Dynamic Simulation and Control in A Non-Interacting-Tank System

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Dynamic Simulation and Control in A Non-Interacting-Tank System

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Abstract

Relative Gain Array (RGA) analysis has been previously implemented on design of control configuration of Non-Interacting-Tank (NIT) system [Hermawan et al, 2010]. The previous work produced the process control configuration of NIT system. The aim of this research is to examine the resulted process control configuration of NIT system through closed loop dynamic simulation. The developed mathematical model is solved numerically. Trial and error method has been used for tuning of the feedback control parameters. According to my dynamic simulation, the resulted process control configuration of NIT system produces stable responses to a change in the input mass disturbance load.

Keywords: Closed Loop; Control Configuration; Dynamic Simulation; Non-Interacting-Tank.

1. Introduction

The multi-capacity processes such as Non-Interacting-Tank (NIT) and Interacting-Tank (IT) are frequently used in chemical process industries. However, the propagations of mass and thermal disturbances are possibly occurred in those multi-capacity processes. Therefore, implementation of automatic process control on the multi-capacity processes is very important to overcome the disturbances.

There are some contributions to the study of process dynamic and control. Composition dynamic in a mixing tank has been studied experimentally [Hermawan et al, 2012]. Dynamic simulation and composition control in a mixing tank has also been presented recently [Hermawan, 2012]. Process Reaction Curve was implemented for tuning of temperature control parameters in a stirred tank heater [Hermawan, 2011]. The use of Relative Gain Array (RGA) for design of process control configuration of NIT system has been studied experimentally [Hermawan et al, 2010]. This study produced the control configuration of NIT system, with 4 couples of CV-MV (Controlled Variable – Manipulated Variable).

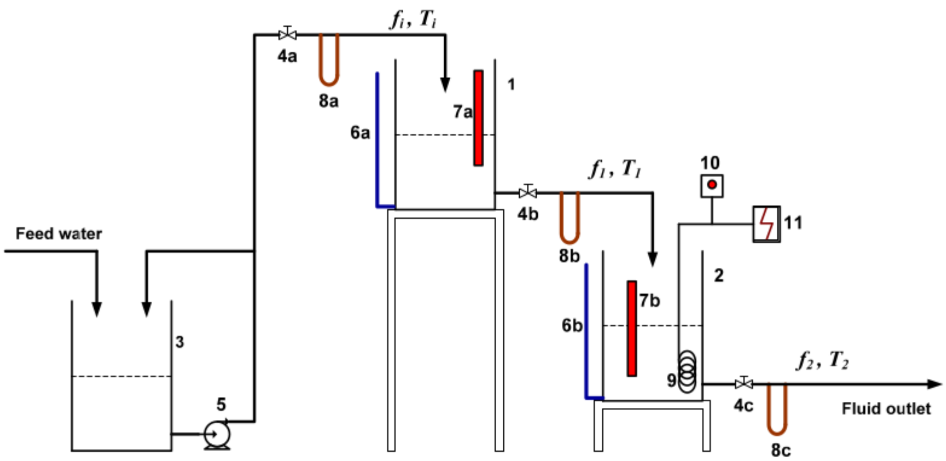
The goal of this research is to examine the control configuration of NIT system which is resulted by our previous work [Hermawan et al, 2010]. The mass disturbance load is made to examine the performance of control configuration of NIT. PI (Proportional Integral) Control is implemented in all control loops of NIT system. PI Control parameters are tuned based on trial and error method. Dynamic behaviors of NIT's control system will be explored trough rigorous dynamic simulation. The Scilab software is utilized to carry out dynamic simulation.

2. Experimental

Experimental apparatus setup is shown in **Figure 1**. As can be seen from **Figure 1**, tanks No. 1 and No. 2 are considered as a NIT system. In this research, water was used as a fluid with both of its density and its heat capacity are assumed constant. Tank-1 has an input stream with volumetric rate of f_i (cm^3/sec) and temperature of T_1 (oC). The output stream of Tank-1 is then flowed to Tank-2. Electric heater was employed in Tank-2 to heat liquid in the tank. The liquid levels of both Tank-1 and Tank-2 are indicated by means of glass level indicator. The liquid temperatur and flowrate are measured by means of thermometer and U-tube manometer respectively. The steady state parameters of NIT system are shown in **Table 1**. This steady state parameters results are then used as the initial conditions for closed loop dynamic simulation.

Table 1. Steady state parameters of NIT System [Hermawan et al, 2010].

Tank-1		Tank-2	
Parameters	**Value**	**Parameters**	**Value**
Input flowrate, f_i [cm^3/sec]	15.2	Input flowrate, f_i [cm^3/sec]	15.2
Output flowrate, f_1 [cm^3/sec]	15.2	Output flowrate, f_1 [cm^3/sec]	15.2
Liquid level, h_1 [cm]	15.5	Liquid level, h_1 [cm]	15.1
Temperature, T_1 [^{o}C]	28	Temperature, T_1 [^{o}C]	39.5
Input valve open (%)	40	Electric heat, q_e [watt]	800
Output valve open (%)	50	Input valve open (%)	50
Tank surface area, A_1 [cm^2]	491	Output valve open (%)	50
		Tank surface area, A_2 [cm^2]	491



Notes:

1 : **Tank-1** for NIT system
2 : **Tank-2** for NIT system
3 : Storage Tank
4 : Valve
5 : Pump
6 : Level Indicator
7 : Thermometer
8 : U-Tube Manometer
9 : Electric Heater
10 : Watt-meter
11 : Electricity

Figure 1. Experimental apparatus setup [Hermawan et al, 2010].

Mass balance of Tank-1 can be written as follow:

$$\frac{dh_1(t)}{dt} = [f_i(t) - f_1(t)]/A_1 \quad (1)$$

Mass and energy balance of Tank-2 are:

$$\frac{dh_2(t)}{dt} = [f_1(t) - f_2(t)]/A_2 \quad (2)$$

$$\frac{dT_2(t)}{dt} = \left[f_1(t)\overline{T}_1 - f_2(t)\overline{T}_2 + q_e(t)/(\rho c_p) - \overline{T}_2(f_1(t) - f_2(t))\right]/V_2 \quad (3)$$

Control configuration of NIT system resulted by our previous work is ilustrated in **Figure 2**. There are 4 couples of CV-MV in NIT's control configuration as shown in **Table 2**; They are flow controller in the input stream of Tank-1, liquid level controller in Tank-1, liquid level controller in Tank-2, and liquid temperature controller in Tank-2. Tuning control parameters for all controllers are also listed in **Table 2**. In this work, feedback PI controls are implemented to maintain the controlled variables as its set point. Manipulated variables for all controllers are as follow:

Manipulated variable of FC-01: $f_i(t) = f_i^{SP} + K_c e_1(t) + \frac{K_c}{\tau_I}\int e_1(t)dt$ (4)

Where: $e_1(t) = f_i^{SP} - f_i(t)$ (5)

Manipulated variable of LC-01: $f_1(t) = \bar{f}_1 + K_c e_2(t) + \frac{K_c}{\tau_I}\int e_2(t)dt$ (6)

Where: $e_2(t) = h_1^{SP} - h_1(t)$ (7)

Manipulated variable of LC-02: $f_2(t) = \bar{f}_2 + K_c e_3(t) + \frac{K_c}{\tau_I}\int e_3(t)dt$ (8)

Where: $e_3(t) = h_3^{SP} - h_3(t)$ (9)

Manipulated variable of TC-01: $q_e(t) = \bar{q}_e + K_c e_4(t) + \frac{K_c}{\tau_I}\int e_4(t)dt$ (10)

Where: $e_4(t) = T_2^{SP} - T_2(t)$ (11)

The developed mathematical model of NIT control configuration system 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 input mass disturbance load is made in order to examine the performance of NIT control configuration. The closed loop responses of control system to a change in the mass disturbance load will then be explored in this work.

Table 2. Couples of CV-MV and tuning control parameters of NIT System

Controller	CV	MV	Control Type	Tuning Control Parameters	
				K_c	τ_I
FC-01	f_i	f_i	PI	0.01	10 [sec]
LC-01	h_1	f_1	PI	-5 [cm^2/sec]	60 [sec]
LC-02	h_2	f_2	PI	-5 [cm^2/sec]	60 sec]
TC-01	T_2	q_e	PI	15[watt/^{o}C]	10 [sec]

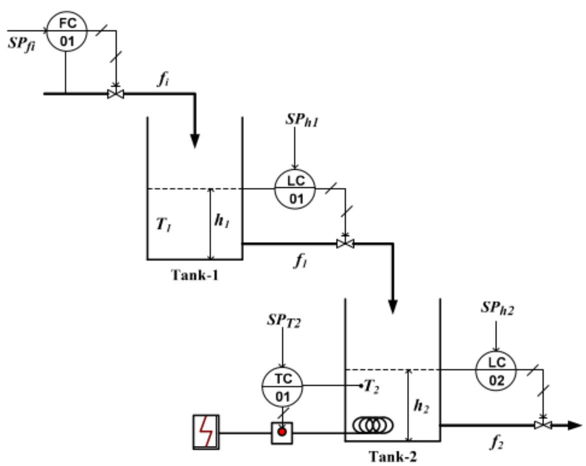


Figure 2. Control configuration of NIT System

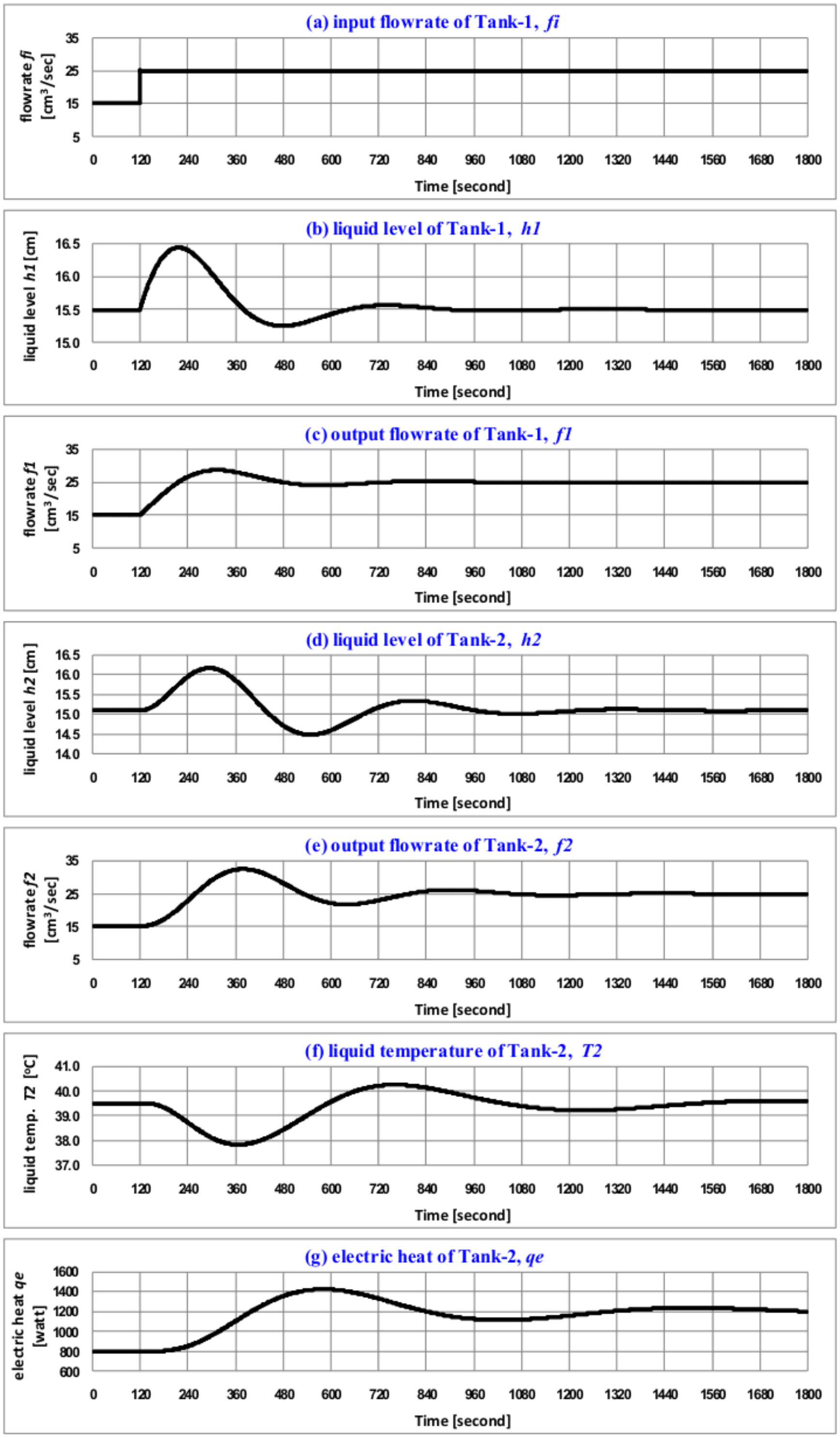


Figure 3. Dynamic responses of NIT control system to a change in set point of f_i.

3. Results and Discussion

Figure 3 shows the closed loop responses to a change in the input flowrate of Tank-1 (f_i). The set point of input flowrate f_i is increased by an amount of 10 cm^3/sec at time equals 120 seconds (**Figure 3.a**). Since the input flowrate of Tank-1 increases, it is understandable that the liquid level in Tank-1 (h_1) rises first, and then it can be returned to its set point of 15.5 cm at time about 960 seconds (**Figure 3.b**). The output flowrate of Tank-1 (f_1) is manipulated to maintain the liquid level in Tank-1 at its set point (**Figure 3.c**). Finally, the flowrate f_1 achieves new steady state value of 25 cm^3/sec at time equals 960 seconds (**Figure 3.c)**.

The characteristic change of Tank-1 propagates to the next tank, i.e. Tank-2. The dynamic behavior of liquid level inTank-2 is similar with that in Tank-1. However, the liquid level of Tank-2 can be returned to its set point of 15.1 cm at time equals 1560 seconds (**Figure 3.d**). The output flowrate of Tank-2 (f_2) is manipulated to keep the liquid level in Tank-2 constant. The flowrate f_2 rises a new steady state value of 25 cm^3/sec at time equals 1560 sec (**Figure 3.e**).

As can be seen from **Figure 3.f**, the liquid temperature of Tank-2 (T_2) decreases first as the input flowrate increases. The liquid temperature T_2 is controlled by manipulating the electric heat q_e. The electric heat must be increased to rise the liquid temperature T_2. Finally, the electric heat q_e achieves a new steady state value of 1200 watt at time equals 1560 sec (**Figure 3.g**).

4. Conclusion

This paper has discussed dynamic simulation and control in a NIT system. The resulted control configuration of NIT system has been examined through rigorous dynamic simulation. As can be seen from our closed loop dynamic simulation, the NIT control configuration gives stable responses to a change in the input mass disturbance load. This study also reveals that by developing the appropriate control configuration, i.e. proper couples of CV-MV, stable and fast responses can be achieved.

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Nomenclature

$A_{1,2}$	surface area of Tank 1,2 (cm^2)
c_p	heat capacity of fluid (J/(gr.^{o}C))
$e_{1,2,3,4}$	error for FC-01, LC-01, LC-02, and TC-01
$f_{i,1,2}$	volumetric flowrate of stream i, 1, 2 (cm^3/second)
$h_{1,2}$	liquid level of Tank 1, 2 (cm)
h_1^{SP}	set point of liquid level of Tank-1 (cm)
h_2^{SP}	set point of liquid level of Tank-2 (cm)
K_c	proportional gain controller
q_e	electric heat/energy (Watt or J/second)
$T_{1,2}$	liquid temperature of Tank 1, 2 (^{o}C)
T_2^{SP}	set point of liquid temperature of Tank-2 (^{o}C)
t	time (second)
$V_{1,2}$	liquid volume in Tank 1,2 (cm^3)
Greek letters	
ρ	liquid density (gr/cm^3)
τ_I	integral time constant (second)

Abbreviations

CV	Controlled Variable
FC	Flow Controller
LC	Level Controller
MV	Manipulated Variable
NIT	Non-Interacting-Tank
TC	Temperature Controller

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