Control and Management of Waste Water by pH Neutralization Process

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***Abstract* -- In many Industries pH is the most important parameter to Control, due to the nonlinearity of the Process. Modelling and Control of pH process is highly nonlinear and robust. The pH control process is done by mixing acid and alkaline solutions in a proper proportion so as to obtain a required pH value. The Control mechanism involves flow of acid and alkaline solutions. Conventional Proportional – Integral – Derivative (PID) and Fuzzy logic based pH controller is designed for the neutralization system. In this paper, the response of PID and the fuzzy controller is simulated and further the combined fuzzy PID based pH controller is designed and simulated using MATLAB simulink.**

Keywords— pH control, PID control, Fuzzy logic control, MATLAB.

I. INTRODUCTION

Control of pH in Waste water is important in many chemical plants like pharmaceuticals, fermentation, and metal finishing industries. pH control is very difficult to control due to high nonlinearity and it is sensitive to small disturbances when working near to the point of neutrality. Characteristic of waste water may change based on the type of industries. It is very difficult to control pH in order to achieve high performance and robust due to their time varying and nonlinear characteristics. pH is monitored and controlled by acid-base chemical reaction in which hydrogen ions and hydroxide ions are combined to form water.

pH sensor is used for online measuring for control in industries. In this paper, strong acid (HCL) is made to react with strong base (NaOH) in order to maintain a pH value at neutral between acid and base region.

The value of pH ranges between 1 to 14 and is a scale of measure of acidity of any system. If the pH value of a solution is less than 7 then the solution is said to be acidic, the concentration of hydrogen ions in the solution will be high. If the pH value of a solution is greater than 7 then the solution is said to be basic, the concentration of hydroxyl ions in the solution will be high. If the pH value of solution is 7, then the solution is considered to be neutral.

The low efficiency of chemical operations and spillage of chemicals, cause a significant pollution hazard and make the treatment of discharged wastewater a complex problem [1]. Neutralization process is used to control the pH of wastewater so that it does not have impact over the environment when discharged.

It is difficult to control the pH process due to its nonlinearities, time-varying properties and sensitivity to small disturbances. The pH is the reference indicator for neutralization. It is the negative of the logarithm to base 10 of hydrogen ion concentration in a solution [2].

PID control mechanism is based on optimal tuning of control parameters such as proportional gain(p), integral gain (I), and derivative gain (D) [3]. Fuzzy logic control is based on the choice of a proper membership function for the input and output set of parameters. Fuzzy implications and reasoning are also used extensively to build a fuzzy model for various industrial process plants [6]. Classical PID control or fuzzy logic based control does not provide an ideal performance. A Combined Fuzzy logic based PID control provides an optimally performing intelligent system [14].

II. pH NEUTRALIZATION PROCESS

The concept of pH is introduced by Serenson in 1909, where pH is defined as

$$pH = -log_{10} C_H \qquad (1)$$

where C is the Concentration of the solution (gram moles/liter).

Lewis introduced the concept of ionic activity as the pH galvanic cell was used to measure ionic activity rather than concentration, here the pH is defined as

$$pH = -log_{10} H^+ \qquad (2)$$

where H^+ is hydrogen ion concentration of the solution (gram moles/ liter).

III. PROPORTIONAL INTEGRAL DERIVATIVE (PID) CONTROL

The pH measurement is the measurement of dissociation of the acid or alkali molecules into ion. The PID mechanism is used in industrial control systems [15]. A PID controller gives the difference between the set point and the process variable by yielding the response with the desired value [14]. The PID controller is the most commonly used control algorithm in process control applications.

The PID controller has three parameters [4], where the proportional (P) (depends on the present error) gives a change in the input (manipulated variable) directly proportional to the control error. The integral (I) (accumulation of past errors) gives a change in the input proportional to the integrated error and to eliminate offset. The derivative (D) is prediction of future errors, based on present rate of change.

The simulink block representation for the PID control of pH neutralization process is shown in Figure 1 and the output step response of the PID controller is more oscillatory and is shown in Figure 2. The overall controller output is the sum of all three terms. The value of gain that is used are obtained by using Ziegler Nicholos tuning method [10]. Based on Table 1 Proportional gain K_p =26.456, Integral gain K_i =2.730322 and Differential gain K_d =0.572737

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \qquad (3)$$

Table 1: Ziegler Nicholos tuning formula for a closed loop system.

Type of Controller	P	PI	PID
Proportional K_p	0.5G	0.45G	0.6G
Integral K_i	-	$1.2K_p/P$	$2K_p/P$
Differential K_d	-	-	$K_pP/8$

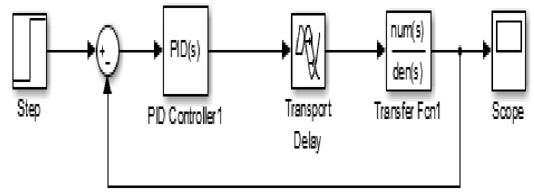

Figure 1: SIMILUNK Block diagram for pH Neutralization Process.

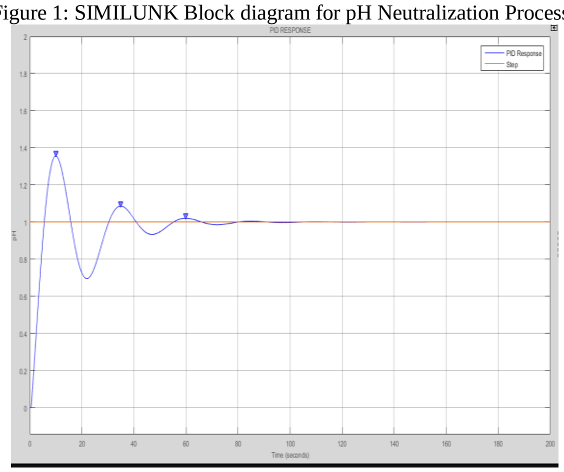

Figure 2: Step response of pH neutralization process.

IV. FUZZY LOGIC CONTROL

Fuzzy logic Controller consists of three parts: (i) Fuzzification: Converts system inputs (process variables) into grades of membership for linguistic of fuzzy sets, (ii) Fuzzy interference: maps input space to output space using membership functions, logic operations and if-then rule statements and

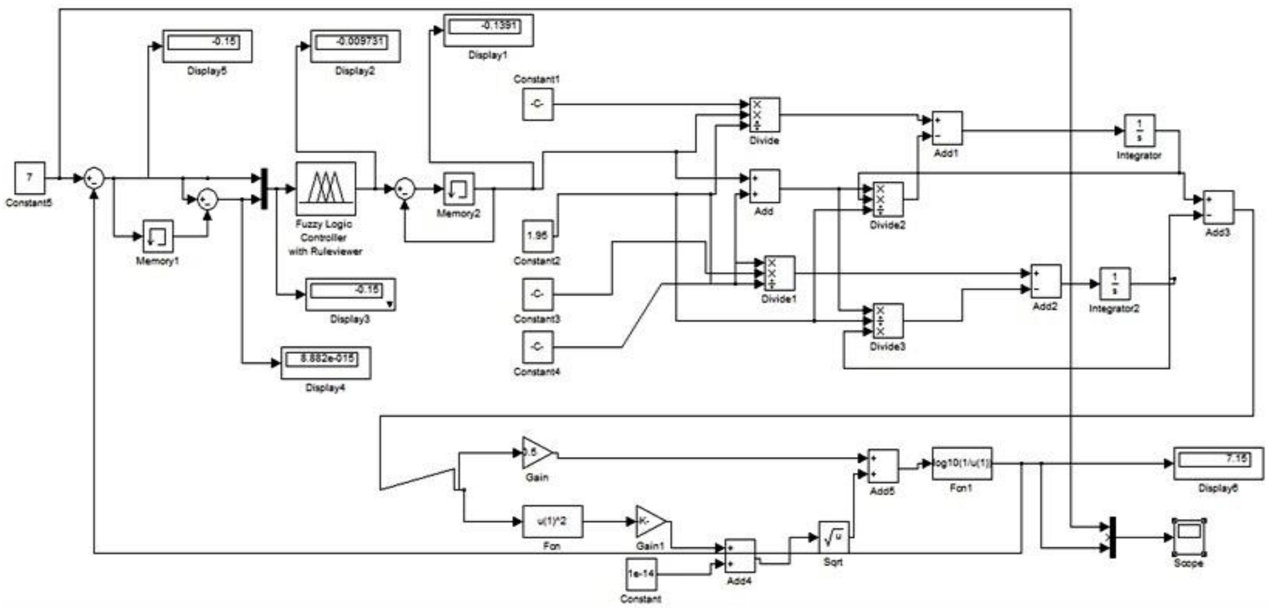

Figure 3: SIMULINK Block diagram of fuzzy logic based pH control

(iii) Defuzzification: generates a result for each and invokes appropriate rules and then combines the result of the rules [11].

The fuzzy logic controller performance mainly depends on the selection of input and output sets.

The most commonly used methodology fuzzy logic based controller for pH neutralization process is based on Mamdani fuzzy inference system (FIS). The set point of the desired pH value is entered manually while other process control variables are controlled automatically based on the feedback coming from the plant output. The fuzzy logic controller maintains the corresponding pH value while manipulating the process control variables [12].

When the pH value is less than the desired value, Fuzzy logic controller sets a new point for the valve flow rate controller [13]. The new value of current set point depends upon the difference between the current pH value of the plant reactor and the desired pH value.

Figure 3 shows the Simulink block of the Fuzzy Logic Control of pH neutralization process and the output step response of the Fuzzy controller having more disturbances is shown in Figure 4.

Table 2: Rule base for fuzzy logic based pH control

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

The relations between the inputs to output of the system are shown by the rule base Table 2.

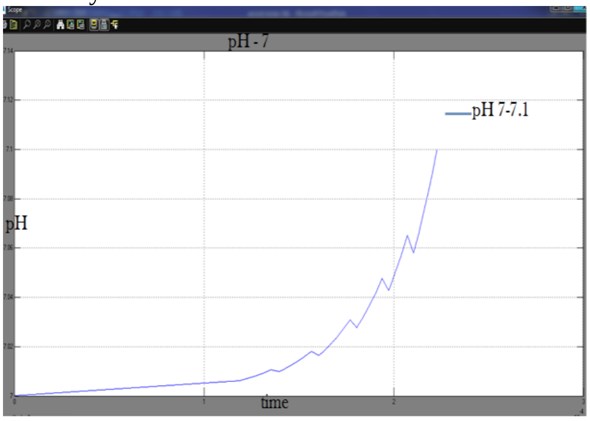

Figure 4: Response of fuzzy controller for set point pH=7, the value lies between 7-7.1

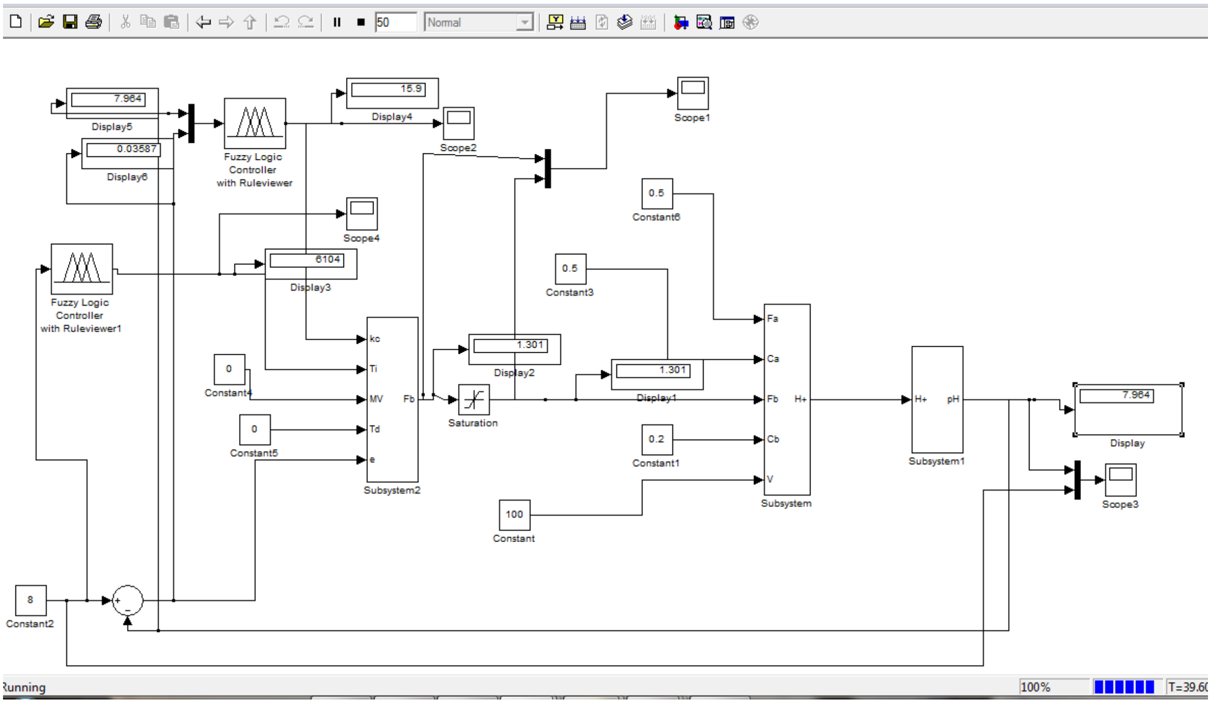

Figure 5: hybrid PID control of pH neutralization process (Fuzzy PID)

V. FUZZY LOGIC BASED PID CONTROL

The controller mainly used to directly control the pH neutralization process is the PID controller. However, a PID is a linear controller which does not suit for a nonlinear process like pH control. Gain scheduling gives a partial solution due to its rigid structure and its ability to adapt to newer parameters if hard-coded into the controller [9]. Fuzzy logic supervises the closed-loop operation of the PID controller, thus complementing and extending the conventional control algorithm as defined by Driankov [5]. Since fuzzy logic controller suits for nonlinear function, the pH process curve can be compartmentalized into linear sections for the PID controller to work on and its adaptivenes, (i.e. software), gives a huge edge over the gain scheduling method. The PID controller model is used based on the position equation PID and it is a form of parallel acting PID controller.

Mamdani FIS

The most commonly used fuzzy system and it employs shape-like membership functions in both the input and output variables [8]. The weights assigned to the inputs through the rules and the actual input parameter itself combines to create a fuzzified output shape, related by linguistic rules linking input and output, where the output is defuzzified.

Sugeno FIS

The sugeno type Fussy inference system (FIS) structure developed by Michio Sugeno [7] differs from its mamdani counterpart by having constants or linear equations for output variables. The linear equation depends on the actual input value for its computation:

Constant $y=k$, $k=$ *calculated*

Linear $y=m_1x_1+m_2x_2+.......+m_nx_n+c$

Where $m_1, m_{2,...,}m_n =$ gradient to the *n*th input, $x_1, x_2, ..., x_n$ =input variable value to the *n*th input, *c*=*y*-intercept, *y*=output variable

The manual set point used is pH=7. The typical amount of *HCL* is mixed with typical amount of *NaOH and* changes are made in order to determine the response time of the system.

Figure 5, shows the Simulink block of the Fuzzy Logic based PID Control of pH neutralization process. The rule viewer for mamdani type and sugeno type are shown in Figure 6 & Figure 7. The output step response of the Fuzzy PID controller which is free from oscillations in transient period is shown in Figure 8.

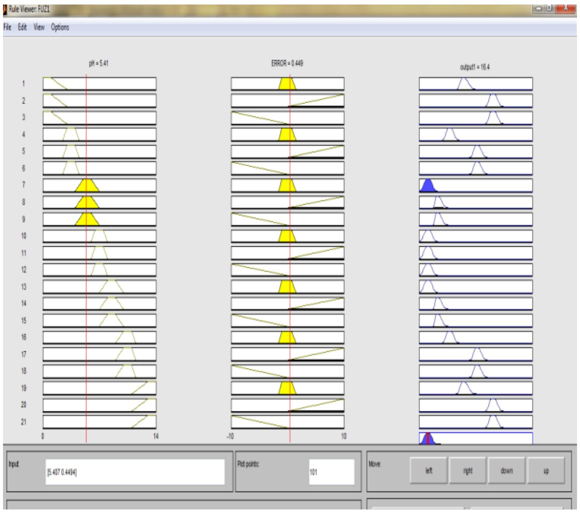

Figure 6: rule viewer- mamdani type

The performance of the combination controller of Fuzzy Logic and PID controller against normal Fuzzy logic controller for pH value =7 is observed and the response time is determined.

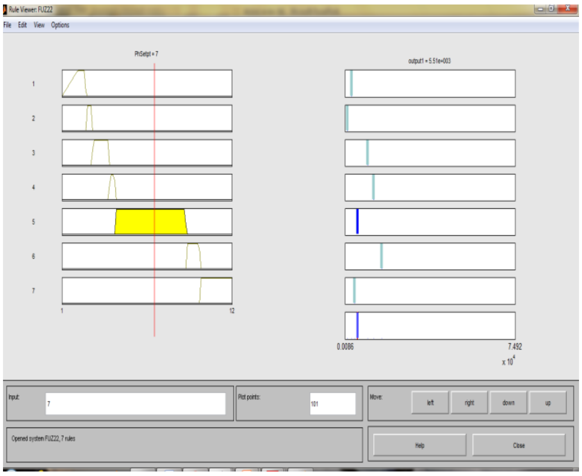

Figure 7: rule viewer – sugeno type

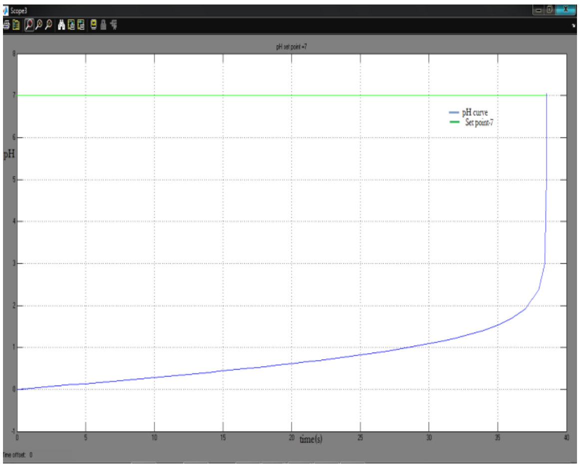

Figure 8: Response of fuzzy controller for Set point =7, output at time 100sec is 6.973

VI. RESULTS

Initially the pH value is set to 7 and at a time interval of 100 sec, the output of the system tracks the input with some disturbances. There is a delay in the output as the classical PID controller is dependent on the flow valves of acid and alkaline streams. In Fuzzy PID control the output follows the input as seen. The control valves have different rise and fall time and so the time delays are also different.

The combination control mechanism (PID and fuzzy logic controller) for control of pH neutralization process plant covers the existing Operating range of all pH values. The combination controller is high on stability when compared to the normal fuzzy logic controller. This design methodology is applicable to any general pH neutralization process plant with mechanical flow meters. The sturdiness of the combination controller is dependent on the flow rate control valve, pH meter as these instruments are the manipulating variables during real time controller design and implementation.

Proposed future work is to design an adaptive neural network based controller in order to achieve a better performance of the Process.

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