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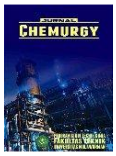

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DINAMIKA PROSES PADA SISTEM TIGA TANGKI MENGGUNAKAN PENDEKATAN *FIRST ORDER PLUS TIME DELAY* (FOPTD)

PROCESS DYNAMICS ON THREE-TANKS SYSTEM USING FIRST ORDER PLUS TIME DELAY (FOPTD) APPROACH

Zahrotul Azizah[1]*, Aida Nurmala[1], Medya Ayuda Fitri[1], Ahmad Musonnifin Aziz[1], Hairul Huda[2]

[1]Program Studi Teknik Kimia, Fakultas Teknik, Universitas Nahdlatul Ulama Sidoarjo
Jl. Lingkar Timur KM 5.5 Rangkah Kidul, Indonesia
[2] Program Studi Teknik Kimia, Fakultas Teknik, Universitas Mulawarman
Jl. Sambaliung No. 9, Gunung Kelua, Samarinda, Indonesia

*email : azizah.tkm@unusida.ac.id

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Abstrak

Berbagai keadaan operasi selama proses produksi di mana unit-unit proses sering kali saling memengaruhi atau berinteraksi satu sama lain. Variabel-variabel dalam setiap proses juga saling berinteraksi. Berdasarkan variabel masukan dan keluaran, sistem dapat dibagi menjadi dua kategori, yaitu *Single Input Single Output* (SISO) dan *Multi Input Multi Output* (MIMO). Secara umum, pengujian berbagai sistem kontrol untuk desain tiga tangki menggunakan sistem MIMO. Tujuan dari penelitian ini adalah melakukan simulasi *loop* terbuka pada sistem tiga tangki menggunakan perangkat lunak NI LabView. Tahapan penelitian yang dilakukan untuk menyelesaikan penelitian ini meliputi pembuatan model matematika dari sistem tiga tangki, kemudian menentukan spesifikasi proses tangki, selanjutnya melakukan simulasi *loop* terbuka, dan mengidentifikasi fungsi *transfer* menggunakan metode uji langkah (*step test*). Hasil yang diperoleh dari penelitian ini menunjukkan bahwa sistem tiga tangki dapat membentuk sistem MIMO 2x2 dengan dua variabel yang dikendalikan (h1 dan h3) serta dua variabel yang dimanipulasi (U1 dan U2). Fungsi transfer dapat diidentifikasi menggunakan metode uji langkah dengan pendekatan *First Order Plus Time Delay* (FOPTD).

Kata Kunci: FOPTD, sistem tiga tangki, variabel yang dikendalikan, variabel yang dimanipulasi

Abstract

The different operating states during the production process in which the process units often influence or interact with each other. Variables interact with each other in each process. Based on the input and output variables, the system can be divided into two categories, namely Single Input Single Output (SISO) and Multi Input Multi Output (MIMO). In general, testing of various control systems for a three-tank design uses the MIMO system. The purpose of this study is to perform an open loop simulation on a three-tank system using NI LabView software. The stages of research carried out to complete this research is to make a mathematical model of the three-tank system, after that determine the process specifications of the tank, then do an open loop simulation and identify the transfer function using the step test method. The results obtained from this study are a three-tank system can form a 2x2 MIMO system with two controlled variables (h1 and h3) and two

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manipulated variables (U1 and U2). Transfer functions can be identified using the step test method with the First Order Plus Time Delay (FOPTD) approach.

Keywords: *controlled variable, FOPTD, manipulated variable, Three-Tanks*

1. INTRODUCTION

Better process control is needed, because in the chemical industry the process that occurs is converting raw materials into products in very large quantities and demands a very high level of safety. Different operating states exist during the production process where the process units often influence or interact with each other. Variables interact with each other in each process.

Based on the input and output variables, the system can be divided into two categories. Single Input Single Output (SISO) and Multi Input Multi Output (MIMO) are the first and second types. It is known that the three-tank design is a MIMO system suitable for testing various non-linear control systems. The square root relationship between flow and level in the tank is what causes a non-linear model (1). The MIMO system has an impact on several control variables which are used to show the interactions brought about by many input variables. There are several significant interactions in the three-tank system, including in tanks 1,2, and 3. This occurs because the input from pump 1 fills tank 1 and pump 2 fills tank 3, and there are interactions between tanks 1, 2 and 3 (2). The three-tank system was chosen because of its uncomplicated device design and its ability to describe interactions and practice an interacting 2x2 system model. There is an interaction between the levels of each of the three connected tanks.

In this study, a simulation of a three-tank system will be carried out to study the interactions that occur in the system. The LabView software was chosen to simulate a three-tank system.

Three-Tank System

The three-tank system can be seen as a prototype for many industrial applications in industrial processes, such as chemical and petrochemical plants, oil and gas systems. The typical control problem involved in the system is how to maintain the desired level of liquid in each tank. The principle schema of the model is shown in Figure 1.

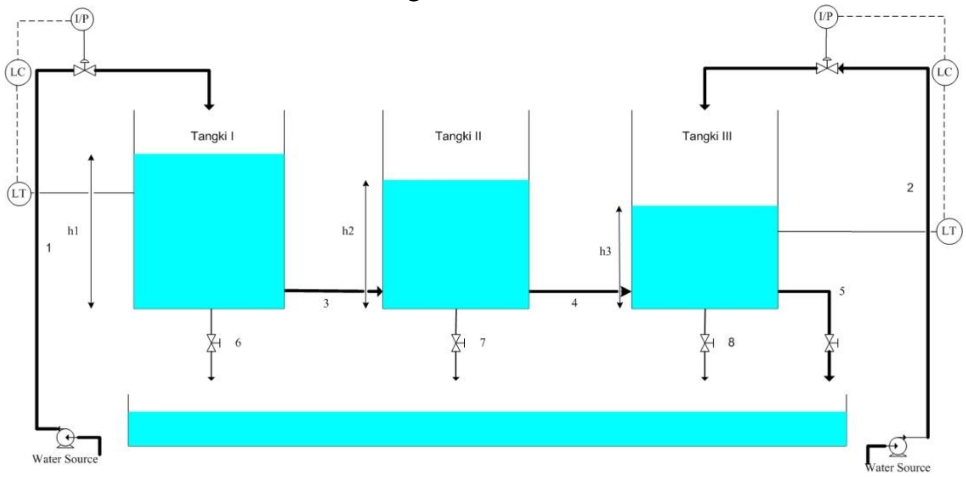


Figure 1. Schematic of the Three Tank System Model Principle

The basic equipment consists of three tanks numbered from left to right as Tank 1, Tank 2 and Tank 3. These are connected sequentially to each other by cylindrical pipes. Water is collected in the reservoir, pumped into Tank 1 and Tank 3. Where the controlled variables are h1 and h3 while the manipulated variables are U1 and U2. There is an interaction between Tanks 1,2 and 3, if the level of Tank 1 is changed then the level of Tank 3 will also change through Tank 2.

Step Test

Ziegler and Nichols suggest a tuning method based on a step test, according to Seborg (3). The experimental process is quite easy. The controller is set manually when the process reaches or approaches steady state. The step test was changed in the controlled variable by (3-5%). According to the process curve, the control settings are applied in the open loop state. This tuning approach is described as the step test method or the process curve method.

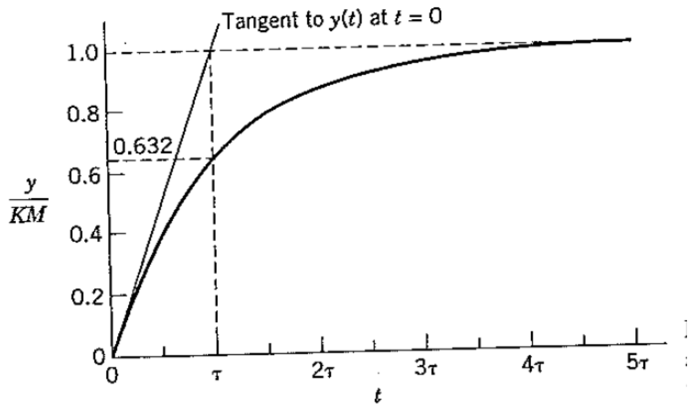
The process curve is a graphical representation of the reaction of the process to changes in the input stage. The model parameters can be found from the identification of the reaction curve if the process can be matched with a first-order or second-order linear model. For example, a first-order process on the deviation variable,

$$\tau \frac{dy}{dt} + y = Ku \tag{1}$$

Description:

τ	: time constant
dy	: differential y
dt	: time differential
y	: *steady state change*
Ku	: ultimate gain

When U(0)=0 and y(0)=0 and the system is in steady state. To normalize the step response if the input U suddenly changes from 0 to M at time t = 0, follow Figure 2.6. 63.2% yield of y(t) is achieved



when t=τ.

Figure 2. First Order System Response Step and Constant Estimation (τ).

The dynamics of a higher-order process, as opposed to a process that follows a first-order process, is described in terms of time delay. These adjustments can improve the model's ability to predict experimental results. Adjustment Model First Order Plus Time Delay (FOPTD) is used for adjustments. This process is used to make modifications, and is described as follows:
Calculating the ratio of changes in the steady state to the magnitude of the change in steps yields profit. The inflection point of the step response is where the tangent is located. Where is the point of intersection of the tangent to the x-axis (t), and the time delay (θ). The point of intersection between the tangent and the steady state response straight line (y=KM) t = + , where the value of is obtained by subtracting it from the value of .

2. RESEARCH METHODOLOGY

a. Create a mathematical model of three-tank system

The mass balance calculation for a three-tank system is as follows:

[*Rate of accumulation*] = [*Rate of in-flow*] – [*Rate of out-flow*] (2)

$$\frac{dm_T}{dt} = m_{in} - m_{out} \quad (3)$$

$$\frac{dv\rho}{dt} = \rho q_{in} - \rho q_{out} \quad (4)$$

$$\frac{dAh\rho}{dt} = \rho q_{in} - \rho q_{out} \quad (5)$$

Constant density $\rho = \rho_1 = \rho_2$ (6)

$$\frac{dAh}{dt} = q_{in} - q_{out} \quad (7)$$

$$A\frac{dh}{dt} = q_{in} - q_{out} \quad (8)$$

q_{in} depends only on the input supplied by the pump:

$$q_{pump_i} = k_i u_i \quad (9)$$

The Bernoulli equation and the liquid flow rate can be used to describe q_{out}, which depends only on the acceleration due to gravity and the water level in the tank. The Bernoulli equation for an incompressible liquid is as follows:

$$p + \frac{1}{2}\rho v^2{}_w + \rho g h = const. \quad (10)$$

$$\frac{1}{2}\rho\, v_w{}^2 \quad (11)$$

$$\frac{1}{2}\rho\, v_w{}^2 = \rho\, g\, h \quad (12)$$

$$V_w{}^2 = \rho\, g\, h \quad (13)$$

$$V_w{}^2 = 2\, g\, h \quad (14)$$

$$V_w = \sqrt{2\, g\, h} \quad (15)$$

The outflow is determined using the water level (Vw = 0) and the bottom of each tank (h=0):

$$q_{out} = a_i \,.\, v_w = a_i\sqrt{2gh_i} \quad (16)$$

Substituting equations (9) and (16) into equation (8) to get the equation:

$$A_i\,\frac{dh_i}{dt} = k_i u_i - a_i\sqrt{2gh_i} \quad (17)$$

Description:

A_i = *tank area*

a_i = *exit hole area*

h_i = *water level*

g = acceleration due to gravity

q_{in} = *inflow to tank*
k_i = *pump constant*
m_T= *accumulation of mass in the tank*
m_{in}= *mass flow rate into the tank*
m_{out} = *mass flow rate out of the tank*
v = *tank volume*
a_{bi}= bottom outlet area
a_{si}= side outlet area

b. Define specifications of three-tanks system

Table 1. Specifications of Modified Model III Three Tank System

Model Specification	Score
Tank Height	50 cm
Tank Diameter	20 cm
Base area of the tank	314,3 cm^2
Bottom Output Pipe Diameter	0,925 cm
Side Output Pipe Diameter	0,683 cm
Bottom Pipe Hole Surface Area	0,6723 cm^2
Side Pipe Hole Surface Area	0,3665 cm^2

Table 2. Process Parameters

Parameter Proses	Quantity	Score
Density	ρ	1000 kg/m^3
Gravity Acceleration	g	9,8 m/s^2
Water Heat Capacity	Cp	4220 J/kg K
Reference temperature	T_{ref}	0 °C
Water temperature	$T_{\textit{fresh water}}$	303 K
Pump constant	k_1=k_2	1

c. Create process simulation of three-tank system

a. Develop a block diagram of the three-tank system in an open loop
b. Simulate the designed process system by incorporating mass balance and tank specifications
c. Analyze the results obtained from the simulation

d. Identifying the transfer function using the step test method

The transfer function of the three-tank system is obtained through identification when the system is in an open-loop condition (Seborg et al., 2011), with a step change of 5%.

3. RESULT AND DISCUSSION

Simulation Steady State

This study aims to perform a simulation of a three-tank system. To perform the simulation stage, the specifications of the tool are determined according to Table 2. The system consists of three tanks with the same diameter and tank height. At the bottom of the outlet pipe has a diameter of 0.925 cm. In a three-tank system, there is an interaction between tank one and tank three through tank two. After determining the specifications, then determining the process parameters in accordance with Table 2. This value is used to calculate the mass balance in the LabView software.

The LabView software is then adjusted based on the equipment specifications, process parameters, and mass balances that have been owned. The schematic of the three-tank system in the LabView simulation can be seen in Figure 1. The three-tank system interacts with each other through tank two, where there are two flow rates (U1 and U2). Where the flow rate (U1 and U2) as the manipulated variable while (h1 and h3) as the controller variable. In accordance with Figure 1. Then the mass balance of each tank is obtained.

Mass Balance in Tank 1

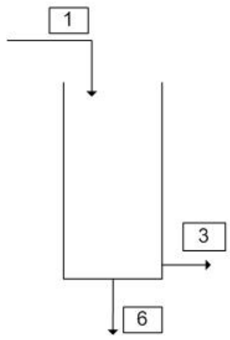


Figure 3. Tank 1

Acc = in – out

$$A1\frac{dh1}{dt} = stream\ 1 - (stream\ 3 + stream\ 6)$$

$$A1\ \frac{dh1}{dt} = k_1 U_1 - (\ a_{s1}\sqrt{2g(h_2 - h_1)} + a_{b1}\sqrt{2gh_1}$$

$$\text{U1} = (a_{s1}\sqrt{2g(h_2 - h_1)} + a_{b1}\sqrt{2gh_1}$$

Mass Balance in Tank 2

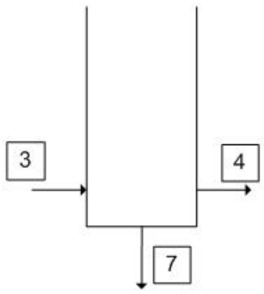


Figure 4. Tank 2

Acc = in – out

$$A2\frac{dh2}{dt} = stream\ 3 - (stream\ 4 + stream\ 7)$$

$$A2\frac{dh2}{dt} = as1\sqrt{2g(h2 - h1)} - as2\sqrt{2g(h3 - h2)} + ab2\sqrt{2gh2}$$

Mass Balance in Tank 3

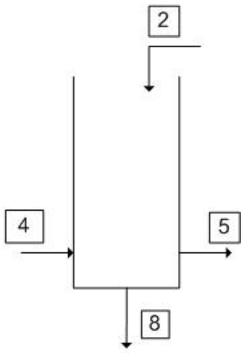


Figure 5. Tank 3

Acc = in – out

$$A3\frac{dh3}{dt} = (stream\ 4 + steam\ 2) - (stream\ 5 + stream\ 8)$$

$$A_3\frac{dh3}{dt} = (k_2U_2 + a_{s2}\sqrt{2g(h_2 - h_3)}) - a_{s3}\sqrt{2gh_3} + ab_3\sqrt{2gh_3}$$

$$U2 = a_{s2}\sqrt{2g(h_2 - h_3)} - a_{s3}\sqrt{2gh_3} + a_{b3}\sqrt{2gh_3}$$

Then the transfer function identification is carried out to determine the interaction between each controller variable and manipulated variable

Identification Transfer Function

The identification of the transfer function is done by adding a 5% step in the open loop system after it is in a steady state. The step test is carried out when the time shows 1000 s and the disturbance is given by changing the input signal. The changed input signals are U1 and U2. The response graph obtained was identified based on the FOPDT approach as described in Chapter 2. Changes in flow rate (U1 and U2) affect the control variable, the level of tank 1 increases due to the addition of flow to tank 1. flow in tank 3. Thus, the transfer function matrix obtained is

$$\begin{bmatrix} h1(s) \\ h3(s) \end{bmatrix} = \begin{bmatrix} Gp11 & Gp12 \\ Gp21 & Gp22 \end{bmatrix} \begin{bmatrix} U1(s) \\ U2(s) \end{bmatrix}$$

A step test is carried out for a three-tank system in an open loop state, this is done by changing the inflow U1 and obtaining several response graphs, namely:

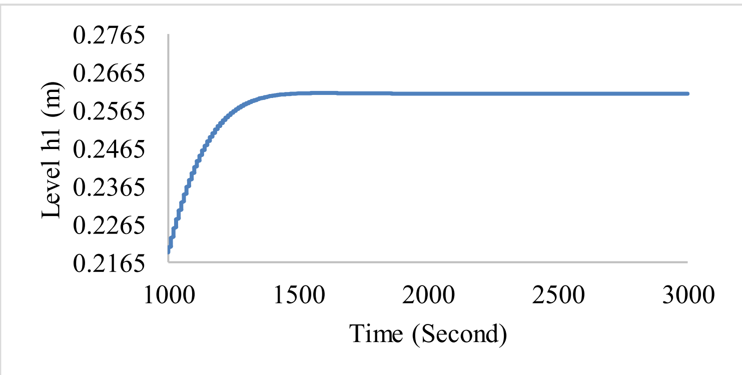


Figure 6. Graph of Response to Changes in U1 to h1

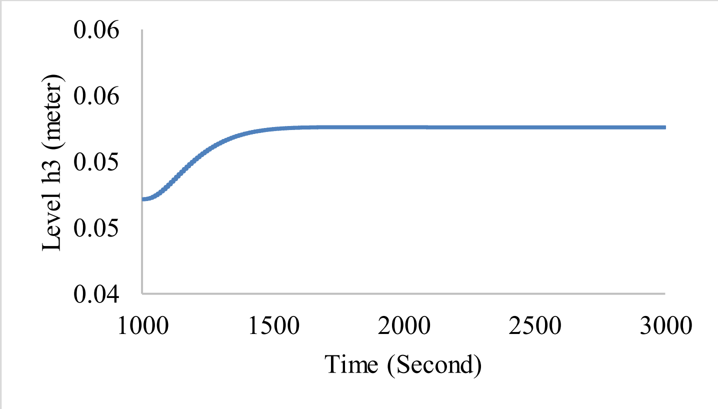


Figure 7. Graph of Response to Changes in U1 to h3

The second is to change the inflow of U2 in an open loop state and obtain some response graphs, namely:

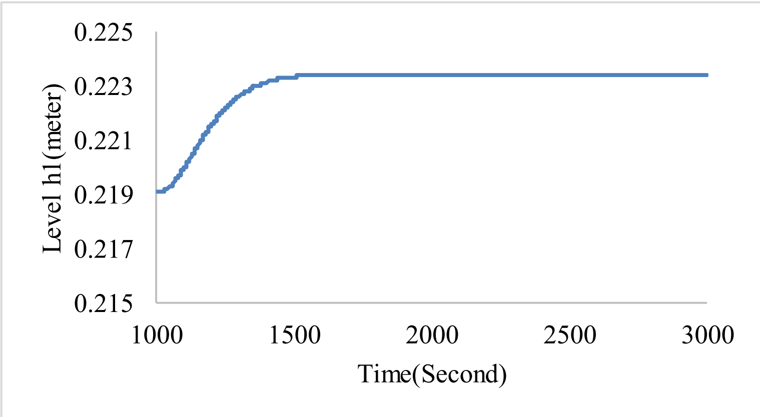


Figure 8. Graph of Response to Changes in U2 to h1

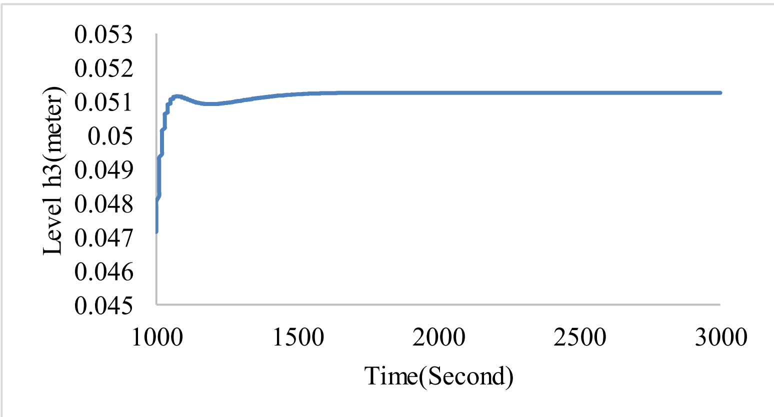


Figure 9. Graph of Response to Changes in U2 to h3

Based on the results of the step test, the three-tank system transfer function matrix obtained is:

$$\text{Gp } 11 = \frac{h1}{U1} = \frac{839.586\, e^{-0.1\, s}}{130.000\, s+1}$$

$$\text{GP } 12 = \frac{h1}{U2} = \frac{112.986\, e^{-10.000\, s}}{190.000\, s+1}$$

$$\text{Gp }21 = \frac{h3}{U1} = \frac{109.529\ e^{-0.000\,s}}{230.000\ s+1}$$

$$\text{Gp }22 = \frac{h3}{U2} = \frac{107.731\ e^{-10.000\,s}}{450.000\ s+1}$$

4. CONCLUSION

Simulation of the three-tank system in open loop conditions can run well. The three-tank system can form a 2x2 MIMO system with two controlled variables (h1 and h3) and two manipulated variables (U1 and U2). Transfer functions can be identified using the step test method with the First Order Plus Time Delay (FOPTD) approach.

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