Dynamic Simulation and Composition Control in A 10 L Mixing Tank

Yulius Deddy Hermawan

Chemical Engineering Department, Faculty of Industrial Technology, UPN "Veteran" Yogyakarta
Jl. SWK 104 (Lingkar Utara), Condongcatur, Yogyakarta INDONESIA
***E-mail** : ydhermawan@upnyk.ac.id*

Abstract :

The open loop experiment of composition dynamic in a 10 L mixing tank has been successfully done in laboratory. A 10 L tank was designed for mixing of water (as a stream-1) and salt solution (as a stream-2 with salt concentration, c_2¬ constant). An electric stirrer was employed to obtain uniform composition in tank. In order to keep the liquid volume constant, the system was designed overflow. In this work, 2 composition control configurations have been proposed; they are Alternative-1 and Alternative-2. For Alternative-1, the volumetric-rate of stream-1 is chosen as a manipulated variable, while the volumetric-rate of stream-2 is chosen as a manipulated variable for Alternative-2. The composition control parameters for both alternatives have been tuned experimentally. The volumetric-rate of manipulated variable was changed based on step function. The outlet stream's composition response (c_3) to a change in the input volumetric-rate has been investigated. This research gave Proportional Integral Derivative (PID) control parameters. The gain controllers K_c [cm^6/(gr.sec)] for Alternative-1 and Alternative-2 are –34200 and 40459 respectively. Integral time constant (τ_I) and Derivative time constant (τ_D) for both alternatives are the same, i.e. τ_I = 16 second, and τ_D = 4 second. Furthermore, closed loop dynamic simulation using computer programming was also done to evaluate the resulted tuning parameters. The developed mathematical model of composition control system in a mixing tank was solved numerically. Such mathematical model was rigorously examined in Scilab software environment. As can be seen from our closed loop simulation, closed loop responses in PID control were faster than those in P and PI controls.

Keywords: closed loop, open loop, PID control, mixing tank, step function.

1. Introduction

A mixing tank is frequently used in chemical process industries, for examples as a blending tank and/or a continuous stirred tank reactor. Liquid composition in a mixing tank is one of important parameters for mixing processes or chemical reaction processes in reactor. The propagation of mass disturbance is possibly occurred in mixing processes. Therefore composition control should be implemented to overcome the propagation of mass disturbances.

Composition control parameters such as proportional gain controller (K_c), integral time constant (τ_I), and derivative time constant (τ_D) should be tuned properly, since they really affect the stability of mixing process. However designed composition control system must be able to give a stable response in facing the mass disturbances. Therefore the study on dynamic simulation and composition control is very important.

Some studies of process dynamic and control have been done. Recently, Hermawan et al **[1]** have presented the open loop composition dynamic in a 10 L Mixing Tank experimentally. Hermawan et al **[2]** have also presented the design of control configuration of non-interacting-tank system using quantitative analysis of relative gain array. Hermawan **[3]** has implemented Process Reaction Curve (PRC) for tuning of temperature control parameters in a 10 L Stirred Tank Heater. Widayati and Hermawan **[4]** have studied the mixing characteristic in a horizontal stirred tank.

The goals of this research are to propose the composition control configuration and to tune the composition control parameters (PID Control parameters) in a 10 L Mixing Tank. The resulted composition control parameters of proposed configurations are examined through dynamic simulation. In order to achieve the aims of this research, this work was done in two parts, i.e. open loop experiment in laboratory for tuning of composition control parameters and closed loop simulation using computer programming to explore dynamic behavior of controlled system. The open loop experiment in laboratory was carried out to tune composition control parameters. The volumetric rate of input stream was chosen as a manipulated variable to maintain the concentration of output stream at the constant value. In order to examine the control configuration, the mass disturbances were made based on step function. The Scilab software was utilized to carry out dynamic simulation.

Notes:
1 : Main Tank (as a mixing tank)
2 : Feeding tank of stream-1
3 : Feeding tank of stream-2
4 : Tank for making a disturbance ***c₂***
5 : Storage tank
6 : Transfer pump
7 : *Three way valve*
8 : Valve
9 : Stirrer

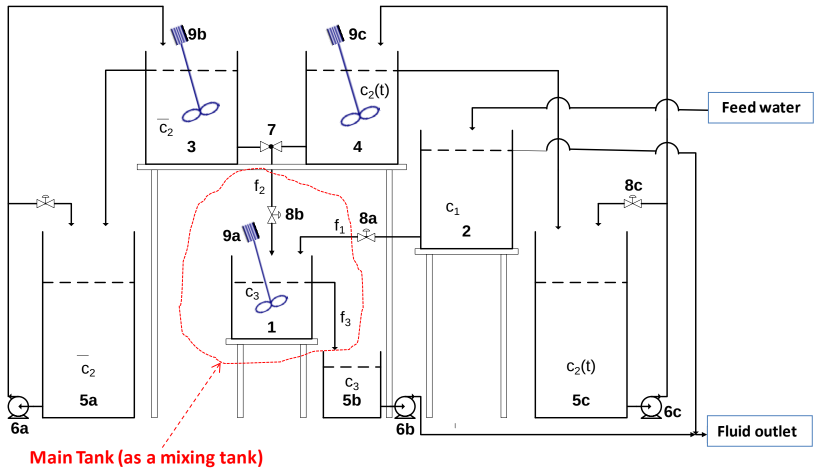


Figure1. Experimental apparatus setup

2. Material and Methods

Experimental apparatus setup is shown in Figure 1. As can be seen from Figure 1, No.1 is a main tank that represents a mixing tank. This mixing tank has 2 input streams, i.e. stream-1 and stream-2, and 1 output stream, i.e. stream-3. In normal condition, stream-1 and stream-2 come from the feeding tank No. 2 and No. 3 in Figure 1, respectively. In this work, water was used as a stream-1 with its volumetric rate f_1 [cm3/sec], and salt solution as a stream-2 with its volumetric rate f_2 [cm^3/sec] and concentration c_2 [gr/cm^3]. The input concentration c_2 is constant. The output stream (stream-3) has volumetric rate f_3 [cm^3/sec] and concentration c_3 [gr/cm^3]. The concentration c_3 is measured by means of Conductivity-meter. Since the liquid volume is kept constant, the system is designed overflow. A stirrer is employed to obtain uniform composition in the mixing tank. The material balance of the mixing tank can be written as follows:

$$\frac{dc_3(t)}{dt} = [f_1(t)\bar{c}_1 + f_2(t)\bar{c}_2 - (f_1(t) + f_2(t))c_3(t)]/V \qquad [1]$$

In this research, 2 composition control configurations are proposed, i.e. Alternative-1 and Alternative-2 as shown in Figure 2. Open loop tuning experiment is done for either alternatives by changing the opening valve of stream-1 (No. 8a in Figure 1) or stream-2 (No. 8b in Figure 1) to increase/decrease its volumetric rate immediately. The output concentration (c_3) response to a change in input volumetric rate is then investigated. The resulted response will similar with that response given by first order plus dead time (FOPDT) model. PID Control parameters are then tuned by fitting the resulted FOPDT as proposed by Ziegler-Nichols **[5]**. These open loop experiments should be started from its initial (normal) conditions.

In order to evaluate the resulted PID Control parameters, dynamic simulation is carried out by means of computer. A simple feedback control system is implemented to maintain liquid concentration in tank (c_3) constant by manipulating the volumetric rate of stream-1 or stream-2. Thus, the equation of manipulated variables for both of control configuration alternatives can be written as follow:

Alternative-1: $$f_1(t) = \bar{f}_1 + K_c e(t) + \frac{K_c}{\tau_I}\int e(t)dt + K_c \tau_D \frac{de(t)}{dt} \qquad [3]$$

Alternative-2: $$f_2(t) = \bar{f}_2 + K_c e(t) + \frac{K_c}{\tau_I}\int e(t)dt + K_c \tau_D \frac{de(t)}{dt} \qquad [4]$$

Where e(t) is defined as:

$$e(t) = c_3^{SP} - c_3(t) = \text{error} \qquad [5]$$

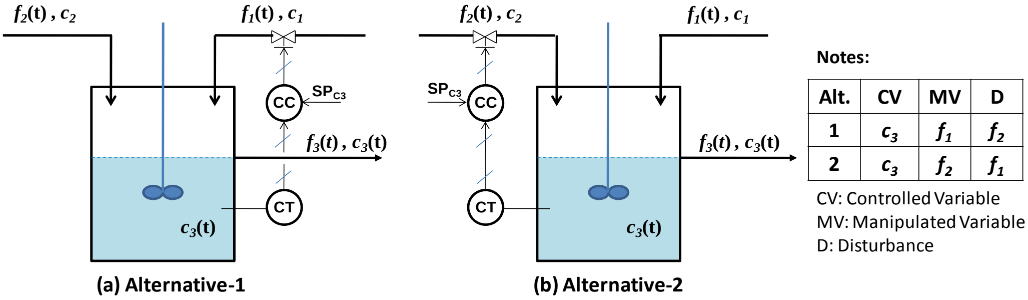


Figure 2. Composition Control Configuration: (a) Alternative-1, (b) Alternative-2.

The developed mathematical model of composition control system in the mixing tank is solved numerically with the easiest way of explicit Euler. The free software Scilab is chosen to carry out the closed loop dynamic simulation. The closed loop responses of composition control will then be explored in this work.

3. Result and Discussion.

Steady state parameters of mixing tank are listed in Table 1. Based on steady state material balance, the process time constant is found 37 seconds (0.6 minutes). Therefore the system is considered quite sensitive to the changes of input disturbances.

3.1. Tuning of Composition Control Parameters for Alternative-1

For Alternative-1, volumetric rate of water (f_1) is considered as a manipulated variable to maintain liquid composition in tank (c_3). Figure 3.a shows the influence of f_1 on c_3. Volumetric rate of water is decreased by an amount of 76 cm^3/sec immediately; the concentration c_3 rises about 0.01 gr/cm^3. The tuning results of composition control parameters (P, PI, and PID) for Alternative-1 are listed in Table 2.

3.2. Tuning of Composition Control Parameters for Alternative-2

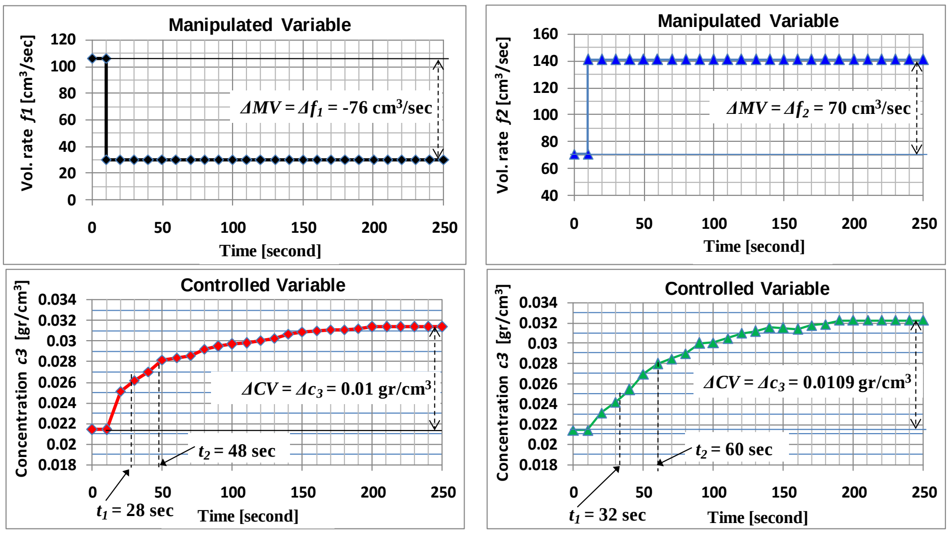
For Alternative-2, volumetric rate of salt solution (f_2) is considered as a manipulated variable to maintain liquid composition in tank (c_3). Figure 3.b shows the open loop composition response to a change in the volumetric rate f_2. The concentration c_3 increases (about 0.01 gr/cm^3) as the volumetric rate f_2 increases (about 70 cm^3/sec). The tuning results of composition control parameters (P, PI, and PID) for Alternative-2 are also listed in Table 2.

Table 1. Steady state parameters

No	Variable	Steady state
1	Volumetric rate of stream-1, f_1 (cm^3/second)	106
2	Volumetric rate of stream-2, f_2 (cm^3/second)	71
3	Volumetric rate of stream-3, f_3 (cm^3/second)	177
4	Concentration of stream-1, c_1 (gr/cm^3)	0
5	Concentration of stream-2, c_2 (gr/cm^3)	0.05
6	Concentration of stream-3, c_3 (gr/cm^3)	0.0214
7	Liquid volume in tank, V (cm^3)	6600

Table 2. Tuning results of composition control parameters.

Type of Feedback Control	*Proportional Gain* Kc [cm^6/(gr.sec)]			*Integral time* τ_I [sec]			*Derivative time* τ_D [sec]		
	Kc	Alt-1	Alt-2	τ_I	Alt-1	Alt-2	τ_D	Alt-1	Alt-2
P	$\tau/(K.t_D)$	-28500	33716	-	-	-	-	-	-
PI	$0.9\,\tau/(K.t_D)$	-25650	30344	$3.3t_D$	27	27	-	-	-
PID	$1.2\,\tau/(K.t_D)$	-34200	40459	$2t_D$	16	16	$0.5t_D$	4	4



Ziegler Nichols Fitting:

0.283(ΔCV) → $t_1 = 28$ sec

0.632(ΔCV) → $t_2 = 48$ sec

$$\tau = \frac{3}{2}(t_2 - t_1) = 30\,\text{sec}$$

$$t_D = (t_2 - \tau) - 10 = 8\,\text{sec}$$

$$K = \frac{\Delta CV}{\Delta MV} = -1.32E-4\,\frac{gr.\text{sec}}{cm^6}$$

Ziegler Nichols Fitting:

0.283(ΔCV) → $t_1 = 32$ sec

0.632(ΔCV) → $t_2 = 60$ sec

$$\tau = \frac{3}{2}(t_2 - t_1) = 42\,\text{sec}$$

$$t_D = (t_2 - \tau) - 10 = 8\,\text{sec}$$

$$K = \frac{\Delta CV}{\Delta MV} = 1.56E-4\,\frac{gr.\text{sec}}{cm^6}$$

(a) Alternative-1 **(b) Alternative-2**

Figure 3. Tuning of Composition Control Parameters: (a) Alternative-1, (b) Alternative-2.

3.3. Dynamic Simulation of Composition Control for Alternative-1

Closed loop responses to a change in volumetric rate f_2 are illustrated in Figure 4. The disturbances were made by following both functions of step increase and step decrease. For step increase's disturbance, volumetric rate f_2 is increased by an amount of 70 cm^3/sec at time equals 10 seconds. As can be seen, the composition controller (P, PI, and PID) attempts to return concentration c_3 to its normal value of 0.0214 gr/cm^3. Concentration c_3 can be returned to its set point by both of PI and PID Controls. P Control produces an offset of 0.0019 gr/cm^3. Closed loop response of PID Control is fastest compared to P and PI Controls; Concentration c_3 can be returned to its set point at time equals 150 seconds.

For step decrease's disturbance, volumetric rate f_2 is decreased by an amount of 56 cm^3/sec at time equals 10 seconds. The concentration c_3 decreases first, and then rises to its normal value. However P Control still produces an off-set of about 0.0028 gr/cm^3. Closed loop response of PID Control is the fastest; the set point of c_3 can be achieved at time equals 120 sec.

3.4. Dynamic Simulation of Composition Control for Alternative-2

Figure 5 shows closed loop responses to a change in volumetric rate f_1. For this alternative, the disturbances were also made by following both functions of step increase and step decrease. For step increase's disturbance, volumetric rate f_1 is increased by an amount of 106 cm^3/sec at time equals 10 seconds. As shown in Figure 5, concentration c_3 decreases as volumetric rate f1 increases, and then concentration c_3 can be returned to its set point by both of PI and PID Controls. P Control produces an offset of 0.0019 gr/cm^3. Closed loop response of PID Control is the fastest one; concentration c_3 can be returned to its set point at time equals 150 seconds.

For step decrease's disturbance, volumetric rate f_1 is decreased by an amount of 76 cm^3/sec at time equals 10 seconds. The concentration c_3 increases as the volumetric rate of water decreases, and then drops to its normal value for PI and PID Controls. Again, P Control still produces an off-set of about 0.0014 gr/cm^3, and PID Control gives the fastest response.

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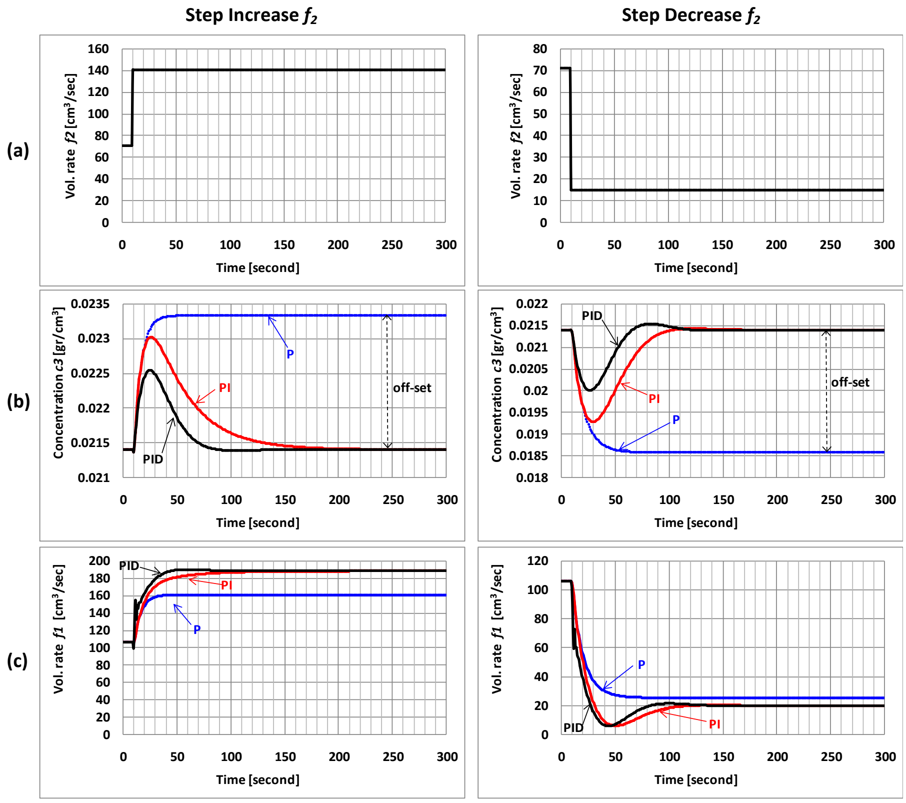

Figure 4. Closed Loop Responses of Composition Control Alternative-1 to a change in volumetric rate f_2: (a) Volumetric rate f_2, (b) Concentration c_3, (c) Volumetric rate f_1

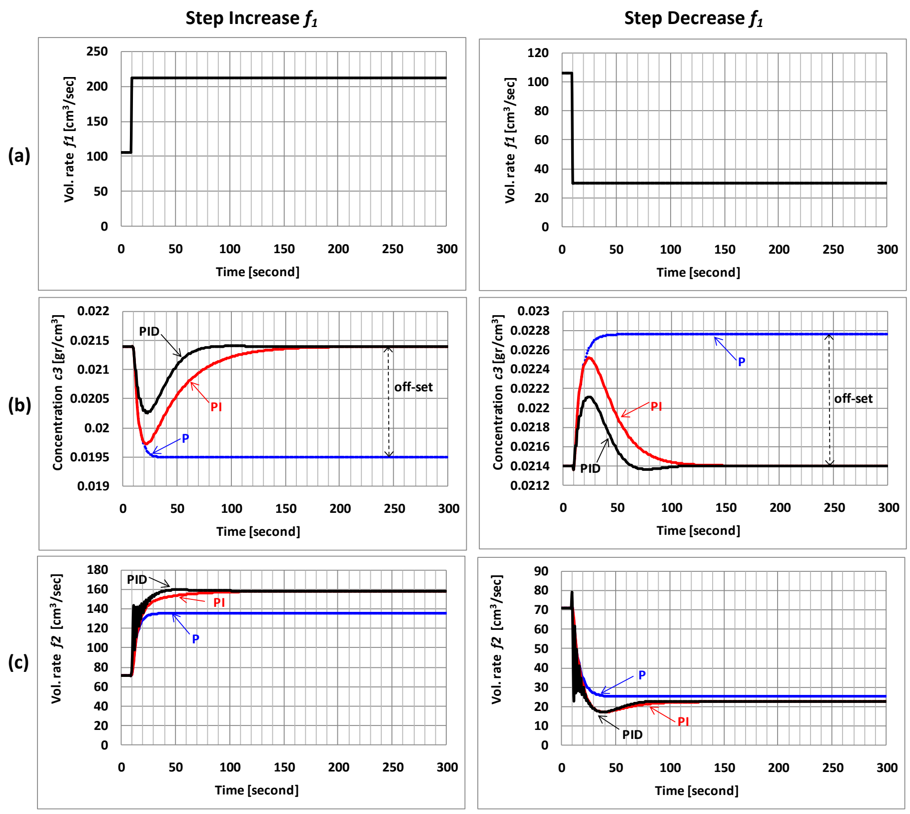

Figure 5. Closed Loop Responses of Composition Control Alternative-2 to a change in volumetric rate f_1: (a) Volumetric rate f_1, (b) Concentration c_3, (c) Volumetric rate f_2

4. Conclusion

This paper has discussed tuning of composition control parameters and dynamic simulation in a 10 L mixing tank. Two alternatives of composition control configurations have been proposed. Closed loop dynamic behaviours of the two control configurations have been explored. According to my dynamic simulation, the tuning results of composition control parameters produce stable responses. This research reveals that PID Composition Control produces the fastest responses compared to both of P and PI Composition Controls.

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Nomenclature

$c_{1,2,3}$	concentration of stream 1, 2, 3 [gr/cm3]
c_3^{SP}	set point of liquid concentration in tank [gr/cm3]
e	error [gr/cm3]
$f_{1,2,3}$	volumetric rate of stream 1, 2, 3 [cm3/second]
K	steady state gain of the process [(gr.second)/cm6]
K_c	proportional gain controller [cm6/(gr.second)]
t_1	time at which c3 = 0.283 □c3s [second]
t_2	time at which c3 = 0.632 □c3s [second]
t_D	effective process dead time [second]
V	liquid volume in tank [cm3]
Greek letters	
ΔCV	steady state change in controlled variable [gr/cm3]
ΔMV	step change in manipulated variable [cm3/second]
τ	effective process time constant [second]
τ_D	derivative time constant [second]
τ_I	integral time constant [second]

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