Fuzzy Model for IMC Based PI Controller for a nonlinear pH Process

M. Florance Mary*, Department of Electronics and Instrumentation
Pondicherry Engg. College, Puducherry , India, *florancemary@pec.edu*

R. Ananda Natarajan, Department of Electronics and Instrumentation
Pondicherry Engg. College, Puducherry , India, *ananda_natarajan@pec.edu*

Institution address:
Department of Electronics and Instrumentation,
Pondicherry Engg. College,
Pillaichavady,
Puducherry , India-605014.

Corresponding author's email id: *florancemary@pec.edu*

Abstract:_The control of pH is one of the most difficult challenges in the process industry because of the severe nonlinearities in the behaviour of the system. Different approaches for the pH control are proposed in various literatures. In the present study, control of pH using fuzzy model for internal model controller based PI is proposed. Modelling of the pH process is supposed to be a difficult task because one needs to have knowledge about the components and their nature in the process stream in order to model its dynamics. In this work, fuzzy model is proposed using the first principle equation of the nonlinear pH process and used for controlling the pH process effectively using IMC based PI.

Keywords:- *Fuzzy, internal model control based PI, pH process*

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1. INTRODUCTION:

Nearly all process plants in industries 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 in practical cases. Results of this are lesser product quality and material waste. Examples of areas where pH control processes are in extensive use are water treatment plants, many chemical processes, production of pharmaceuticals and biological processes. With ever increasing demands to improve plant efficiency, effective and continuous pH control is extremely required. A control of pH process is highly nonlinear because the pH value versus the reagent flow(i.e., acid flow or base flow) has a logarithmic relationship.

Modelling of the pH process is supposed to be a very difficult operation because one needs to have knowledge about the components and their nature in the process stream in order to model its dynamics. Otherwise assuming some fictitious components and parameters defining their nature as linear model is needed, which might not be accurate in all cases. A model for the pH neutralization process with a single-acid single base system was developed [1]. This model has been widely accepted in the literature for process identification. A generalized model for pH system with an arbitrary number of acids and bases using the reaction invariant concept [2]was also attempted.

Fuzzy Logic was initiated in 1965 by Lotfi A. Zadeh [3]-[6]. In the past decade, fuzzy logic has been adopted to model complex systems [7]. The need for fuzzy logic concept has been dealt in [8]. Fuzzy logic based modeling methodologies can be classified into two types as mamdani and sugeno. [9],[10]. Internal Model Control for PID Controller Design was already done[11],[12] to show that its better features in practical case. IMC Based PID Controller Design for a Jacketed CSTR was also done[13]. Here in this work, fuzzy logic model is done with reasoning based on mamdani. Once an adequate ANN process model was developed, suitable control structure which could accommodate the model is chosen. That is internal model control based on PI controller.

Rest of the paper is dealt as follows:

Section 2 deals with the description of the process. Fuzzy logic modelling for pH process is dealt in section 3. The controller part of the pH process is done using IMC based PI controller which is dealt in section 4. Simulation studies carried out on simulink base of matlab is dealt in section 5 and conclusion is drawn in section 6.

ISSN: 2321-8169
1090 - 1098

2. DISCRIPTION OF THE PROCESS

Modelling of the pH process is supposed to be a very difficult operation because one needs to have knowledge about the components and their nature in the process stream in order to model its dynamics. Otherwise assuming some fictitious components and parameters defining their nature as linear model is needed, which might not be accurate in all cases. The system under consideration is a continuously stirred tank reactor (CSTR), in which a strong acid (Hydro Chloric acid) neutralised by adding a strong base (Sodium Hydroxide) continuously in a CSTR . The flow rate of strong base is manipulated to get the required pH. Material and ionic balance gives a set of linear differential equations and nonlinear static equation which is used for simulation.

$$V\frac{dx_a}{dt} = F_a C_a - (F_a + F_b)x_a \quad (1)$$

$$V\frac{dx_b}{dt} = F_b C_b - (F_a + F_b)x_b \quad (2)$$

$$x_b - x_a + 10^{-pH} - 10^{(pH - pK_w)} = 0 \quad (3)$$

where x_a and x_b are state variables, F_b is the manipulated variable and pH is the system output. The remaining symbols in the above equations are defined in Table. I. The simulink model of the pH process is obtained from the equation (1) to (3) as shown in Fig.1. The steady state characteristic titration curve for the acid base system generated by simulink model for variation in the base flow rate (F_b) from 0 to 60 Lit /hr is shown in Fig.2.

3. FUZZY LOGIC MODELLING

When process modeling is done with limited experimental data it is almost a difficult task. It becomes even more difficult if the process is highly nonlinear and has many inputs and outputs. Under such conditions, fuzzy logic shows its capabilities for model development. Fuzzy modeling and identification from measured data are effective tools for the approximation of nonlinear systems. Here , the model is developed using two inputs and one output. The inputs are pH(k) and flowrate(k) and output is taken as pH(k+1). Here, reasoning using if then rules is done to find the next pHvalue pH(k+1) from the present pH and flowrate value. Flow rate(k)is constructed using seven triangular membership function and pH(k) and pH(k+1) ranging from (0-14) is also constructed using seven membership functions. The abbreviation used for these linguistic values are VVL(very very low),VL(very low), N(neutral), VH(very high),VVH(very very high) considering 7pH to be the neutral point(N).

4. IMC BASED PI CONTROLLER

The IMC uses a model based procedure, where a process model is included in the controller. The IMC structure is rearranged to get a standard feedback control system so that open loop unstable system can also be handled. This improves the input disturbance rejection. The IMC based PI structure uses the process model as in IMC design. In the IMC procedure the controller $Q_c(s)$ is directly based on the invertible part of the process transfer function. IMC based PI procedures uses an approximation for the dead time. And if the process has no time delays it gives the same performance as does the IMC.

The block diagram of IMC based PI is shown in fig 3. Here r(s) stands for input and y(s) stands for output. Here, the process model is G_p*(s)for an actual process plant G_p(s). The controller Q_c(s)is used for controlling the process in which the disturbances d(s)enters into the system at any time . In this work, the G_p*(s) is modelled using fuzzy logic where the module rule base are considered to function similar to the process. Once modelled, the above block diagram is to be constructed to understand the controller performance.

Fig 4. shows simulink block of fuzzy logic model for IMC based PI controller was constructed to control the nonlinear pH process using simulink. Since the system is nonlinear an intelligent technique based on fuzzy logic is used to model the system for better performance.

5. SIMULATION STUDIES

Relay feedback test is used to tune the PI controller . Fig. 5 illustrates the typical response curves for pH process for relay feedback test. The test provides ultimate gain (k_{cu}) and ultimate period (P_u) of the pH process at nominal operating point. Here relay control action height is represented by h and (A) stands for amplitude of plant response. Controller tuning to find K_c and T_i via the above mentioned relay feedback test is attractive, since no priori knowledge of system is needed and it is operated under closed-loop. The PI controller tuning parameters are obtained using Zeigler-Nichols method

- The simulation results for servo response of conventional PI, fuzzy logic model for IMC based PI are shown in figures (6-10). The simulation results show that the fuzzy logic model for IMC based PI has less overshoot and fast response compared to the conventional PI. The response for the Set point change from pH 7to pH 6 is shown in fig 6. Here, it is found that fuzzy logic model for IMC based PI shows a much better response by achieving the set point at a much faster rate than PI.
- The response for the Set point change from pH 7 to pH 8 is shown in fig 7. Here, it is found that fuzzy logic model for IMC based PI shows a much

ISSN: 2321-8169
1090 - 1098

better response by achieving the set point at a much faster rate than PI.

- The response for the Set point change from pH 7 to pH 9 is shown in fig 8. Here, it is found that fuzzy logic model for IMC based PI shows a much better response by achieving the set point at a much faster rate than PI.
- The response for the Set point change from pH 7to pH 11 is shown in fig 9. There is a nonlinear transition in the system. Here, it is found that fuzzy logic model for IMC based PI shows a better ISE and IAE values than PI.
- The response for the Set point change from pH 7 to pH 3 is shown in fig 10. There is a nonlinear transition in the system. Here, it is found that fuzzy logic model for IMC based PI shows a better ISE and IAE values than PI.

In many practical cases the effluent from waste water treatment plant must be neutralized to pH 7 to maintain the environmental limits. A simulation work is considered in our work as shown in fig. 11,12 where a solution entering the CSTR has a pH of 8. Here, it is found that fuzzy logic model for IMC based PI shows a better ISE and IAE values than PI. Similarly a simulation work is considered in our work where a solution entering the CSTR has a pH of 6. Here, it is found that fuzzy logic model for IMC based PI shows a better ISE and IAE values than PI.

The performance analysis for servo and regulatory response was also done by obtaining the ISE and IAE values as shown in TABLE II and TABLE III for the controllers and it also concludes that fuzzy logic for IMC based PI shows very low ISE and IAE values compared with PI. Hence we find that control of pH process using fuzzy logic for IMC based PI shows better response than PI . When fuzzy logic for IMC based PI was applied on the pH process it improved the speed of the response and there was no steady state error.

6. CONCLUSION

For practical applications on an actual process in industries, IMC based PI controller algorithm is simple and robust to handle the model inaccuracies. Since fuzzy logic includes little intelligence , it can handle nonlinearities. For this reason, fuzzy logic model is incorporated so that robustness to model inaccuracies is obtained. So we can conclude that IMC-PI along with fuzzy logic model shows better performance with low ISE and IAE values for set point change and regulatory response on a pH process.

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TABLE I
System Specifications

Variable/parameters	Nominal Value
Volume of reactor	5.7 lit
Flow rate of acid , F_a	20 lit/hr
Conc. Of acid , C_a	0.2N
Conc. Of base , C_b	0.2N
Equilibrium constant for water dissociation , K_w at 25 ^OC	10^{-14}

TABLE II performance analysis for servo response

SP CHANGE In pH	PI CONTROLLER		FL-IMC-PI CONTROLLER	
	IAE	ISE	IAE	ISE
7-8	4.95	1.137	1.549	0.381
7-9	40.5	12.9	15.2	4.5
7-11	501.4	385.2	412	267.6
7-6	4.929	1.137	1.52	0.3808
7-3	508.2	385	413.8	267.2

TABLE III Performance Analysis for regulatory response

DISRUBANCE REJECTION FOR NOMINAL OPERATING POINT OF 7 pH	PI CONTROLLER		FL -IMC–PI CONTROLLER	
	IAE	ISE	IAE	ISE
8pH	4.951	1.137	1.549	0.3788
6pH	4.951	1.137	1.549	0.3788

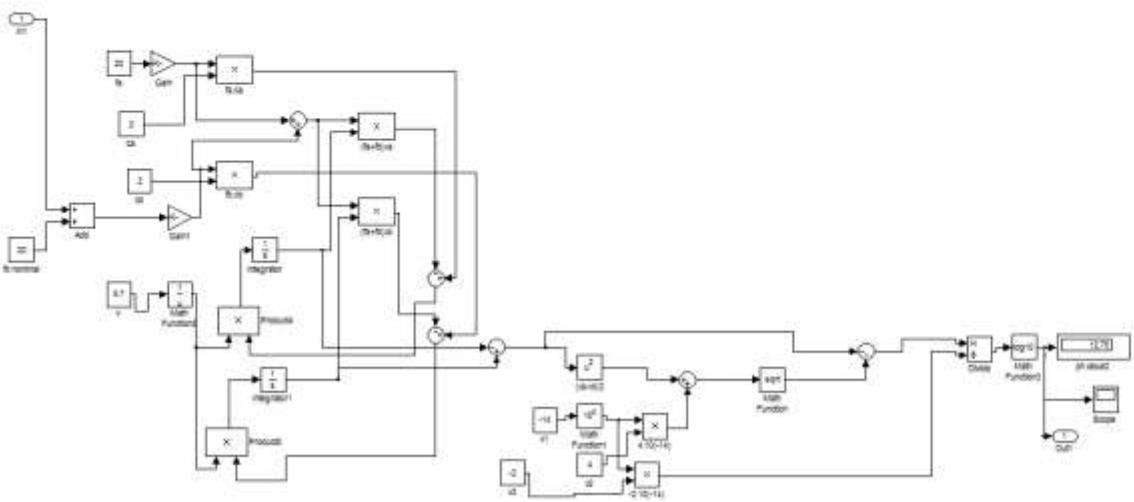

Fig. 1. Simulink block of the nonlinear pH process used.

ISSN: 2321-8169
1090 - 1098

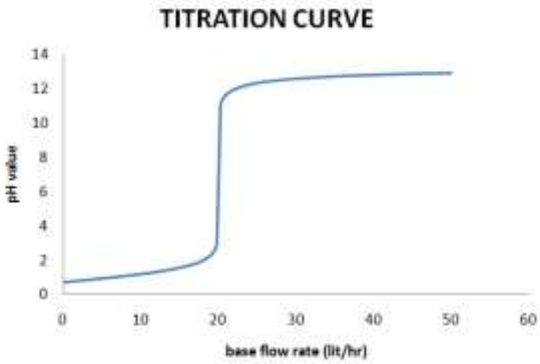

Fig.2. Steady State characteristic titration curve of process considered.

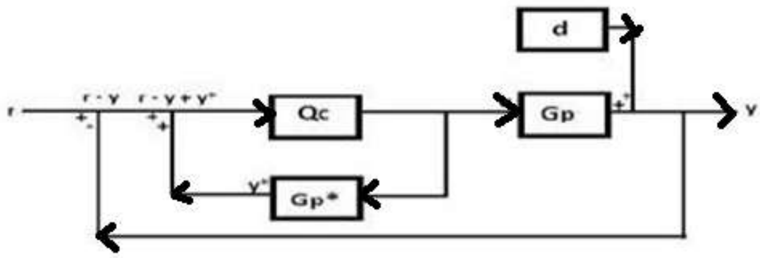

Fig 3. Block diagram of IMC based PI controller

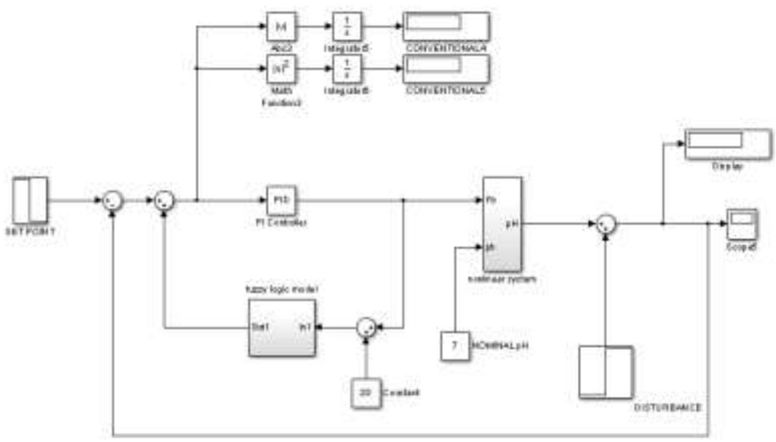

Fig 4. Simulink block of Fuzzy Logic model for IMC based PI controller

ISSN: 2321-8169
1090 - 1098

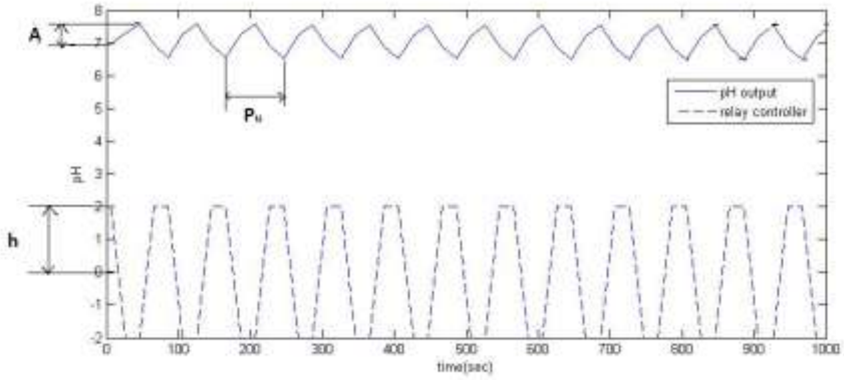

Fig 5. Relay feedback test for pH process

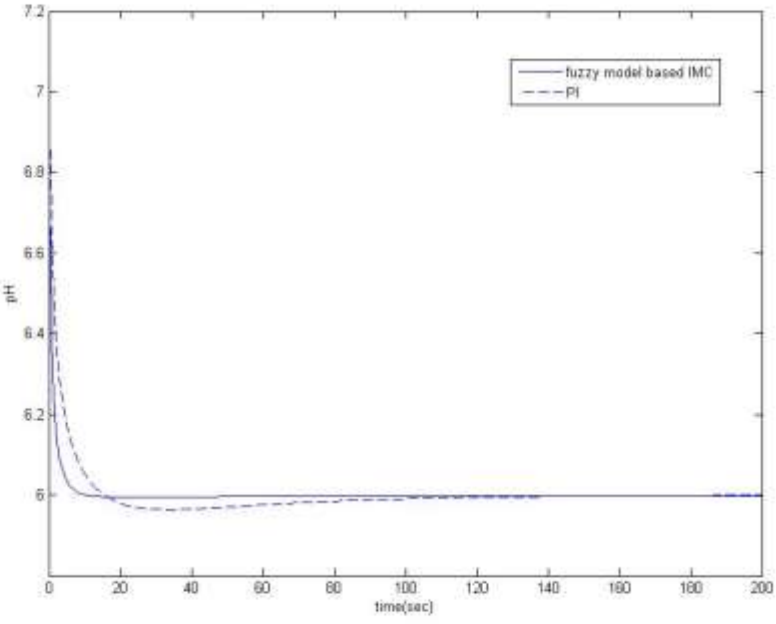

Fig 6.Servo response for pH change from pH 7 to pH 6

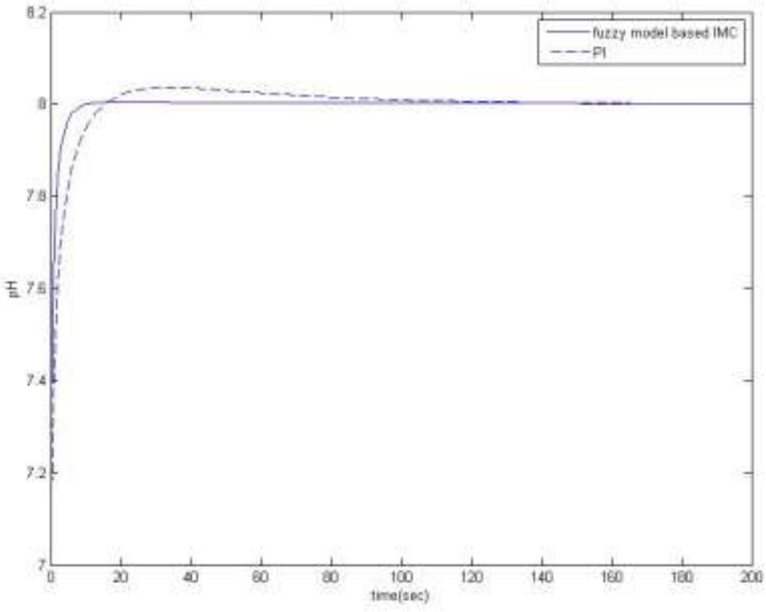

Fig 7. Servo response for pH change from pH 7 to pH 8

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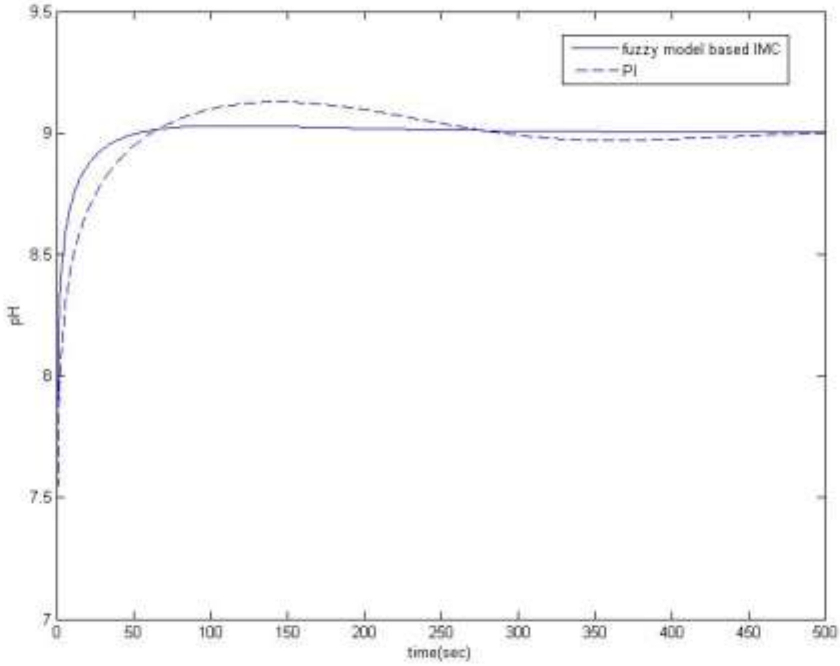

Fig 8. Servo response for pH change from pH 7 to pH 9

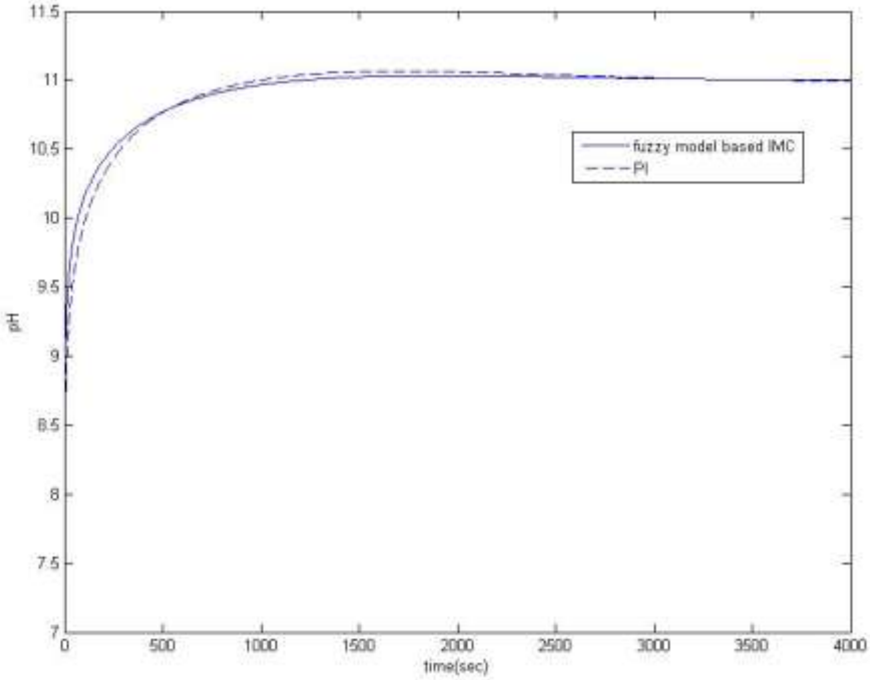

Fig 9. Servo response for pH change from pH 7 to pH 11

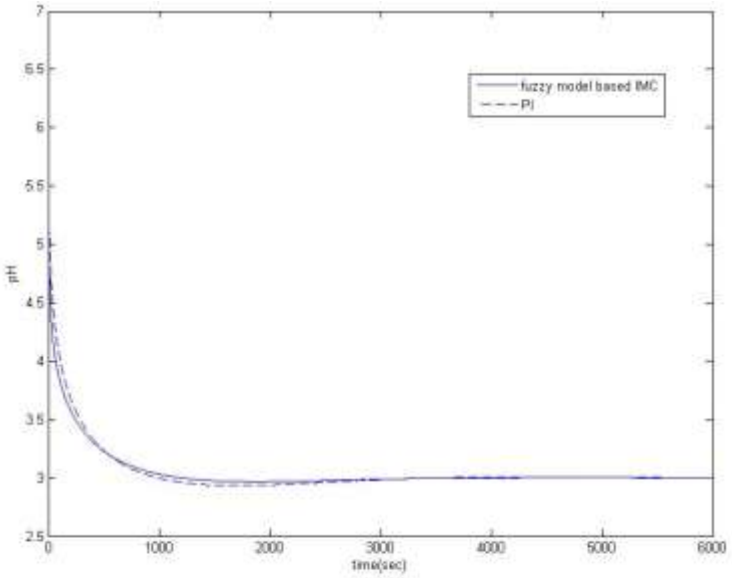

Fig 10. Servo response for pH change from pH 7 to pH 3

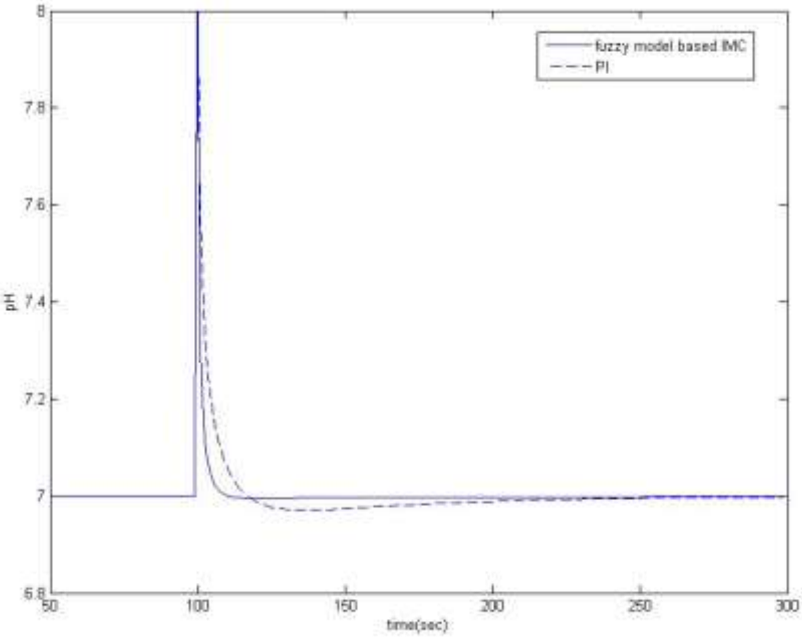

Fig 11. Regulatory response for disturbance of +1 pH

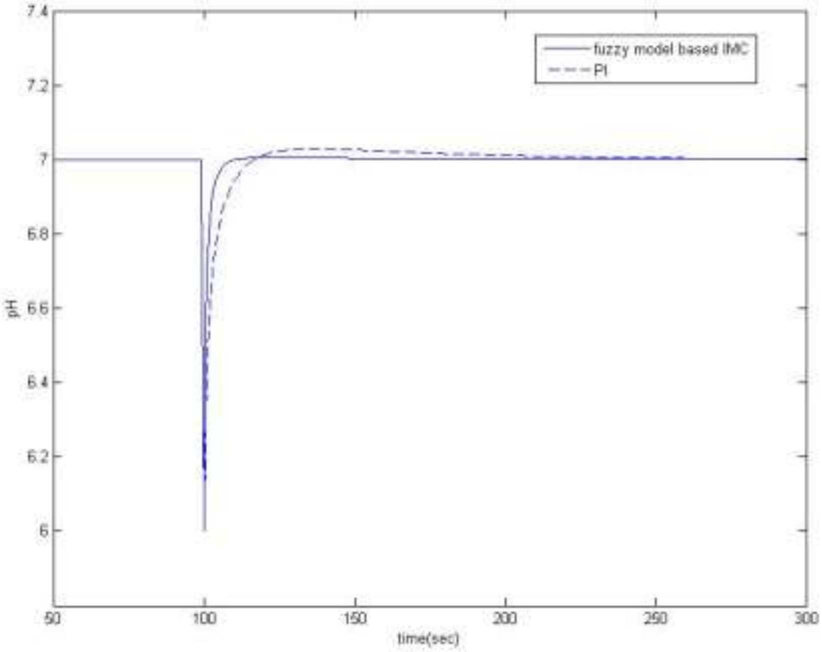

Fig 12. Regulatory response for disturbance of -1 pH

LEGENDS

PI – proportional and integral controller

FL – fuzzy logic

IMC – internal model control

Fuzzy model based IMC– fuzzy logic for internal model controller based PI.

TABLES

TABLE I - System Specifications
TABLE II. Performance Analysis for servo response
TABLE III. Performance Analysis for regulatory

AUTHOR BIOGRAPHY

M.FLORANCE MARY

ASSISTANT PROFESSOR,

DEPARTMENT OF ELECTRONICS AND INSTRUMENTATION ENGG.

PONDICHERRY ENGINEERING COLLEGE

PONDICHERRY

PHONE NUMBERS: 9047691848

Dr.R. ANANDA NATARAJAN
PROFESSOR
DEPARTMENT OF ELECTRONICS AND INSTRUMENTATION ENGG.

PONDICHERRY ENGINEERING COLLEGE

PONDICHERRY