

Adaptive Genetic PH Control of a Wastewater Treatment Unit via LABView

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Abstract

This work focuses on study the dynamics and pH control of a wastewater treatment unit contaminated with toxic metals; Cu, Cr and Fe. PH is the major key factor of the precipitation process. Sodium sulfide (Na_2S) was selected, as a chemical additive to adjust the pH of water.LABview is the powerful tool to operate and control the experimental lab scale treatment unit. The predicted dynamic model of the pH process is first order lag system with dead time. The reliable tuning of control parameters could be obtained by the Internal Model Control (IMC) technique. PD scheme was undesirable control for the noisy mixed system. PI mode has found the best control strategy for the unsteady state pH process. Genetic algorithm (GA) is the suitable global stochastic technique for adaptation the controller's settings. PI genetic adaptive mode could improve the pH control of the wastewater.

Keywords: Adaptive genetic; Control; Heavy metals; LABview; pH; Wastewater.

1. Introduction

Wastewater from metal finishing industries contains contaminants such as heavy metals, organic substances, cyanides and suspended solids at levels, which are hazardous to the environment and pose potential health risks to the public. Heavy metals, in particular, are of great concern because of their toxicity to human and other biological life. Heavy metal typically present in metal finishing wastewater are; cadmium, chromium, copper, iron, zinc …etc (Sultan, 1998).

Conventionally, metal finishing waste streams are treated by chemical means and the quality of treated effluents much meets discharge standards. Several methods are used for the wastewater treatment plants such as; membranes, adsorption process and electro-chemical treatment. For large scale and industrial application, the technique used in the convention treatment of wastewater involves precipitation of metals flocculation, settling and discharge. The treatment requires adjustment of pH as well as the addition of chemicals (acid and caustic … etc).

PH is monitored and controlled by manipulating a base stream, which is usually a solution of a lime or sodium sulphide. Modern treatment plants involve physical and chemical precipitation (Chaudhuri, 2006) .Effective metal removal by sulphide precipitation (Figure 1) requires that the pH of the wastewater be controlled within the neutral to slightly alkaline range (Anast *et al*., 1995, Marchioetto *et al.*, 2002 and EPA 2005). It is difficult to formulate and identify a mathematical model for the pH process as small as amount of polluting element will change the process dynamics considerably (Shinskey, 1973).For industrial application, it is widely used on-line and PID control for control the pH of a wastewater treatment plants. The on-off type is used where the holdup time constant (time lag) of the process is high (more than 10 minutes). However, where hold up time is relatively short, multimode (PID) control is applicable (Emerson, 2004).

(Chaudhuri, 2006) studied the pH control in a neutralization process. Attempts had been made to correlate pH of the mixing process based on fundamental laws of titration under dynamic conditions and four control logics, namely, Model Predicted Control (MPC), Modified Linear control (MLC), Artificial Neural Network Control (ANN) and Fuzzy Logic Control (FLC) had been developed. PID control model was the fastest one among the other control models as far as the rise time is concerned.LABview (Laboratory Virtual Instrument Engineering Workbench) is a graphical programming language that has its roots in automation control and data acquisition (Canete *et al.*, 2008). LABview enables to interface dried environment has been applied to a wide variety of control problems such as bioprocess control (Zeng *et al.*, 2006) and thermal system control (Lin & Yin, 2007).

2. Motivation and scope of the work

PH control enhances the efficiency of the heavy metals recovery from the wastewater. Dynamic characteristics of the system provide the selection of the control settings**.** The Internal Mode Control (IMC) criteria will implement to determine the optimal settings of PID controllers. Improving the performance of control system by using advanced modes such as; adaptive and genetic adaptive schemes.LABview technique enhances the operation and control of the neutralization process with the aid of on-line digital computer.

3. Materials and methods

3.1. *Experimental Set-up*

The experimental rig is designed and constructed into the best way to simulate the real process and obtain the desirable data as shown in Figure 2.The performance of the control software system is enhanced by using LABview technique (Figure 3).

The precipitator is filled with two litters of the wastewater (pH=7.2) that contains metals; Cu, Cr and Fe at room temperature of 25 °C. The system operates automatically by using LabVIEW to monitor and control the pH of water at desired value. After reaching the desired value (pH=8), the system will shutdown automatically. Input/output signal unit includes; amplifier (AD-524), transducer and noise filter to reject any undesirable noise. Coaxial wires are using to prevent out side noise from surrounding to the interface system.

3.2. *Process reaction curve method*

It is difficult to formulate and identify a mathematical model for the pH process as small as amount of polluting element will change the process dynamics considerably (Shinskey, 1973). The pH process would be considered as a dynamic batch titration process with fast reaction and its response yields sigmoid shape curve (Chaudhuri, 2006). Precipitation is poorly known phenomenon so it is difficult to derive an accurate model for the system (Barraud *et al.*, 2009). In the present work, the dynamic characteristics of the fast pH process is obtained by the analysis of the on-line process reaction curve (Stephanopoulos, 1984) with the aid of the computer program.

3.3. *Tuning of controllers*

The Internal Model Control, IMC (Chau, 2001), adaptive and genetic adaptive control are implemented to determine the optimum settings (k_c, τ_I & τ_D) of the controllers. Since the process is very fast, the Integral absolute Error (IAE) criterion is used to determine the controllability of the closed loop system.

4. Results and Discussions

The pH responses in Figures (4-7) represent the deviation of pH above its initial value (pH=7.2).

4.1. Dynamic characteristics

Figure 4 shows that the present pH process is non-linear and has S shape under dynamic conditions. The transfer function of the neutralization process tank is:

$$G_p(s) = \frac{PH(s)}{F(s)} = \frac{1.4}{6s+1} e^{-5s} \qquad (1)$$

From technical sheets of the instruments, the transfer functions of pH electrode and control valve are:

$$G_m(s) = \frac{1}{s+1} \qquad (2)$$

$$G_v(s) = \frac{1}{6s+1} \qquad (3)$$

Equation 1 show that the neutralization process tank is approximately first order lag system with dead time (Barraud *et al.*, 2009). Dead time because of combining; pH-electrode lag, computer interface lag and bad mixing. The dynamic lags of the process caused sluggish control.

Actually, the pH system dynamically is a multi-capacitance system. Two systems in series; first represents the mixing tank as a first lag system. In addition, the second is the pH-electrode, which is almost considered as a first lag system (Equation 2). Since the time lag of pH-electrode is small (one second) when compared to that of the process (five seconds), then the system could be considered approximately as the first order lag system with dead time.

The dynamic parameters (K_c, τ_I& τ_D) are functions of tanks dimensions and operating variables (flow rate, mixing and speed …etc). These parameters are very important to obtain the optimum settings of the PID control by various methods.

Since the system is unsteady state batch process, so that the dynamic characteristics are varied with time. Then the on-line predicted model (Equation 1) is valid for the present operating and design conditions.

4-.2.*Digital control*

Table 1 explains the optimum settings of controllers. The performance of a tuned PID with IMC is not reliable because of the nonlinear characteristic of the process (Salehi *et al*., 2009).
Figure 5 proves that the proportional-integral (PI) controller is the effective and suitable scheme for the process.PH response has lower Integral of absolute of Error (IAE) and settling time when compared to proportional (P) and proportional-integral –derivative (PID) controllers. The derivative action is very sensitive action that increases the proportional gain (K_c) which possible producing excessive oscillation as shown in Figures (6a and b). However, the proportional-derivative (PD) control is not suitable for the present pH neutralization process due to minor lag, time delay and mixing noise. Generally, the wastewater pH control can present a very difficult control problem. For this reason, pH control by conventional PID controller is ineffective (Henson *et al.,* 1994).
The main reasons to use the adaptive controllers in the present process are; the process is non-linear and non-stationary (i.e. their characteristic change with time. Adaptive PI control is used with the aid of MATLAB program to generate new values of control settings. The adapted values are; K_c is 2.7 and τ_I is 20 sec.The adaptive control enhances the closed loop system as shown in Figure 7.This technique is unreliable because of the deterministic methods for tuning the control settings are not suitable for the nonlinear pH process (Salehi *et al.,* 2009).The accuracy of controller could be improved by using stochastic genetic algorithm (GA). The stochastic adaptation by GA is based on mechanics of natural selection. Table 2 explains the best parameters of GA. The adapted settings by GA are; K_c=1.34 and τ_I =18.7 sec.The stochastic GA search has found more reliable than the deterministic method for the adaptation of the PI control settings. Figure 7 illustrates the pH responses with conventional, adaptive and genetic adaptive PI control. The performance of the controlled pH system could be enhanced by the adaptive genetic control. Adaptive genetic PI control is fast to reach the desired value with lower IAE compared to the others control schemes (conventional and adaptive) as shown in Table 3 and Figure 7.

5. Conclusions

1. LABview is the powerful and versatile programming language for operate and control the fast pH system.
2. On-line process reaction curve technique is more reliable to predict the moving dynamic model of the nonlinear unsteady state neutralization process.
3. PI mode is more effective than P and PID controllers were. PD scheme was undesirable for the noisy mixed system.
4. The adaptation of controller's parameters for unsteady state nonlinear process could improve the action of the controllers.
5. Genetic algorithm has found the suitable global stochastic technique for tuning the controllers. Genetic adaptive PI control is the best scheme for adjusting the pH of the wastewater treatment unit.

Nomenclatures

F Chemical additive flow rate [cc/sec]

G Transfer function [-]

K_c Proportional gain [mv /pH]

PH Acidity [-]
s Laplacian variable, [sec^{-1}]

Substract
m measuring
p process
v valve

Greek Symbols

τ_p	Time constant [sec]
τ_D	Derivative time [sec]
τ_I	Integral time [sec]

List of Abbreviations

IMC	Internal model control
IAE	Integral of Absolute of Error
P	Proportional
PI	Proportional-Integral
PID	Proportional-Integral-derivative

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Table1.Estimated control parameters by IMC

Control scheme	Parameters		
	K_c	τ_I	τ_D
PI	0.46	5	-
PID	0.934	7.0	1.42

Table 2. Adapted parameters of GA.

Parameter	Type/value
Population type	Double vector
Population size	80
Crossover function	Scattered
Crossover fraction	0.8
Mutation function	Adaptive
Migration direction	Forward
Migration fraction	0.2
No. of generation	13
Function tolerance	1.0E-6

Table 3.Comparison between control schemes,

Type	IAE
Conventional PI	76.605
Adaptive PI	71.135
Genetic PI	65.92

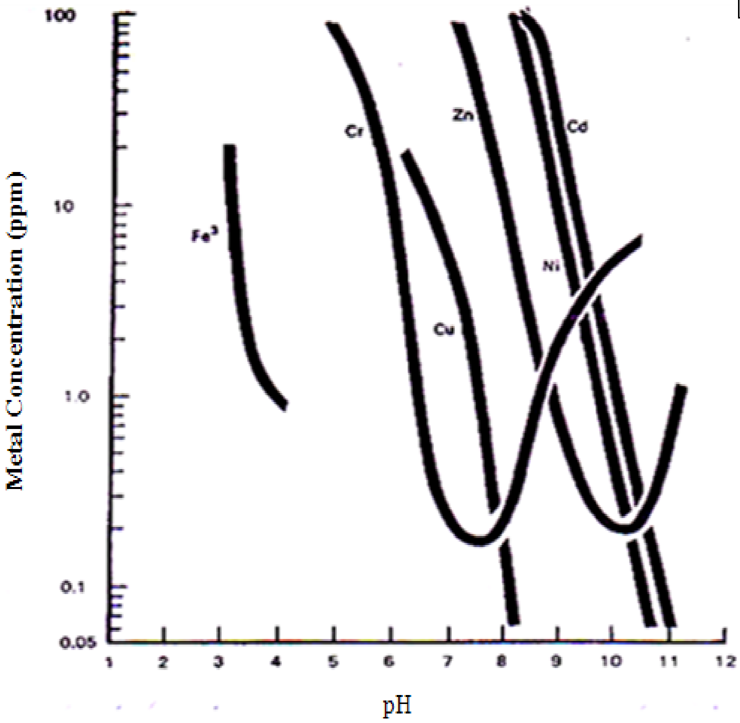


Figure 1.Precipitation of metals as a function of pH, (EPA, 2005).

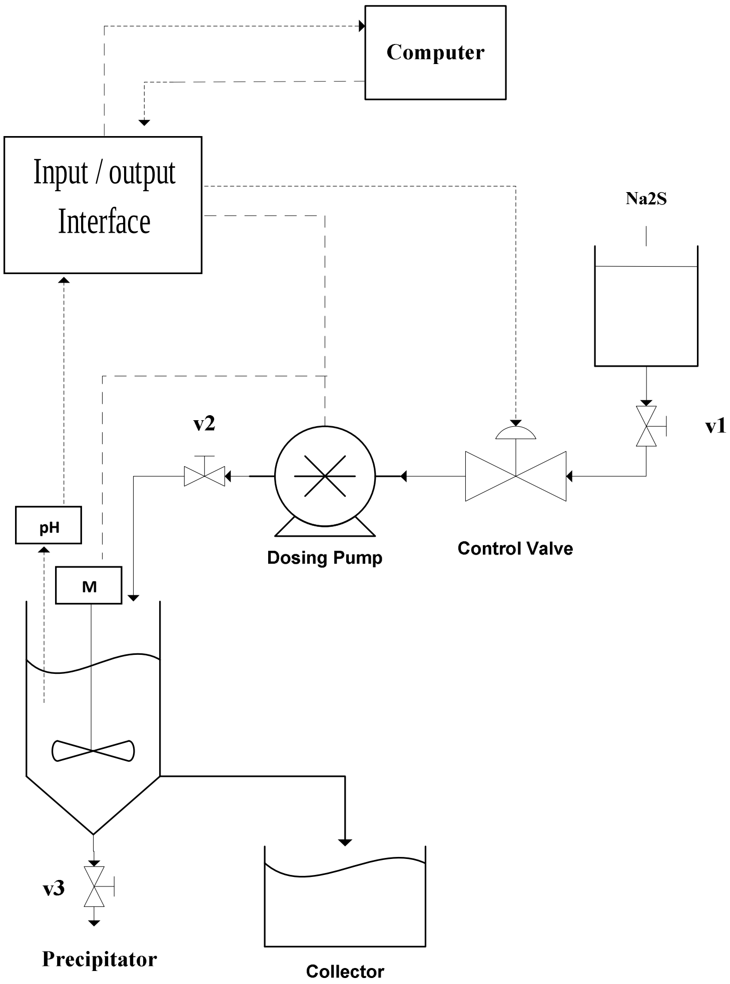


Figure 2.Experimental set-up

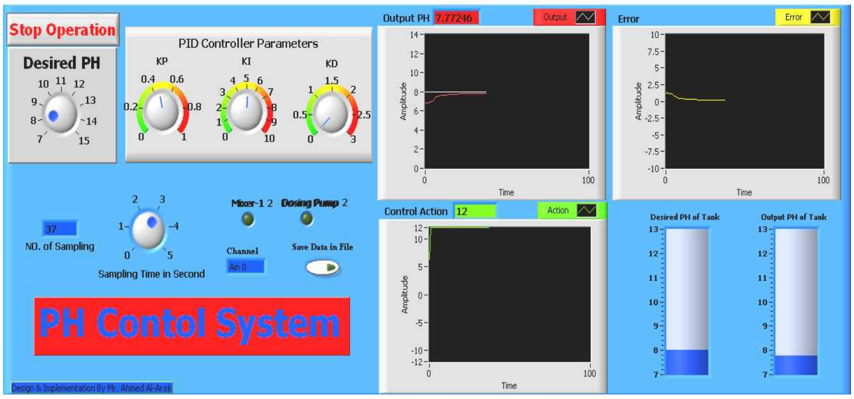


Figure 3.Front control panel of LAB view.

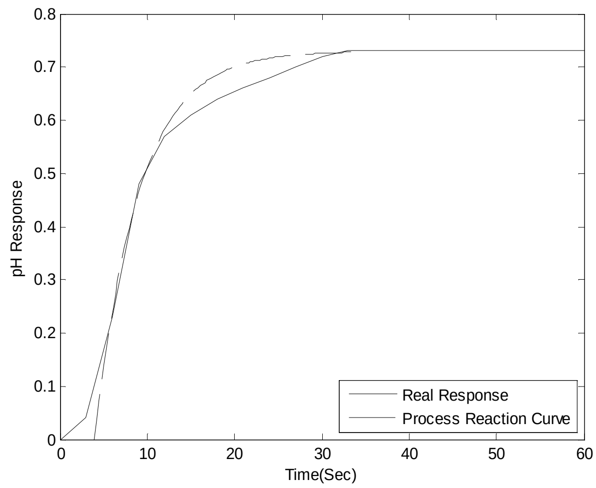


Figure 4. Dynamic analysis of pH response.

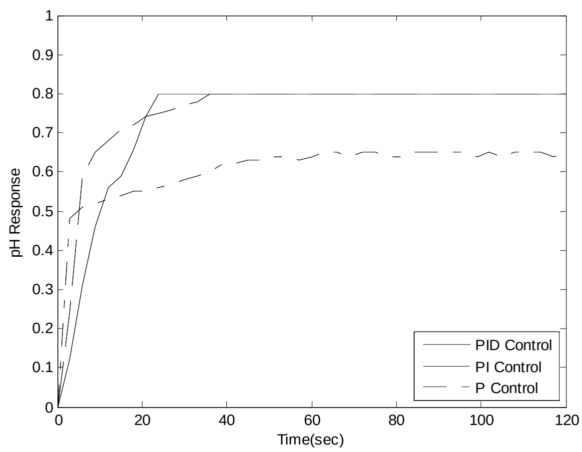
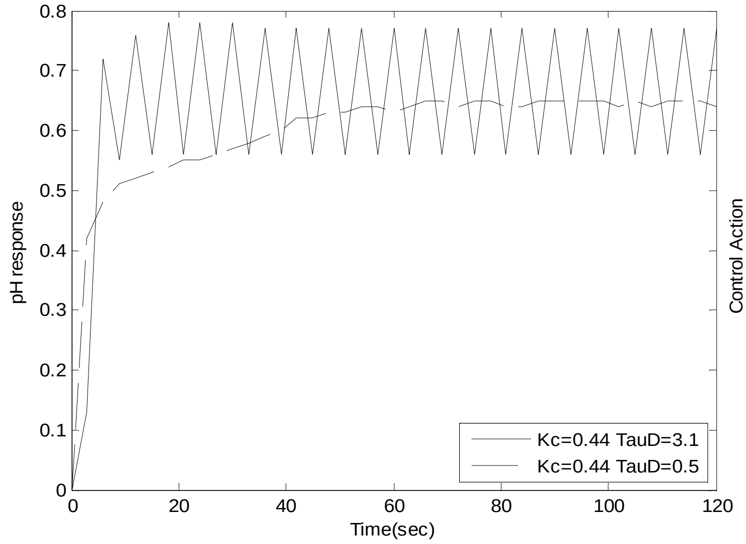
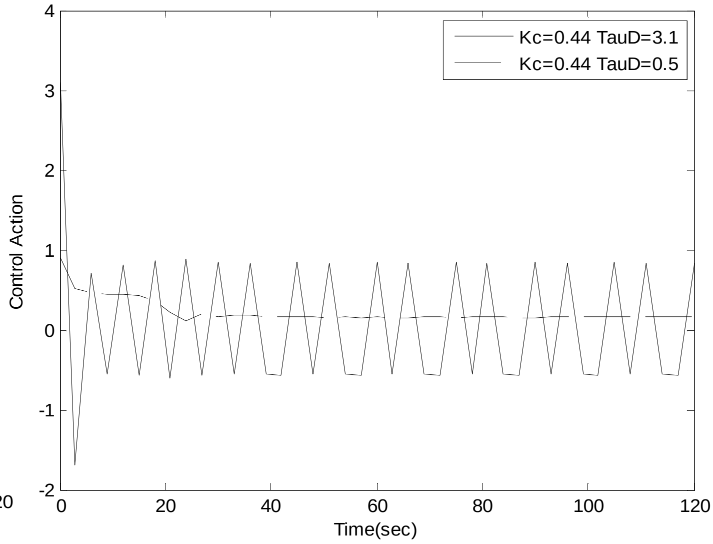


Figure 5. PH responses for different conventional PID control.



(a)



(b)

Figure 6.Responses with PD control ;(a) pH process,(b)controller action.

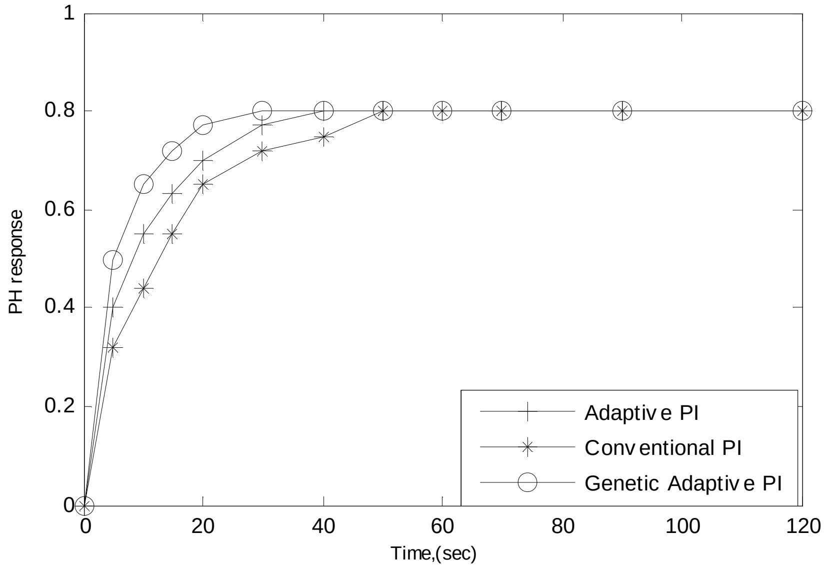


Figure 7. PH responses with different control schemes.