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An Evaluation Of pH Neutralization Control Using IMC Strategy And Artificial Intelligence

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***Abstract*— The pH control process is an unavoidable part in wide range of industries including wastewater treatment, biotechnology, pharmaceuticals and chemical processing. The general aim is to maintain the pH value within a liquid at a specific level. The objective of this process is to neutralize the fluid under test by regulating the reagent solution flow rate until the mixture stabilizes at set point. After analyzing the mathematical model of the process, Simulink model of the system is developing. Neutralization process is controlling by artificial intelligence technique like fuzzy logic and IMC PI. Comparing the performance of the controllers for the system**

***Index Terms*— Artificial Intelligence based Controller, FOPTD Process,Fuzzy Logic Controller,IMC,pH Neutralization Process**

I.INTRODUCTION

Studies on pH neutralization control in process industries have shown a significant increase in the last years. Control of pH is a difficult problem and has received considerable attention because it is an un avoidable part of many industries. It is one of the most challenging problems in process industries due to severe non linearity and time varying nature of titration curve. Even a small change in composition can affect titration curve, So modelling and control of pH neutralization plants are tough. The pH process is also used as benchmark for testing new models and control algorithms.

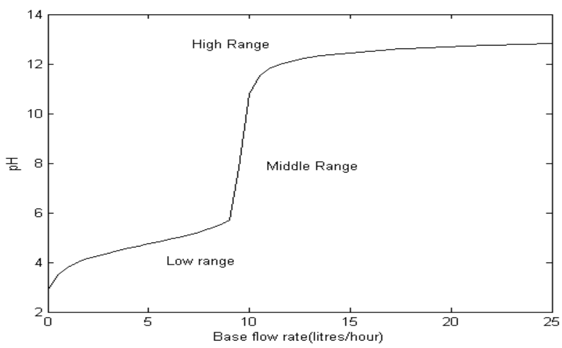

Fig 1. Non linear Characteristics of Neutralization Process

A perfect and simple mathematical modelling of pH process is introduced by McAvoy is a mile stone in the development of pH process [1]. Fuzzy and Neural network based models also performs well [2].CDM –PI controllers are designed for IMC based PI,PID controllers are also used to control the neutralization reaction[5] . Fractional order PI controller is a good option for the pH neutralization process [6] .Most of the papers are based on fuzzy logic controller, FLC provides good performance for the system. In some studies the set point of process also given as input [7] . But in most cases the ordinary FLC with two inputs and one output is used [8]. Hybrid fuzzy PID controllers can be used for control strong acid–strong base neutralization[9]. Here the output of fuzzy logic controller used to adjust the PID parameters.Adaptive fuzzy sliding mode control also introduced in some papers[10] . Model based controller is a good attempt for the control of both strong acid –strong base and weak acid – strong base neutralization reaction. MRAC have shown excellent control of the process[11] . Most of the papers propose MIT rule to design MRAC. There are some papers which compare the performance of MRAC and AIMC on the process [12]. Some papers describes the use of model predictive controller (MPC)[13]. Adaptive non linear control strategy also developed for the process. Studies are taking place to control the pH using robust loop shaping approach[14] .

Here section 2 provides the detailed working of system and section 3 is mathematical modelling of the system. Section 4 deals with design of controllers and 5 is performance analysis of controllers. The last section is the conclusion

II. pH NEUTRALIZATION PROCESS

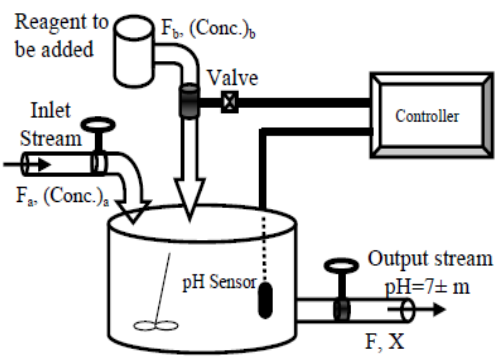

Fig 2.pH Neutralization Process

The pH neutralization system The system consists of a CSTR with 2 input streams. One is influent stream (acidic) with the concentration $(Conc.)_a$ moles/L and flow rate of F_a L/min another is reagent stream with concentration

$(Conc.)_b$ moles/L and flow rate of F_b L/min. The objective of this process is to neutralize the inlet fluid from the input stream by regulating the reagent solution flow rate F_b until the mixture stabilizes at pH equal to 7 or between the specified. The volume in the tank is constant and equal to V

II.MATHEMATICAL MODELLING

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pH is defined as the negative logarithm of hydronium ion[H+]
(hydrogen ion) concentration . It is given by:

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

The chemical reaction between the two solutions (Strong Acid Strong Base system) taking place in the CSTR

$H^+ + Cl^- + Na^+ + OH^- = H_2O + Na^+ + Cl^-$ (2)

Thus, the ionic concentration of $[Na^+]$ and $[Cl^-]$ in effluent stream would be related to the flows F_a, F_b and feed concentration of HCl & NaOH entering the tank .Hence the mass balance equation is given by:

$V\frac{d}{dt}[Cl^-]=[Cl^-]F_a-[Cl^-](F_a+F_b)$ (3)

$V\frac{d}{dt}[Na^+]=[Na^+]F_b-[Na^+](F_a+F_b)$ (4)

The concentration must also satisfy the electro neutrality equation

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

Dissociation equation for water at equilibrium at 25^0C

$[H^+][OH^-]=K_w=10^{-14}$ (6)

From (5) we can write

$[H^+]-[OH^-]=[Cl^-]-[Na^+]$ (7)

Let

$X=[H^+]-[OH^-]$ (8)

Therefore from (6) and (8)

$[H^+]=\frac{X}{2}[\sqrt{1+\frac{4K_w}{X^2}}-1]$ (9)

From equation (3) and (4)

$V\frac{d}{dt}[[Cl^-]-[Na^+]]=[Cl^-]F_a-[Na^+]F_b-XF$ (10)

Where $F=F_a+F_b$

From (7) and (8)

$V\frac{d}{dt}X=[Cl^-]F_a-[Na^+]F_b-XF$ (11)

The equations (1),(9),(11) corresponds to pH neutralization model. Using this equations we find out a first order plus time delay transfer function for the process.

$$G(s)=\frac{.04912\,e^{-20s}}{320s+1}$$

IV. DESIGN OF CONTROLLERS

A. Design Of IMC-PI Controller

Model based control systems are helpful to achieve desired set points and reject small external disturbances. The internal model control (IMC) design is based on the fact that control system contains some representation of the process to be controlled then a perfect control can be achieved.

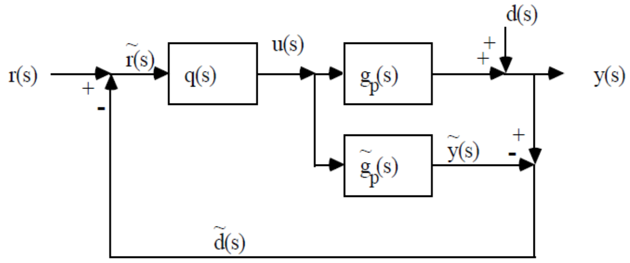

Fig 3.IMC Structure

Here we have to develop a feedback equivalent to IMC from the above given block diagram using block diagram manipulation.$q(s)$ represents the controller,$g_p(s)$ represents the actual process and the $\tilde{g_p}$(s) represents model of the process

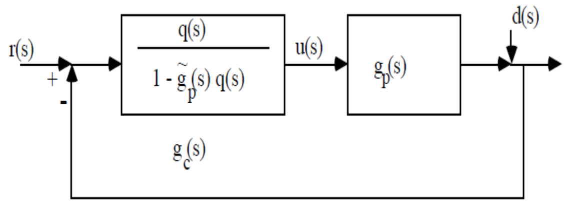

Fig 4.Standard feedback Equivalent to IMC

The standard feedback controller which is equivalent to IMC is given as

$g_c(s)=\frac{q(s)}{1-\tilde{g_p}(s)q(s)}$ (12)

In order to arrive at a PI equivalent form for processes with a time-delay, we must make some approximation to the dead time, using either a zeroth or a first-order Padé approximation for the dead time.

Here zero-order Padé approximation is used, that is

$\tilde{g}_p(s)=\frac{k_p e^{-\theta s}}{\tau_p s+1}\approx\frac{k_p}{\tau_p s+1}$ (13)

1. Find the IMC controller transfer function, q(s), which includes a filter to make *q(s)* semi proper

$q(s)=\tilde{g}_{p-}^{-1}.f(s)=\frac{\tau_p s+1}{k_p}\frac{1}{\lambda s+1}$ (14)

Note: Internal model controller is designed as inverse of the process model which is in series with the low pass filter

i.e $G(s)=G_c(s)f(s)$

Where *f(s)*= $\frac{1}{\lambda s+1}$ (15)

λ = Filter Tuning Parameter

2 .Find the equivalent standard feedback controller using the transformation

$g_c(s)=\frac{q(s)}{1-\tilde{g}_p(s)q(s)}=\frac{\tau_p s+1}{k_p\lambda s}$ (16)

recall that the transfer function for a PI controller is

$g_c(s)=k_c\frac{\tau_{I(s)+1}}{\tau_{I(s)}}$ (17)

3. Rearrange (18) to fit the form of (20). Multiplying (18) by ${}^{\tau_p}/_{\tau_p}$

$g_c(s)=\left(\frac{\tau_p}{k_p\lambda}\right)\frac{\tau_p s+1}{\tau_p s}$ (18)

Equating 19 and 20 we get IMC based PI tuning parameters

$$k_c = \frac{\tau_p}{k_p \lambda} \qquad (19)$$

$$\tau_I = \tau_p \qquad (20)$$

Since dead time has been neglected, creating quite a bit of model error, it is recommend that $\lambda > 1.7\theta$
Here λ is taken as 34.5
k_c=188.83
k_i=.5909

B. Design Of Fuzzy Logic Controller

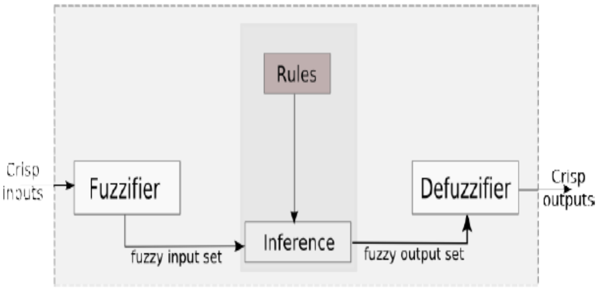

Fig 5. A Fuzzy Logic System

A fuzzy logic system (FLS) can be defined as the nonlinear mapping of an input data set to a scalar output data . A FLS consists of four main parts such as fuzzifier, rules, inference engine, and defuzzifier. The general architecture of a FLS is given in the figure

Initially, a crisp set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step is known as fuzzification. Afterwards, an inference is made based on a set of rules. Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzification step.

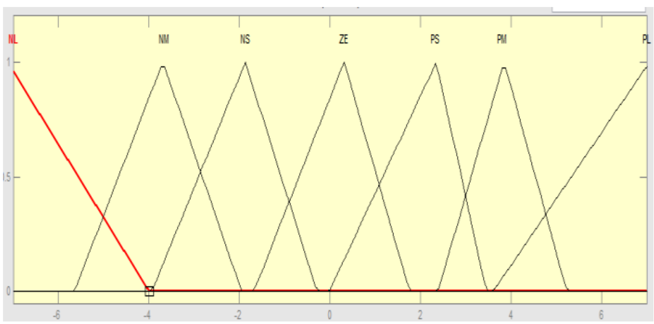

Fig 6.Membership function of error and change in error

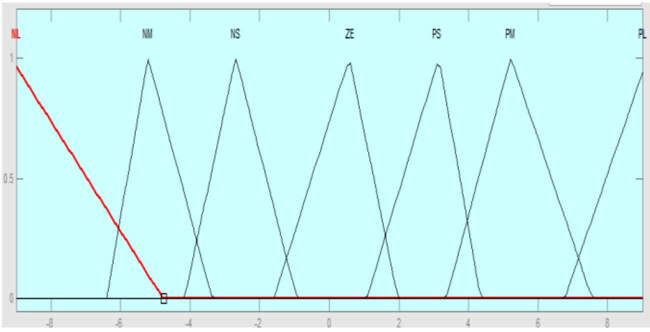

Fig 7.Membership function of controller output

In this work the error and change in error of pH is taken as inputs to the fuzzy logic controller and the adjustment of flow is taken as the controller output. The error and change in error is converted into seven linguistic values namely NB, NM ,NS,ZE,PS,PM and PB. Similarly controller output is converted into seven linguistic values namely NB,NM,

NS,ZE,PS,PM and PB. Triangular membership function is selected and the elements of each of the term sets are mapped on to the domain of corresponding linguistic variables. The membership functions for error change in error and controller output is shown in the figure.

Table I .Rule Base of fuzzy logic

ce(t) / e(t)	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

V. PERFORMANCE ANALYSIS OF CONTROLLERS

In this section performance of controllers are evaluated using simulation results and performance indices.

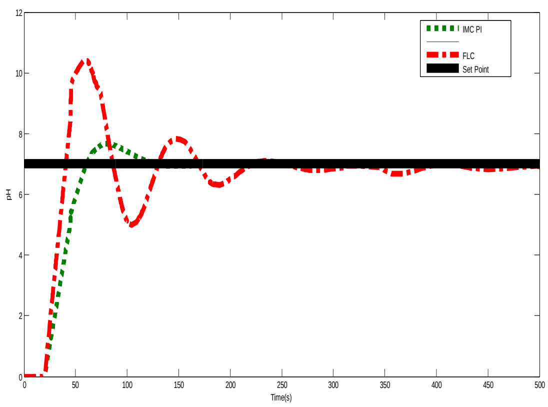

Fig 8. Regulatory Response of the system

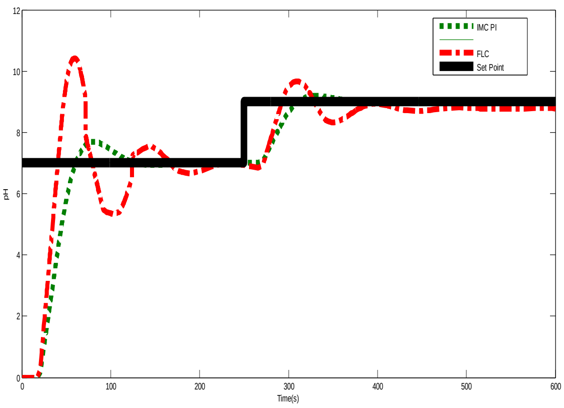

Fig 9. Servo Response of the system

The performance of the two controllers can be evaluated using performance indices namely Integral Square error (ISE), Integral Absolute Error (IAE) and Integral Time Absolute Error(ITAE) . A control system is considered optimal when it minimizes the above integrals. Table given below summarizes the integral error values for the two control schemes. IMC PI controller has the least ISE and IAE value

Table II.Performance Analysis Of Controllers

Performance Indices	Servo Response		Regulatory Response	
	IMC PI	FLC	IMC PI	FLC
IAE	378.8	530	292.9	447.8
ISE	1691	1787	1559	1720

VI. CONCLUSION

This work clearly shows that IMC based PI controller performs well for pH neutralization system when compared with FLC. IMC PI have excellent set point tracking without offset .

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