Reaktor, Vol. 5, No. 2, Desember 2001, Hal.: 54 - 58

CONTROL SYSTEM STRATEGY OF THE SAPONIFICATION PROCESS BETWEEN ETHYL ACETATE AND SODIUM HYDROXIDE

M. Djaeni, Suherman, K. Jalasanti and R. R. Mukti *)

Abstract

The research looks into the performance of Proportional (P), Proportional Integral (PI), and Proportional Integral Derivative (PID) controller to maintain soap concentration. To facilitate the study, the mathematical model of saponification process is derived using information cited from literature. Then the model is validated using experimental data. Based on the model, the control system using Proroprtional (P), Proportional Integral (PI) and Proportional Integral Derivativev (PID) are designed. In this case, the constant of each controller is tuned using Ziegler Nichols method. The result showed that the PID controller with Integral Square Error (ISE) of 5.77936E-08 is the strongest for disturbance rejection among the others. The performance of PID controller is also good for set point tracking with ISE of 1.28227E-05.

Key words : *control, mathematical model, simulation, saponification*

Introduction

Saponification process is a reaction between Sodium Hydroxide (NaOH) and Ethyl Acetate. This reaction named saponification because reaction between two reactants mentioned products soap and ethanol. This reaction carried out in a Continuous Stirred Tank Reactor (CSTR). In the limit of perfect mixing, a tracer molecule that enters at the reactor inlet has equal probability of leaving in the next time increment. Consequently, there will be a brood distribution of residence times for various tracers molecular. Because some of molecules have short residence times, there is a rapid response at the reactor outlet to changes in the reactor feed stream.

During the process, there are some of disturbances namely fluctuation, so it is necessary to provide strong control system for saponification process. This research will look into the effect of input to output process using derivative mathematical model and validity by experimental data. Based on that data, the control system using P, PI, PID are designed.

The purpose of this research is to simulate the strong control system for saponification of Ethyl Acetate using Sodium Hydroxide based on disturbance rejection and set point tracking. By studying about the control system on the saponification process, this research could be as a consideration in implementing control system for real work of saponification process in industrial scale.

Concept of feedback control

The purpose of the feedback control loop is to minimize error between the controlled variable and the set point by adjusting the manipulated variable, as presented in Figure 1.

In a typical plant operation, the controller must be able to deal with two situation *i.e.*, changes of its set point and disturbance from other process inputs. For the first case, the desired value of the operating variable may be subjected to step increase or decrease depending on the process. In the latter, changes in the selected process inputs are imposed. The reactions of the controller to these changes are observed. In a normal steady state operation of a process plant, disturbance rejection is an important issue because the multivariable nature of the plant causes interaction of variables and causes disturbances to control loop.

There are three type of feedback controller; Proportional (P), Proportional Integral (PI) and Proportional Integral Derivative (PID). The each type has advantage and drawback. The Proportional Controller could accelerate the response of a controlled process but it produces an offset for all process. The Proportional Integral Controller could reduce the offset but its response is slow, and it could produce sluggish and long oscillation. The Proportional Integral Derivative Controller is more perfect than others. Practically, the selection of type is based on the characteristics of process, and parameter to be controlled.

*) Department of Chemical Engineering, Universitas Diponegoro
Jl. Prof. Soedarto, SH. Kampus Tembalang, Semarang, 50239
Email: mzaini98@yahoo.com

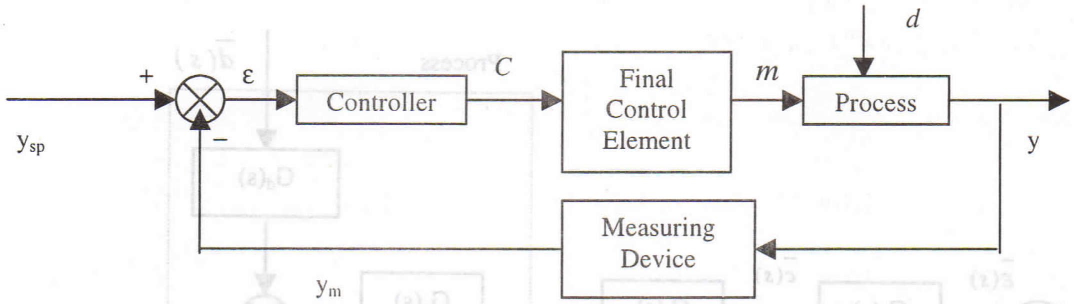

Figure 1: Feedback Loop Control System

Closed-loop Response

The control system can be done if there are some disturbances d and the set point y_{SP} changes. For the closed-loop system below, for its four components (process, measuring device, controller mechanism, and final control element), we can write the corresponding transfer function relating its output to its input (Stephanopoulos, 1984).

Process: $\bar{y}(s) = G_p(s)\bar{m}(s) + G_d(s)\bar{d}(s)$

Measuring device: $\bar{y}_m(s) = G_m(s)\bar{y}(s)$

Controller mechanism:

Comparator $\bar{\varepsilon}(s) = \bar{y}_{SP}(s) - \bar{y}_m(s)$

Control action $\bar{c}(s) = G_c(s)\bar{\varepsilon}(s)$

Final control element $\bar{m}(s) = G_f(s)\bar{c}(s)$

Ziegler-Nichols Controllers Tuning

The example of closed-loop procedure is the Ziegler-Nichols Controllers Tuning technique This technique has many advantages, e.g., nominal stability of the remaining system is guaranteed, no need for trial and error . Based on Stephanopolous (1984), and Marlin (1995), the Zeigler-Nichols formulations are expressed in the following table.

Table 1: Ziegler-Nichols Controller Settings

Type of control	K_c	τ_I (min)	τ_D (min)
Proportional	Ku/2	-	-
Proportional Integral	Ku/2.2	Pu/1.2	-
Proportional Integral Derivative	Ku/1.7	Pu/2	Pu/8

Methodology

The methodology of this research consists of eight steps as seen as in Figure 3.

1. Experimental work using the CSTR reactor with manipulated variables are variation of sodium hydroxide and ethyl acetate flow rate at sodium hydroxide constant flow rate.
2. The mathematical model is developed to predict dynamic condition from continuous saponification reaction.

   $(dc_i/dt) = f(F_i, C_i)$

   Where, c_i is the concentration of i-component (mole/liter), t is the time (minute) and F_i, is the flow of i-componen.)
3. The Mathematical Model is simulated to obtain initial condition.
4. The model is then validated with experimental data using minimization of Sum of Square Error (SSE) method.
5. Characterizing the model is based on the step change of sodium hydroxide flow rate and ethyl acetate flow rate.
6. The program has been developed for Proportional (P), Proportional Integral (P), and Proportional Integral Derivative (PID) controller.
7. The control system performance is evaluated with disturbance rejection to select best controller
8. The best controller is tested by set point tracking

Results and Discussion

Validating of Model

Figure 4 and 5 present the comparison between experimental data with simulation result. The model is good with the Sum Square of Error (SSE) of 6.42E-17. The respone of soap concentration is exponential with the step change of NaOH and ethyl acetate flow rate exponential which indicate the first order process. In this case, the increase of NaOH and ethyl acetate flow rate make the soap concentration decrease due to the shorter residence time than initial condition.

The Selection of input-ouput pairing

The selecting of pairing to control process is done in two types, namely qualitative and quantitative. Qualitative method based on the cost of materials, while method based on the effect of the reactant to the product. In this research, the effect of NaOH and Ethyl Acetate to product is similar. Hence, Ethyl Acetate is preferred to manipulate the control variable due to its lower cost.

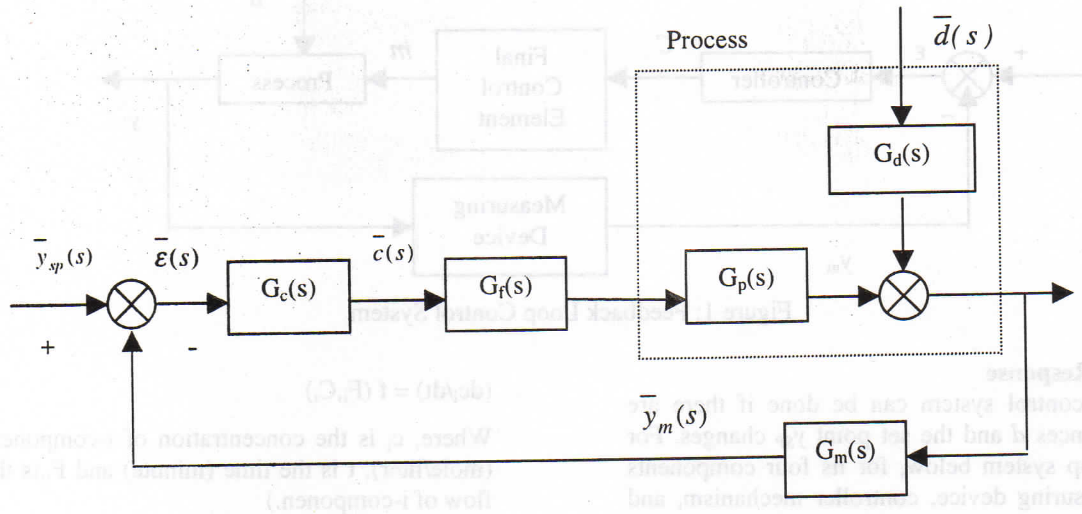

Figure 2: Block diagram of generalized closed-loop system

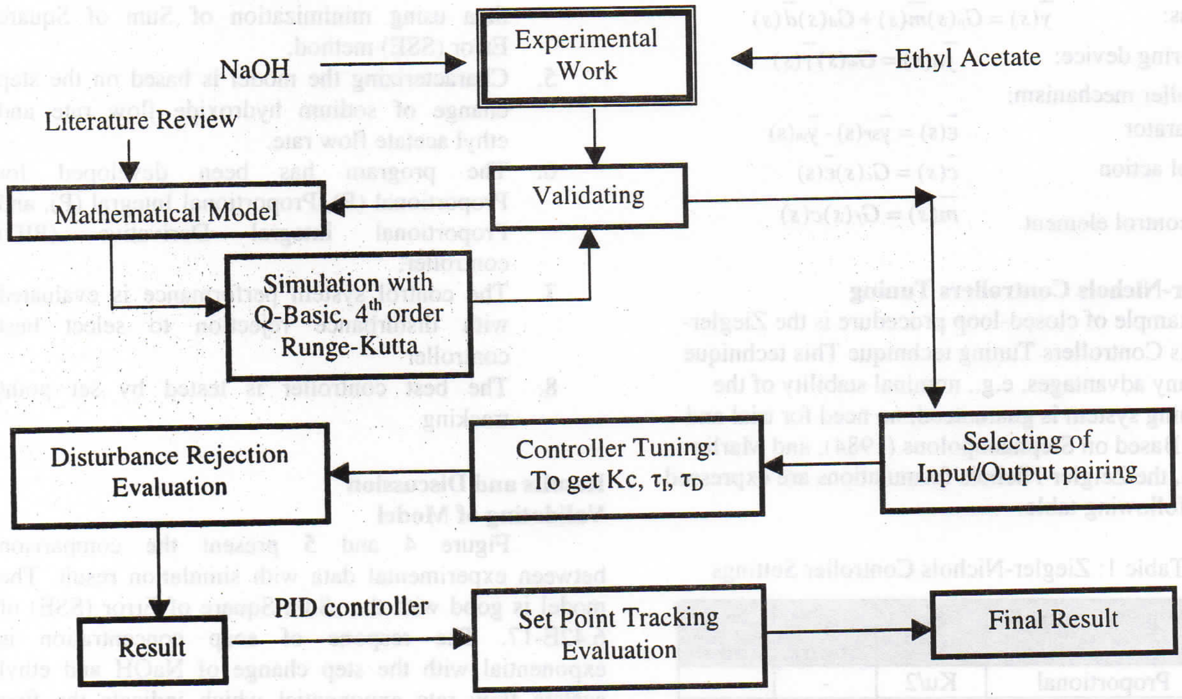

Figure 3: Schematic diagram of the methodology of research

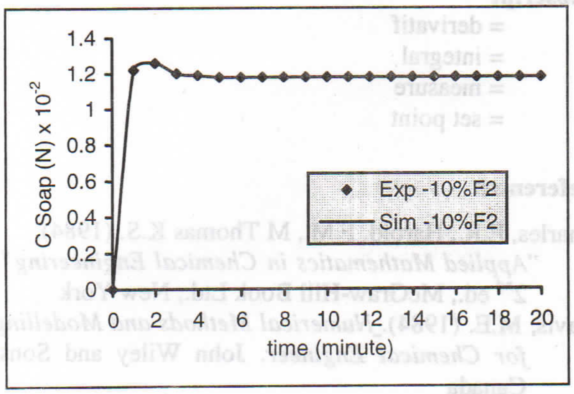

Figure 4: The comparison of soap concentration response based on simulation and experiment with the step change of ethyl acetate flow rate

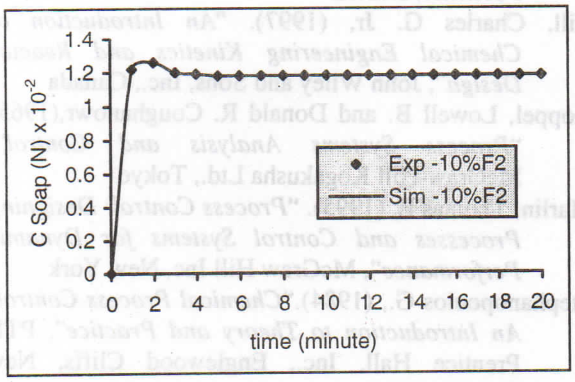

Figure 5: The comparison of soap concentration response based on simulation and experiment with the step change of NaOH flow rate

Constant controller

The constant of controller for various controller was calculated using Ziegler-Nichols method as seen in the Table 2.

Table 2: Data of Kc, τ_I, τ_D for P, PI, PID controller based on Ziegler-Nichols settings

	Proportional (P)	Proportional Integral (PI)	Proportional Integral Derivative (PID)
Kc	-15876	-14432.73	-18677.65
τ_I	-	1.67	1
τ_D	-	-	0.25

Performance for disturbance rejection

The performance for each controller also evaluated based on the disturbance rejection to identify the best controller. The results were presented in the Figure 6, 7, and 8.

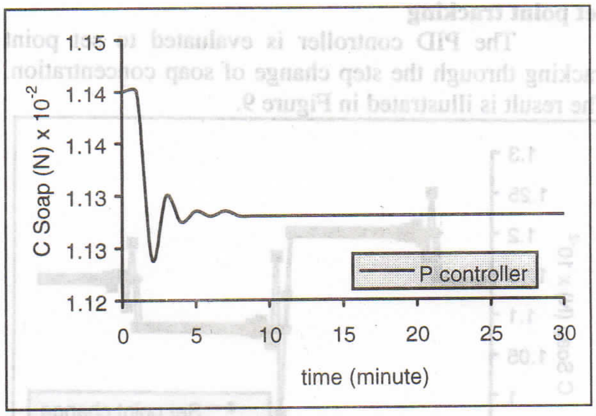

Figure 6. The response of P controller (ISE 1.40-06)

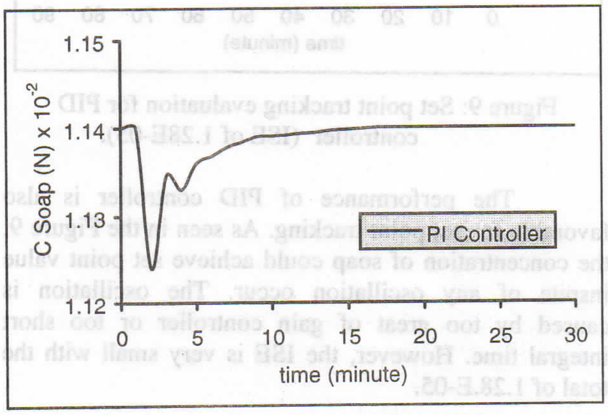

Figure 7: The response of PI controller (ISE 1.94E-05)

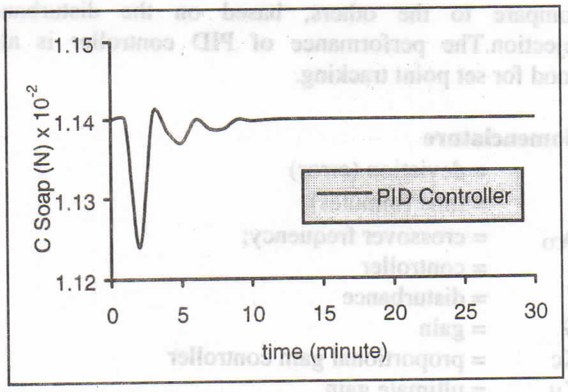

Figure 8: The response of PID controller (ISE 5.78E-08)

Refers to Figure 6, 7, and 8, PID controller shows the strongest controller compared with the others, based on its response and ISE. In this case, P controller gives the offset as seen in Figure 2. Beside that the ISE is greater than PID in spite of the fast response, while the response of PI controller is too slow due to too long integral time. Additionally, the ISE (5.78E-08) of PID is the smallest than the other. Hence, it could be concluded that PID controller is favorable to control the saponification process.

Set point tracking

The PID controller is evaluated to set point tracking through the step change of soap concentration. The result is illustrated in Figure 9.

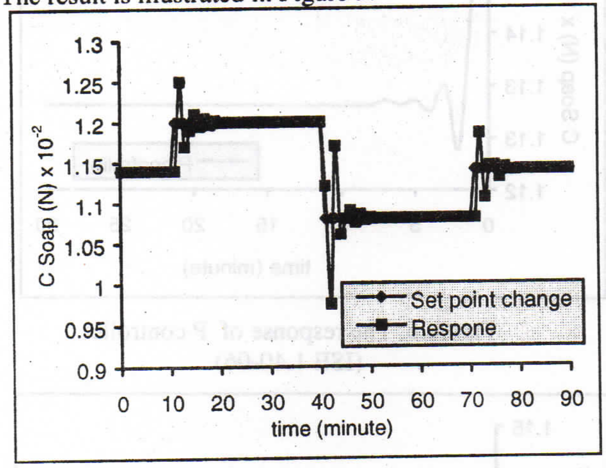

Figure 9: Set point tracking evaluation for PID controller (ISE of 1.28E-05).

The performance of PID controller is also favorable for set point tracking. As seen in the Figure 9, the concentration of soap could achieve set point value inspite of any oscillation occur. The oscillation is caused by too great of gain controller or too short integral time. However, the ISE is very small with the total of 1.28.E-05.

Conclusion

The PID controller shows the best performance compare to the others, based on the disturbance rejection.The performance of PID controller is also good for set point tracking.

Nomenclature

ε = deviation (error)
τ = time (minutes)
ω_{co} = crossover frequency;
c = controller
d = disturbance
G = gain
Kc = proportional gain controller
Ku = ultimate gain
M = amplitude ratio
Pu = ultimate period
s = signal

Subscript

D = derivatif
I = integral
m = measure
sp = set point

References

Charles, E.R., Harold, F.M., M Thomas K.S. (1984). *"Applied Mathematics in Chemical Engineering"*, 2nd ed., McGraw-Hill Book Ltd., New York

Davis, M.E. (1984). *Numerical Methods and Modelling for Chemical Engineer*. John Wiley and Sons, Canada

Fressenden, Ralph J. and Joan S. Fessenden, (1983). *"Techiniques and Experiments for Organic Chemistry"*, Prindle, Weber and Schmidt Publisher, Boston

Hill, Charles G. Jr, (1997). *"An Introduction of Chemical Engineering Kinetics and Reactor Design"*, John Wiley and Sons, Inc., Canada

Koppel, Lowell B. and Donald R. Coughanowr,(1965) *"Process Systems Analysis and Control"*, McGraw-Hill Kogakusha Ltd., Tokyo

Marlin, Thomas E, (1995). *"Process Control: Designing Processes and Control Systems for Dynamic Performance"*, McGraw Hill Inc, New York

Stephanopoulos G., (1984).*"Chemical Process Control: An Introduction to Theory and Practice"*, PTR Prentice Hall, Inc., Englewood Cliffs, New Jersey

Ullman, (1992). *"Ullman's Encyclopedia of Industrial Chemistry Vol B4 : Principles of Chemical Reaction Engineering and Plant Design"*, VCH Verlagsgesellschaft mbH, D-6940 Weinheim

William L. Luyben, (1990). *"Process Modelling, Simulation and Control for Chemical Engineerings"*, McGraw-Hill Book Co., Singapore