JELENKA B. SAVKOVIĆ–STEVANOVIĆ[1]
VARREN D. SEIDER[2]
LYLE H. UNGAR[2]

1Faculty of Technology and Metallurgy, Belgrade, Yugoslavia

2Department of Chemical Engineering, University of Pennsylvania, USA

SCIENTIFIC PAPER

66.012–52+681.5.017"SPEEDUP"

A FUZZY LOGIC CONTROLLER FOR pH CONTROL OF A CHEMICAL STIRRED TANK

This paper studies fuzzy dispersion process modeling and cognitive process analysis incorporated in a SPEEDUP simulation. A fuzzy logic control system was applied for pH control in a chemical stirred tank. A fuzzy controller was developed by modeling the quantitative information from SPEEDUP with qualitative information by fuzzy logic. A fuzzy logic controller – FLC demonstrated more robustness to added noise and changes in plant parameters that a PI controller. This controller improves quality control and determines optimum set points. The FL–PI controller showed successful control and exhibited adequate robustness properties. Also, this paper contributes to process cognitive analysis by fuzzy logic.

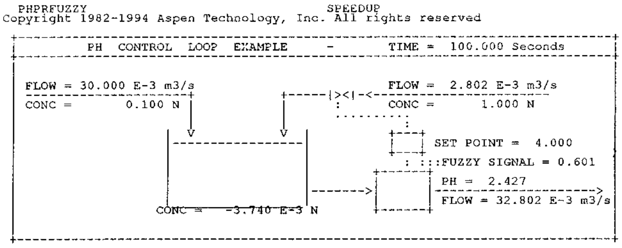
Many processes are highly non–linear and difficult to define using those equation based on first principle models. Fuzzy logic models have shown promise for such applications. A fuzzy controller uses fuzzy logic to perform real time comparisons between incoming data and historical data and can resolve fuzzy matches, error correction and image recognition. A fuzzy controller is suitable for product quality control, controller design and operations [1–5].

Fuzzy rules were applied for parameter free PID gain tuning to separator temperature control and to pH control [6, 7]. Fuzzy logic controlles–FLC have been demonstrated to control the pH in a stirred tank reactor [8, 9]. A tuning method of a multilevel fuzzy logic controller – MFLC was demonstrated in a tuning formula based on the gains and phase margins [10].

A fuzzy control system based on qualitative fuzzy variables and quantitative parameters from SPEEDUP is demonstrated for pH control of a stirred tank in this paper. Interactive simulation by SPEEDUP is extraordinarily important for economical fuzzy controller design, which must reduce the number of membership classes and input/output rules as much as possible.

pH CONTROL OF A CHEMICAL STIRRED TANK

A chemical stirred tank – CST is shown schematically in Figure 1. The CST has two input streams, one containing acid and the other alkali. A dynamic model for the pH control loop can be obtained using the approach presented in SPEEDUP. The model unit, was used from the SPEEDUP library [11,12]. By setting material balances on the alkali and total acid and assuming that acid–base equilibrium and electroneutrality relationships hold, one obtains:



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  PHPRFUZZY                                     SPEEDUP
Copyright 1982-1994 Aspen Technology, Inc. All rights reserved
+------------------------------------------------------------------------+
|         PH  CONTROL  LOOP  EXAMPLE     -        TIME =  100.000 Seconds |
+------------------------------------------------------------------------+
|                                                                        |
| FLOW = 30.000 E-3 m3/s                      FLOW =  2.802 E-3 m3/s      |
| ----------------------+        +-----|><|-<----------------------       |
| CONC =        0.100 N |        |     :      CONC =      1.000 N         |
|                       |        |     ..........                         |
|                       V        V              :                         |
|                    |  ----------------|     +---+                      |
|                    |                  |     |   | SET POINT =  4.000   |
|                    |                  |     +---+                      |
|                    |                  |       : :::FUZZY SIGNAL = 0.601|
|                    |                  |     +-------+                  |
|                    |                  |     |       | PH =  2.427      |
|                    |                  |---->|       |---------------->|
|                   CONC =   -3.740 E-3 N     |       | FLOW = 32.802 E-3 m3/s
|                                             +-------+                  |
+------------------------------------------------------------------------+
```

Figure 1. pH control loop – Signal flow diagram

total acid balance:

$$F_1c_1 - (F_1 + F_2)c = V\frac{dc}{dt} \qquad (1)$$

alkali balance

$$F_2c_2 - (F_1 + F_2)c = V\frac{dc}{dt} \qquad (2)$$

F_1 is acid flow, F_2 is alkali flow, c_1 is the inlet concentration of acid and c_2 is the inlet concentration of alkali, c is the current concentration and V is the CST volume. The CST parameters considered are given in Table 1. After 20s the acid flow is increased to 0.30E–02 m^3/s.

HAS equilibrium

$$\frac{[AC^-]\,[H^+]}{[HAC]} = K_a \qquad (3)$$

water equilibrium:

$$[H^+]\,[OH^-] = K_w \qquad (4)$$

electroneutrality:

$$\xi + [H^+] = [OH^-] + [AC^-] \qquad (5)$$

The dynamic response and control for the step disturbance to the acid stream flow is shown in Figure 2. The alkali flow was selected as the manipulated variable. The control objective was to operate the tank as close to the required pH value as possible.

Author address: J. B. Savković–Stevanović, Department of Chemical Engineering, Faculty of Technology and Metallurgy, University of Belgrade, Karnegijeva 4, 11000 Beograd
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Table 1. Operation parameters used for pH control loop simulation

Name	Value
Volume of tank V	5 m^3
Flow rate of acid F1	30.00E–3 m^3/s
Steady state pH	4.00
Concentration of acid c1	0.1000 mole/dm^3
Concentration of alkali c2	1.000 mole/dm^3
Initial flow rate of acid F1	25.00E–3 m^3/s
Initial flow rate of alkali F2	2.49 E–4

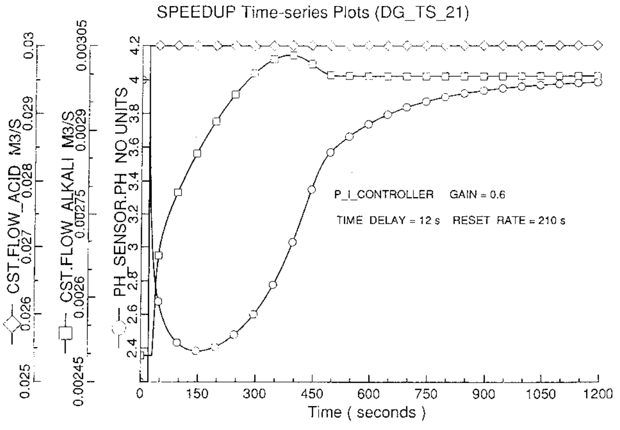

Figure 2. Dynamic response and control for the step disturbance in the acid flow with a PI controller

PI CONTROLLER MODEL

The model contains the classical proportional and integral action terms. The output can be clipped to be within the upper and lower limits and also scaled.

$$\text{Output} = \text{bias} + \text{Proportional} + \text{Integral} \qquad (6)$$

$$\text{Controller output} = \text{bias} = K_p\,(E_p + 1/T_i \int E\,dt) \qquad (7)$$

where bias is the steady state control action, K_p is the controller gain, T_i is the integral time constant, E_p the proportional mode error, and E the integral mode error.

The system may become unstable at certain controller settings by obtaining the state space module of the pH control system, the stability of the system can be verified using a control system package. MATLAB [13] was used for design by the gain/phase contour.

The obtained results show significant effects of the gain controller design, reset rate and time delay effluent. Time delay in closed control loops can lead to oscillation and a low value for the controller gain is used in order to avoid this. The response is very damped owning to the low gain required by the controller to avoid instability. The results for the PI controller were obtained with gain 0.6, time delay 12 s and the reset rate 210 s.

Also, dynamic modeling and simulation were performed for a step disturbance in the acid flow and random disturbance in the alkali flow and pH-sensor. The PRBS – Pseudo Random Binary Sequences model was used for random disturbance (Figure 3).

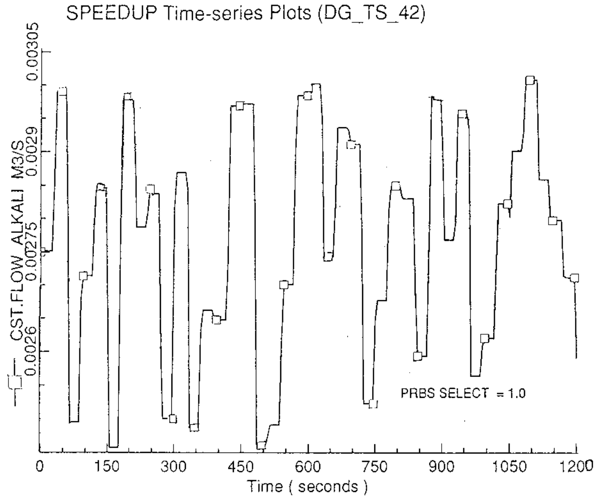

Figure 3. The PRBS random disturbance with varying amplitude

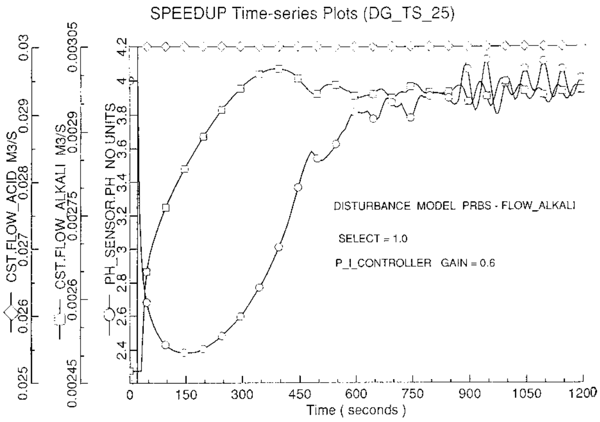

Figure 4. Dynamic response and control of the pH control loop for a PRBS disturbance with varying amplitude on the alkali flow stream with a PI controller

A Pseudo Random Binary Sequences – PRBS superimposed upon in the steady state value. The effects of noise on the alkali flow and pH signal were investigated. The dynamic response of 1% PRBS with a sampling time of 4 s and varying amplitude on the alkali flow stream is shown in Figure 3. In this case, the pH control loop is shown to be unstable. The response of the pH control loop for a PRBS disturbance with varying amplitude on the alkali flow is shown in Figure 4. The dynamic response of the pH control loop for a PRBS disturbance with fixed amplitude on the alkali flow stream is shown in Figure 5.

The obtained results show good stability of the pH control loop to step disturbance in the acid flow. In this case the PI controller stabilized the disturbance well as seen in Figure 2. For random disturbance the PI controller does not show good performance in the

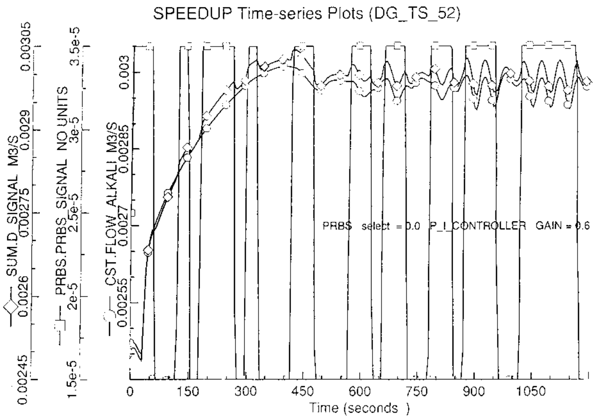

Figure 5. Dynamic response and control of the pH control loop for a PRBS disturbance with fixed amplitude on the alkali flow stream with a PI controller

control loop as shown in Figures 4 and 5. Figures 4 and 5 show instability in the pH and alkali flow streams for PRBS disturbances.

Because the pH control loop was showing instability for random disturbances on the alkali flow stream a fuzzy controller was incorporated in the pH control loop as shown in Figure 1.

FUZZY LOGIC CONTROLLER MODEL

The qualitative variables acid flow, alkali flow and pH were considered for building a qualitative model. a systematic cause – event analysis was made with qualitative variable states:

Input variables:

- Alkali flow (low, medium, high)
- Acid flow (low, medium, high)

Output variables:

- pH (increasing, slow by increasing, normal, slow by decreasing, decreasing)

Table 2 shows fuzzy variables and their fuzzy terms for the pH control loop based on qualitative / quantitative process knowledge. The meaning of the linguistic values is defined by the LR–type membership function:

$$\mu(x) = \begin{cases} L\,(A-x)\,/\,(A-a) & \text{if } x < A \\ 1 & \text{if } A < x > B \\ R\,(x-B)\,/\,(\beta-B) & \text{if } x > B \end{cases} \tag{8}$$

where x is current fuzzy value, A, B are the maximum values of the fuzzy number, a and β are the left and right spreads, and L and R are the appropriately chosen functions.

A systematic cause – event analysis is defined by fuzzy rules according to the following equation:

$$\text{IF (acid Flow}_{1in} = l_{Ai}\text{) AND (alkali Flow}_{2in} = \\ = l_{Bi}\text{) THEN (pH}_{out} = l_{Di}\text{)} \tag{9}$$

Fuzzy production rules are given in Table 3.

Table 2. Fuzzy variable term definition for pH control

Qualitative variable 1	Acid flow, m^3/s			
	Min. value = 0.024		Max. value = 0.030	
Term	a	A	B	β
Low	0.02450	0.02500	0.02650	0.02670
Medium	0.02670	0.02700	0.02850	0.02870
High	0.02871	0.02880	0.03000	0.03010
Qualitative variable 2	Alkali flow, m^3/s			
	Min. value = 0.0023		Max. value = 0.0030	
Term	a	A	B	β
Low	0.00239	0.00245	0.00265	0.00267
Medium	0.00271	0.00272	0.00285	0.00286
High	0.00287	0.00288	0.00300	0.00301
Qualitative variable 3	pH			
	Min. value = 1.00000		Max. value = 4.50000	
Term	a	A	B	β
Increasing	2.00000	2.50000	2.70000	2.90000
Slow by increasing	2.92000	2.95000	3.00100	3.20000
Normal	3.21000	3.25000	3.50000	3.70000
Slow by decreasing	3.71100	3.70000	3.45000	4.40000
Decreasing	3.75000	3.71000	4.45000	4.40000

Table 3. Selected fuzzy rules for pH control

Ruler set number 2			
IF	Acid flow	is medium	AND
IF	Alkali flow	is medium	
THEN	pH	is normal	AND gain = gainn
Rule set number 4			
IF	Acid flow	is medium	AND
IF	Alkali flow	is low	
THEN	pH	is slow by decreasing	AND gain = (gainl/2)
Rule set number 5			
IF	Acid flow	is low	AND
IF	Alkali flow	is high	
THEN	pH	is increasing	AND gain = gainh
Rule set number 7			
IF	Acid flow	is medium	AND
IF	Alkali flow	is high	
THEN	pH	is increasing	AND gain = (gainh/2)

A standard fuzzy logic controller was generated using nine rules, which make up a control expert system. Figure 6 shows the response of the FL controller. The fuzzy logic control system showed

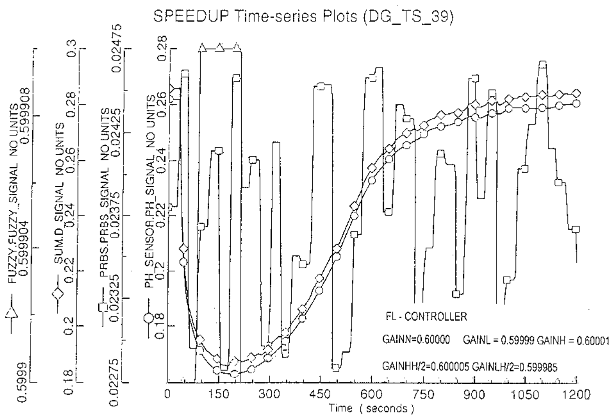

Figure 6. The dynamic response and control of the pH control loop for a PRBS disturbance with varying amplitude on the pH sensor with a FL controller

robustness to added noise and parameter changes and good control performances.

PI–FL CONTROLLER MODEL

A PI–FL control loop involving equations (6)–(9) and the following equation:

$$\text{gainn} = K_p \tag{10}$$

Figure 7 shows the response of the pH control loop with a PI–FL controller. This dynamic respons shows the best controller performance and stability.

CONCLUSION

A fuzzy logic control system and process cognitive analysis were demonstrated by a SPEEDUP simulator. The pH control loop shows instability for random disturbances on the alkali flow stream. A fuzzy controller was incorporated in the pH control loop. The ability to stabilize the control loop in the first trial is important for technical control problems. The dynamic response of the pH control loop to a PRBS disturbance with varying amplitude alkali flow stream with fuzzy logic controller shown in Figure 6, gives good stability of the non–linear control of the pH of a chemical stirred tank. A fuzzy logic controller was demonstrated to successfully control the system and to exhibit desirable robustness properties compared to a conventional PI control. A FLC improves quality control, determines optimum set points, updates planning models and troubleshoots day – to – day operating problems. This capability also allows the fuzzy controller to adapt a system which varies slowly over time. A PI–FL controller showed the best control performance as shown in Figure 7.

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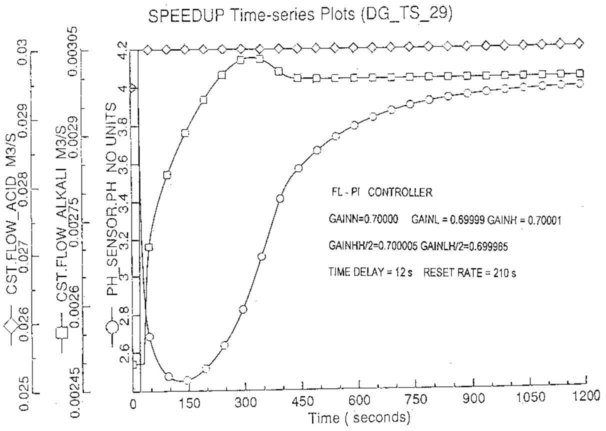

Figure 7. The dynamic response and control of the pH control loop for a PRBS disturbance with varying amplitude on the alkali flow stream with a PI–FL controller

NOTATION

A, B	– bounded values for left and right spreads
c	– concentration, mole/dm^3
F	– flow rate, m^3/s
E	– integral error
E_p	– proportional error
K_p	– gain
Δh	– increment
L, R	– chosen functions
K_w, K_a	– dissociation constants
T_i	– integral time constant
t	– time, s
V	– volume, m^3

Substript

1	– acid
2	– alkali

Greek letters

ξ	– electroneutrality constant
α, β	– left and right spreads

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IZVOD

JEDAN FAZI LOGIČKI REGULATOR ZA REGULACIJU pH HEMIJSKOG REZERVOARA SA MEŠANJEM

(Naučni rad)

Jelenka B. Savković–Stevanović[1], Warren D. Seider[2], Layer H. Ungar[2]
[1]Tehnološko-metalurški fakultet, Beograd, Jugoslavija
[2]Univerzitet Pensilvanija, Filadelfija, SAD

Rad proučava fuzzy disperziono modelovanje i kognitivnu analizu procesa pomoću SPEEDUP simulacija. Jedan fuzzy logički regulacioni sistem primenjen je za regulaciju pH u rezervoaru sa mešanjem. Modelovanjem kvantitativnih informacija iz SPEEDUP–a sa kvalitativnim informacijama fuzzy logike razvijen je jedan fuzzy regulator. Fuzzy logički FLR–regulator pokazuje veću preciznost na premećaje i promene parametara postrojenja nego PI regulator. Ovaj regulator poboljšava kvalitet upravljanja i određuje optimalnu postavku zadatih vrednosti. FLR–PI regulator razvijen u ovom radu pokazuje uspešnu regulaciju i ispoljava adekvatnu preciznost. Ovaj rad takođe doprinosi razvoju procesa kongitivne analize pomoću fuzzy logike.

Ključne reči: • pH regulacija • fuzzy logički regulator • SPEEDUP simulacije • slučajni poremećaji • fuzzy funkcija •
Key words: • pH control • Fuzzy logic controller • SPEEDUP simulation • Random disturbances • Fuzzy functiions •