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Research Article
Comparison of Different Tuning Methods for pH Neutralization in Textile Industry

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Abstract

Background: pH neutralization control has been widely used in several chemical industries and wastewater treatment. The textile industry uses neutralization process to control the pH of wastewater so that it does not have impact over the environment when discharged. However, it is difficult to control pH process with adequate performance due to its severe nonlinearity, sensibility to small disturbance and time varying characteristics. Hence, more reliable, accurate, efficient and flexible control techniques are required for pH neutralization. **Methodology:** In this study, the pH neutralization process is modelled as a First Order Plus Delay Time model which is developed using 2-point method from the system response. A comparative study of six different tuning methods for PID controllers using MATLAB and SIMULINK is done. **Results:** From the simulation results obtained, time domain characteristics are calculated for different tuning methods of Proportional Integral Derivative (PID) controller. **Conclusion:** The results suggested that Cohen Coon tuning formula gave least rise time and minimum overshoot percentage while Zeigler Nichols and Tyreus Luyben tuning methods give reduced settling time.

Key words: pH neutralization, FOPDT, SIMULINK, tuning methods

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The textile industry consumes large quantities of water and produces large volumes of wastewater from different stages of textile production[1]. 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[2]. Neutralization process is used to control the pH of wastewater so that it does not have impact over the environment when discharged. However, it is difficult to control the pH process with adequate performance due to its non-linearities, time-varying properties and sensitivity to small disturbances when working near the equivalence point[2,3]. Therefore, more reliable, accurate, efficient and flexible control systems are required for pH neutralization process.

The pH is the reference indicator for neutralization[4]. It is the negative of the logarithm to base 10 of hydrogen ion concentration in a solution[5]. At 25°C, if the pH value is below 7 the solution has a higher concentration of hydrogen ions and thus the solution is acidic. If the pH value is 7 it shows that the solution is neutral and if the pH value is more than 7, it indicates that the solution is alkaline[6]. Wastewater treatment is one of the most challenging pH control problems encountered in the textile industry. This is mainly due to disturbances in the feed composition which are difficult to handle as different compositions will require different sets of control parameters[6]. The purpose of the chemical plant is to neutralize the waste product solution before discharging it to the environment[6]. The required pH value for effluent from a wastewater treatment unit is in the range 6-8. This is mainly to protect both aquatic and human life and also to avoid damage due to corrosion. A pH control system is used to maintain the pH value of a solution at a specific level. It measures the pH of the solution and controls the addition of a neutralizing agent to maintain the solution at the pH of neutrality or within certain acceptable limits.

Neutralization is a process for reducing the acidity or alkalinity by mixing acids and bases to produce neutral solution. It is a reaction where an acid and a base react to form water and a salt. Strong acid and strong base neutralization has a pH equal to 7 whereas the neutralization of a strong acid and weak base will have a pH of less than 7. The resultant pH when a strong base neutralizes a weak acid will be greater than 7.

As discussed by Kambale *et al.*[7], the pH neutralization system consists of two liquid streams acid and base, one feeding the acidic substance and the other feeds the base liquid. The added liquid is controlled by a proportional control valve by the controller whereas the base liquid is manually operated. To make the mixture homogeneous, a variable speed mixer or stirrer is used. The pH is picked up with the aid of a probe placed into the mixing vessel close to the outlet[7].

A proportional integral derivative (PID) is a control loop feedback mechanism widely used in industrial control systems[7]. It has good clarity and it is easy to implement. A PID controller helps to bring down the difference between the process variable and the set point by outputting the response with the desired value[8]. The PID controller is the most common control algorithm used in process control applications. As discussed by Skogestad[9], the PID controller has three principal control effects. The proportional (P) action gives a change in the input (manipulated variable) directly proportional to the control error. The integral (I) action gives a change in the input proportional to the integrated error and its main purpose is to eliminate offset. The less commonly used derivative (D) action is used in some cases to speed up the response or to stabilize the system and it gives a change in the input proportional to the derivative of the controlled variable. The overall controller output is the sum of the contributions from these three terms. The corresponding three adjustable PID parameters are most commonly selected to be[10]:

- Controller gain Kc-increased value gives more proportional action and faster control
- Integral time Ti-decreased value gives more integral action and faster control
- Derivative time Td-increased value gives more derivative action and faster control

The transfer function of PID controller is given by the Eq. 1:

$$Gc(s) = Kc\,\frac{1+1}{Ti \times s + Td \times s} \tag{1}$$

where, Kc is the proportional gain, Ti is the integral time and Td is the derivative time. Different methods have been proposed in this study to estimate the three parameters by performing a simple experiment on the plant.

MATERIALS AND METHODS

Controller tuning is adjustment of control parameters to the optimum values for obtaining the desired control response. Stability is a basic requirement. The most widely used simple feedback control strategy applied to pH control involves the PID algorithm. Adjustment of the PID settings should be performed to ensure some desired performance criteria[11]:

- Closed-loop system must be stable
- Rapid, smooth response is obtained
- Offset is eliminated
- Specific overshoot, decay ratio or rise time is obtained
- Excessive control action is avoided
- The control system is robust

The different tuning methods used for the comparative study in this project are as follows:

Zeigler nichols: The Ziegler-Nichols design method is one of the most popular methods used in process control to determine the parameters of a PID controller. It is a trial and error method which is based on sustained oscillations given by Zeigler and Nichols. It also known as continuous cycling method. Using the ultimate gain and ultimate period, the controller parameters obtained[12] are shown in Table 1. Design criteria for this method is quarter amplitude decay ratio.

Tyreus luyben: This method is similar to Zeigler-Nichols as it uses ultimate gain and ultimate period but the controller parameters are different[13] as shown in Table 1.

C-H-R method: Chien, Hrones and Reswich proposed this tuning method which is a modification of open loop Ziegler and Nichols method. They gave formulae for servo and regulatory response i.e., set point responses and load disturbance responses respectively with 0 and 20% overshoot as design criterion. The formula used[13] is the one corresponding to set point responses with 0% overshoot as given in Table 1.

Integral time absolute error: The minimum error approach is used to develop controller design relation based on a performance index that considers the entire closed loop response. Shahrokhi and Zomorrodi[13] and Smith and Corripio[14] developed tuning formulas for minimum error criteria based on a first order plus dead time transfer function as shown in Table 1. Integral of the time weighted absolute value of the error index is given by the Eq. 2:

$$\text{ITAE} = \int_0^{\infty} |e(t)|\,dt \qquad (2)$$

Internal model control: It is a two-step process which provides an appropriate trade-off between robustness and performance. Table 1 gives the formulas for first order system with dead time.

Cohen coon: Cohen Coon method is also known as process reaction curve method and its tuning formula[13-15] is given in Table 1. It is similar to the Ziegler and Nichols method and this technique sometimes brings about oscillatory responses[15].

Modelling and simulation: Per Tavakoli and Tavakoli[15], the First Order Plus Dead Time model is given as shown in Eq. 3:

$$G(s) = \frac{K \times e^{-ds}}{\tau \times s + 1} \qquad (3)$$

This project uses the transfer function developed by Kumar and Deepika[16] through open loop response curve. The process parameters are derived here using 2-point method from the system response. The transfer function hence obtained by Kumar and Deepika[16] is given in Eq. 4:

$$G(s) = \frac{5.54 \times \exp(-0.424s)}{2.210s + 1} \qquad (4)$$

The simulation is done using MATLAB and SIMULINK. The pH neutralization PID control has been created in SIMULINK as shown in Fig. 1 using the required blocks from the Simulink Library in MATLAB. Set the step block parameters as: Step time = 1, initial value = 0, final value = 7. For the PID controller set the values of P, I and D as the values of Kc, Ti and Td obtained in Table 2 using the tuning formulas given in Table 1. Set transfer function block parameters as: Numerator coefficients = [5.54], Denominator coefficients = [2.2101]. Set transport delay block parameters with time delay = 0.424. Give any appropriate variable name for Workspace block

Table 1: Different tuning formulas

Tuning methods	Kc	Ti	Td
ZN	$0.6 \times kcu$	Pu/2	Pu/8
Tyreus luyben	kcu/3.2	$2.2 \times Pu$	Pu/6.3
CHR	$(0.6 \times \tau)/(K \times d)$	τ	0.5d
ITAE	$(a1/k) \times (d\tau)^{b1}$	$(\tau/a2) \times (d\tau)^{b2}$	$(a3 \times \tau) \times (d\tau)^{b3}$
IMC	$(0.769 \times \tau)/(K \times d)$	τ	$\tau/2$
Cohen coon	$[(1 \times \tau)/(K \times d)] \times [4/3+d/4 \times \tau]$	$d \times [(32+6 \times d\tau)/(13+8 \times d\tau)]$	$d \times [4/(11+2 \times d\tau)]$

a1: 0.965, a2: 0.842, a3: 0.308, b1: -0.855, b2: 0.738, b3: 0.9292 as given by Shahrokhi and Zomorrodi[13]

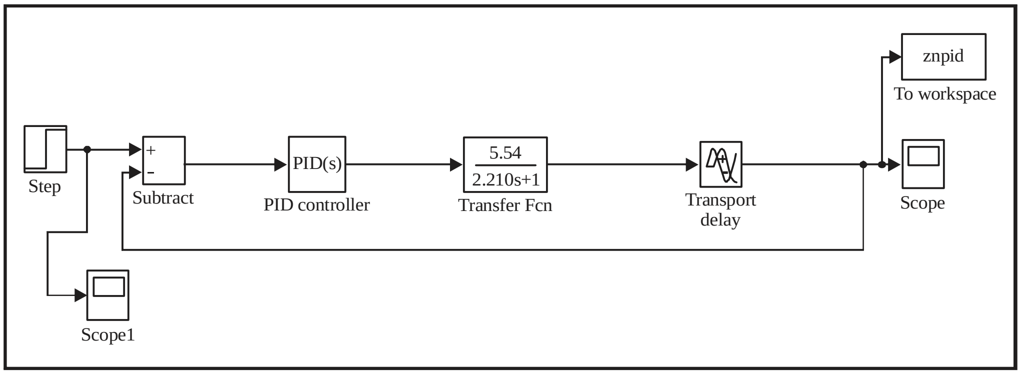

Fig. 1: SIMULINK Block diagram for pH neutralization

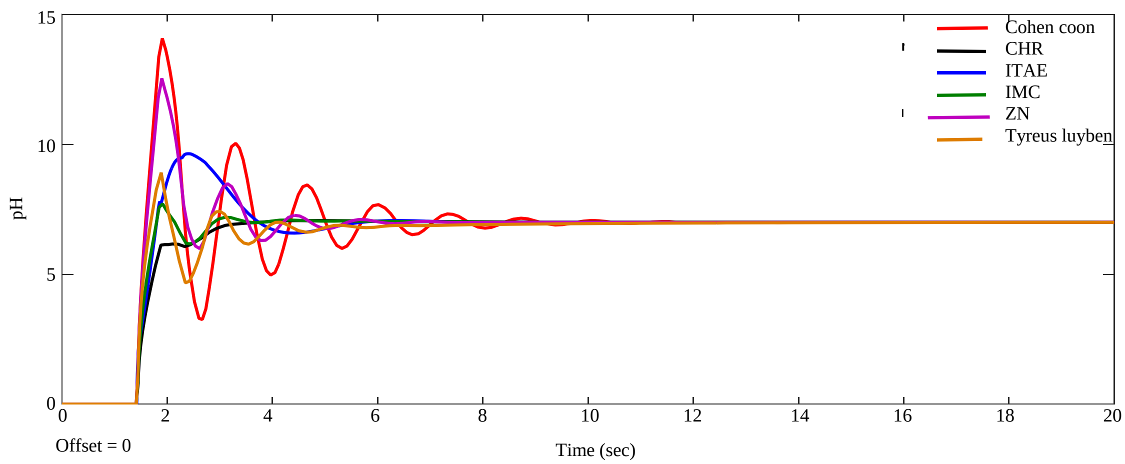

Fig. 2: Step response of different PID controllers

Table 2: Kc, Ti, Td values for different tuning methods

Tuning methods	Kc	Ti	Td
ZN	1.0588	1.324	0.212
Tyreus luyben	0.818	0.232	0.208
CHR	0.564	0.255	0.120
ITAE	0.715	0.921	0.107
IMC	0.720	0.326	0.153
Cohen coon	1.300	1.344	0.193

Table 3: Time response parameters

Tuning methods	Rise time (sec)	Settling time (sec)	Overshoot (%)
ZN	3.3767	4.9120	22
Tyreus luyben	3.4800	4.9360	16
CHR	0.1600	5.9440	14
IMC	0.4000	5.9520	12
ITAE	0.2105	6.9360	16
Cohen coon	0.0667	11.9520	12

parameters and save as array format. Change any values if required in Model Configuration Parameters. Run the simulation and check Scope for the output response.

From the SIMULINK simulation results, time domain specifications that is rise time, settling time, peak overshoot are calculated for different tunings methods of PID controller.

RESULTS

With the values of Kc, Ti and Td in Table 2, step response of the six different tuning methods obtained using MATLAB and SIMULINK are shown in Fig. 2.

Time response parameters such as rise time, settling time and percentage overshoot obtained for different PID tuning techniques are summarized in Table 3.

From Table 3 it can be observed that least rise time of 0.0667 sec and minimum overshoot percentage of 12% is achieved using Cohen Coon tuning formula. However, this method was not recommended as it gave largest settling time. Though reduced settling time of 4.912 and 4.9360 sec are reported in Zeigler-Nichols and Tyreus Luyben, respectively, they resulted with huge rise time and percentage overshoot as compared to other tuning methods which were not acceptable. Reduced rise time of less than 1 sec is shown by CHR, ITAE and IMC. Among these three tuning methods, CHR gave the smallest rise time and settling time with acceptable percentage overshoot. Hence, CHR tuning method gave the best performance as compared to the other five tuning methods in terms of rise time, settling time and percentage overshoot.

DISCUSSION

The PID controller for pH neutralization modelled as first order plus time delay system (FOPDT) was tuned using different tuning methods and the results obtained are examined and analyzed for the best tuning method. Previous study[7,8,12,15-18] done by Krishnan and Karpagam[8] and Korsane *et al*.[12] on First Order Plus Time Delay system show the performance index of CHR method PID controller is better than other PID controllers in terms of time domain specifications which is similar to the results obtained in this project. As studied by Juneja *et al*.[17] IMC controller provides best performance in comparison to other controllers like ZN, ITAE and Tyreus Luyben. The possible reason for this can be the fact that study was not done on CHR tuning method. This confirms again that CHR gives best results followed by IMC. However, Saeed and Mahdi proposed Dimensional analysis for tuning PID parameters for FOPTD system which was shown to have a clear advantage over Ziegler-Nichols and Cohen-coon methods. In addition, robustness studies performed in Tavakoli and Tavakoli[15] proved the robustness of dimensional analysis method in comparison with two other methods. Tan *et al*.[18] observed that robustness measure should lie between 3 and 5 to have a good compromise between performance and robustness. In addition to time domain specifications, Kumar and Deepika[16] calculated Error indices from the simulation results for better comparison of the different tuning methods which could be adopted for future study of this project. Also for controlling the pH neutralization process, different control strategies like Fuzzy based model, neural network based model and hybrid models apart from PID controllers could be tried as suggested by Kambale *et al*.[7] to obtain ideal control system that will perform in critical environment.

CONCLUSION

This study makes a comparative study of the different tuning methods for pH neutralization in textile industry for a first order system with time delay. Total six different PID tuning techniques were implemented and their performances analyzed. Due to high non-linearity and instability of chemical process, the most optimum and desired controller system will be the one providing: Minimum settling time to reach the set point, reduced oscillations, short rise time, eliminate offset, minimum percent overshoot, high stability in the presence of noise signals and disturbances. Among the six PID tuning techniques, the Chien, Hrones and Reswick Method PID controller gives the best results for a first order time delay system.

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