.

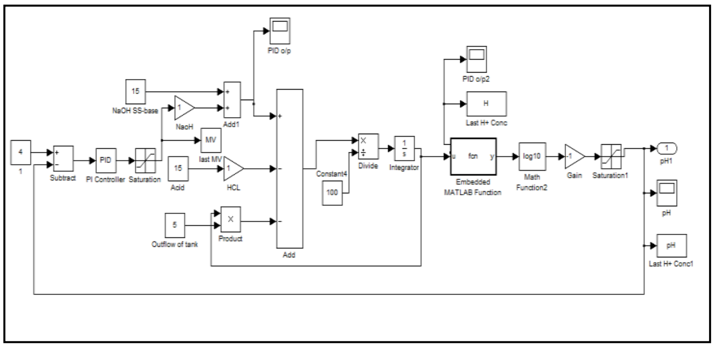

**Fig. 3.** MATLAB-Simulation representation for the overall pH control using PI controller, with pH=4.

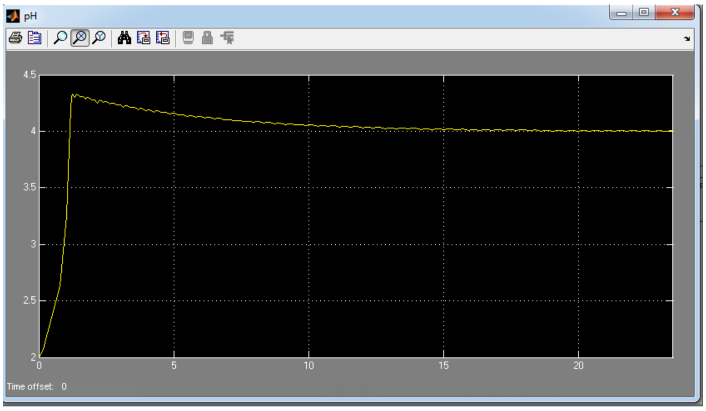


**Fig. 4.**Simulation graph for pH=4, when PI setting are kp=0.8 and ki=0.01

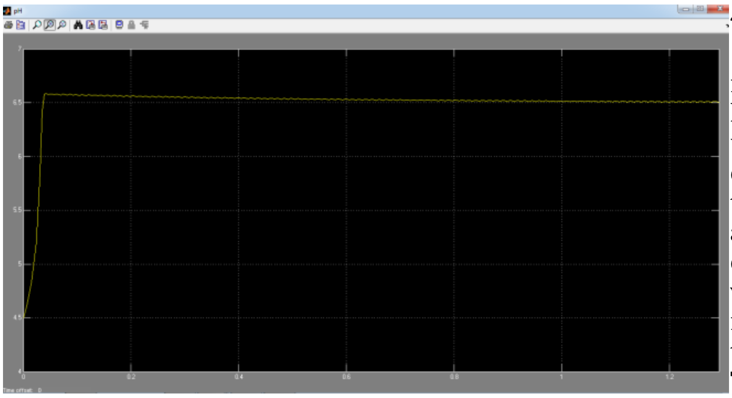

**Fig. 5.**Simulation graph for pH=4, when PI setting are kp=0.06 and ki=0.1

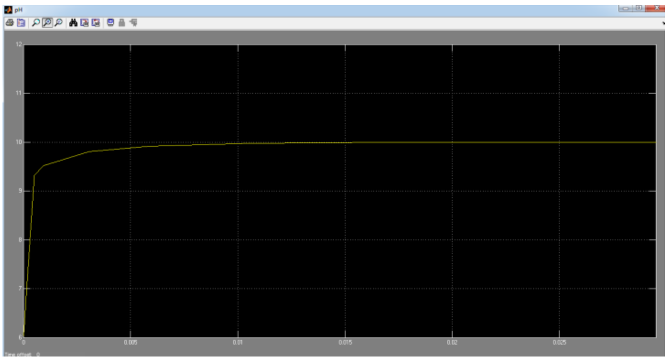

**Fig. 6.**Simulation graph for pH=10, when PI setting are kp=5 and ki=0.1.

| pH | 10 | 6.5 | 4 |
|---|---|---|---|
| With kp1=5, ki1=0.1 | 8.74 | 128977 | 13 |
| With kp2=0.06,ki2=0.1 | 31.1 | 13 | 205 |
| With kp3=0.8,ki3=0.01 | 15.98 | 17687.2 | 14.6 |

**Table 1.**IEA Result for various values of pH using PI controller

## Disadvantages of PI controller in pH control

1) For a nonlinear process like pH, controller gain needs to follow the changes in process gain
2) Linear structure of PI controller is intended to work with linear processes only.
3) PI settings need to be changed as per the change in process gain.
4) pH neutralization process gain varies with strength of Acid/Base and needs to be captured in a model which is not considered in conventional PI controller.

Thus controlling pH requires a model based nonlinear controller.

Above disadvantages are needs to be taken into the consideration while designing new controller

## 4.2) pH Neutralization using Fuzzy Controller

A Fuzzy inference system is a process that forms the mapping for the input and output variables using a fuzzy logic approach. This process involves several steps. It usually starts with identifying and defining the boundary of the input and output variables involved( i.e. establishing the relevant Fuzzy Set).This first procedure is quite crucial as the result of this will show the pattern of the input and output sets and provides general ideas about how these variables are linked. This information makes it is easier to move on to the next process, which involves identifying the membership functions for the input and output sets. The simplest and most commonly used membership function is a triangular membership function, which is used in this thesis. The final process is to develop a set of it-then rule statements. Such statements are used to formulate the conditional statements that comprise the fuzzy logic approach.

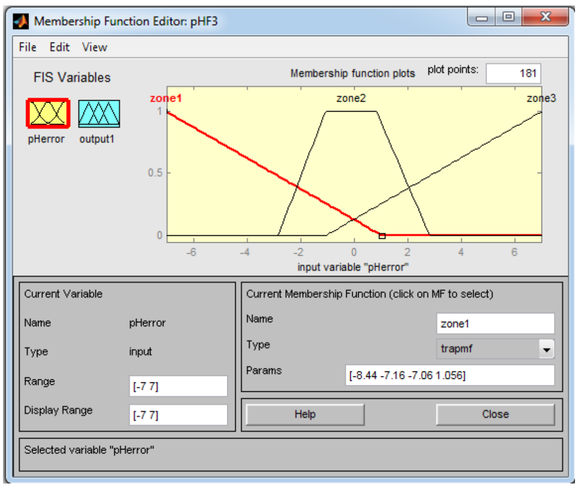


**Fig. 7.**Membership function for input set

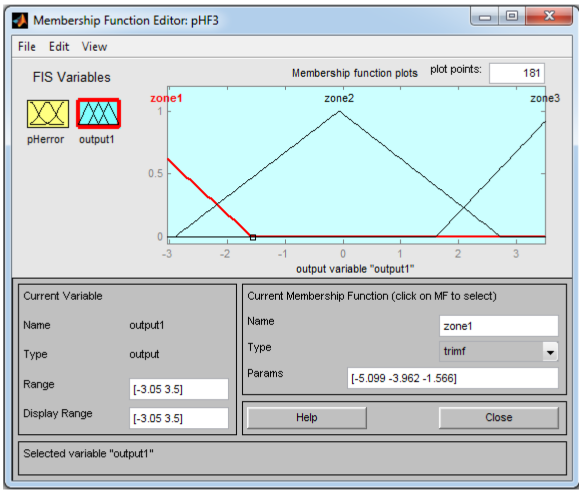


**Fig. 8.** Membership function for Output set.

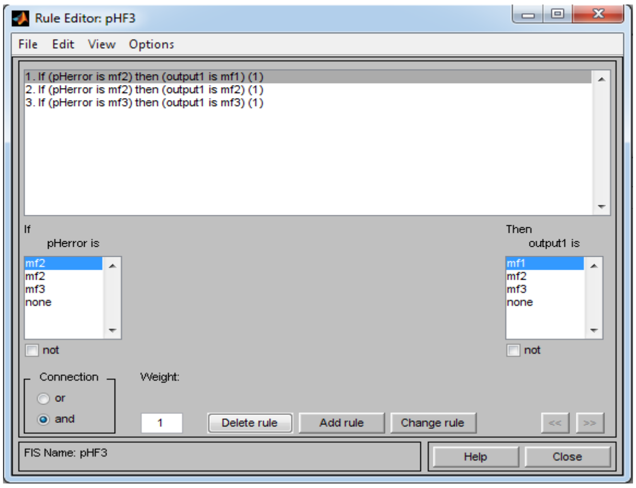


**Fig. 9.**Fuzzy Rule Set

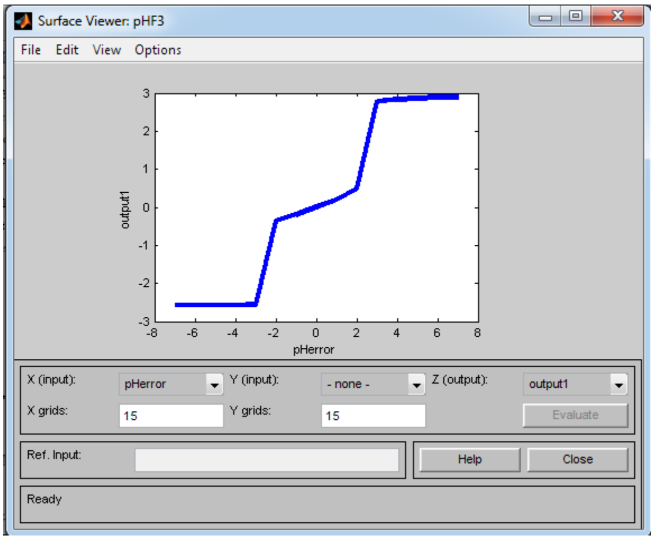


**Fig. 10.** The response of the fuzzy logic controller in terms of the manipulated variable as a function of the error.

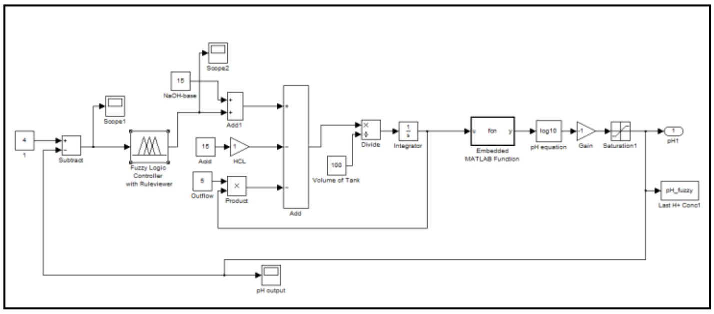

**Fig.11.** MATLAB/Simulink representation of the overall system using Fuzzy Logic Controller

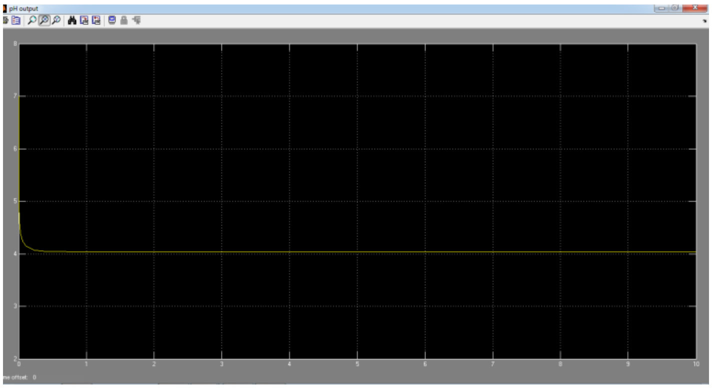

**Fig. 11.** Response obtained from the system with Fuzzy controller tuned for an operating point at pH=4

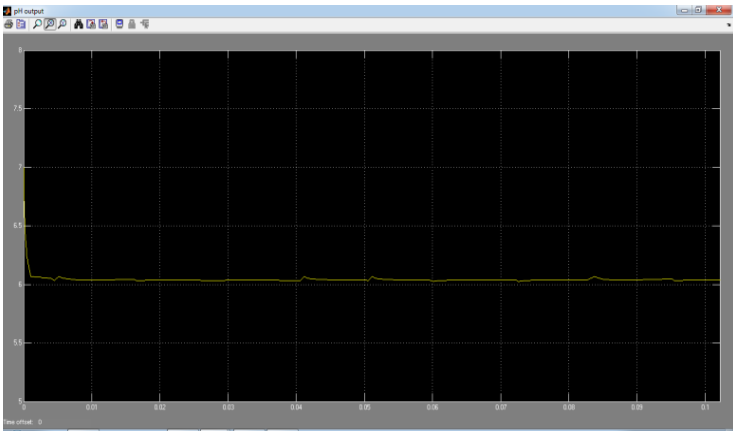

**Fig. 12.** Response obtained from the system with Fuzzy controller tuned for an operating point at pH=6

**Fig. 13.** Response obtained from the system with Fuzzy controller tuned for an operating point at pH=10

## 3. CONCLUSIONS

1) Application of PID control is limited to linear process with constant gain.
2) For non-liner process with varying gain, gain of the PID controller also needs to be changed (kp, ki)
3) Fuzzy Logic is known to capture non-linear dynamic of the process with simple representation.
4) Using Fuzzy Logic, non-linear dynamics of pH neutralization process can be conveniently captured.
5) Thus Fuzzy controller can suitably used as non-linear model based control for controlling complicated process such as pH neutralization.

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