Dynamic Modeling for a Second Order System of Tanks in Series Non-interacting System Using Simulink in Matlab

By

Muhammad Farzal Nasaruddin

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

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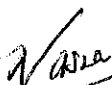
CERTIFICATION

CERTIFICATION OF APPROVAL

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Approved by,

_____

(Mr. Nasser Mohamed Ramli)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2004

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Muhammad Farzal Nasaruddin

ABSTRACT

Series non-interacting tank system is a series of tank that been align together after each other. The level of both tank are the control variables in this system meanwhile the flowrate inlet and outlet of the tanks are the manipulated variables. Since a tank is design at certain limit, thus the level of the tank must always be monitored so that it would not go beyond the design level as this will give bad effect to the tank itself. Indeed it is also a safety precaution; excess level may cause spillage and spoil the tank as well as the product quality.

For the purpose of study, this dynamic model has been developed to give a reliable mathematical model so that it will give an ease for future system monitoring. Level of each tank really depending on one another as the tanks is arranged in series; furthermore the level must also be controlled.

In this dynamic modeling, two tanks in series have been taken as an example. This is only to grab the concept of series tank. The number of tank can be extended but still the two series tank concept is taken as a baseline. And this is the reason why this experiment is using the second order system.

Simulink is the core software for this dynamic modeling. The simulation as well as the PID tuning is done using this software. The values that have been substituted in this simulation are taken from a real figure from PETRONAS in Dexter. However, there are still some assumptions have been made such as pumps stroke, valve opening etc. Those figures also been varied in order to study its trending. But when come to the real application, those values can be substituted back with the actual value from plant.

ACKNOWLEDGEMENT

Final Year Research Project (FYP) is one of the core engineering courses for final year student. I feel very lucky to perform it in this semester as I manage to gather lot of new knowledge and experience while doing it. My research would not be possible without facilitate and support from personnel. Their sincere willing to give me the most out of them indeed deserves my deepest gratitude.

First and foremost, I would like to thank Mr. Naseer Mohamad Ramli, my FYP supervisor, for giving me opportunity to take his proposed topic and guide me throughout this semester. He is a very supportive and helpful; and personally I fell very lucky to be under his supervision. I would also like to thank Miss Yuliana Yuhana, FYP Coordinator; she is the responsible personnel that ensure every student get benefit from this FYP and managed to complete in allocated time.

My grateful goes to lecturers who giving me valuable lesson and sparing their time to assist me even though they are in the middle of hectic works. Without them I would not be able to accumulate this much of knowledge to finish up my FYP.

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ABBREVIATION AND NOMENCLATURES

P	Proportional-only control
PI	Proportional-integral control
PID	Proportional-integral-derivatives control
Q	Flowrate
K	Process gain
IAE	Integral Absolute Error
ITAE	Integral Time-weight Absolute Error

CHAPTER 1

INTRODUCTION

1. INTRODUTION OF THE STUDY

Automatic control systems enable a process to be operated in a safe and profitable manner. Thus it is a meant of this project which is to design an automatic control system specifically for a series of non-interacting tanks. Generally, this system optimization can be achieved by continually measuring process operating parameters such as temperatures, pressures, levels, flows and concentrations, and then making decisions to, for examples, open valves, slow down pumps and turn up heaters in order to maintain the desired values.

This Case Study module presents industrially relevant process control challengers including level control in tanks. These real-world challenges will provide hands-on experience as you explore and learn the concepts of process dynamics and automatic process control presented in the remainder of this book.

1.1 Background of Study

Simulink is an interactive tool for modeling, simulating, and analyzing dynamic, multidomain systems. It accurately describes, simulates, evaluates, and refines a system's behavior through standard and custom block libraries. Simulink integrates seamlessly with MATLAB, provide immediate access to an extensive range of analysis and design tools. These benefits make Simulink the tool of choice for control system

design, signal processing system design, communications system design, and other simulation applications.

To estimate outlet flowrate of a tank is one of an existence engineering problem. Process flow is very significant as it will affect the process chemistry of a system. Thus, in real refinery plant for example, valves are installed at every tank outlet so that they can have better control of the outlet flowrate. However, in a tank, we can not rely on constant level. The level of liquid in a tank will surely fluctuate that will affect the outlet flowrate. It is a pain in the ass to keep adjusting the outlet flowrate (valve opening) manually. Thus, this project is emerged to develop a mathematical model so that the outlet flowrate can automatically be controlled.

1.2 Problem Statement

This study is to investigate how the height of the tanks response with respect to the outlet flow rate of the tanks. Different height of tank will surely affect the flowrate of the liquid that come out from it. From common sense it is known that the higher the level is will lead to a higher flowrate outlet. This is due to the higher pressure exerted by the liquid itself in the tank. As the level become low, the outlet flowrate also reduce. In the other hand, for this series non-interacting tank, the level in the second tank is very crucial as it is depend directly with the outlet flow of both tanks. Thus, this project is done to develop a mathematical model that will represent this phenomenon so that in the future we would have an automated control of this system to maintain the tank level at requirement and to ensure that the tank would not completely drain during operation.

1.3 Objectives and Scope of Study

The purpose of Final Year Research Project (FYP) is to develop a framework, which will enhance students' skills in the process of applying knowledge, expanding thoughts, solving problems independently and presenting findings through minimum guidance and supervision. Besides, with this kind of learning approach, learning process is gained

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through "by-doing" experience. Perhaps this undertaken project can be used as a basis for job employment by fully exploiting the learning that has been gone through.

This case study module comes with several objectives as listed and described below:

1. Develop the mathematical model that describes the process

The mathematical model is developed based on the inlet and outlet flowrate of the in the system matlab is used to convert the model into block diagram.

2. Study the response of the process in manual mode

Student will study the behavior of the system by varying the height of the tank. Thus, relation between the height and the outlet flowrate can be estimated. This phase is also known as step test.

3. Study the step response of a second order under-damped process in automatic mode.

Understand of how PID tuning response to maintain the outlet flowrate with varies tank level.

The project can be in the form of laboratory experiments, computer programming, modeling, simulations, analysis and product design. However, for the sake of this topic, the project is more on modeling in which Matlab is the main software used to develop the mathematical model. Students are to explore research problems, build research objectives, apply appropriate methodology, analyze and produce outcomes, and report the findings. The area and scope of the project should be narrowed down so that the project is feasible and could be completed within the allocated time frame.

The parameters used in this project are still in narrow scope, taking laboratory equipments as reference. However, for real application this parameters can be scale up to the real plant environment values as the system that have been develop is valid for any figure as long as the values been key in into the system.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2. BASIC THEORY OF THE PROJECT

2.1 Interacting and non interacting systems

Consider a process with several invariables and several output variables. The process is said to be *interacting* if:

- o Each input affects more than one output, or
- o A change in one output affects the other outputs

Otherwise, the process is called *non- interacting*.

In general, transfer functions for interacting processes are more complicated than those for non interacting processes. As an example, we will consider the two liquid-level storage systems shown.
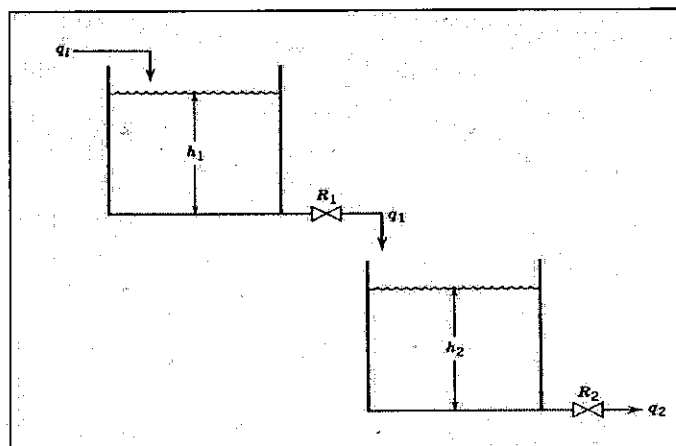
Figure 2.1: A Non-Interacting System Two Surge Tanks in Series
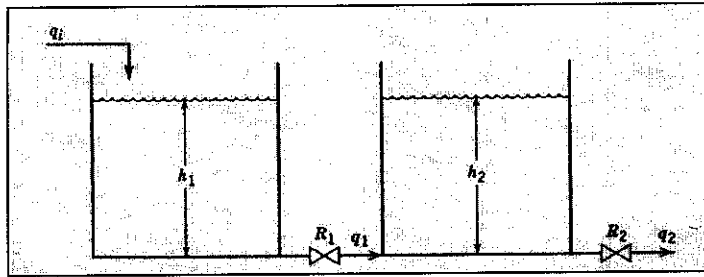
Figure2.2: Two Tanks in Series Whose Liquid Levels Interact

Simplified second order transfer function

$$\frac{Q_2(s)}{Q_i(s)} = \frac{1}{(\tau_1 s + 1)(\tau_2 s + 1)}$$
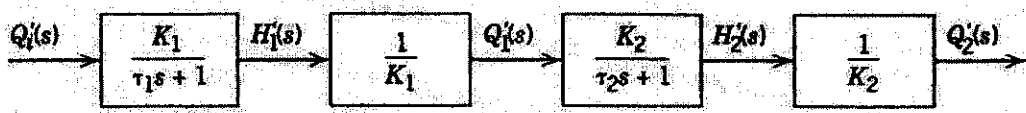
Figure 2.3: Input-output model for two liquid surge tanks in series.

Tank level control:
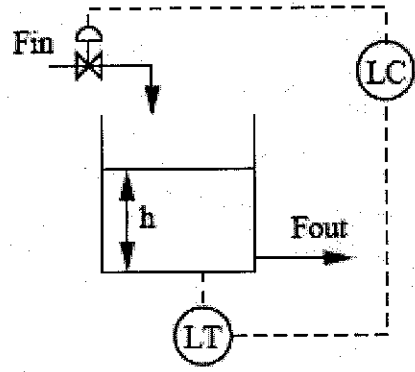
Figure 2.4: Tank Level Control

$$Accumulated = in - out$$

$$Ac\frac{dH}{dT} = F_{in} - F_{out}$$

$$\frac{dH}{dT} = \frac{F_{in}}{Ac} - \frac{ch}{Ac}$$

$$\frac{dh}{dt} + h = \frac{F_{in}}{2}$$

$$e^t\frac{dH}{dt} = \frac{F_{in}}{2}e^t$$

$$\frac{d}{dt}\left[e^t h(t)\right] = \frac{F_{in}}{2} + k$$

$$h(t) = h(0) + \left[\frac{(F_{in} - F^{ss}_{in})}{2}\right](1 - e^t)$$

2.2 Automatic system control

A control system may consist of a number of components. To show the function performed by each component, in control engineering, we commonly use a diagram called the block diagram.

Block diagram of a system is a pictorial representation of the function performed by each component and of the flow of signal. Such a diagram depicts the interrelationships that exist among the various components.

Response in manual mode will be illustrate by an open loop block diagram meanwhile the automated mode shows by a closed loop block diagram which also include the PID controller.

2.3 Tuning method

2.3.1 Ziegler Nichols PID Tuning

Ziegler and Nichols have developed PID tuning methods back in the early fourties based on open loop tests (less known than for example the Cohen-Coon formulas) and also based on a closed loop test, which is maybe their most widely known achievement.

The open loop method allows calculation of PID parameters from the process parameters.

The procedure:

Step 1: Make an open loop plant test (e.g. a step test)

Step 2: Determine the process parameters: Process gain, deadtime, time constant (see below: draw a tangent through the inflection point and measure L and T as shown.)

Step 3: Calculate the parameters according to the following formulas:

K = time constant / (process gain * deadtime)

PI: Proportional gain = 0.9 * K, integral time = 3.3 * deadtime

PID: Proportional gain = 1.2 * K, integral time = 2 * deadtime, derivative time = 0.5 * deadtime
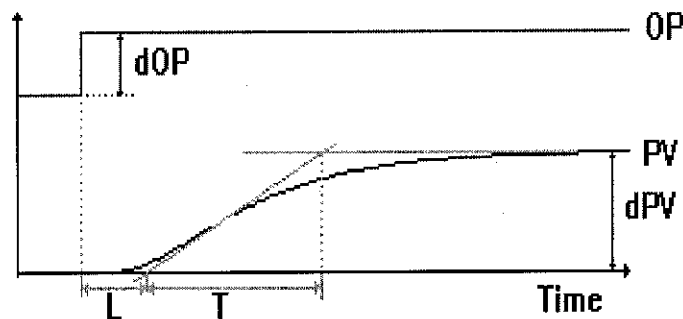
Figure 2.5: Tuning Procedure

Process gain = dPV / dOP, deadtime = L, time constant = T

The closed loop method prescribes the following procedure:

Step 1: Disable any D and I action of the controller (--> pure P-controller)

Step 2: Make a set point step test and observe the response

Step 3: Repeat the SP test with increased / decreased controller gain until a stable oscillation is achieved. This gain is called the "ultimate gain" Ku.

Step 4: Read the oscillation period Pu.

Step 5: Calculate the parameters according to the following formulas:

PI: Proportional gain = 0.45 * Ku, integral time = Pu / 1.2

PID: Proportional gain = 0.6 * Ku, integral time = Pu / 2, derivative time = Tu / 8
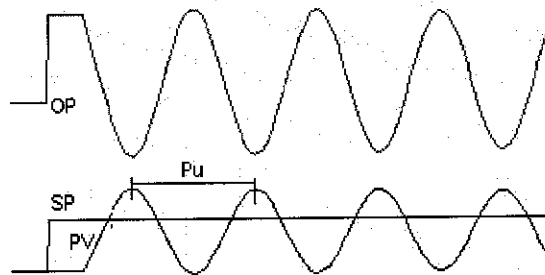
Figure 2.6: Ziegler Nichols Test

Characterization:

Both methods give a good starting point but require further fine-tuning.

The open loop method is based on a measurement range of 0-100 and continuous control. This requires adjustments for other measurement ranges and for the control interval in digital systems (the method was developed in the times when only analog controllers existed).

The closed loop methods does not require adjustments, a big advantage, since both process and controller are part of the test, but suffers from one major disadvantage: Bringing the loop into stable, sustained oscillation is simply out of the question for industrial processes.

Both methods do not distinguish between set point and load tuning and are for self-regulating processes only, not for integrating processes like liquid level.

2.3.2 Cohen Coon Tuning Method

Steps of using Cohen Coon tuning method:

1. Under Manual mode, wait until the process is at steady state.
2. Next, introduce a step change in the input.
3. Based on the output, obtain an approximate first order process with a time constant t delayed by t_{DEL} units from when the input step was introduced.

The values of t and t_{DEL} can be obtained by first recording the following time instances:

$$t_0 = \text{time when input step was initiated}$$
$$t_2 = \text{time when half point occurs}$$
$$t_3 = \text{time when 63.2\% point occurs}$$
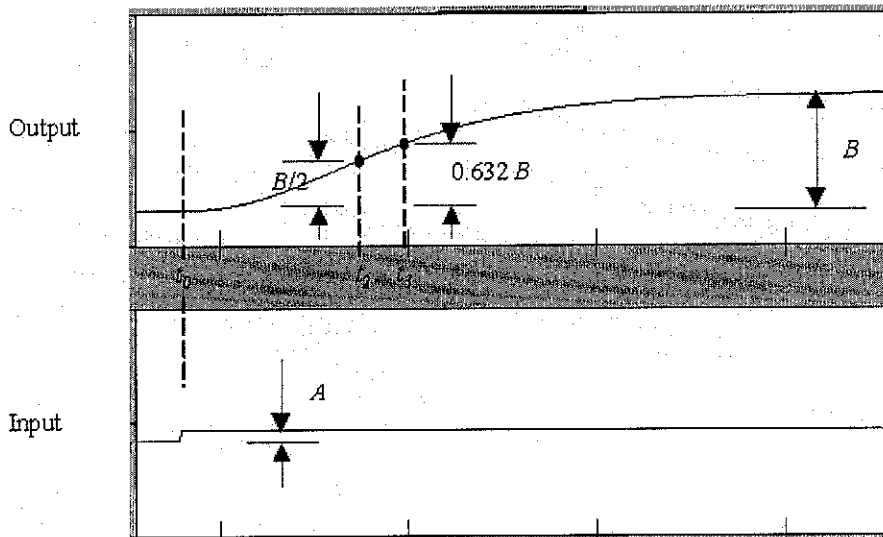
Figure 2.7: Step Graph and t Determination

4. From the measurements based on the step test: t_0, t_2, t_3, A and B, evaluate the following process parameters:

$$t_1 = (t_2 - \ln(2)\, t_3)/(1 - \ln(2))$$

$$\tau = t_3 - t_1$$

$$\tau_{DEL} = t_1 - t_0$$

$$K = B/A$$

5. Based on the parameters K, τ and τ_{DEL}, the following formulas prescribe the controller parameters K_c, t_I and t_D:

Table 2.1: Cohen Coon Tuning Formula

	K_c	t_I	t_D
P	$\dfrac{1}{K \cdot r}\left(1 + \dfrac{r}{3}\right)$		
PI	$\dfrac{1}{K \cdot r}\left(0.9 + \dfrac{r}{12}\right)$	$\tau_{DEL} \cdot \dfrac{30 + 3 \cdot r}{9 + 20 \cdot r}$	
PID	$\dfrac{1}{K \cdot r}\left(\dfrac{4}{3} + \dfrac{r}{4}\right)$	$\tau_{DEL} \cdot \dfrac{32 + 6 \cdot r}{13 + 8 \cdot r}$	$\tau_{DEL} \cdot \dfrac{4}{11 + 2 \cdot r}$

where $r = \dfrac{\tau_{DEL}}{\tau}$

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CHAPTER 3

PROJECT OVERVIEW

3. METHODOLOGY / PROJECT WORK

Some procedure has been followed in order to ensure the smoothness of this project. This is some kind of strategy so that the objectives of the project can be achieved and will finish within the allocated time.

3.1 Preliminary / pre-design step

Pre-design step have been taken out in order to ensure that the specific tasks in the project being well recognize before starting with the next step which is to design the system using simulation. Thus, some simple paces have been made as listed and described below:

o Identify problem

Understand the title and background of the project. Problem statement of this project should also been understood to get clear objectives.

o Literature review and gather information

The important term such as "second order system" and "series non-interacting" must be considered so that the research will go beyond the topic only. Some research will be made through reading and surfing. It is also important to view any former theory that has close relation with this kind of project.

o Learn and understand Matlab software

Since matlab is the main software used for this modeling project, it is important to get use of it at first place for familiarization. This is to ensure student would not have any problem when applying the theoretical part to the software. Besides that, software such as Microsoft word and excel will also been used especially for recording data and paper works.

o Develop transfer function and apply into simulink

The crucial part of this project is to develop transfer function. This is where all the variables need to be identified. Then only simulink will be used to illustrate the appropriate tuning.

3.2 Simulation / system design step (Matlab software)

After the mathematical models have been developed, the subsequent step can be launched which is to start designing the system. This is where the Simulink in Matlab software play it major roles. But it is advice to have a sketch of the system in black and white first to get the clear view of the system. Converting mathematical equation into simulink is not an easy chore. Those variables, constants and controlled parameters must be identified at first place. Besides, some assumptions must be made and justified to ease the development of the system. Furthermore, the mathematical model developed in pre-design step can not be directly applied into simulink. Rearrangement and modification must be made to suit the system tools and software.

3.3 Step test

This is the most crucial part in this project which is the step test. Before the actual start up, variables in the system were filled with some desired value. Values of area, inlet and outlet flow etc. have to be figured out. Then, simple calculation has been made to determine the value of valve characteristic, Cv. After putting in all the variables, a trial and error been made to determine the percentage of valve opening at stable operation for

both tanks. Basically, a flat output line will indicate that the operation is stable. Then only the actual step test takes place.

Step test is an experiment in which a disturbance being made to a stable operation in order to study the behavior of the system. In this project, all the parameters are let constant, only the valve opening being varied to study the behavior of the tank level when changes have been made to the percentage opening of respective valves.

3.4 Calculation / PID determination

The parameters obtained from the step test such as gain, time constant, dead time, etc. been strongly used in this step. The figures will then been substituting into respective method of calculation to determine the proportional, integral and derivative (PID) value for the next automated control step. Various method of calculation such as decay ratio, Ziegler Nichols, Integral of the Absolute Value of the Error (IAE), Cohen Coon etc. will be used for the determination.

3.5 Automated control

Once the PID value been identified, the system is then been modified a little bit to give space for automated control. PID tuning tools been attached to the old system, thus make the current system enhance a little bit with the ability to perform automatic tuning. From the values that have been put in, the best value of PID can be determined by varying the existence PID value. A perfect tuning will produce a stable curve at set point with minimize fluctuation on MV value.

Preliminary / pre-design step
- identify problem
- literature review
- learn matlab simulink
- develop mathematical model

Simulation / design step
- rearrange and modified mathematical model
- convert into simulink software

Step test
- key in parameters / assumption
- figure out valve characteristic, Cv value
- find stable operation
- apply disturbance

Calculation / PID determination
- determine gain, time constant, dead time etc
- calculate PID using Cohen Coon, Ziegler Nichols method etc

Automated control
- modified system (add PID controller)
- substituting calculated PID value
- trial and error new PID value

Figure 3.1: Flowchart of Summarization Project Methodology

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CHAPTER 4

RESULT AND DISCUSSION

4. RESULT AND DISCUSSION

4.1 Mathematical modeling

Based on series non-interacting tank as shown in figure below, a mathematical modeling is being developed. This project only considers two tanks in series with one inlet and two outlet streams. Two valves exist on outlet stream of both tanks in order to control the outlet flow to avoid over level or total drain from the tanks. Over level of water will cause spillage meanwhile total drain will lead to pump surging. Thus the level must be kept at certain level not only to nurse the solution, but also to protect the equipments.

Levels for both tanks are the parameter that being monitored in this system. The system developed through simulink would display both tanks level as the graphic output.
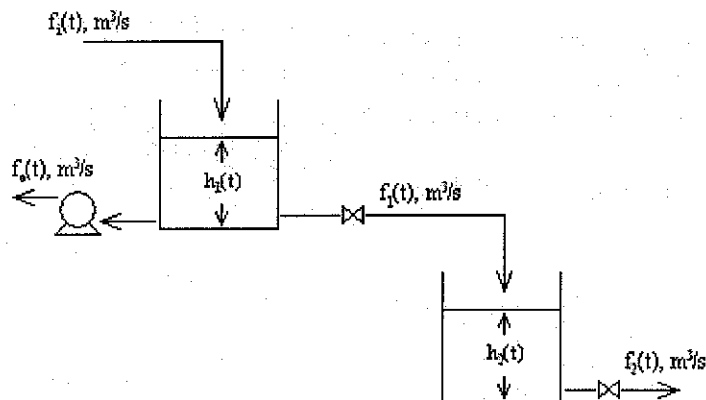
Figure 4.1: Series Non-Interaction Tank

Unsteady state mass balance:

Rate of mass into the tank	–	Rate of mass out of tank	=	Rate of accumulation mass in tank

For tank 1:

$$\rho f_i(t) - \rho f_1(t) - \rho f_0(t) = \frac{d}{dt} m_1(t) \qquad (1)$$

Where, f_i = inlet flow

$\qquad f_1$ = outlet of tank 1 / inlet of tank 2

$\qquad f_0$ = outlet of tank 1

$\qquad m_1$ = mass of water in tank 1

But; $\quad m_1(t) = \rho A_1 h_1(t) \qquad (2)$

Thus, substituting (2) into (1) and rearranging equation;

$$f_i - f_1 - f_0 = A_1 \frac{d}{dt} h_1$$

$$\int \frac{f_i - f_1 - f_0}{A_1} = h_1 \qquad (3)$$

But; $\quad f_1(t) = Cv_1 x \sqrt{\frac{\Delta P(t)}{G_f}} \qquad (4)$

Known that $\quad \Delta P(t) = P_u(t) - P_d = P_a + \rho g h(t) - P_a = \rho g h(t) \qquad (5)$

Where, C_v = valve coefficient

$\qquad x$ = percentage valve opening

$\qquad \Delta P$ = pressure drop across valve

$\qquad Pu(t)$ = upstream pressure from valve, Pa

Pd = downstream pressure from valve, Pa

Pa = atmospheric pressure, Pa

ρ = density of liquid, kg/m^3

h = level of tank, m

g = acceleration due to gravity, 9.8 m/s^2

G_f = specific gravity of liquid, 1

Substituting (5) into (4);

$$f_1(t) = Cv_1 x \sqrt{\rho g h_1(t)} \qquad (6)$$

For tank 2:

$$\rho f_1(t) - \rho f_2(t) = \frac{d}{dt} m_2(t) \qquad (7)$$

Where, f_2 = outlet of tank 2

m_2 = mass of water in tank 2

But; $m_2(t) = \rho A_2 h_2(t) \qquad (8)$

Thus, substituting (8) into (7) and rearranging equation;

$$f_1 - f_2 = A_2 \frac{d}{dt} h_2$$

$$\int \frac{f_1 - f_2}{A_2} = h_2 \qquad (9)$$

But; $f_2(t) = Cv_2 x \sqrt{\rho g h_2(t)} \qquad (10)$

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4.2 Simulink

Based on mathematical models obtained above, a system is developed by using matlab simulink software. The mathematical model is being converted respectively into simulink form as shown in the following figures:
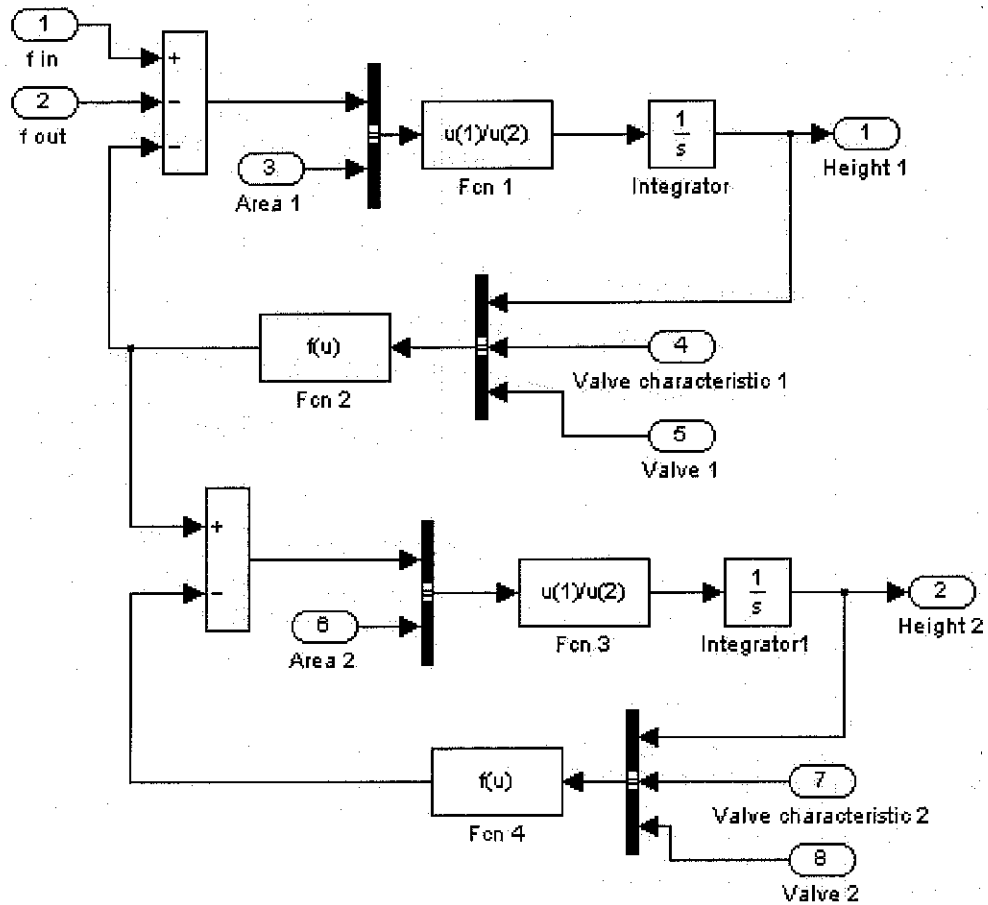
Figure 4.2: Subsystem

This complex system is then been simplified to an appropriate design leaving the variables and output at the outside. Those variables can be substituted with any desired values depending on the plant scale (equipments) that going to be tested. The variables so called manipulated variables were arranged such a way to make ease of any changes that going to be made in future. The simplified or overall system is as shown in the figure 4.3 below:

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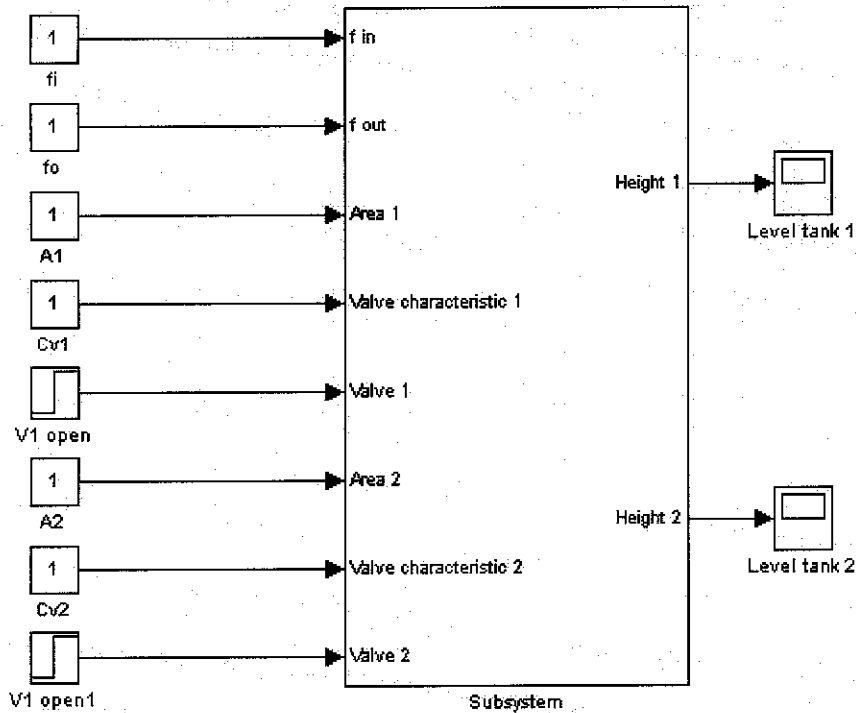
Figure 4.3: Complete Manual System

4.3 Step test

Step test is a procedure in where disturbance is being applied into a stable system in order to study the behavior of the process. However, before proceeding to the step test, the initial system must reach it stability first. Thus, as for the start, all the parameters / variables which have been left empty must be substituted with a valid value. In order to make substitution possible, some reasonable assumptions have been made.

4.3.1 Assumptions

For this project, the variation only been made at the percentage valve opening. This due to valve gives direct impact to the level of the tank and can control the inlet and outlet flow as well. The other values such as area / tank size, inlet flowrate to tank 1, outlet flowrate of tank 1 and valve coefficient are let constant. Initial / start up level in both tank also been fixed at certain level. This initial level is important to prevent pump surging.

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Operating condition:

1. constant temperature (ambient temperature)
2. at atmospheric pressure
3. process liquid is water

Parameters:

Tank diameter = 1.5 m

Thus giving, area1 = area2 = 1.7671 m^2

f_i = 3.5 m/s

f_0 = 1 m/s

$Cv_1 = Cv_2 = 0.036 \, m^3/s - Pa^{1/2}$

Initial / start up value:

Level tank 1 = 1.0 m

Level tank 2 = 1.5 m

4.3.2 Stable operation determination

A trial and error value for percentage valve opening have been made to determined the figure that will yield a constant flat line (in the system output graph). This indicates the operation is stable at that respective percentage opening. The constant parameters as indicate in assumption part being substituted into the respective slots as simplified in figure 4.3 at the beginning of this chapter.

Percentage valve opening of valve 1 which gives a stable operation is 70% meanwhile for valve 2 is 57.3%. Logically, if this percentage opening is being unvaried through out the operation, the level of the tank will stay at where it is at initial condition as the total inlet flow equal to outlet flow of the system. This is the reason for flat line on the output.

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4.3.3 Test Run

Some sample test runs are as listed below. The left side of the figure is properties of tank 1 output graph meanwhile the right side of the figure would be for the tank 2. 5s delay time have been mate to let the operation stable first.

First test run

First valve opening is set to vary from 70% − 50% meanwhile the second valve is from 57.3% − 50%.
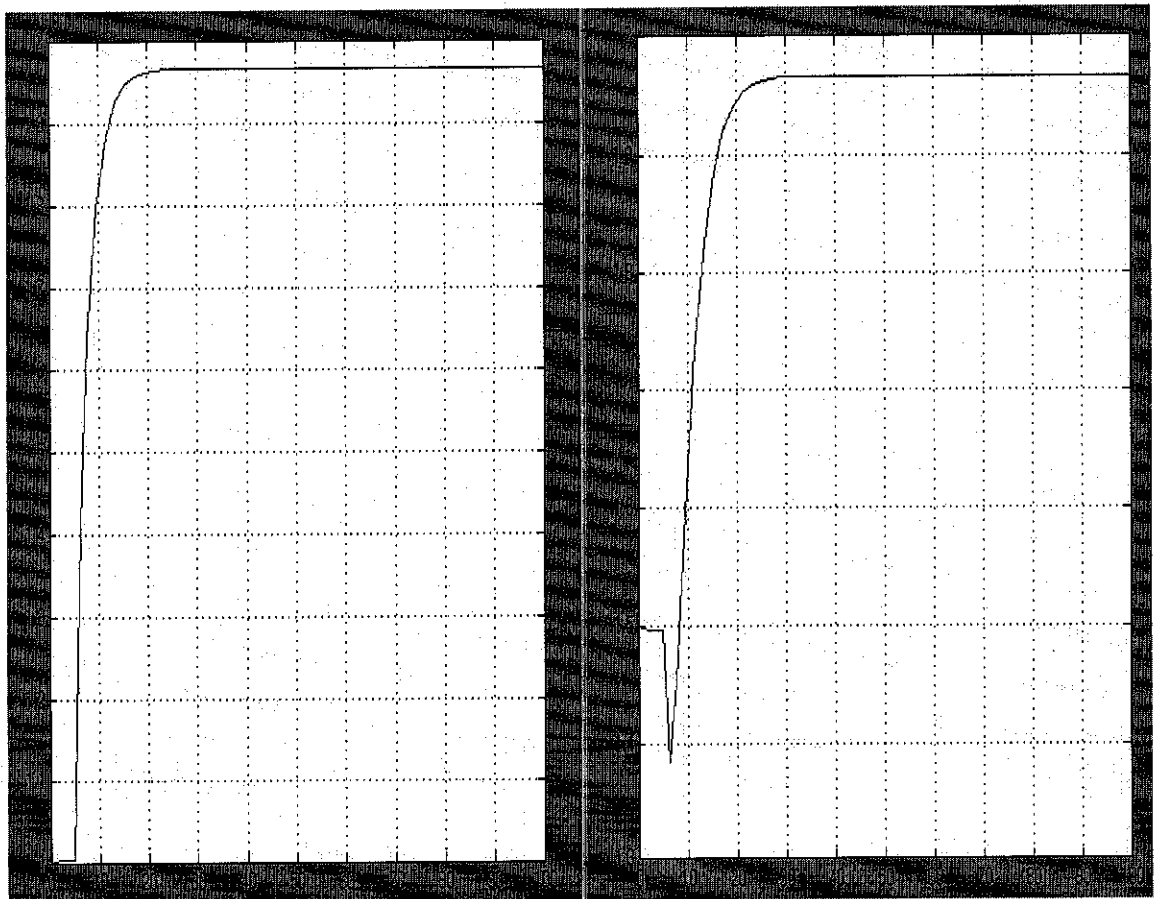
Figure 4.4: First Test Run Result

Second test run

First valve opening is set to vary from 70% – 60% meanwhile the second valve is from 57.3% – 50%.
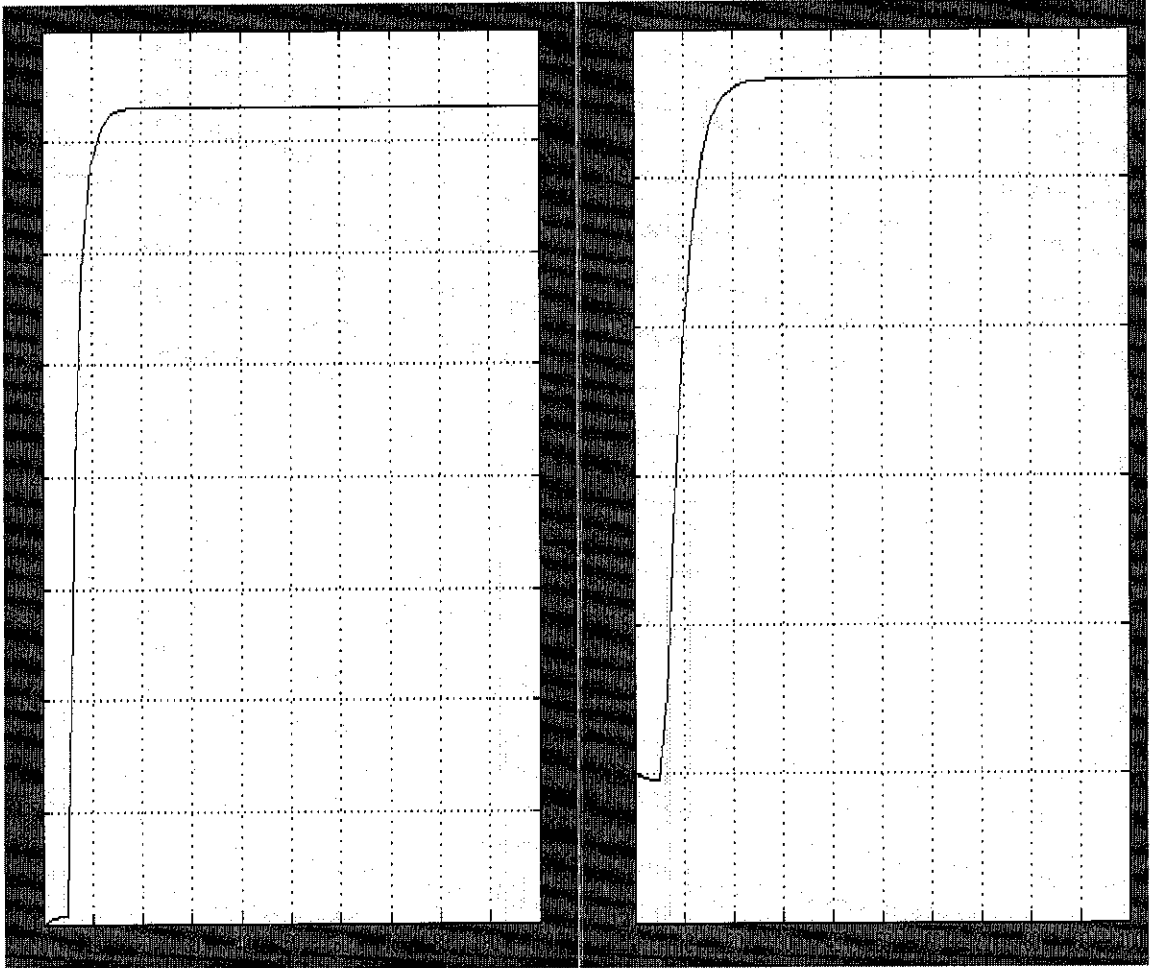
Figure 4.5: Second Test Run Result

Third test run

First valve opening is set to vary from 70% – 80% meanwhile the second valve is from 57.3% – 65%.
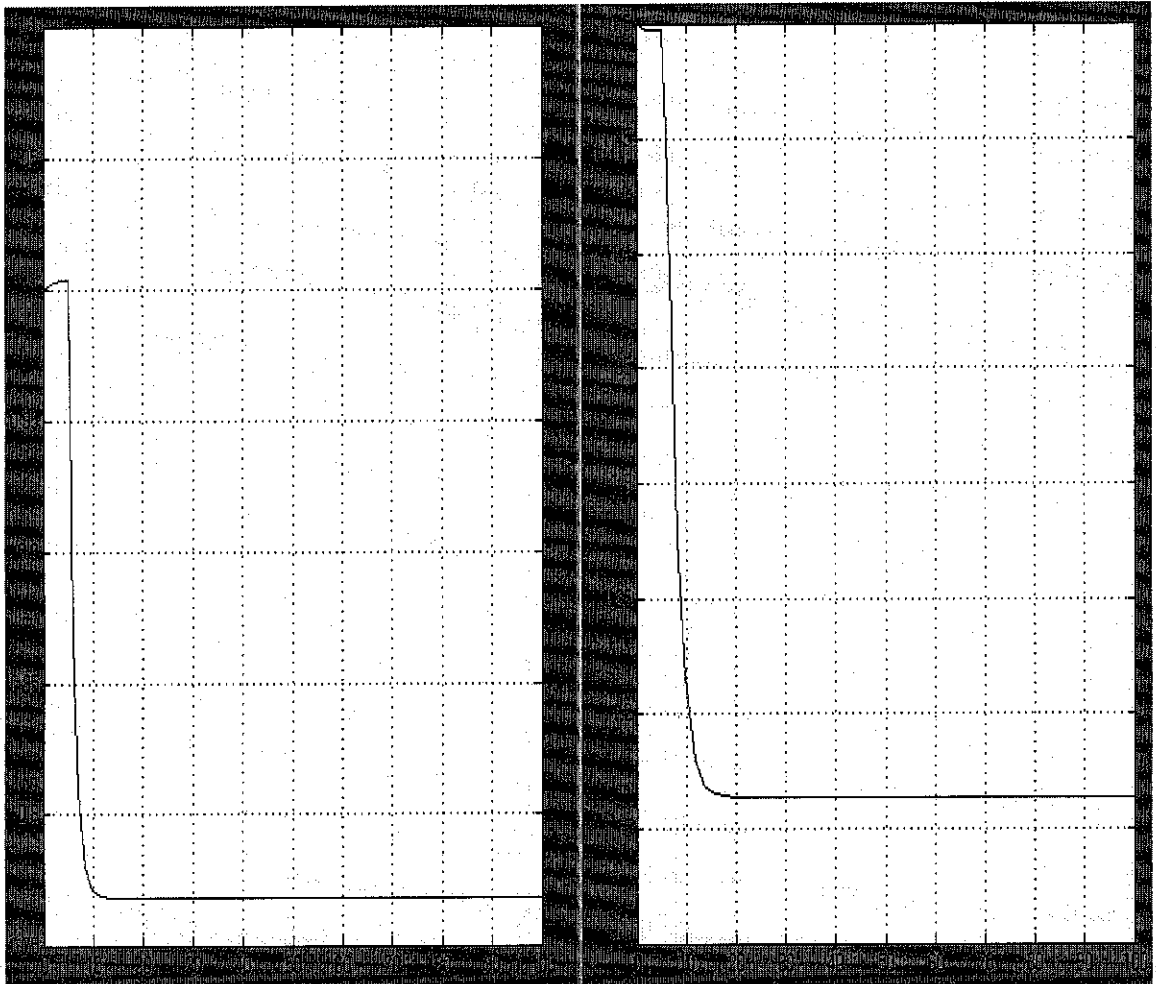
Figure 4.7: Fourth Test Run Result

4.4 Calculation / PID determination

4.4.1 Output graphs evaluation

First test run

First tank:

$$\Delta x = 0.5 - 0.7 = -0.2$$
$$\Delta y = 1.96 - 1.0 = 0.96$$

Thus Process gain $= 0.96 / -0.2 = -4.8$

From the graph at 63.2% level;

Level $= 1.61$m

Thus, $\tau = 2.65$s

Second tank:

$$\Delta x = 0.5 - 0.573 = -0.073$$
$$\Delta y = 1.96 - 1.38 = 0.58$$

Thus Process gain $= 0.58 / -0.073 = -7.95$

From the graph at 63.2% level;

Level $= 1.75$m Dead time, $t_0 = 2$s

Thus, $\tau = 6.9$s $- 2$s $= 4.9$s

Second test run

First tank:

$$\Delta x = 0.6 - 0.7 = -0.1$$
$$\Delta y = 1.36 - 1.0 = 0.36$$

Thus Process gain $= 0.36 / -0.1 = -3.6$

From the graph at 63.2% level;

Level $= 1.23$m

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Thus, $\tau = 1.92$s

Second tank:

$\Delta x = 0.5 - 0.573 = -0.073$

$\Delta y = 1.96 - 1.5 = 0.46$

Thus Process gain $K = 0.46 / -0.073 = -6.3$

From the graph at 63.2% level;

Level = 1.79m   Dead time, $t_0 = 1.4$s

Thus, $\tau = 4.94$s $- 1.4$s $= 3.54$s

Third test run

First tank:

$\Delta x = 0.8 - 0.7 = 0.1$

$\Delta y = 0.768 - 1.0 = -0.232$

Thus Process gain $= -0.232 / 0.1 = -0.232$

From the graph at 63.2% level;

Level = 0.854m

Thus, $\tau = 1.2$s

Second tank:

$\Delta x = 0.65 - 0.573 = 0.077$

$\Delta y = 1.164 - 1.5 = -0.336$

Thus Process gain $= -0.336 / 0.077 = -4.36$

From the graph at 63.2% level;

Level = 1.29m

Thus, $\tau = 3.1$s

4.4.2 Cohen Coon PID tuning

Table 4.1: Cohen and Coon Controller Design Relation

controller	settings	Cohen – Coon
P	K_C	$\dfrac{1}{k}\dfrac{\tau}{\theta}\left(1+\theta/3\tau\right)$
PI	K_C	$\dfrac{1}{k}\dfrac{\tau}{\theta}\left(0.9+\theta/12\tau\right)$
	τ_1	$\dfrac{\theta\left[30+3\left(\theta/\tau\right)\right]}{9+20\left(\theta/\tau\right)}$
PID	K_C	$\dfrac{1}{k}\dfrac{\tau}{\theta}\left(\dfrac{16+3\theta}{12\tau}\right)$
	τ_1	$\dfrac{\theta\left[32+6\left(\theta/\tau\right)\right]}{13+8\left(\theta/\tau\right)}$
	τ_D	$\dfrac{4\theta}{11+2\left(\theta/\tau\right)}$

Table 4.2: Cohen Coon PID Calculation Result

Test run 1

k	-4,8
τ	2,65
t_0	1

k	-7,95
τ	4,9
t_0	2

valve 1

controller	P	PI	PID
Kc	-0,6215	-0,5142	-0,7882
τ_1		1,8814	2,1390
t_D			0,3403

valve 2

controller	P	PI	PID
Kc	-0,3501	-0,2878	-0,4423
τ_1		3,6385	4,2359
t_D			0,6770

Test run 2

k	-3,6
τ	1,92
t_0	1

k	-6,3
τ	3,54
t_0	1,4

valve 1

controller	P	PI	PID
Kc	-0,6259	-0,5031	-0,7806
τ_1		1,6255	2,0461
t_D			0,3322

valve 2

controller	P	PI	PID
Kc	-0,4543	-0,3745	-0,5748
τ_1		2,5820	2,9771
t_D			0,4749

Test run 3

k	-0,232
τ	1,2
t_0	1

k	-4,36
τ	3,1
t_0	1

valve 1

controller	P	PI	PID
Kc	-6,6092	-5,0144	-7,9741
τ_1		1,2662	1,8814
t_D			0,3158

valve 2

controller	P	PI	PID
Kc	-0,7875	-0,6590	-1,0054
τ_1		2,0042	2,1781
t_D			0,3435

4.43 Minimum Error Integral PID tuning

Table 4.3: Minimum Error Integral Tuning Formulas for Set Point Change

Error Integral		IAE	ITAE
Proportional-Integral (PI) Controller			
$K_C = \dfrac{a_1}{K}\left(\dfrac{t_0}{\tau}\right)^{b1}$	a_1 b_1	0.758 -0.861	0.586 -0.916
$\tau_1 = \dfrac{\tau}{a_2 + b_2(t_0/\tau)}$	a_2 b_2	1.02 -0.323	1.03 -0.165
Proportional-Integral-Derivatives (PID) Controller			
$K_C = \dfrac{a_1}{K}\left(\dfrac{t_0}{\tau}\right)^{b1}$	a_1 b_1	1.086 -0.869	0.965 -0.855
$\tau_1 = \dfrac{\tau}{a_2 + b_2(t_0/\tau)}$	a_2 b_2	0.740 -0.130	0.796 -0.147
$\tau_D = a_3\tau\left(\dfrac{t_0}{\tau}\right)^{b3}$	a_3 b_3	0.348 0.914	0.308 0.9292

Table 4.4: IAE PID Calculation Result

Test run 1

valve 1

controller	PI	PID
Kc	-0,3655	-0,5277
τ_1	2,9506	3,8353
t_D		0,3784

valve 2

controller	PI	PID
Kc	-0,2062	-0,2976
τ_1	5,5170	7,1331
t_D		0,7518

Test run 2

valve 1

controller	PI	PID
Kc	-0,3692	-0,5318
τ_1	2,2541	2,8559
t_D		0,3681

valve 2

controller	PI	PID
Kc	-0,2674	-0,3860
τ_1	3,9675	5,1410
t_D		0,5277

Test run 3

valve 1

controller	PI	PID
Kc	-3,8226	-5,4847
τ_1	1,5982	1,8997
t_D		0,3535

valve 2

controller	PI	PID
Kc	-0,4605	-0,6658
τ_1	3,3850	4,4409
t_D		0,3836

Table 4.5: ITAE PID Calculation Result

Test run 1

valve 1

controller	PI	PID
Kc	-0,2981	-0,9419
τ_1	2,7384	3,5785
t_D		0,3300

valve 2

controller	PI	PID
Kc	-0,1675	-0,5318
τ_1	5,0901	6,6576
t_D		0,6563

Test run 2

valve 1

controller	PI	PID
Kc	-0,2959	-0,9534
τ_1	2,0338	2,6688
t_D		0,3226

controller	PI	PID
Kc	-0,2176	-0,6894
τ_1	3,6694	4,7976
t_D		0,4605

Test run 3

valve 1

controller	PI	PID
Kc	-2,9850	-9,8986
τ_1	1,3445	1,7817
t_D		0,3120

controller	PI	PID
Kc	-0,3789	-1,1857
τ_1	3,1737	4,1412
t_D		0,3337

4.43 Quarter Decay Ratio Response tuning formula

Table 4.6: Tuning formula for Quarter Decay Ratio Response

Controller type	Proportional gain, K'_C	Integral time, τ'_1	Derivative time, t'_D
Proportional-only, P	$\dfrac{1}{K}\left(\dfrac{t_0}{\tau}\right)^{-1}$	–	–
Proportional-integral, PI	$\dfrac{0.9}{K}\left(\dfrac{t_0}{\tau}\right)^{-1}$	$3.33\,t_0$	–
Proportional-integral-derivatives, PID	$\dfrac{1.2}{K}\left(\dfrac{t_0}{\tau}\right)^{-1}$	$2.0\,t_0$	$\dfrac{1}{2}\,t_0$

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Conversion to ideal PID controller

$$K_C = K'_C \left(1 + \tau'_D / \tau'_1\right)$$

$$\tau_1 = \tau'_1 + \tau'_D$$

$$\tau_D = \tau'_D \, \tau'_1 / \left(\tau'_1 + \tau'_D\right)$$

Table 4.7: Quarter Decay Ratio PID Calculation Result

Test run 1

valve 1

controller	P	PI	PID
K'c	-0,5521	-0,4969	-0,6625
τ'_1		3,3300	2,0000
t'$_D$			0,5000

Kc	-0,5521	-0,4969	-0,8281
τ_1		3,3300	2,5000
t$_D$			0,4

valve 2

controller	P	PI	PID
K'c	-0,3082	-0,2774	-0,3698
τ'_1		6,6600	4,0000
t'$_D$			1,0000

Kc	-0,3082	-0,2774	-0,4623
τ_1		6,6600	5,0000
t$_D$			0,8

Test run 2

valve 1

controller	P	PI	PID
K'c	-0,5333	-0,4800	-0,6400
τ'_1		3,3300	2,0000
t'$_D$			0,5000

Kc	-0,5333	-0,48	-0,8
τ_1		3,3300	2,5000
t$_D$			0,4

valve 2

controller	P	PI	PID
K'c	-0,4014	-0,3612	-0,4816
τ'_1		4,6620	2,8000
t'$_D$			0,7000

Kc	-0,4014	-0,3612	-0,602
τ_1		4,6620	3,5000
t$_D$			0,56

Test run 3

valve 1

controller	P	PI	PID
K'c	-5,1724	-4,6552	-6,2069
τ'_1		3,3300	2,0000
t'$_D$			0,5000

Kc	-5,1724	-4,6552	-7,7586
τ_1		3,3300	2,5000
t$_D$			0,4

valve 2

controller	P	PI	PID
K'c	-0,7110	-0,6399	-0,8532
τ'_1		3,3300	2,0000
t'$_D$			0,5000

Kc	-0,711	-0,6399	-1,0665
τ_1		3,3300	2,5000
t$_D$			0,4

4.5 Automatic mode

For an automatic system, the existence manual mode system being modified a little bit by adding PID controller each the respective valve. The bias value should be same as the total flowrate goes in each tank and the PID values are substituted based on the calculation method made accordingly.
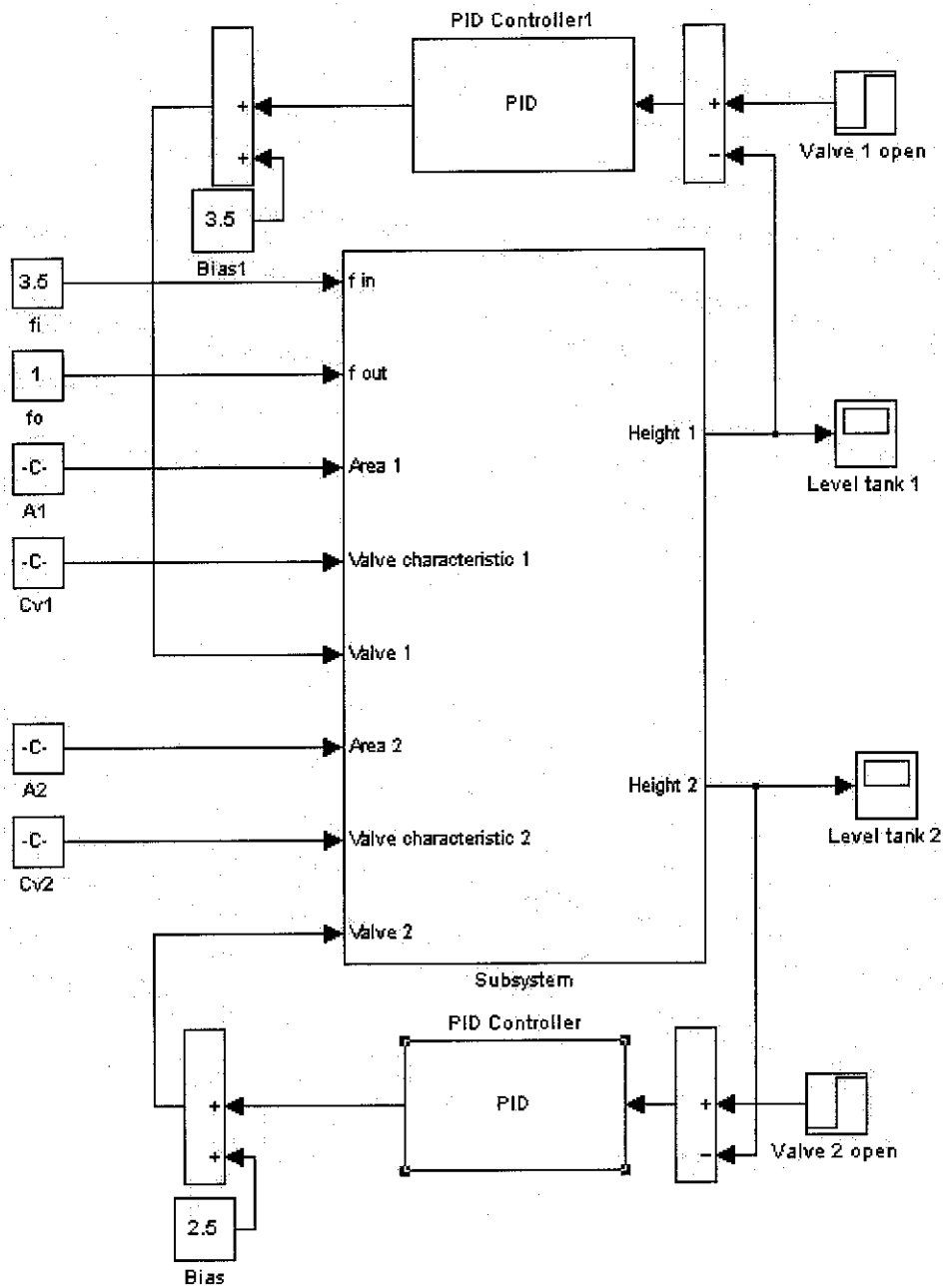

Figure 4.8: Automatic Mode System

4.51 Proportional-only tuning graph

From the output graphs obtain, based on the calculating value, seem that this proportional tuning is not applicable for this kind of process. Thus, Proportional-only tuning is not recommended for this non-interacting tank level control.
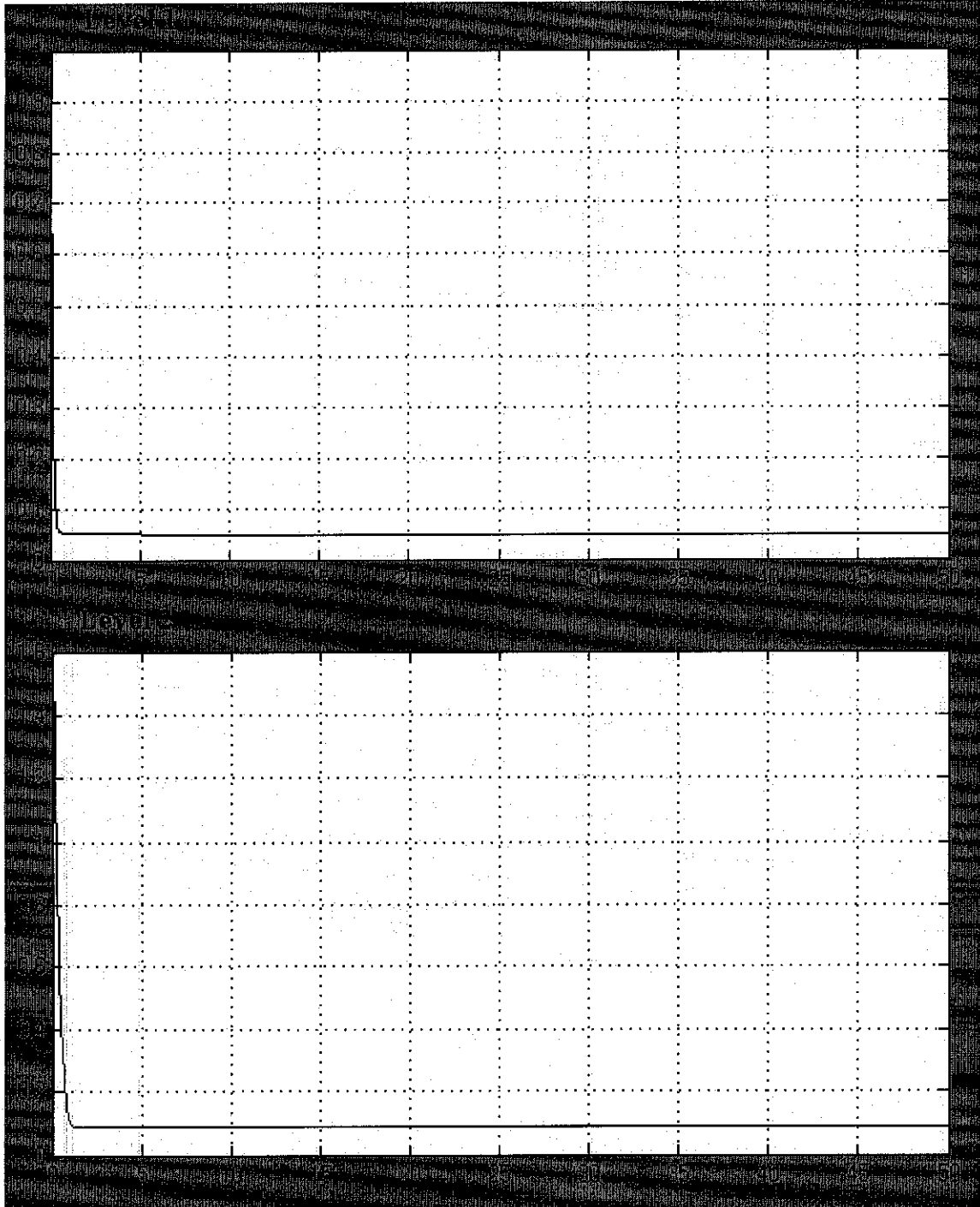
Figure 4.9: Proportional-only Controller Output Graph

4.52 Proportional-integral tuning graph

From the output graph obtain in the proportional-integral control, it is configured that the Cohen Coon PID tuning is the best tuning solution as it gave lower overshoot and faster settling time.
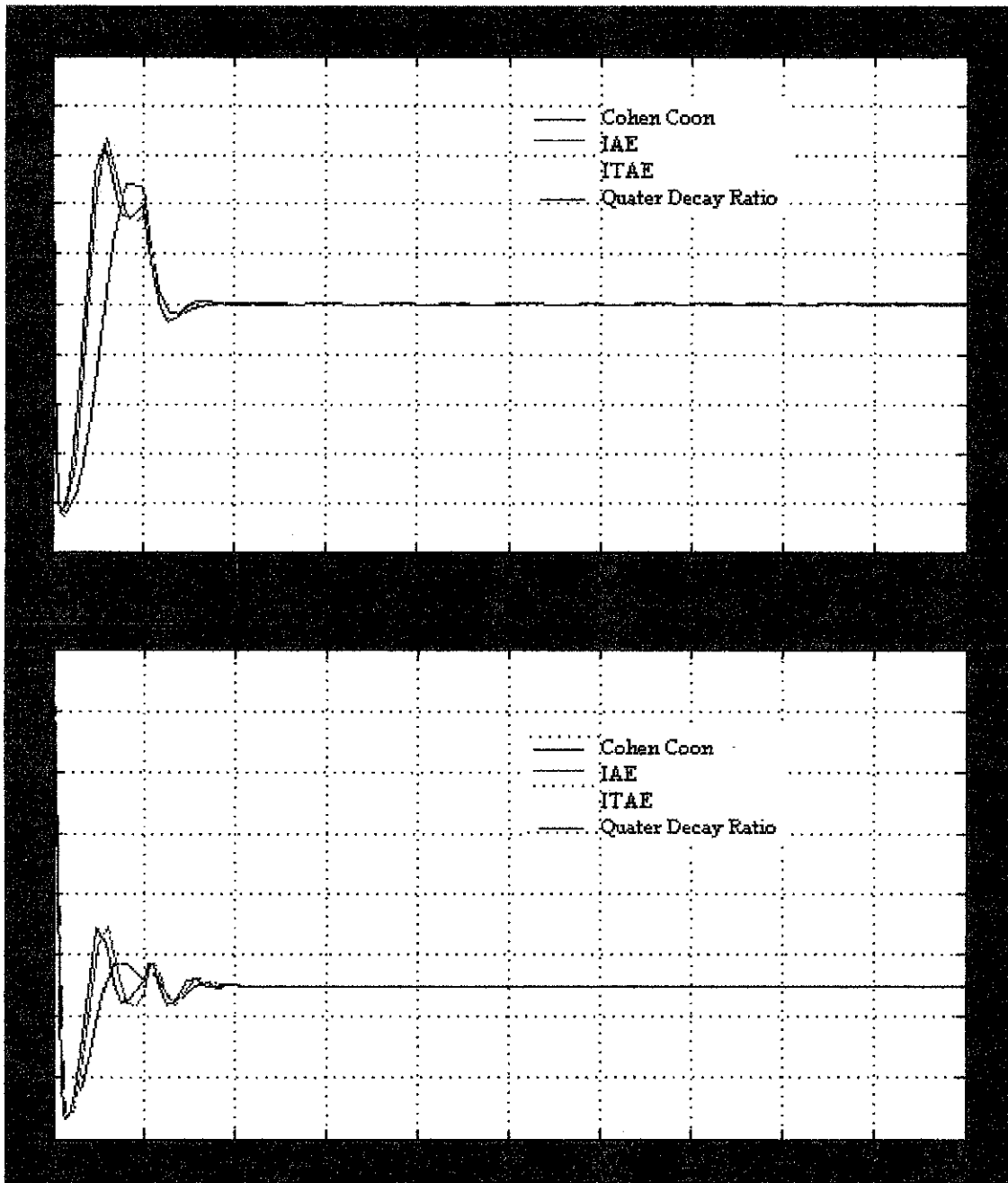
Figure 4.10: Proportional-integral Controller Output Graph for Test Run 1
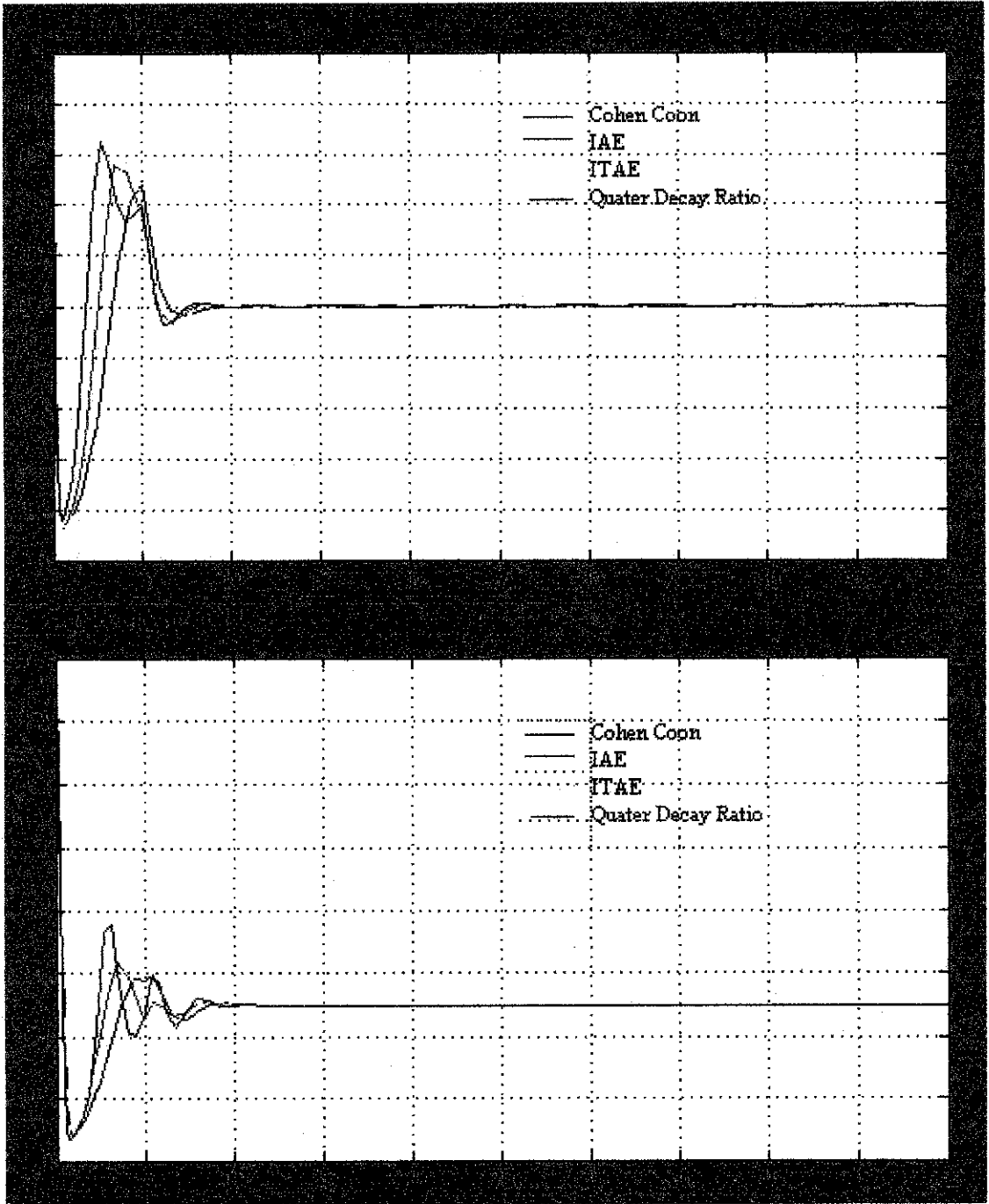
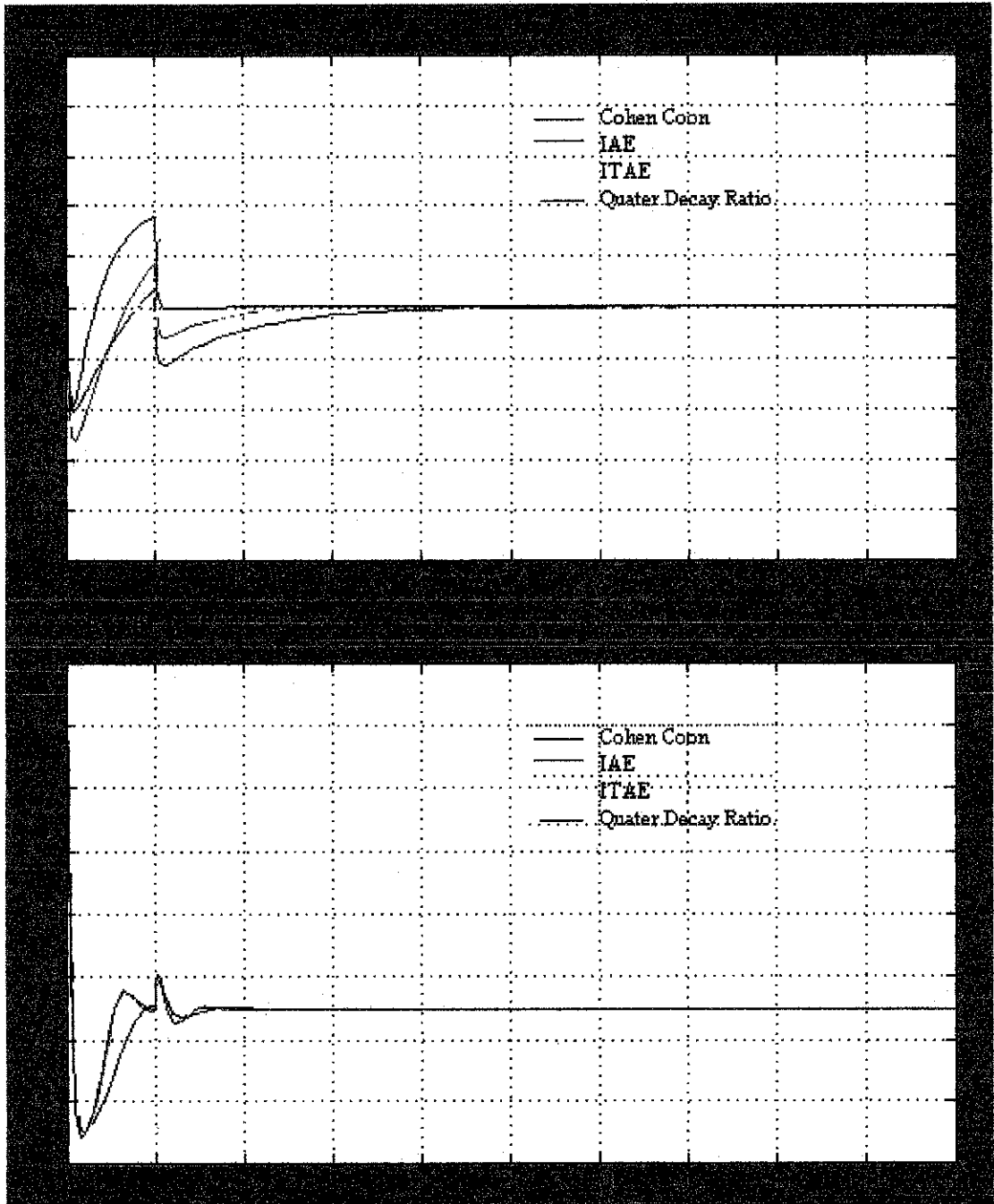Figure 4.11: Proportional-integral Controller Output Graph for Test Run 2

Figure 4.12: Proportional-integral Controller Output Graph for Test Run 3

4.52 Proportional-integral-derivative tuning graph

From proportional-integral-derivative tuning control, the output graph cannot be obtained. The system can only execute Derivatives value, D lower than 0.5. However, the values calculated were mostly higher than that value. For value of D lower than 0.5, when being substituted into the PID controller, the slope of the output similar to the PI tuning, which can be concluded that there is no significant change for derivatives, D value lower than 0.5.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Mathematical models that have been developed from the process are:

$$\int \frac{f_i - f_1 - f_0}{A_1} = h_1 \qquad \text{Where } f_1(t) = Cv_1 x \sqrt{\frac{\Delta P(t)}{G_f}}$$

$$\text{And} \quad \int \frac{f_1 - f_2}{A_2} = h_2 \qquad \text{Where } f_2(t) = Cv_2 x \sqrt{\rho g h_2(t)}$$

From the manual mode study (step test), whenever the percentage valve opening being reduces, the level in the respective tank will increase and vice versa. Results for this, the process gain value, K's in the calculation are negative integer. This clearly indicates the system is a reverse process.

As refer to the PID tuning output graph, the Cohen Coon tuning method appears as the best solution for the level control due to lower overshoot and faster settling time. However, the IAE, ITAE and Quarter Decay Ratio method also can be applied as the output no much different from the Cohen Coon. Proportional-only control seems not applicable for this level control as the tank level approaches zero almost all the time. In the other hand, Proportional-integral-derivatives controller also cannot be determined as the system point out error whenever the D value higher than 0.5. Thus, it is believe Proportional-integral, PI controller would be the best possible alternative to carry out this level control.

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5.2 Recommendation

1. Instead of relying 100% to the simulation, the tuning parameter can also be determined using laboratory apparatus (sample apparatus and its arrangement is shown in appendices).

2. Several more test runs as samples in the step test can be added gain better understanding of the process behavior.

3. This case study can be further enhanced by using fuzzy logic, advance process control etc. Perhaps the upcoming FYP students will take advantage from this study.

4. Assumptions made in this project perhaps can be eliminated in future to improve this study.

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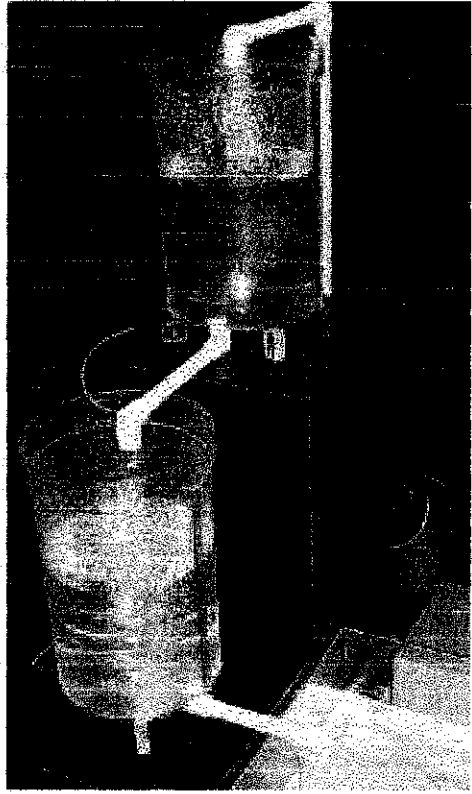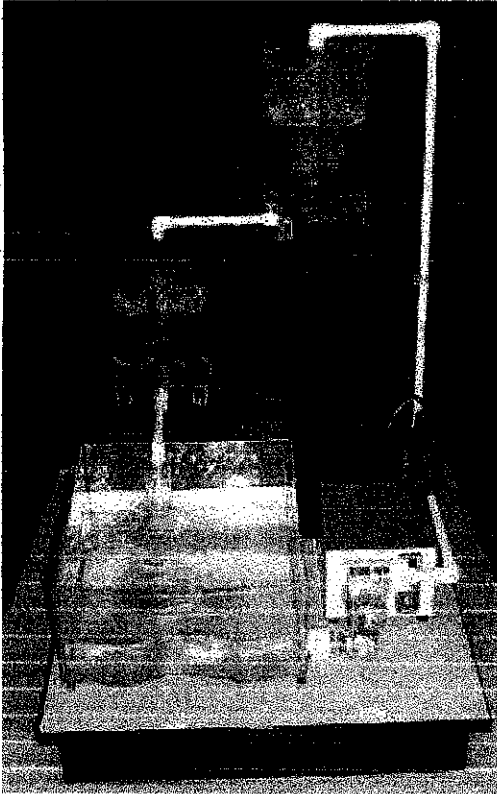4. Douglas J. Cooper, 2003 "Practical Process Control using Control Station",

APPENDICES

Figure 6.1: Series Non-Interaction Tank Laboratory Apparatus