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pH NEUTRALIZATION IN CSTR USING MODELREFERENCE NEURAL NETWORK AND FUZZY LOGIC ADAPTIVE CONTROLLING SCHEMES

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ABSTRACT

Control of the pH neutralization process plays an important role in many applications. Model reference adaptive controller base controlling is applied for pH process and intelligent controller such as fuzzy and neural network is added along with this adaptive controller in order to improve the response. A comparative study of these 3 controller was done in this paper.

Keywords : Model reference adaptive controller; FUZZY based Model reference adaptive controller; NEURAL NETWORK based Model reference adaptive controller.

I. INTRODUCTION

Control of the pH neutralization process plays an important role in different chemical plants, such as chemical and biological reaction, waste water treatment, electrochemistry and precipitation plants, production of pharmaceuticals, fermentation, and food production such as in vegetable oil refining. However, it is difficult to control a pH process with adequate performance point due to its nonlinearities, time-varying properties and sensitivity to small disturbances when working near the equivalence point.

More specifically, the pH was controlled in a continuously stirred tank reactor (CSTR) in this experiment. The reaction being controlled was the acid-base reaction of sodium hydroxide, NaOH, and nitric acid, HNO_3 and $NaHCO_3$ as buffering solution. The pH level is controlled by adding NaOH or HNO_3 solution directly into the CSTR. A control mechanism must be applied in order to determine the amount of solution added to properly compensate for deviations in pH. In this work used a feedback control loop. By manipulating control parameters, the pH level within the system can be kept within a certain range. To determine the proper control mechanism adaptive controlling schemes are used.

II. pH PROCESS CHARACTERISTICS

Basically, a pH control system measures the pH of the solution and controls the addition of a neutralizing agent (on demand) to maintain the solution at the pH of neutrality, or within certain acceptable limits. Titration curves provide information about acids and bases in addition to analyzing the quantity that is present [1]. They can provide information about the strength of the acid or base, the number of ionizable groups, ionization and hydrolysis constants, and molecular weight. A titration curve is a graph of pH vs. volume added. Because of the logarithmic nonlinearity, the gain of a pH process to change.

For the strong acid/strong base system, the gain at the equivalence point is extremely high and it occurs at pH = 7, which is neutral pH. Control of this system near pH 7 would place very high demands both on the accuracy of the control system and on the range ability of the reagent delivery system.

pH is only a measure of the concentration of dissociated hydrogen ions present in a solution When a solution contains a weak acid, most of its hydrogen ions are undissociated this reasoning can be applied to the weak alkali by considering hydroxide ions (OH^-) instead of hydrogen.

These undissociated hydrogen ions dissociate and combine with hydroxide ions when titrated with a base reagent, and there is little effect on the pH solution until all the undissociated hydrogen ions are used. Hence, the solution is buffered against pH changes [2].Buffering explains the apparent contradiction of a solution containing a weak acid requiring more alkali to change its pH from say 3 to 7 than a solution containing only a strong acid. A strong acid is 100% dissociated and hence has no buffering capacity. Unfortunately, for any realistic chemical system, there is no unique relationship between $[H^+]$ or pH and the required volume of neutralizing reagent. The reason for this non-unique relationship between pH and effective acidity/alkalinity is chemical buffering. Hence the pH is non linear in nature.

III. pH CONTROL

These pH control systems are highly varied, and design depends on such factors as flow, acid or base strength or variability of strength, method of adding neutralizing agent, accuracy of control i.e, limits to which pH must be held, and physical and other requirements.

However, it is difficult to control a pH process with adequate performance point due to its nonlinearities, time-varying properties and sensitivity to small disturbances when working near the equivalence point.

Neutralization is a process for reducing the acidity or alkalinity by mixing acids and bases to produce neutral solution.

IV. MATHEMATICAL MODELING OF NEUTRALIZATION PROCESS

Neutralization process block diagram is shown in fig 1. There are three streams of input and one stream of output [3]. Input stream consist of process stream (acid), buffer stream (buffer solution), and titrating stream (base). Output stream is also known as effluent stream.

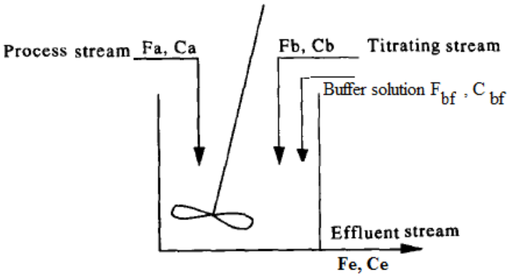

Figure 1.Block diagram of neutralization process

Remark:

1. Momentum does not change under any operating condition.
2. Temperature of the process maintains constant 25 degree Celsius.
3. Density,

$$\rho = \rho_a = \rho_b = \rho_{bf} = \rho_e \quad (1)$$

Consider now the balance of fundamental quantities

Total mass balance:

Accumulation of total mass in the tank / time = [total input to the tank / time] – [total output from the tank/ time]

$$\frac{d}{dt}\varrho V = \varrho_a f_a + \varrho_b f_b + \varrho_{bf} f_{bf} - \varrho_e f_e \quad (2)$$

Based on assumption that density is same equation (2) becomes

$$\frac{d}{dt}(V) = f_a + f_b + f_{bf} - f_e \quad (3)$$

Balance on component:

Accumulation of particular component in the tank / time = [total input of the component to the tank / time] – [total output from the tank/ time]

$$\frac{d}{dt}(C_O . V) = [C_a f_a + C_b f_b + C_{bf} f_{bf}] - C_e f_e \quad (4)$$

PARAMETER SELECTION

$NaHCO_3$: Sodium bicarbonate (buffer solution)

HNO_3 : Nitric acid (acid solution)

NaOH : Sodium hydroxide (base solution)

The pH number is a measure of concentration or more precisely the activity of hydrogen ion in a solution [2].

$$pH = -log\,[H+] \quad (5)$$

$[H^+]$ denote the concentration of hydrogen ion, unit M = mol / l

Kw is the equilibrium constant, has the value 10^{-14} $(\frac{mol}{l})^2$ at 25^{0C}.

Concentration of output solution is (C_o).

$$[H+] = \sqrt{(\frac{Co^2}{4} + Kw)} - \frac{Co}{2} \qquad (6)$$

$$pH = -\log\left[\sqrt{(\frac{Co^2}{4} + Kw)} - \frac{Co}{2}\right] \qquad (7)$$

Substituting the values of the parameters[4] shown in table1, the transfer function is obtained.

$$Gp(s) = \frac{Co(s)}{fb(s)} = \frac{3.14}{(15.4\,s + 1)}$$

C_O can be converted into pH using eqn (7).

TABLE 1.Values of Parameters for neutralization process

$(C_{HNO3})_a$ =0.003M	$(C_{HNO3})_b$ =0 M	$(C_{HNO3})_c$ =0 M
$(C_{NaHNO3})_a$ =0 M	$(C_{NaHNO})_b$ =0.03 M	$(C_{NaHNO})_c$ =0.0005 M
$(C_{NaOH})_a$ =0M	$(C_{NaOH})_b$ =0M	$(C_{NaOH})_c$ =0.003M
F_a=16.6 mL/s	F_b=0.55 mL/s	F_c=15.5 mL/s
W_{1a}=0.003 M	W_{1b}=0.0M	W_{1c}=0.00035 M
W_{2a}=0 M	W_{1b}=0.03 M	V =2900Ml
pK1=6.35	pK2=10.25	pH=7.00

V. ADAPTIVE CONTROL STRATEGIES

pH neutralization control system maintains the pH value equal to 7 by manipulating the alkaline flow rate. Linear feedback control strategies are unsuitable for this nonlinear process. Hence adaptive control scheme is applied. The schemes are shown below.

i. Model Reference Adaptive Control

The model reference adaptive control scheme in fig 2 consists of four blocks. They are process, controller, reference model, and adaptor. The objective of a model reference adaptive control (MRAC) is to obtain a control law and an updating law, such that the closed loop response tracks a reference model. For nonlinear systems, controller design procedure is based on input-output linearization.

A plant (process) contains unknown parameters, a reference model for compactly specifying the desired output of the control system, a feedback control law containing adjustable parameters, and an adaptation mechanism for updating the adjustable parameters [2].

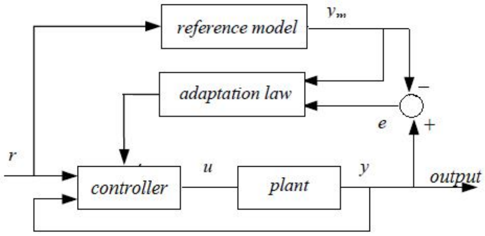

Figure 2. Model reference adaptive controller

The plant is assumed to have a known structure, although the parameters are unknown. For linear plants, the numbers of poles and zeros are assumed to be known, but their locations are not known. For nonlinear plants, this implies that the structure of the dynamic equations is known, but that some parameters are not known.

A reference model is used to specify the ideal response of the adaptive control system to external command. The controller is usually parameterized by a number of adjustable parameters. The controller should have perfect tracking capacity in order to allow the possibility of tracking convergence. The adaptation mechanism is used to adjust the parameters in the control law.

The MIT rule is the original approach to model reference adaptive control [5]. To present the MIT rule, Closed loop system is considered, in which the controller has one adjustable parameter θ. The desired closed loop response is specified by a model output y_m of the model. One possible way to adjust parameter in such a way that the loss function,

$$J(\theta) = \frac{1}{2}e^2 \qquad (8)$$

is minimized. To make J small, it is reasonable to change the parameter in the direction of the negative gradient of J, that is

$$\frac{d\theta}{dt} = -\gamma\frac{\partial J}{\partial\theta} = -\gamma\frac{\partial e}{\partial\theta} \qquad (9)$$

$\frac{\partial e}{\partial \theta}$ is called sensitivity derivative of the system, tells how the error is influenced by the adjustable parameter.

The MIT rule adaptation law is given by the expression:

$$\frac{d\theta}{dt} = -\gamma y_m e \qquad (10)$$

In recent years, an Artificial Neural Network (ANN) and Fuzzy logic techniques has become very popular in many control applications due to their higher computation rate and ability to handle nonlinear system.

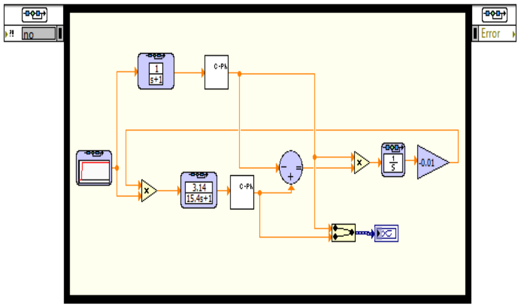

Figure3. Block diagram of MRAC

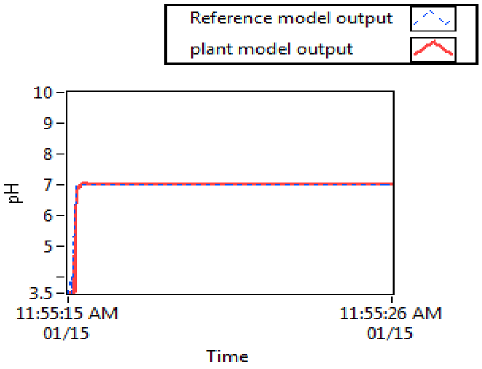

Figure 4. Response MRAC

Figure 4 shows the response of pH neutralization process when using model reference adaptive controller. In this response process model response tracks the reference model response at the time 50 sec onwards. Here adaptation gain is -0.01. Where as It may not assure for controlling nonlinear plants with unknown structure, when the external disturbance occurs where a degradation in the performance due to overshoot is observed.

ii. Fuzzy Logic Controller Based Model Reference Adaptive Controller

FLC has become popular in the field of industrial control applications for solving control, estimation, and optimization problems. Therefore, FLC can the optimization problem. A Fuzzy-Logic Controller based Model Reference Adaptive Controller (FLC-MRAC) scheme is proposed to improve the system performance. The MRAC forces the plant output to follow closely the output of the model which represents the desired closed loop behavior, and the FLC used for various operating conditions, the objective of the fuzzy logic control is to determine the control signal for controlling nonlinear processes. The error and the change in error are given input to the FLC [6].

Even though model is not required to develop such a controller. Fuzzy controllers have no mathematical model; it is difficult to analyze the system. The working of the controller heavily depends on the judgment of the human expert who formulated the rules.

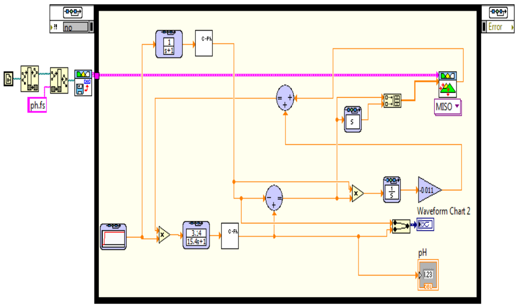

Figure 5. Block diagram of MRAC with FUZZY

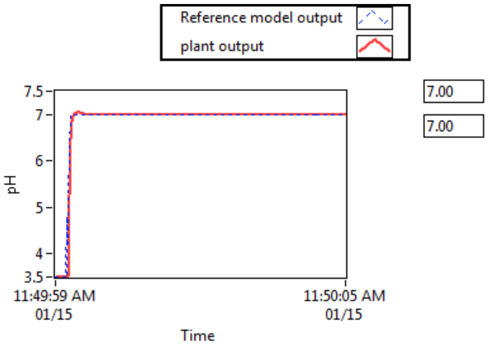

Figure 6. Response of MRAC with FUZZY

TABLE 2 **Fuzzy Rules**

Error	Rate of Error					
		Nb	**Ns**	**Z**	**Ps**	**Pb**
	Nb	Pb	Pb	Ps	Ns	Z
	Ns	Pb	Ps	Ps	Z	Ns
	Z	Ps	Ns	Z	Ns	Nb
	Ps	Ns	Z	Ns	Ns	Nb
	Pb	Z	Ns	Ns	Nb	Nb

Figure 6 shows the response of pH neutralization process when using model reference adaptive controller with fuzzy logic controller. In this response process model response tracks the reference model response at the time 40 sec onwards. Here adaptation gain is -0.01.

iii. Neural Network-Based Model Reference Adaptive Controller

In this scheme, the controller is designed by using parallel combination of conventional MRAC system and neural network controller. Stability of the system and adaptability are then achieved by an adaptive control law tracking the system output to a suitable reference model output, such as that the error $e = yp - ym = 0$ asymptotically stable. The NN provides an adaptive control for better system performance and solution for controlling nonlinear processes.

Here the multilayer back propagation neural network is used in the proposed method. The multilayer back propagation network is especially useful for this purpose, because of its inherent nonlinear mapping capabilities, which can deal effectively for real-time online computer control. The NN of the proposed method has three layers: an input layer with 2 neurons, a hidden layer with 2 neurons and an output layer with one neuron [6].

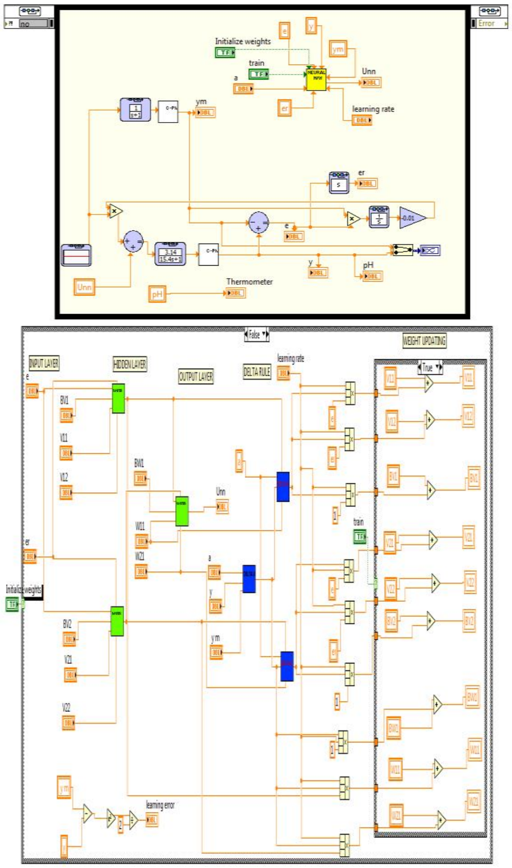

Figure 7. Neural network based MRAC

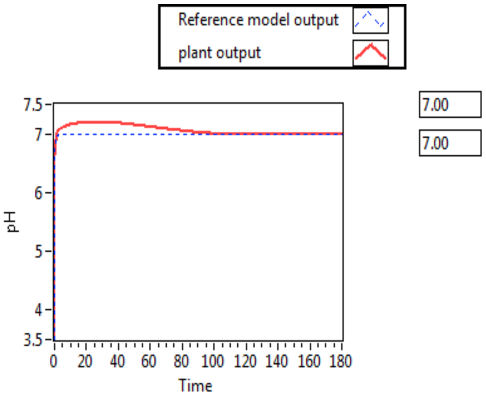

Figure 8. Response of NN-MRAC

VII. CONCLUSION

The objective of this paper is to develop pH control process and to find its feasibility of applying advanced control strategy to it. The modeling of the pH process in continuously stirred tank reactor is developed. The pH control objective is to maintain the pH value of the process at desired value during transient operations by manipulating the alkaline flow rate.

However, it is found that control performance improvement or application of advanced control strategies requires optimizing several process parameters. Theses parameters are the sampling time, tuning settings. Advanced control strategies such as model reference adaptive controller, and MRAC with FUZZY logic controller, MRAC with Neural network is developed. A comparative study of these controllers developed, and the results are shown.

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