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Tuning PID Controller for two-Continuous Stirred Tank Reactors in series with Time Delay

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Abstract.

A continuous stirred tank reactor (CSTR) is at the heart of many chemical processes. Being an important unit, a diverse range of research regarding the area of designing and tuning control systems is being offered. Time delays present further difficulties towards achieving effective control systems due to the excessive phase lag they introduce to the feedback control loop. This paper considers a process consisting of two CSTRs in series where a first order reaction takes place isothermally. Two of the most popular PID tuning methods are implemented, namely Ziegler Nichols (Z-N) and Cohen-Coon (C-C) .Since concentration is commonly the controlled parameter and because it is usually not readily measured on line, measurement delays must be considered when designing feedback control system.The performance of the PID controller for these tuning methods is illustrated using MATLAB simulation environment. The results show that robust and effective control using PID with Z-N tuning method can be achieved for regulatory (disturbance rejection) as well as for servo (set-point tracking) control systems. However, further tuning of these controller parameters is made by experienced control engineers during actual operation to further enhance the desired response.

Keywords: CSTR; PID Controlled; Time Delay; Tuning methods.

1. Introduction

Continues stirred tank reactors are widely used in chemical and petrochemical industries such as water treatment processes, polymerization to produce different kinds of plastics, and many other chemicals. Reaction kinetics and reactor design are important topics for the optimum performance [1]. PID controller is one of the most widely used controllers in the design of continuous-data control system in the chemical process industry. After selecting the type of control structure to be used, the problem of assigning a proper value for each term of the PID controller, namely the proportional gain K_C, the rest time τ_1 and the derivative time τ_D has to be solved. This process is called controller tuning [2,3].The tuning method plays a very vital role. The values of the parameters in the controller can affect the performance of the system. Tuning method is the determination of the parameters of PID controller values for getting the optimum or the acceptable performance from the process. In the process control system, better performance is accomplished by adjusting the control parameters to provide the desired process responses [4]. In this paper two controller tuning methods are considered, namely Cohen and Coon (C-C) and Ziegler-Nichols (Z-N) [5,6]. These methods are widely used to adjust the values of PID parameters. The objective of this paper is to compare the performance of these methods on the case study considered here.

2.1 Process Description

A liquid stream enters reactor 1 at a volumetric flow rate F(m^3/min), and contains reactant A at an initial concentration of (c_0 kgmol A/m^3). Reactant A decomposes in the reactors according to the irreversible chemical reaction as shown in Figure 1.

$$A \rightarrow B$$

The reaction is first-order and proceeds at a rate

$$r_A = -kC_A$$

where: r_A is the rate of decomposing of A, (kgmol A)/m^3.min.

k is the reaction rate constant, min^{-1}

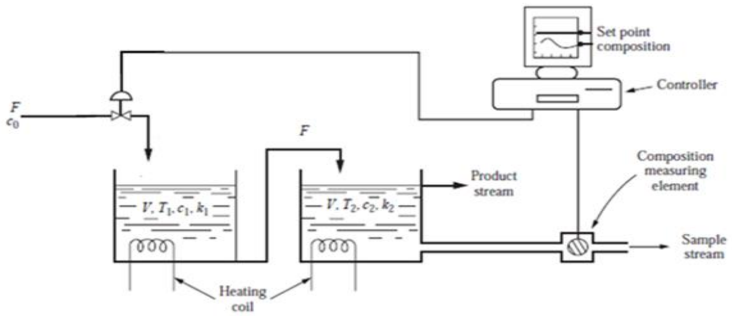

Figure 1: Schematic diagram of 2-CSTRs control system

The reaction is to be carried out in a series of two continuous stirred- tank reactors. The reactors are maintained at different temperatures. The temperature in reactor 2 is to be greater than the temperature in reactor1, with the result that k_2, the reaction rate constant in reactor 2, is greater than that in reactor1. Any changes of physical properties due to chemical reaction.

The purpose of the control system is to maintain c_2, the concentration of A leaving reactor 2, at some desired value in spite of variations in inlet concentration c_0.

2.2 Process Modeling

Figure 2. shows a simplified block diagram of the process. We begin the analysis by making a material balance around reactor1. Assuming that the volumetric flow rates are equal and constant gives,

$$V\frac{dc_1}{dt} = Fc_0 - Fc_1 - k_1Vc_1 \quad (1)$$

Rearranging equation (1) gives,

$$V\frac{dc_1}{dt} + (F + k_1V)c_1 = Fc_0 \quad (2)$$

This last equation may be written as,

$$\frac{V}{F + k_1V}\frac{dc_1}{dt} + c_1 = \frac{F}{F + k_1V}c_0$$

$$\tau_1\frac{dc_1}{dt} + c_1 = \mathrm{K_{P1}}\, c_0 \quad (3)$$

Where,

τ_1 is effective time constant for reactor1 = $\frac{V}{F+k_1V}$, (min)

K_{P1} is the static gain for the reactor1 = $\frac{F}{F+k_1V}$, (dimensionless)

At steady state, $dc_1/dt=0$, and equation (3) becomes

$$c_{1s} = K_{P1}c_{0s} \quad (4)$$

Where: s refers to steady state.

Subtracting equation. (4) from equation (3) and introducing the deviation variables

$C_1=c_1-c_{1s}$, $C_0=c_0-c_{0s}$, give

$$\tau_1\frac{dC_1}{dt} + C_1 = K_{P1}C_0 \quad (5)$$

Taking the Laplace transform of equation. (5) yields the transfer function of the first reactor:

$$C_1(s) = \frac{\mathrm{K_{P1}}}{\tau_1 s + 1}C_0(s) \quad (6)$$

A material balance around reactor 2 gives

$$V\frac{dc_2}{dt} = F(c_1 - c_2) - k_2 V c_2 \qquad (7)$$

$$\frac{V}{F + k_2V}\frac{dc}{dt} + c_2 = \frac{F}{F + k_2V}c_1 \qquad (7a)$$

As with reactor1, this last equation can be written in terms of deviation variables and arranged to give.

$$\tau_2\frac{dC_2}{dt} + C_2 = \mathrm{K}_{\mathrm{P2}}C_1 \qquad (8)$$

Where

C_2 is the concentration in deviation variable for reactor2, $C_2 = c_2\text{-}c_{2s}$, and

τ_2 is the effective time constant for reactor2.

K_{P2} is the static gain for reactor 2

Taking the Laplace transform equation (8) gives the transfer function for the second reactor:

$$C_2(s) = \frac{K_{P2}}{\tau_2 s + 1}C_1(s) \qquad (9)$$

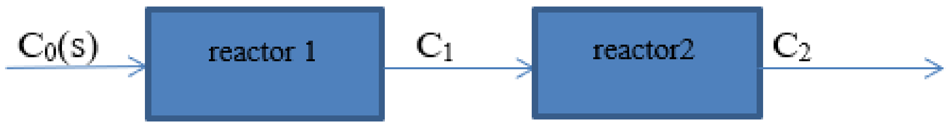

Figure 2 The block diagram of the two-reactor system

To obtain numerical results for the steady state condition of c_{1s} and c_{2s} ,the process data listed in Table 1 is applied for the present case study.

Table 1: Steady state operating data [7].

Parameters	Symbols	values
Molecular weight of A	MW_A	**100 kg/kgmol A**
Inlet concentration of A	C_{0s}	**1.6 kgmol A/m^3**
Volumetric flow rate	F	**2.83 m^3/min**
Holdup volume of reactor	V	**8.50 m^3**
Effective time constant for reactor 1	τ_1	**2 min**
Effective time constant for reactor 2	τ_2	**1 min**
Time delay	τ_d	**0.5 min**
Reaction rate constant in reactor1	k_1	**1/6 min^{-1}**

Reaction rate constant in reactor2	k_2	**2/3 min^{-1}**
Steady state concentration of A in reactor 1	C_{1s}	**1.17 kg mol/m^3**
Steady state concentration of A in reactor 2	C_{2s}	**0.39 kg mol/m^3**

2.3 Time delay

It is also known as transportation lag or dead time presents two major consequences, namely complicates the analysis and design of feedback control systems and makes satisfactory control more difficult to achieved. In the present case study measurement delay must be considered since concentration is measured by taking a sample and injecting it to a gas chromatography instrument and then fed to the control system. This delay is estimated to be 0.5 minutes. The transfer function of this delay is given by, $G(s) = e^{-0.5s}$.

2.4 PID Controller

This type of control system consists of three terms, namely

- proportional (P) control which found to cause steady state error (offset).
- integral (I) control which gives zero steady state error (offset).
- derivative (D) control which improves the stability of the control system.

A combination of these terms, namely P, PD, PI, PID may be used. In this paper these four types of controller are investigated and compared.

2.5 Controller Tuning Methods

2.5.1 PID controller tuning using Ziegler-Nichols method

The Ziegler-Nichols (Z-N) is a closed loop method based on experiments executed on an established control loop (a real system or a simulated system). This method starts by zeroing the integral and derivative times and then raising the proportional gain until the system starts to oscillate. K_C is then recorded as Ku and the period of oscillation is recorded as Pu (ultimate period). The last step determines the parameter's values of PID as shown in Table 2.

Table 2. Z-N PID Controller Settings[4]

	K_C	τ_I	τ_D
P controller	0.5Ku	0	0
PI controller	0.45ku	$P_u/1.2$	0

PD controller	0.8Ku	0	$P_u/8$
PID controller	0.6Ku	$P_u/2$	$P_u/8$

2.5.2 PID controller Tuning using Cohen-Coon (C-C) method

It is an empirical method known as reaction curve method. C-C observed that most chemical processes respond to a step change has a sigmoidal shape which can be approximated by a first order plus dead time (FOPD). They derived expressions for the best controller setting for the PID controller.

3. Case Study Block diagram

The block diagram shown in figure 3 presents the feedback control system which is simulated using MATLAB software environment.

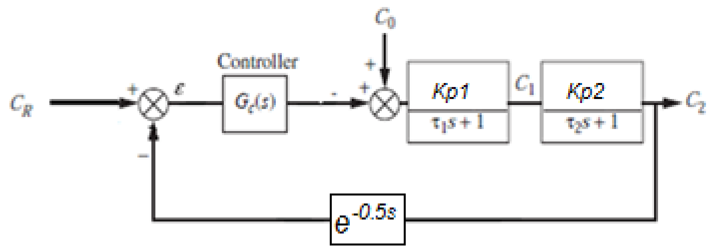

Figure 3: Process Block Diagram

4. Results and Discussion

To illustrate the performance of the two methods of controller tuning considered here, the response of $C_2(t)$ to a step change in $C_0(t)$, disturbance rejection (load) case, and $C_R(t)$, set-point tracking (servo) case, is presented graphically for the four combinations of PID.

4.1 Proportional (P) **Control**

Figure 4 shows the response of $C_2(t)$ for a step change in $C_0(t)$ and $C_R(t)$. As expected proportional only control did not eliminate the error (offset). However, in both cases, load and servo cases Z-N settings gave response with less overshoot, less offset, and less oscillation.

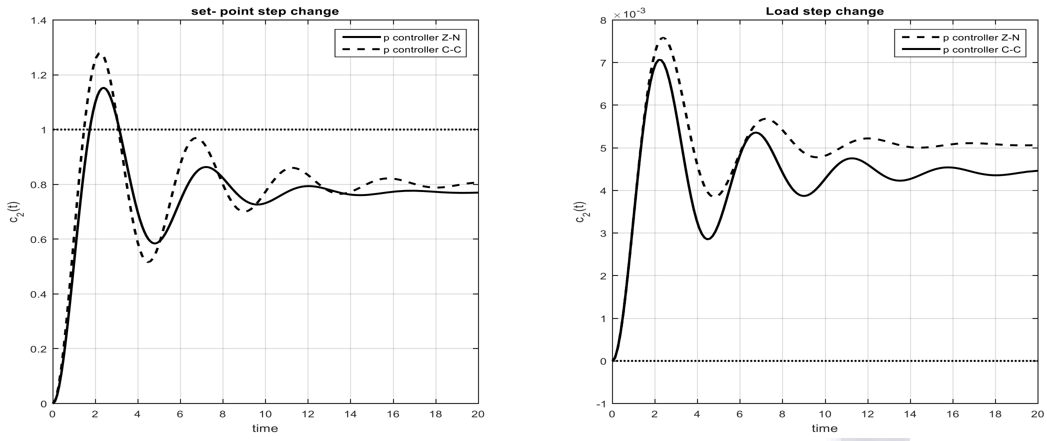

Figure 4 $C_2(t)$ response comparison using P- controller by (Z-N) and (C-C) methods

4.2 Proportional plus derivative(PD) controller

Addition of the derivative term mad the response more stable for both cases as can be seen in figure 5. That is, less overshoot, less offset, less oscillation and less response time than that in figure 4. However, Z-N settings again gave better and more stable response.

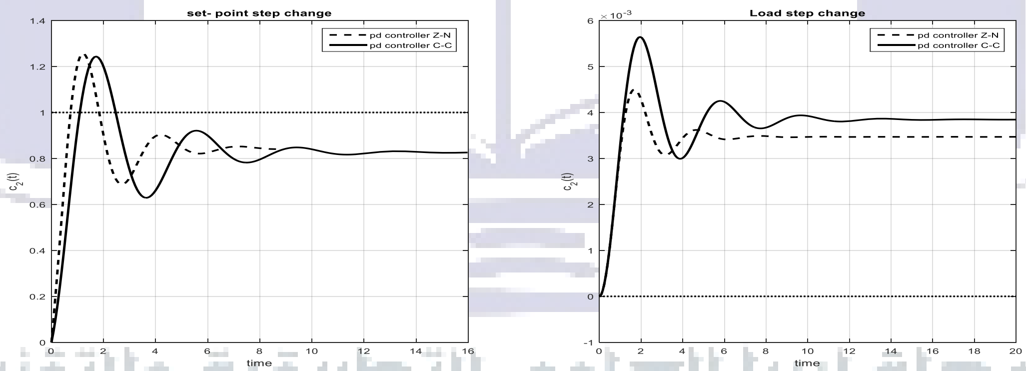

Figure 5 $C_2(t)$ response comparison using PD-control by (Z-N) and (C-C) methods

4.3 Proportional plus integral (PI)control

The integral action reduces the offset to zero. This is illustrated in figure 6. However, the response of $C_2(t)$ for both cases shows more oscillation, larger overshoot, and more response time. This is due to the nature of the integral action which makes the response sluggish, and therefore to reduce these oscillations the value estimated for the proportional gain by Z-N and C-C should be reduced. This reduction is more necessary for the values estimated by C-C method, since this response exhibits larger oscillations than that by Z-N. Finally, the setting values of Z-N gave better and more satisfactory response.

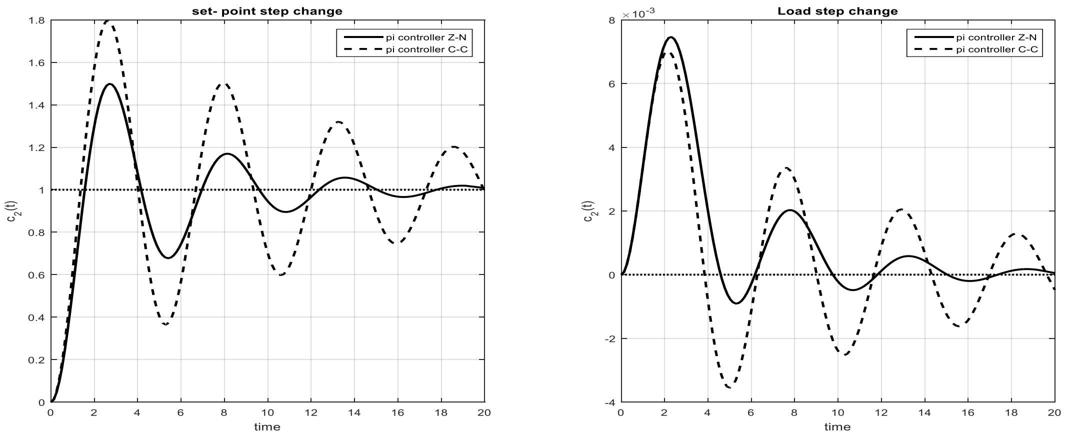

Figure 6 comparison of the system response using PI control by (Z-N) and (C-C) methods

4.4 Proportion plus integral plus derivative (PID) control

The stable effect of the derivative action on the response is well illustrated in figure 7 for both tuning methods. The oscillations introduced by the integral action is being largely damped and the offset and response time is being tremendously reduced. The figure demonstrates that the performance of Z-N tuning method showed better results than C-C Method.

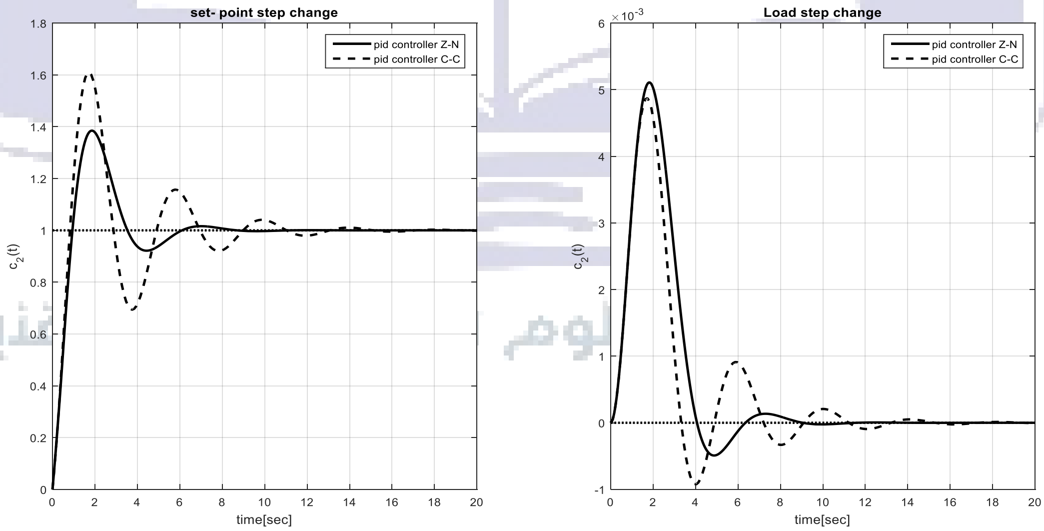

Figure 7 Response of the system using PID control by (Z-N) and (C-C) methods

5. Conclusion

In this paper, a comparative study for a system consisting of 2-CSTR in series with measurement delay using two well-known tuning methods namely, Z-N and C-C is carried out. In general, the results show that good control can be achieved even with the presence of significant time delays. The Z-N tuning method showed overall better performance than C-C tuning method for this case study. In order to eliminate the offset in the response the integral action is necessary., However, the negative effect of integration such as large oscillations and high response time can be reduced by introducing the derivative action as can be seen for PID response figure 7. The large overshoots indicated in all four cases is due to the presence of relatively large time delays. It may be concluded that Z-N tuning with PID controller is better suited to give acceptable control results. Finally, it should be emphasized that the controller settings evaluated by these tuning methods are regarded as preliminary values, and further adjustment is made by experienced control engineers during actual process.

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