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Textile Wastewater Treatment with Coagulation and GPC Control

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This paper presents an experimental application of Linear Generalized Predictive Control (LGPC) to study the coagulation process of wastewater treatment in a commercial textile dye plant. Firstly, the coagulant ($MgCl_2$) was added to the textile dye wastewater, thereby depressing the pH and the reaction proceeded before pH was increased to a desired level (variable pH pathway) by the lime-water solution using GPC (Generalized Predictive Control) controller. H_2SO_4 solution of 10 % was sent to the reactor simultaneously with the manipulated variable (lime-water) to hold the desired set point of pH at 12. Linear (CARIMA) model is utilized in the GPC algorithm. A Pseudo Random Binary Sequence (PRBS) signal was employed to operate the system. The model parameters are evaluated by using Least Squared Regression. Finally, the GPC performance has shown in a reduction of 78 % absorbance value or suspended solids in the treatment of industrial waste.

1. Introduction

Generalized Predictive Control (GPC), which was originated by Clarke et al. (1987) and Camacho and Bordon (1999), has been widely studied theoretically and used in industrial applications. But in the literature, a few studies have investigated the use of two-stage or multistage coagulant addition processes for textile dye water treatment with advanced control techniques or GPC. In one of the methods, the coagulant was added to the water, thereby depressing the pH, and the reaction proceeded before pH was increased to a desired level (variable pH pathway) with manipulated variable. In another method the coagulant was mixed with base prior to contact with the water (constant pH pathway) Tommaso and Benshoten (1996). Other studies, Zeybek et al. (2007 a, b) have carried out to develop a reliable and effective real-time control strategy by integrating artificial neural network (ANN) process models to perform automatic operation of dynamic continuous-flow or batch systems.

In our study, GPC focuses on the effect of pH in different influent systems with single type of coagulants. The purpose of this study is to improve and apply the pH control of two-stage treatment of high-strength dye wastewater on the basis of GPC. In this study, $MgCl_2$ is used as the coagulant. $MgCl_2$ is a commonly used coagulant in the industrial wastewater treatment as alum and PAC. A number of researchers have revealed that enhanced removal of impurities or pollutants has been observed in the presence of magnesium by Tan et al. (2000) and Gao et al. (2007). Liao and Randtke (1986) reported good coagulation could be achieved if enough Mg^{2+} ion was presented in the system of lime treatment.

2. Experimental Setup

Clarification experiments were carried out in a 1liter glass-jacketed reactor as shown in Figure 1. The pH was measured with a pH meter and was recorded on-line every 1 second by a computerized data acquisition system. The pH meter converts the pH signal (0 to 14) into a voltage signal (0 to 10V) for onward transmission to an A/D (analogue-to-digital) channel of an IBM 586-compatible control computer. The control programs were written in Visual Basic (VISIDAQ). In the experiments, the GPC based strategy took data from the on-line pH monitor and adjusted the peristaltic control pump. The control pump delivered a solution of concentrated $Ca(OH)_2$ into the wastewater reactor recycle line at a maximum rate of 9.5 ml min^{-1}. During start-up the $Ca(OH)_2$ flow rates were maintained at 5.8 ml min^{-1}.

In the experimental work, the reactor was first charged with wastewater from a commercial dye plant. The contaminants of the dye wastewater are listed in Table 1. The coagulant used in this plant is magnesium chloride ($MgCl_2$). The coagulant is added to the wastewater medium, before the reaction starts. Dosages of this chemical is 5 g/l in the reaction medium. In the case of magnesium chloride, the optimum pH for coagulation tends to lie between 11.5 and 12. Thus pH adjustment is essential before coagulation begins. Once the desired steady state is reached, control is switched to the algorithm under study. Agitation is provided by a mechanical stirrer operating at 450 rpm. The control valve on the $Ca(OH)_2$ stream is the final control element while the H_2SO_4 is used to introduce at the desired flow rate into the system.

As shown in Figure 1, the acidic stream is fed into the reactor by a metering pump from the top of the reactor. It is not controlled, but flows in as a step disturbance effect and the acid flow rate is set according to reactor volume. Then the pH is monitored.

Table 1 Analysis results of the commercial textile dye plant wastewater

Sample	*Pollutants*	*Raw mg/L*	*Treated mg/L*	*Pollutants*	*Raw mg/L*	*Treated mg/L*
Textile Wastewater	Al	0.023	0.032	Cu	0.003	-
	B	0.045	0.030	Fe	0.113	0.006
	Cd	-0.013	-	Mn	0.005	-
	Co	-0.013	-	Ni	-0.014	-
	Cr	0.047	0.004	Pb	-0.009	-
	Cu	0.003	-	Zn	0.056	-

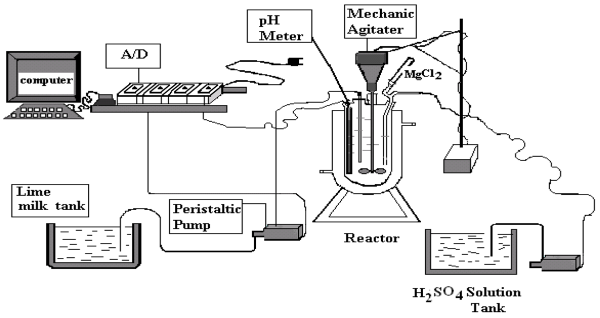

Figure 1: Experimental set-up

At the end of the reaction (after approximately 400 s), polyelectrolite is added and the reactor is agitated slowly for 20 minutes. The addition of additive chemicals (e.g. polyacrylamides at 1 mg/L) enhances the coagulation through promoting the growth of flocks. The samples are then allowed to stand for 60 min, after which the color and absorbance value of the supernatant water are measured.
The wastewater in this study from chemical plants is composed of a number of different streams drawn from different sources. The overall composition and the concentrations of the individual species are both unknown and non-stationary. Generally, neutralization processes are non linear and difficult to model. Usually detailed first principle dynamic models are amenable to practical control designs. The success of an MPC algorithm depends heavily on the quality of the model chosen. It is therefore of greatest importance to select a model structure and a set of model parameters to obtain a model with sufficient predictive precision. In the present work, process models have been developed as a CARIMA model. The GPC control method has been implemented to pH control for color and contaminants removal of the textile dye wastewater.

2.1 Formulation of generalized predictive control

Most single-input single-output (SISO) plants, when considering operation around a particular set point and after linearization can be described by

$$A\left(z^{-1}\right)y(t) = z^{-d}B\left(z^{-1}\right)u(t) + C\left(z^{-1}\right)e(t) \tag{1}$$

Where u(t) and y(t) are the control and output sequence of the plant and e(t) is a zero mean white noise. A, B and C are the following polynomials in the backward shift operator z^{-1}:

$$A\left(z^{-1}\right) = 1 + a_1 z^{-1} + a_2 z^{-2} + \ldots + a_{na} z^{-na} \tag{2}$$

$$B\left(z^{-1}\right) = b_0 + b_1 z^{-1} + b_2 z^{-2} + \ldots + b_{nb} z^{-nb} \tag{3}$$

$$C\left(z^{-1}\right) = 1 + c_1 z^{-1} + c_2 z^{-2} + \ldots + c_{nc} z^{-nc} \tag{4}$$

Where d is the dead time of the system. This model is known as a Controller Auto-Regressive Moving Average (CARMA) model. It has been argued that for many industrial applications in which disturbances are non-stationary an integrated CARMA(CARIMA) model is more appropriate. A CARIMA model is given by

$$A\left(z^{-1}\right)y(t)=B\left(z^{-1}\right)z^{-d}u(t)+C\left(z^{-1}\right)\frac{e(t)}{\Delta} \tag{5}$$

with $\Delta = 1 - z^{-1}$

For simplicity in the following the C polynomial is chosen to be 1. Notice that if C^{-1} can be truncated it can be absorbed into A and B.

Consider the vector error (ε) composed of predicted future system errors $W(t+j)-\hat{y}(t+j)$. W is the reference signal. The suggested future control sequence $\{u(t+j)\}$ is chosen by GPC at time t to minimize a cost-function such as

$$J\left(N_1, N_2, NU, \lambda\right)=\sum_{J=N_1}^{N_2}\varepsilon^2\left(t+j\right)+\lambda\sum_{j=1}^{NU}\Delta U^2\left(t+j-1\right) \tag{6}$$

N_1 is the minimum costing horizon, N_2 is the maximum costing horizon, N_U is the control horizon, λ is the (optimal) control weighting.

3. Results

In this study, the use of GPC for modeling and pH control in a textile dye wastewater treatment reactor is demonstrated experimentally. This control which model parameters are estimated by using CARIMA model and calculates the manipulated variable from GPC. In addition, the work applies only to single-loop systems where changes in process gain outweight those in process time-constant.

Open loop trends of the state variable (pH) when the pump feeding rate of concentrated lime solution as a control input is varied randomly are given in Figure 2. For this purpose, the model parameters calculated using the least squares regression method are given as follows:

$$y(t)=\frac{B}{\Delta A}u(t-1) \tag{7}$$

$$\left[y(t)-y(t-1)\right]=-a_1\left[y(t-1)-y(t-2)\right]-a_2\left[y(t-2)-y(t-3)\right]+b_0u(t-1) \tag{8}$$

$a_1 = 0.5877$ $a_2 = 0.283$ $b_0 = 0.00146$

These coefficients (b_0, a_1 and a_2) were found by using a pseudo random binary sequence as the input function. A second order polynomial is sufficient to represent the denominator plant dynamics. The system is defined and the model parameters are calculated using the least squares regression method given as follows. Regression coefficient (R^2) is found as 0.99

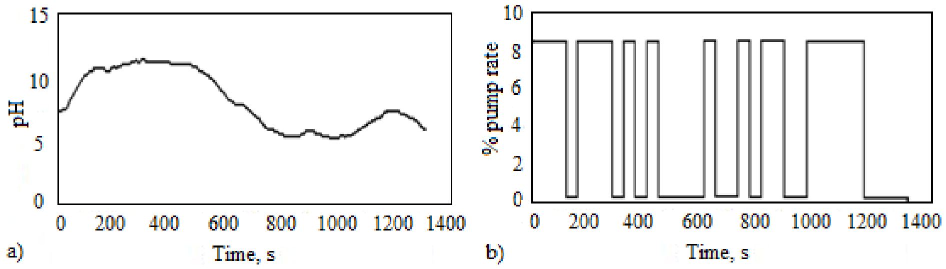

Figure 2: PRBS Signals a) pH response b) Controller outputs

Suitable parameters which are N_1, N_2, N_u are taken as default parameter such as N_1=2, N_2=7, and N_u=1. Adjustment parameter which is λ was determined and taken as λ=1.125. Experimental control results are shown in Figure 3 and 4, for GPC. For GPC, as it can be seen, the pH closely follows the optimum set point of 12.

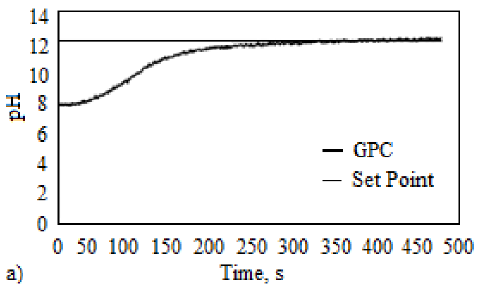

Figure 3: GPC Performance for the commercial textile plant output of treated wastewater without control a)pH responses b)Lime flows

Although there is a difficult control at pH 12, the GPC adapts better to the optimal set point trace. It is noted that the absorbance value obtained by using GPC algorithm is less than one without treatment (see Table 2).

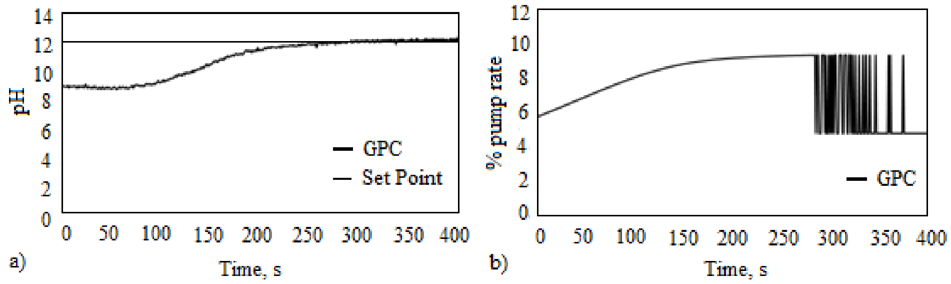

Figure 4: GPC control performance for raw textile dye wastewater a) pH responses b)Lime-water flowrate changes with time

Table 2 The percentage removal of coloring matters from a dye effluent by $MgCl_2$

Test	*Sample*	*Raw (Abs.)*	*Treated (Abs.)*	*% Removal*
Colour	1	0.327	0.071	78
	2	0.562	0.151	73

4. Conclusion

The GPC control strategy is discussed and is tested by controlling a SISO pH textile treatment system. This work shows the ability to apply model based predictive controllers for controlling a state variable in a nonlinear system. The nonlinearities in the process require nonlinear properties in the controller. But linear GPC is sufficient to realize the pH control and color removal. The use of a GPC for system identification is a feasible alternative when model equations are known or only historical input-output data are available.

From the experimental results, it is noted that suggested control system shows good control performance for processes with nonlinearities and model–plant mismatch. Also magnesium chloride is good coagulant for this suggested dye treatment system strategy.

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