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pH CONTROL OF A WASTEWATER TREATMENT UNIT USING LabVIEW AND GENETIC ALGORITHM

GHANIM M. ALWAN
Assist. Prof. Dr.
University of Technology, Chemical Engineering Department, Iraq
ghnm_mag@yahoo.com

FAROOQ A. MEHDI
Assist. Lecturer
University of Technology, Chemical Engineering Department, Iraq
Farooqahmed721@yahoo.com

MURTADHA SABAH MURTADHA
University of Technology, Chemical Engineering Department, Iraq
Mur7sabah@yahoo.com

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ABSTRACT

LabVIEW technique is the powerful graphical programming language that has its roots in operation, automation control and data recording for the wastewater system with multiple contaminants of heavy metals; Cu, Cr, and Fe from the electroplating process. LabVIEW is a flexible language that contains large number of functions and tools, which enhance the performance of the process. pH of wastewater is the major key of precipitation process which selected as the desired value of the treatment system. The flow rate of chemical reagents (acid and base) can be selected as the effective decision variable. The pH process dynamically behaved as the first order lag system with dead time. Proportional-integral (PI) mode would be proven as the best scheme for control the fast pH process. Genetic algorithm (GA) was found the suitable stochastic technique for adaptation controller parameters of the unsteady state nonlinear system. PI genetic adaptive controller improves the performance of the process.

INTRODUCTION

Water pollution is a great problem that threat man's life, so water treatment is a very important issue in order to find best solution for this problem, there are many types of water pollution like biological, thermal, heavy metals and other pollution.

Wastewater from metal finishing industries is one of types that contain 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 (Sultan, 1998). It was shown that the wastewater neutralization processes performing in a continuous form present a very difficult and challenging control problem due to neutralization process is highly nonlinear and sensitivity of the water acidity (pH) to reagent addition tends to be extreme near the equivalence point, and small portion of reagent can result in a change of one pH unit.

pH has the major role for precipitation process of heavy metals from a wastewater (Figure 1). pH control in clean water treatment is relatively easy and consequently can often be satisfactorily controlled using PI control (Henson et al, 1994).

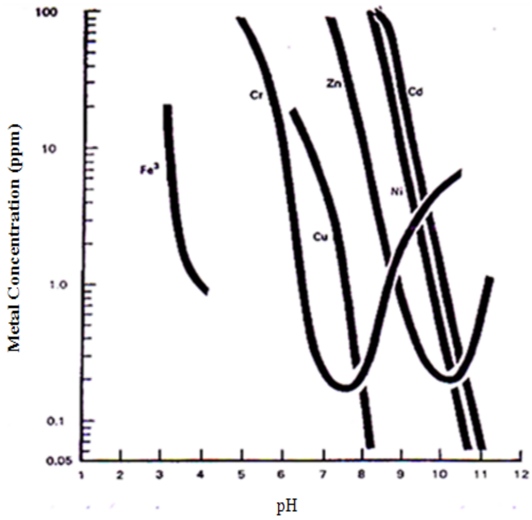

Fig. 1. Precipitation of metals as a function of pH. (EPA, 1973)

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a graphical programming language that uses icons instead of lines of text to create applications. In contrast to text-based programming languages, instructions determine the order of program execution (Zeng et al, 2006).

LabVIEW was used as a computational tool for monitoring and control system to enhance the performance of pH control for wastewater treatment unit.

The stochastic search is more suitable than deterministic algorithms for nonlinear process. GA is search algorithm based on mechanics of natural selection and natural genetics.GA is based on Darwin's theory of 'survival of the fittest'. There are several genetic operators, Such as; population, selection, crossover and mutation…etc. Each chromosome represents a possible solution to the problem being optimized, and each bit (or group of bits) represents a value of variable of the problem (gene). A population of chromosomes represents a set of possible solution. These solutions are classified by an evaluation function, giving better values, or fitness, to better solution (Gupta et al, 2006).

OBJECTIVE OF THE WORK

1. Study the process variables that may affect the pH of wastewater in order to find the decision variables that can be considered as manipulated variables.
2. Study the dynamic characteristics of the nonlinear pH systems.

3. Implementing of the optimal criteria for selecting the PID controllers' settings.
4. Improving the control system using adaptive and genetic adaptive control algorithms.

EXPERMENTAL SET-UP

The Lab-scale experimental wastewater treatment set-up was used to evaluate the performance of the control software developed in LabVIEW (Figure 2). The experimental rig was designed and constructed into the best way to simulate the real process and collect the reliable data (Figures 2 and 3). The process consists of the following equipments:

1. Two precipitators' tanks.
2. Two chemical reagent storages for H_2SO_4 and NaOH.
3. Dosing pump for chemical reagents.
4. Motorized control valve.
5. Inputs/output interface system.
6. Digital computer (*hp* Laptop).

The precipitators are filled with 2 litters of the wastewater that contain heavy metals; Cu, Cr and Fe at room temperature of 25 ℃. The system will operate automatically using LabVIEW to monitor and control the pH of water at desired values for acidic and hydroxide processes. After reach to steady state, the system will shutdown automatically.
The treatment process includes the following steps:

1. Adjustment of the pH of wastewater**.**
2. Reaction of heavy metals ions with sulphuric acid then with sodium hydroxide respectively.
3. Precipitation of sludge**.**
4. Evacuations and filtration of clear water thorough sand filter.

pH of the wastewater has the major effect on the precipitation process of heavy metals. Therefore, the acidity control of the wastewater becomes the essential aim for treatment process (Sultan, 1998).

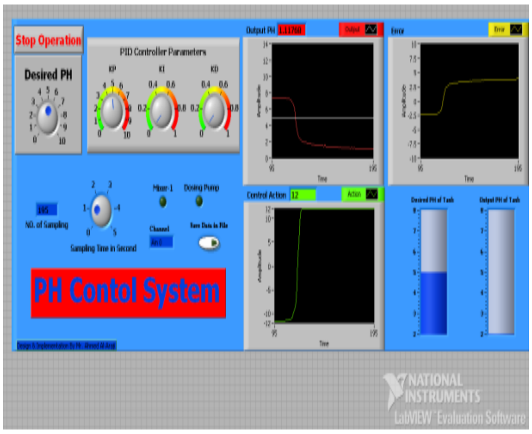

Fig. 2. LabVIEW front panel of pH control system.

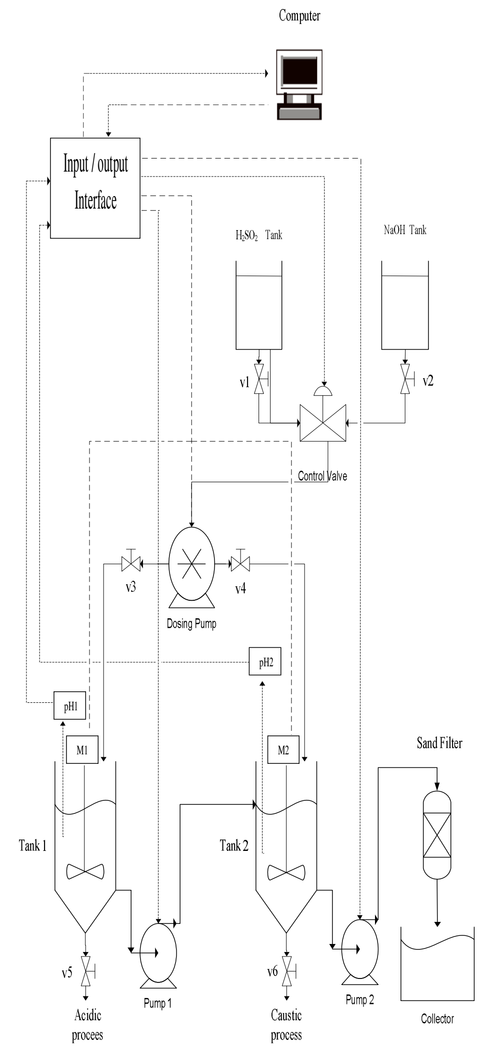

Fig. 3. Schematic diagram of experimental set-up.

RESULTS AND DISCUSSION

Selection of manipulated variables

Two critical variables could be selected as the decision variables that are; the inlet flow rate & concentration of sulphuric acid and sodium hydroxide. These variables are selected as the manipulating variables in process control.

Formulating of the process correlations

Newton-Quasi method is used to formulate the developed correlations of the process depended on experimental data with the aid of the computer program (MATLAB Version 7.10 (R2010a)). The empirical equations correlate the desired values with the decision (manipulating) variables. The interacted correlations are:

For acid neutralization tank:

$pH_1=6.5–7.367N_1^{0.2}F_1^{0.229}$ (1)

And, for base neutralization tank:

$pH_2=4+2.92N_2^{0.039}F_2^{0.233}$ (2)

With inequality constraints:

$1.5 < F_1 < 4.0$

$0.5 < F_2 < 2.0$

$0.005 < N_1 < 0.05$

$0.05 < N_2 < 0.1$ (3)

Equations (1 and 2) are used to select the effective variable on pH. It shows that the power of flow rate (F) is greater than that of concentration (N), so the flow rate can be considered, as the more effective variable will be used as the manipulated variable for two process tanks. As in the most industrial processes, the flow rate of chemicals is used as a manipulated variable due to simpler design control system (Marchioetto, 2002).

The optimum value of pH for acidic neutralization tank is (≅2) while equal to (≅8) for basis tank. These values would be taken as the desired values of the controlled systems.

Dynamic characteristics

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). It is better that the dynamics characteristics of the pH process will be studied without precipitation using process reaction curve at the desired operating conditions. 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). Figures (4 and 5) show that the present pH process is non-linear and has S shape under dynamic conditions.

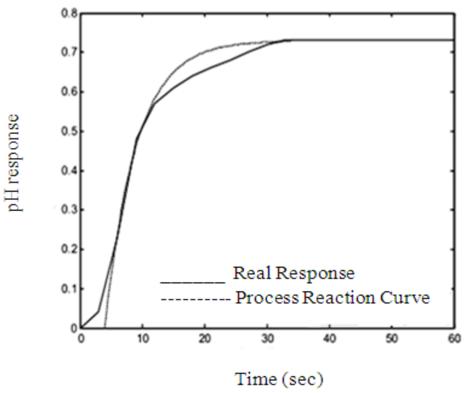

Fig. 4. pH dynamic response of acidic reagent using PRC.

The dynamic responses of the neutralization tanks against step change in the chemical reagents (acid / base) flow rates were illustrated in Figures (4 and 5). Process reaction curve (PRC) method was implemented for two processes (Stephanopoulos, 1984). Figure (5) explains the PRC analysis of hydroxide neutralization process. In addition, the similar analysis was applied to the sulphuric acid neutralization tank.

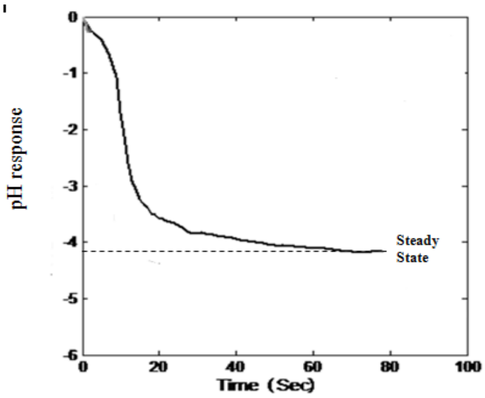

Fig. 5. pH dynamic response of hydroxide reagent using PRC .

However, the transfer functions of the pH systems are:

For acid process:

$$G_{p1}(s) = \frac{pH(s)}{F(s)} = \frac{-1.04}{4s+1} e^{-3s} \quad (4)$$

While for base process:

$$G_{p2}(s) = \frac{pH(s)}{F(s)} = \frac{1.6}{6s+1} e^{-4s} \quad (5)$$

From Equations (4 and 5), the dynamic approach of the pH process is the first order lag system with dead time.The dynamic model of the system is valid for the certain operating conditions (Equation 3) .The transfer functions of the processes are required for estimation the optimum controllers settings by different control schemes. Actually, the pH system can be dynamically described as a multi-capacitance system. Two systems in series; first represents the mixing is tank as a first lag system and the second is the pH-electrode which can be almost represented by first lag system. Since the time lag of pH-electrode was small (about one second) when compared to that of the process, then the system approximately can be represented by the first order lag with dead time model. Since the system was unsteady state pH process, so that the dynamics characteristic could be varied with time.

Conventional PID Controller

In the present work, the process reaction curve method (Stephanopoulos, 1984) was used to find the initial control settings. Figures (6 & 7) and Tables (1 & 2) prove that the proportional-integral (PI) controller is the effective and suitable scheme for both processes. This is due to that the 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 will increase the proportional gain (K_c) which possible producing excessive oscillation as shown in Figures (8-a and 8-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).

Table 1. Conventional PID controllers for acidic process.

Type of Control	IAE	Settling time(sec)
P	96.99	23
PI	76.60	19
PID	92.02	24

Table 2. Conventional PID controllers for hydroxide process.

Type of Control	IAE	Settling time(sec)
P	146.9	81
PI	129.5	66
PID	137.1	72

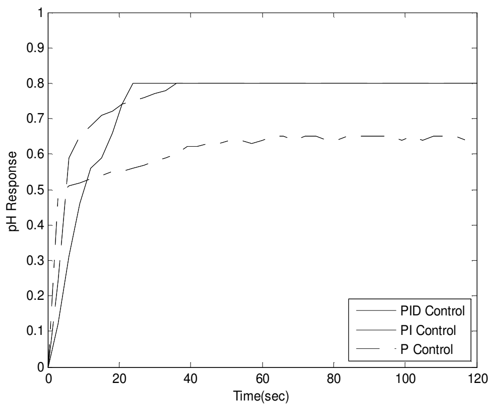

Fig.6. pH responses of acidic process using conventional PID control.

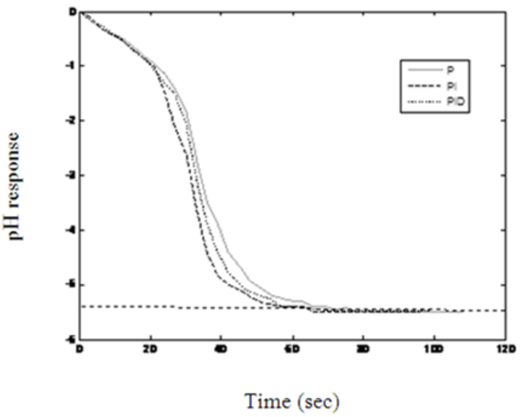

Fig. 7. pH responses of hydroxide process using conventional PID control.

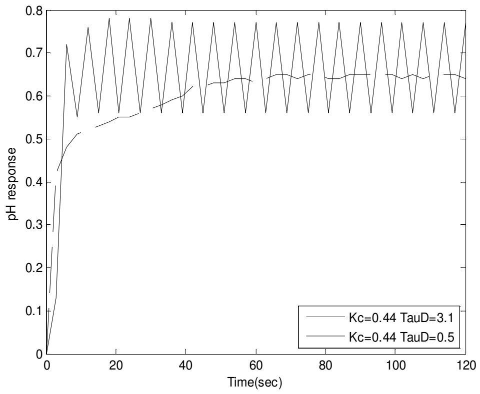

Fig. 8-a: pH responses using PD control for hydroxide process.

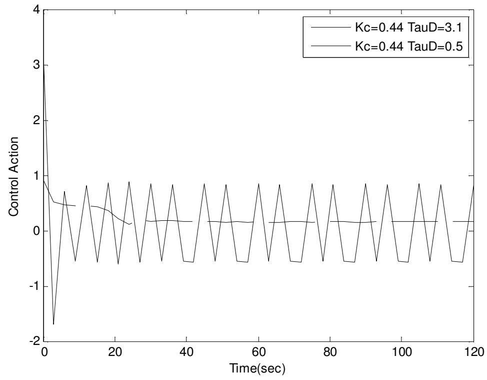

Fig. 8-b. PD control action for hydroxide process.

The performance of a tuned PID with PRC technique was not satisfactory due to the nonlinearity characteristic of the process (Salehi et al, 2009).

Adaptive PI controller

The main reasons to use the adaptive controllers in the present pH process are; the process is non-linear and non-stationary (i.e. their characteristic change with time. Adaptive PI control was used with the aid of MATLAB program to generate new values for proportional gain (K_c) & integral time constant (τ_I) as shown in Table (3) for both acidic and caustic processes. The deterministic adaptations mechanism is based on the present transfer functions of the system in s-domain and depending on criteria of minimizing the error (Henson et al, 1994 and Salehi et al, 2009).The inaccurate results in the adaptive technique was due to that the sequence of controller parameters adaptation operated in series i.e., estimating the optimum K_c firstly, then the optimum τ_I was calculated secondly after interval time .The deterministic method was not accurate estimation since the pH system was highly nonlinear and the process variables were suddenly changed (Salehi et al, 2009).

Table 3. Adaptive control system results.

Process	Acidic	Caustic
K_c	1	2.7
τ_I,sec	8	20

Genetic Adaptive Control

The stochastic genetic algorithm (Figure 9) was implemented to improve the settings of PI controller of acidic and caustic processes with the aid of the MATLAB computer program. GA is search algorithm based on mechanics of natural selection and natural genetics. The stochastic adaptations mechanism is based on the present transfer functions of the system in z-domain. Table (4) explains the best operators of GA. The stochastic mechanism of adaptation by genetic algorithm used to determine the optimum controller settings (K_c & τ_I) as shown in Table (5).The stochastic genetic search method has found more reliable than the deterministic method for adaptation of the PI controller setting. Figure (10) and Table (6) show the improvement in the response of pH by adaptive PI control regarding to the conventional type.

Figure (10) illustrates the pH responses with conventional, adaptive and genetic adaptive PI control. Genetic adaptive PI control was fast to reach the desired value and with low IAE compared to the others control schemes (conventional & adaptive) as shown in Table (6).

Table 4. Adapted operators of GA.

Operator	Type and values
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 5. Genetic algorithm controllers' settings for acidic & caustic processes.

Process	Acidic	Caustic
K_c	0.98	1.34
τ_I,sec	6.25	18.7

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Tables 6. Comparison between control types for acidic & caustic processes.

Process	Type	IAE
Acidic	Conventional PI	129.555
	Adaptive PI	122.415
	Genetic PI	116.52
Caustic	Conventional PI	76.605
	Adaptive PI	72.135
	Genetic PI	66.92

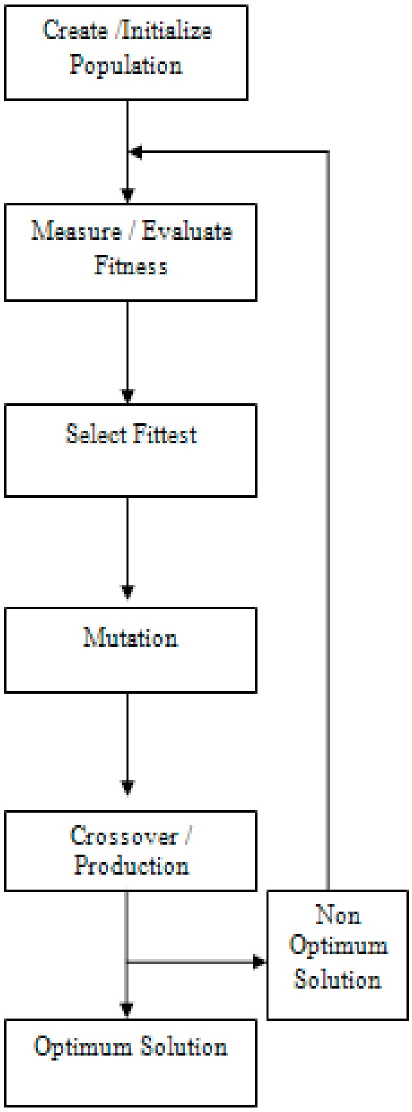

Fig.9.Flowchart of Genetic algorithm.

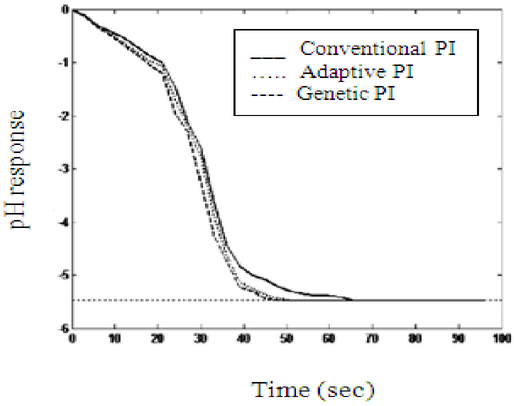

Fig.10. pH responses using different control scheme for acidic process.

CONCLUSIONS

1. LabVIEW was found the powerful and versatile programming language for operating and controlling the fast pH process.
2. The flow rate of chemical reagents (NaOH & H_2SO_4) can be selected as the effective and manipulated variable for control the pH of the wastewater treatment system.
3. PI mode is more effective than P and PID controllers were. PD scheme may be undesirable for the noisy mixed system.
4. The adaptation of controller parameters for unsteady state and nonlinear system enhances the efficiency of the controller.
5. Genetic algorithm was found the suitable stochastic search technique to evaluate the controller parameters. Genetic adaptive PI control is the best scheme for adjusting the pH of the wastewater treatment process.

NOMENCLATURE

F_1 Flow rate of sulphuric acid, [cm^3/sec] F_2 Flow rate of sodium hydroxide, [cm^3/sec] $G_{p1}(s)$ Transfer function of acidic system, [pH/ cm^3 /sec] $G_{p2}(s)$ Transfer function of base system, [pH/ cm^3 /sec] N_1 Inlet concentration of acid solution, [mole/ L] N_2 Inlet concentration of base solution, [mole/ L] s Laplacian variable, [sec^{-1}]

Greek Letters

K_c Proportional gain, [Mv/pH]
τ_I Integral time constant, [sec]

LIST OF ABBREVIATIONS

IAE Integral of Absolute of Error
GA Genetic Algorithm
LabVIEW Laboratory Virtual Instrument Engineering Workbench
P Proportional
PD Proportional-Derivative
PI Proportional-Integral
PID Proportional-Integral-Derivative
PRC Process Reaction Curve

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