COMPUTER CONTROL OF AN INDUSTRIAL PLANT

By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
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CERTIFICATION OF APPROVAL

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Approved by,

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TRONOH, PERAK

June 2007

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.

NOR FARIENA YANTIE BINTI ISMAIL

ABSTRACT

This report describes the objective, scope of study, problem identification, methodology and the experimentation of the project involves in the development of computer control for an industrial process plant. The project involves the development of computer control for industrial process plant. The objectives of the project are to design and tune a PID controller for the control of temperature in a Gaseous Pilot Plant via real-time using Matlab/Simulink. The Gaseous Pilot Plant in the Plant Process Laboratory, Universiti Teknologi PETRONAS is chosen as the case study. Specifically, the focus is on the monitoring and controlling the temperature of the gas medium in the Gaseous Pilot Plant. The PID controller will operate based on the characteristic and properties of the process. The response of the temperature can be controlled and monitored in real-time during the experimentation process. An extensive study to understand the process plant operation and obtaining its parameters for use in the PID controller have been conducted. Modelling and simulation involves the Matlab/Simulink modelling and the PID controller design. In the experimentation stage, the system's performance is conducted and the result is compared. The real-time PID control of the plant via Matlab/Simulink has been successfully demonstrated on the pilot plant and a number of key results obtained in the development process are presented.

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In the name of Allah, the most Graceful and Most Merciful,

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABBREVIATION AND NOMENCLATURES

UTP	Universiti Teknologi PETRONAS
FYP	Final Year Project
PID	Proportional, Integral and Derivative
P&ID	Piping and Instrumentation Diagram
CV	Controlled Variable
MV	Manipulated Variable
PV	Process Variable
SP	Setpoint
Z-N	Ziegler Nichols
NA	Not Available
RTD	Resistance Thermal Detector
TT	Temperature Transmitter
EH	Heating Element
VL	Vessel
TIC	Temperature Indicator Controller
PCV	Pressure Control Valve
PIC	Pressure Indicator Controller
HV	Hand Valve

CHAPTER 1
INTRODUCTION

1.1 Background of Study

One of the main issues in a plant is on controlling and monitoring the temperature of a process. This project attempts to answer several issues related to the computer control of a plant. In this project a Gaseous Pilot Plant has been selected as the case study. The Gaseous Pilot Plant involves variables such as flow, pressure, level and temperature. The variables need to be set according to the process involved in the plant. The Gaseous Pilot Plant consists of real equipments and components that can be found in the industrial process plant, however, their sizes are of the laboratory scale.

The focus of this project is on the controlling and monitoring of the temperature in a gaseous pilot plant. Temperature is considered as a slow response process because of the process and heat transfer lags. The temperature should be maintained at its desired value when the disturbances occur. Also, in some processes the temperature has to response when there are changes in the desired value. Notably, there are seven control objectives in an industrial plant and they are the safety, smooth operation, product quality, equipment protection, environment protection, product quality, profit optimization and operation monitoring [1].

The PID controller will be designed as the temperature controller. The PID controller is named after the Proportional, Integral and Derivatives control actions. It is a feedback controller in which the output is the error between user-defined setpoint and measured process variable. Each element of the PID controller refers to a particular action taken on the error [2]. The control actions will affect the control loop performance.

1.2 Problem Statement

1.2.1 Problem Identification

The controlling system in the industrial process plant can be done manually by the operators or automatically by the computer control. The control strategy is based on the decision of many aspects that includes the performance requirements of the process designs in Gaseous Pilot Plant involves the measurement of the process variable, final control element characteristic, control structure in Matlab/Simulink and also control calculation for the best performance. All disturbances need to be considered and analyzed to prevent them from affecting the control loop.

In this project, the requirements are that a temperature controller will be developed and response based on the requirement either from the operator or the process itself. The controller should perform well between the operation range and at the desired set point regardless of the disturbances. The stability of the system is also taken into consideration.

1.2.2 Significant of the Project

The automated controller will be designed for used to control the instruments in the process plant. It will minimize the usage of the human resource and to relieve the operator from the tedious task. The monitoring system from the computer is very important to monitor the reliability and effectiveness of the plant. The manipulated variable wills response to any perturbation in the system. One of the significant of this project is a working model of controller and monitoring system of Gaseous Pilot Plant. This would later be used by the researchers for further study using the more advanced controlling and monitoring system.

1.3 Objectives and Scope of Study

- To design the PID controller to control the temperature at the Gaseous Pilot Plant.
- The controller should be able to response to give the best performance in the control loop.
- The system must be stable within the process range and plant requirement.

1.3.1 Relevancy of the project

The gaseous pilot plant is situated in the Process Control Laboratory at Block 23 of the Universiti Teknologi PETRONAS. The Matlab/Simulink and Labview are installed in the workstation at the Process Control Laboratory. A PID controller will be design using Matlab/Simulink. The program will be linked to the Gaseous Pilot Plant using the configuration of the Xpc server. LabVIEW software will be used for the monitoring purpose. In a certain aspect, the development of the temperature controller in this pilot plant is very useful for the future research and development in the Electrical and Electronics Engineering Department, UTP.

1.3.2 Feasibility of the project within the scope and time frame

The final year project has been planned to be completed within two academic semesters. In the first semester, research and literature review of the project has been conducted. The research and literature review includes the understanding of the process, PID controller and familiarization with the software Matlab/Simulink. The PID controller is designed using Matlab/Simulink. The computer simulation and plant experiment is done to observe output trending and analyze the accuracy of the PID controller. In the second semester, the analysis of the performance has been conducted and any corrective action be taken if needed. The disturbance has been introduced to ascertain the applicability of the controller improvement. The monitoring system has been setup in the LabVIEW to monitor the performance.

CHAPTER 2
LITERATURE REVIEW AND/OR THEORY

2.1 Process Control System

A process is defined as progressively continuing operations that consists of a series of a controlled actions or movement systematically directed toward a particular result [4]. There are many types of process variables in the process industrial plant. The commonly found process variables are temperature, flow, pressure, level and concentration.

The system is a combination of components that act together and perform a certain objective. A control system is a device or set of devices to manage, command, direct or regulate the behavior of other devices or systems [2]. The control system can be achieved by the control strategies such as PID Controller, Fuzzy Logic or Programmable Logic Control. The control system usually related to the control objectives which are safety, smooth operation, product quality, equipment protection, environment protection, product quality, profit optimization and operation monitoring [1].

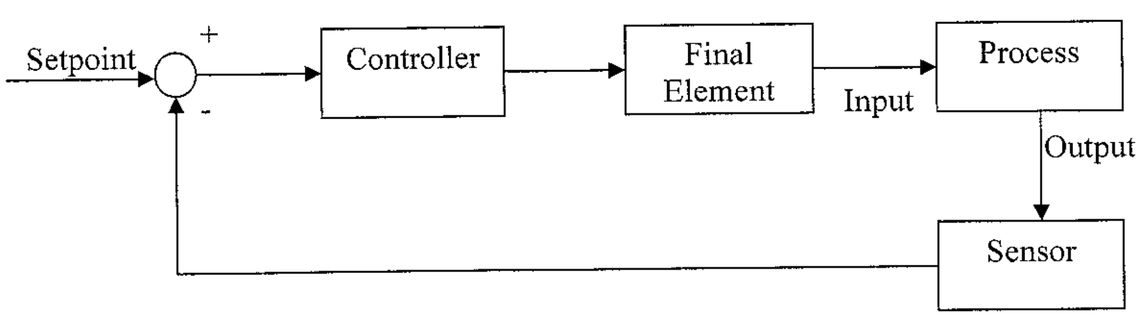


Figure 2.1: Typical Control System Block Diagram

In the control system, there are generally three important components. Sensor is to measure the variable. From the measurement, the information of the variable will be known. The controller is part of a control system that examines the error and determines action that needs to be taken. Usually, the controller operations are performed by computers. It requires input of both measured variable and desired value of the variable. The final element is a device that exerts direct influence on the process and brings the controlled variable to its desired value. It accepts input from the controller which is then converted into proportional operation on the process [1]. For the process that involved temperature variable, the sensor usually used is a device like thermocouple or resistance thermo detector while the final element commonly used is the heater. The process is controlled by the temperature controller.

In the process control system, the process variable and the final element that has causal relationship must be identified. The output of the system is known as controlled variable or process variable and the device or condition that is varied by the controller is known as manipulated variable. In short, the control system is a combination of processes and devices that functions in controlling the output of the system [10].

2.2 PID Controller

The PID controller is named after the Proportional, Integral and Derivatives control actions. It is a common feedback loop component in industrial systems. The controller compares a measured value from a process with a reference set point value. The difference or error signal and then used to calculate a new value for a manipulatable input to the process that brings the process' measured value back to its desired set point [1]. The PID controller can adjust process outputs based on the history and rate of change of the error signal, which gives more accurate and stable control [3].

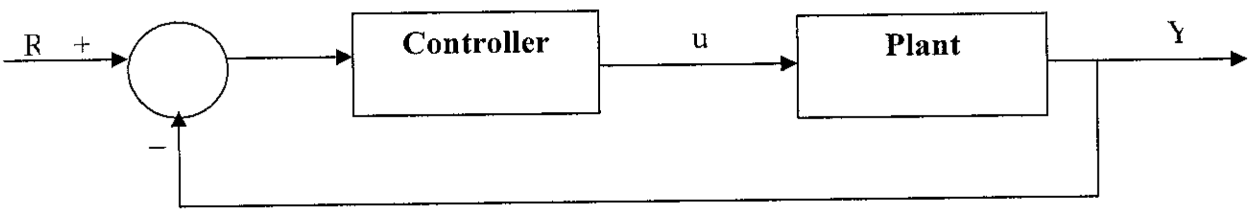


Figure 2.2: Typical Control Loop

where,

R - The input value for the temperature in Gaseous Pilot Plant.

e - The error. The difference between the desired input value (R) and the actual output (Y). The equation for error is as follow:

Error = Setpoint – Process Value

u - The signal that pass from the PID controller

$$U = K_p e + K_i \int e\,dt + K_D \frac{de}{dt}$$

Y - The output value that is measured by the temperature transmitter.

From the concept of control system, the signals that pass through the controller to the plant and the feedback loop are converted to the block diagram in Matlab/Simulink. Each block diagram represents the function in the control system. The input signals are generated from the step input block. The summation of the gain, integrator and derivative represent the PID controller. The process transfer function block and transport delay are for plant model. The figure below shows the PID component is Matlab/Simulink block Diagram:

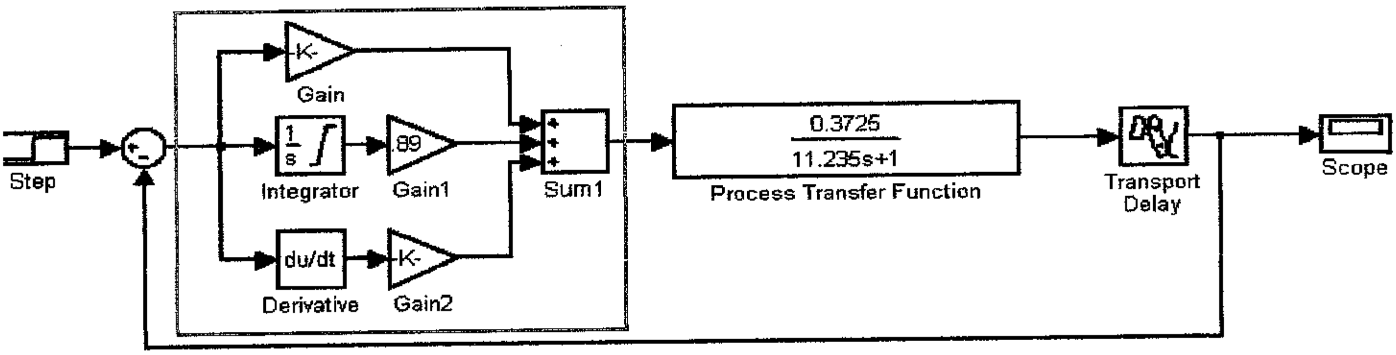


Figure 2.3: PID Controller in Matlab/Simulink

Below is the transfer function for the PID controller:

$$\frac{X(s)}{F(s)} = \frac{K_D s^2 + K_p s + K_i}{s^3 + (10+K_D)s^2 + (20+K_p)s + K_i}$$

Each components of PID controller has a difference effect to the control performance. The PID controller is evaluated based on the important control performances that are the rise time, overshoot, settling time and steady state error. The effect of proportional, integral and derivative control to the PID controller performance is discussed below:

Proportional (Kp) - A proportional controller will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error. Larger K_p typically means faster response since the larger the error, the larger the feedback to compensate [8].

Integral (Ki) - An integral control will have the effect of eliminating the steady-state error, but it may make the transient response worse. Larger K_i implies steady state errors are eliminated quicker. The tradeoff is larger overshoot: any negative error integrated during transient response must be integrated away by positive error before the steady state is reached [8].

Derivative (Kd) - A derivative control will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Larger K_d decreases overshoot, but slows down transient response [8].

Table 2.1 summarizes the effect of increasing each parameter to the system performance:

Table 2.1: The Effect of Increasing PID Controller Parameters

Parameter	Rise Time	Overshoot	Settling Time	S.S. Error
K_p	Decrease	Increase	Small Change	Decrease
K_i	Decrease	Increase	Increase	Eliminate
K_d	Small Change	Decrease	Decrease	None

Even though the PID controller parameters have the effect to the controller performance, it also has some limitations. One common problem is integral windup. It might take too long for the output value to ramp up to the necessary value when the loop first starts up [1]. It can be corrected by disabling the integral function until the measured variable has entered the proportional band. Sometimes this can be fixed with a more aggressive differential term or preloaded the loop with a starting output.

Some PID loops control a valve or similar mechanical device. Wear of the valve or device can be a major maintenance cost. In these cases, the PID loop may have a deadband to reduce the frequency of activation of the mechanical device. This is accomplished by designing the controller to hold its output steady if the change would be small (within the defined deadband range). The calculated output must leave the deadband before the actual output will change. Then, a new deadband will be established around the new output value.

Another problem with the differential term is that small amounts of noise can cause large amounts of change in the output. Sometimes it is helpful to filter the measurements, with a running average, or a low-pass filter. However, low-pass filtering and derivative control cancel each other out, so reducing noise by instrumentation means is a much better choice [1]. Alternatively, the differential band can be turned off in most systems with little loss of control. This is equivalent to using the PID controller as a PI controller.

2.3 Temperature and Heat

This project involved the temperature as the controlled variable. Temperature is a physical property of a system that describe of hot and cold [9]. Usually, something that is hotter has the greater temperature. Temperature is one of the principal parameters of thermodynamics. In order to control the degree of hot and cold, the heat plays an important role. Heat energy flows through substances at a rate proportional to the temperature difference across the substance [3].

$$q = \frac{1}{R}(T_1 - T_2)$$

where,

q = heat energy flow, J/sec

R = thermal resistance, ^{o}C/J

T = Temperature, ^{o}C

Typically, there are several paths for heat to flow into or out of the substance. The net heat-energy flows into a substance affect the temperature of the substance according to the relation,

$$T = \frac{1}{C}q$$

where,

C = thermal capacity

Heat can be transferred by conduction, convection and radiation. It may occur separately or in combination. Heat may transfer only when there is a temperature differences between the systems. When is heat added to a material or substance, the material or substance may change the temperature or it changes the state. The heat capacity is the certain energy needed to raise the temperature of the material. By controlling the heat capacity given to the system, the temperature can be controlled [9].

2.4 Process Flow of Gaseous Pilot Plant

The Gaseous Pilot Plant used in this project consists of real equipments and components which can be found in any industrial process plant. However, the processes involve are of the laboratory scale. The process in this pilot plant involves variables such as flow, pressure, level and temperature. These variables are set based on the process requirement. The diagram below shows the P&ID of the Gaseous Pilot Plant:

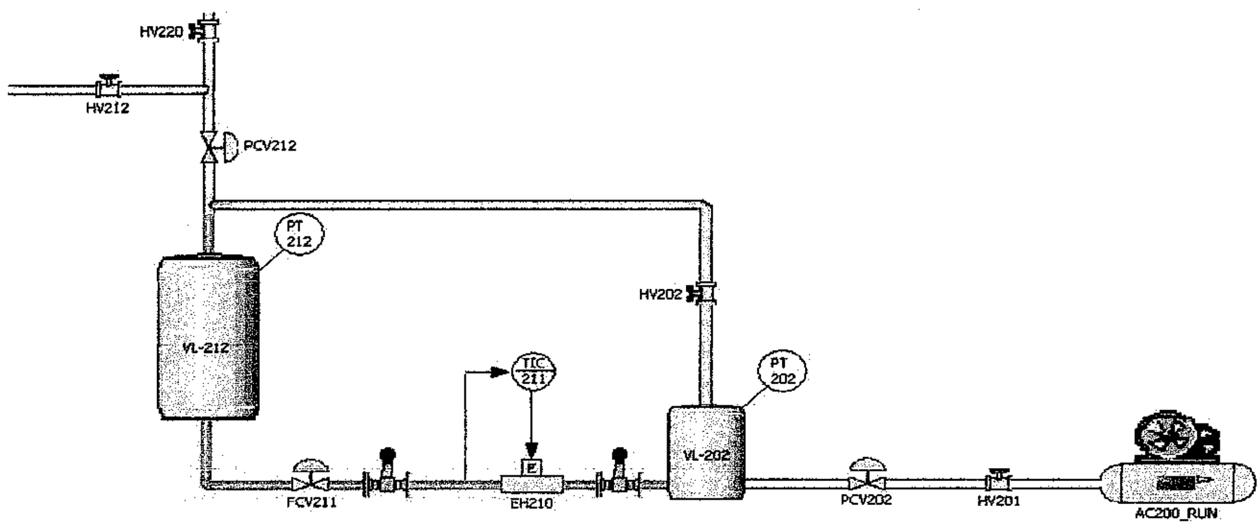


Figure 2.4: Temperature Control Loop

2.4.1 Process Description

In the Gaseous Pilot Plant, for simplicity the medium gas is replaced by normal air. It is supplied from an air compressor. However, the instrument air is externally provided. The air flowed from the right side through the HV 201 and PCV 202 The opening percentage of PCV 202 is controlled by the PIC 202 that is not shown in the diagram. The PIC 202 in the pilot plant responses based on the pressure inside the vessel, VL-202. The vessel is used to store air before it flows to the another vessel, VL 212. HV 202 is closed to avoid the air from flow out. The temperature in VL 202 is heated by the heating element. The heating element is an ON/OFF heater. It will be ON and OFF at certain period based on set point of the controller. If the temperature is lower than the set point the heater will be ONed but if the temperature is higher than the set point the heater will OFFed. The flow of the air in the pipeline is controlled by the controller, FIC 211. The controller is control the FCV211 opening percentage. The air is store in the VL 212 before flowing out.

For the temperature control in the Gaseous Pilot Plant, the control objective is to protect the equipment from the high temperature. The high temperature will give the negative effect to the equipments. The second control objective is for the smooth operation. The process and plant operation will be smooth and reliable if the temperature of the air inside the pipeline is in the operation range. To achieve the control objectives, the controlled and manipulated variable are chosen. The controlled variable is temperature in the pipeline and the manipulated variable is the ON and OFF of the heating element.

The RTD acts as a sensor to measure the temperature. The temperature transmitter (TT211) sent the sensor output to temperature controller (TIC 211). The corrective action will be taken by the controller to make sure the temperature is the same as the set point. The final control element is the heating element, EH 210. At the process unit, the output signal is used to adjust the final control element that is manipulated by the control system. The ON and OFF condition of heating element is chosen as the manipulated variable because it has causal relationship with the controlled variable.

The disturbances are also being considered in order to produce a good controller. It can have the direct affect on the performance of the controlled variable. There are two types of disturbances in this pilot plant, the input disturbance and the plant disturbance. The figure below shows how the disturbances affect the system:

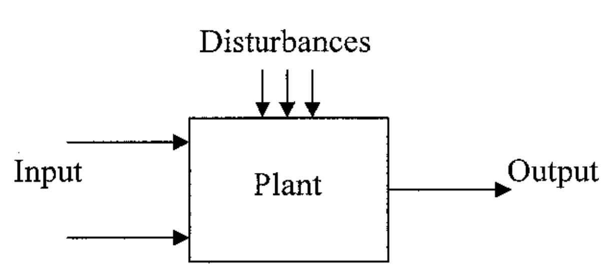


Figure 2.5: Affect of Disturbance

2.4.2 Process Equipment

The Process Equipments in Gaseous Pilot Plant are as follows:

- Storage Vessel
- Heating element
- Temperature transmitter
- Flow transmitter
- Level transmitter
- Pressure transmitter
- Pneumatic control valves
- Pneumatic valve positioner
- Resistance Thermo Detector

This project is focusing on the temperature response. In reference to that, the main devices that support the temperature response are the temperature transmitter, resistance temperature detector and the heating element.

The temperature transmitter is a device that transmits a sensor output to the controller. This is due to the fact that the sensor signal alone is not strong enough to reach the controller without some degradation. The transmitter converts the low level millivolt signal from the sensor to the higher level signal which is from 4 mA to 20 mA.

In Gaseous Pilot Plant the temperature sensor used is Resistance Temperature Detector (RTD). RTD is a temperature sensor that exploits the predictable change in electrical resistance of some materials with changing temperature [1]. The type of RTD that been used in Gaseous Pilot Plant is PT100 which has a nominal resistance of 100 ohms at 0 °C. The PT is the symbol for Platinum, the material it made from. The sensitivity of a standard 100 ohm sensor is a nominal 0.4 ohm/°C. A change of only 0.4 ohm would be expected for a 100 ohm RTD if the temperature is changed by 1°C.

Usually, RTD has a response time of 0.5 to 5 s or more. The slowness response is due to the slowness of thermal conductivity in bringing the device into thermal equilibrium with its environment. It is constructed from the wire that is wound on a form in a coil to achieve small size and improve thermal conductivity to reduce the response time. The advantage of RTD is that it is suitable for the Gaseous Pilot Plant temperature range which is 0°C -100°C. The RTD have high accuracy, low drift and suitable for precision application in measuring the temperature. The limitation of RTD is less sensitive to small temperature changes and has a slower response time.

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

The project involves of several procedures and steps. The procedures and steps are taken to execute the project and to be completed within the given time. Below is the overall flow chart for this project:

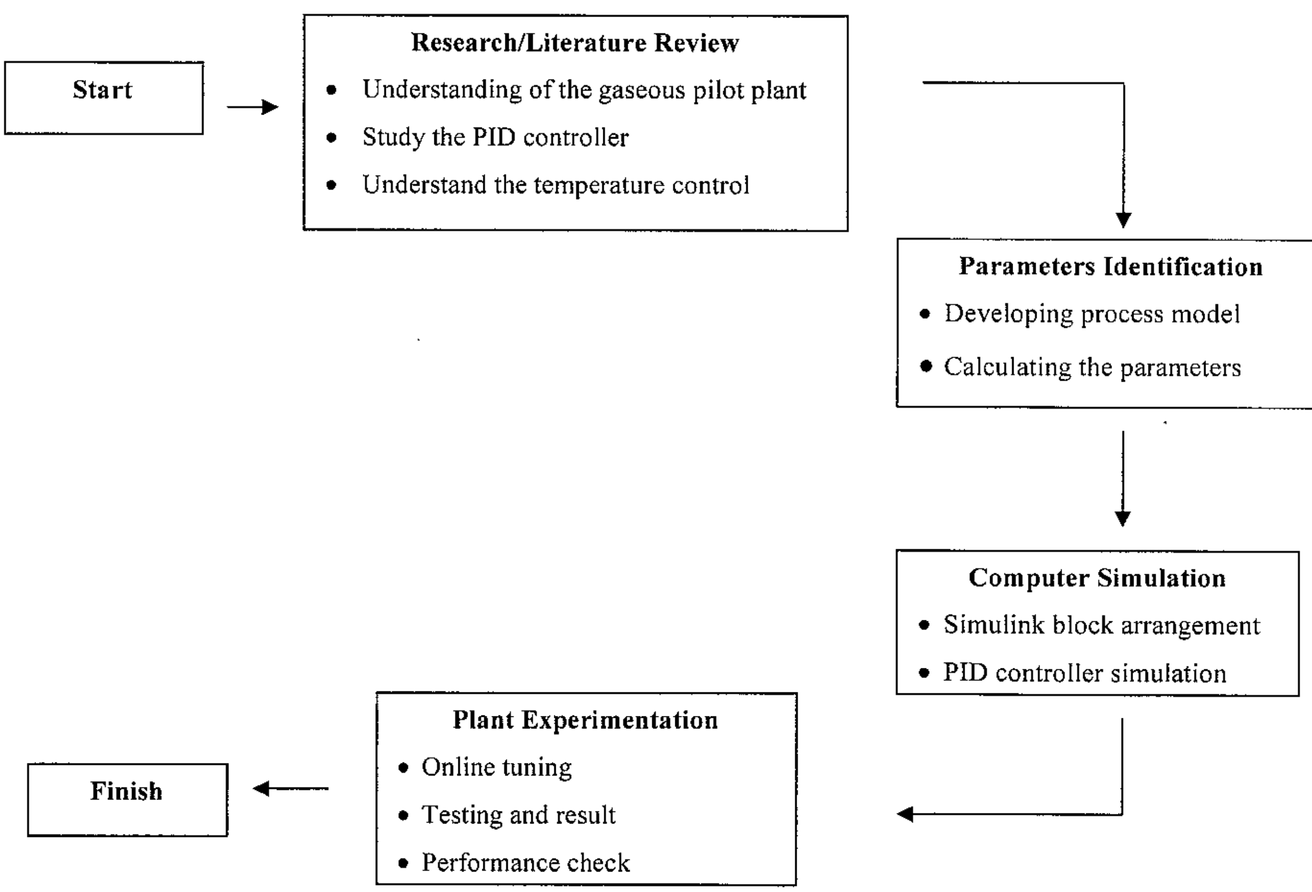


Figure 3.1: A Flowchart of the Project Implementation

The first stage is on the literature review. A revision on the process control area gave a better understanding of the temperature control in the Gaseous Pilot Plant. The research on the PID controller also has been done. The research covers on the characteristic of the PID, function and effect of each controller elements. Initially, a simple model of PID controller has been developed using the Matlab/Simulink, in order to familiarize with the software. This stage helps the author to have a better understanding and knowledge about this project.

The second stage is the parameters identification stage. In this stage the process model is developed using the Empirical Method. By using this method it ensures that proper data is generated through careful experimentation design and execution. The procedures make the best use of the data by diagnosing and verifying results from the initial model parameters calculations. The process model is calculated and the initial value of the PID controller is determined by the Ziegler – Nicholas, Cohen-Coon and Ciancone method. These methods involved the open loop and closed loop analysis.

The computer simulation stage involves the design of the PID controller, block diagram arrangement and simulating the system. The system is developed in the Matlab/Simulink and also in LabVIEW for the monitoring purpose. The block diagram consists of the input and output block of the process variables, PID controller block, digital driver that connect the software to hardware, scopes and other related control system blocks. The system is simulated using the initial values of the PID controller from the previous stage. The responses are compared and the best parameter is determined.

The last stage is the plant experimentation. The parameters of the PID controller are used for the online real-time tuning. During the online tuning the other process value is set to constant values to get the best tuning result. The PID controller with the best parameters is tested online to ensure the system is stable during running. The performance check is done to evaluate the performance of the PID controller.

3.1.1 Open Loop analysis

The open loop analysis is based on the Empirical method. Below are the procedures for the process model modeling and controller design:

1. Ensure that all Utility Services at Gaseous Pilot Plant is ready.
2. Switch on the power supply control panel and air supply system.
3. Start xPC target application at workstation 2.
4. Open the Matlab/Simulink model and connect to the Gaseous Pilot Plant.
5. Place the controller mode in the manual mode.
6. Initial set point is set to the lower values such as 30%
7. Run the process plant.
8. Increase the set point by small amount such as 10% when the temperature is at steady state.
9. The process reaction curve is monitored.
10. Stop the experiment when the temperature is stable
11. The process model and controller parameter is calculated based on the process reaction curve.

There are two methods to get the process model based on the Process Reaction Curve. The first developed method is the Method I. For this method, it is proned to errors because the evaluation of the slope (Appendix 1). The calculation is using the formula:

$$Kp = \Delta / \partial$$

$$t = \Delta / S$$

$$\theta = \text{Shown in Appendix 1}$$

So, the recommended method is Method II. Method II is required only for simple calculation with following formula (Appendix 2):

$$Kp = \Delta / \partial$$

$$t = 1.5\ (t_{63\%} - t_{28\%})$$

$$\theta = t_{63\%} - t$$

3.1.2 Closed Loop method

The closed loop method is based on the Ziegler Nichols Closed Loop method. Below are the steps taken to design the controller using this method:

1. Ensure that all Utility Services at Gaseous Pilot Plant is ready.
2. Switch on the power supply control panel and air supply system.
3. Start xPC target application at workstation 2.
4. Open the Matlab/Simulink model and connect to the Gaseous Pilot Plant.
5. Place the controller mode in the auto mode.
6. Insert the low gain for proportional, no reset and derivative.
7. Gradually increase the gain, making small changes in the setpoint until oscillations start.
8. Adjust the gain until the oscillations continue with constant amplitude.
9. Stop the experiment and note the gain and the period for one cycle of oscillation
10. The controller parameters are calculated based on the gain and period of the oscillation.

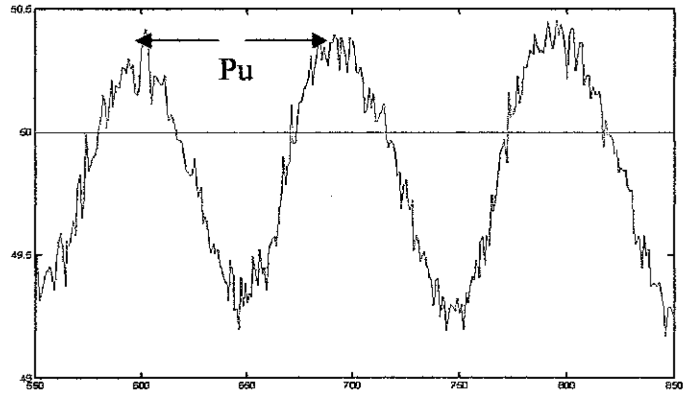


Figure 3.2: Continuous Oscillation

Pu – Ultimate Period. The time for one oscillation period

Gu – Ultimate Gain. The gain at which the oscillations continue with constant amplitude

3.2 Tools and configurations

The project configuration involves of the hardware and software setup. The setup and configuration is made to connect the software and hardware to allow the communication. These setups allow the signal from the workstation to be transferred to the Gaseous Pilot Plant and to ensure the hardware work as specified. The following is the hardware and software setup:

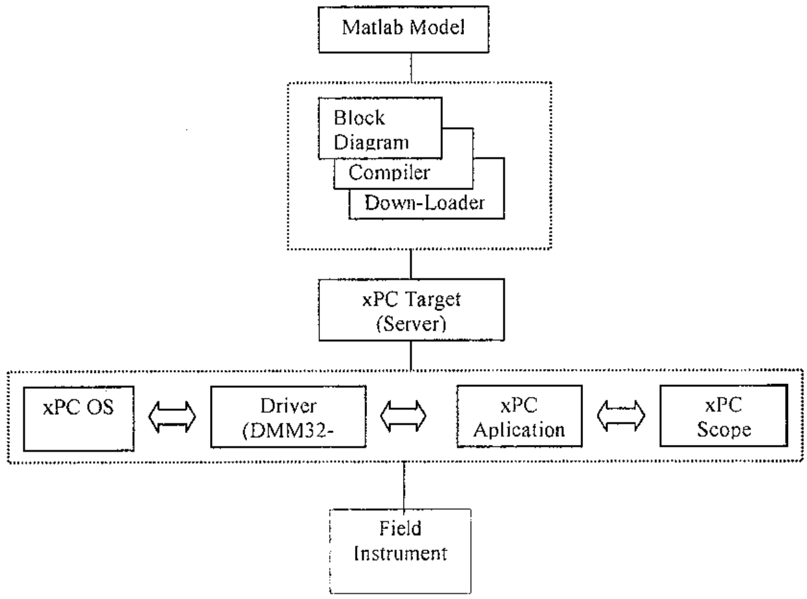


Figure 3.3: Software Configuration

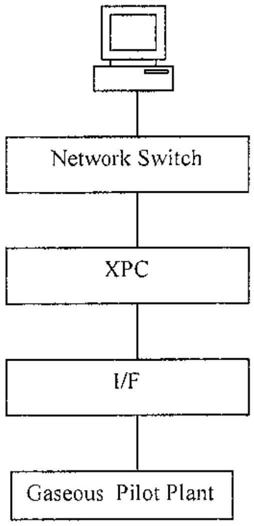


Figure 3.4: Hardware Configuration

3.2.1 Matlab/Simulink software

Matlab/simulink is the powerful software to for modeling, simulating and analyzing dynamical systems. In this project, it is use to design, tune, test and simulate the PID controller. The control block diagram is constructed in the Simulink. To create a Simulink model, it involves the adding of the necessary block such as step input, scope, xPC target scope block or output block based on the application needed. The suitable parameters are entered for the scope block to view the result. The Simulink output block is added to log the result for analysis. The xPC target is added to visualize signal while running the target application. In this project, the external simulation mode is chosen because the model is connected to the Gaseous Pilot Plant.

3.2.2 LabVIEW Application

LabVIEW application is one of the realtime monitoring system. In this project, it is used to monitor the process during the experiment. In the LabVIEW, The process variables that have to be monitored can be specified and represent in the graphic. The LabVIEW is connected to the Gaseous Pilot Plant by the xPC target and can run simultaneously with the Matlab/Simulink application.

3.2.3 xPC target industrial PC

The xPC target industrial PC acts as server and interface system to connect the Simulink model and Gaseous Pilot Plant. The xPC target is connected to the Gaseous Pilot Plant by the Local Area Network, 100 Mbps. The signal from Simulink model is write to the server via xPC target scope block. The xPC target kernel automatically creates the scope on the target when the target application is downloaded to the target PC. For this project, the target PC is UTP workstation 2. The workstation consists of the computer with XP operating system and an uninterruptible power supply.

3.2.4 Gaseous Pilot Plant

Gaseous Pilot Plant is the process plant that has been used as the case study. The pilot plant is situated in the Plant Process Laboratory at Block 23, Universiti Teknologi PETRONAS. The gaseous pilot plant used in this project consists of real equipments and components which can be found any industrial process plant such as valve, transmitters, controller and others instruments. However, the processes involve are of the laboratory scale. The process in this pilot plant involves variables such as flow, pressure, level and temperature.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Open Loop Analysis

The following discussion is related to the control of temperature of a gaseous pilot plant. The experiment is conducted to get the data for the process modeling. The calculation is made based on the process reaction curve (Appendix 3). The change of manipulated variable, dM, change in ultimate value, dBu, apparent time constant, T and apparent dead time, Td, are show in the reaction curve. The values are used to get the process model. Below is the calculation for each parameter.

Table 4.1: Result from Process Reaction Curve

Parameters	**Value**
Change Manipulated Variable, dM	20%
Change in Ultimate Value, dB_u	7.25
Apparent Time Constant, t	677.25 sec or 11.2875min
Apparent Dead Time, Θ	135.45Sec or 2.2575 min
Steady State Process Gain, Kp	0.3625
Fraction dead time, R= Θ / t	0.2

<u>Process Model, Gp(s)</u>

$$Gp(s) = \frac{[Kp\ e^{-Tds}]}{(Ts+1)}$$

$$= \frac{[0.3625\ e\text{-}2.2575]}{(11.2875s+1)}$$

The process model obtained shows that the process is the first order with dead time process. The model is simulated using a control loop that is constructed in the Matlab/Simulink. In this control loop, there are four main important elements which are transfer function block, PID block, step input block and scope. The step input is for the setting of input and step. The transfer function block is for process model. Scope is to view the simulation result. The model is simulated using the following block diagram:

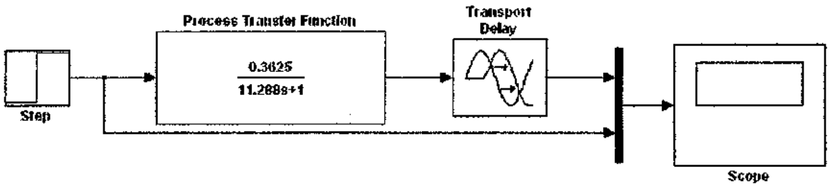


Figure 4.1: Simulation Block Diagram

The simulation result shows that it is the same as the process reaction curve. It verified that the process model can be used for the next step of calculating the PID controller. Below is the simulation result:

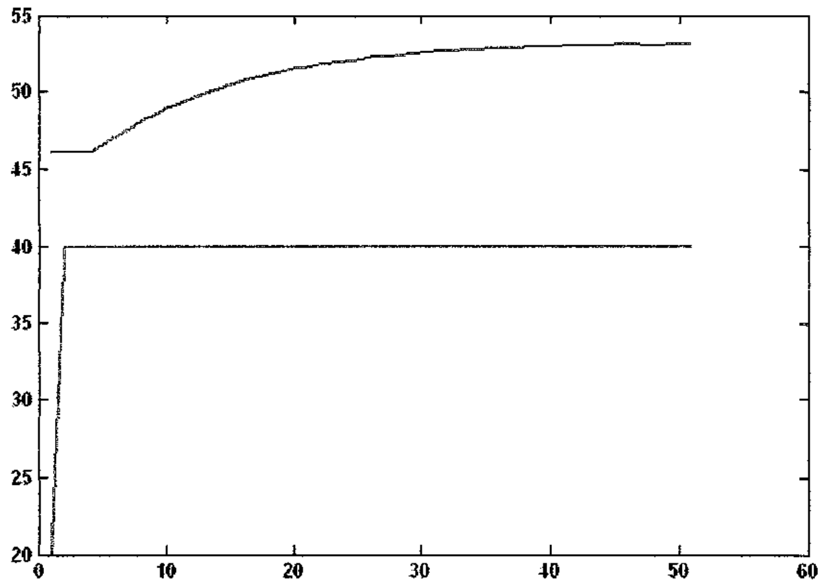


Figure 4.2: Simulation of the model

4.1.1 Ziegler-Nichols Tuning Method

From the simulation, the result obtained is slightly the same as the experimental result. So the parameter of model can be used for the PID parameters calculation. The Ziegler-Nichols Tuning Method is a commonly used method for the open loop analysis. The result from this method can be the used as the starting value for the better performance. The calculation of the PID controller parameters is as follow:

Table 4.2: PID Controller Parameters for Ziegler-Nichols Tuning Method

Controller/ Parameter	PI Controller	PID Controller
Kc	= (0.9/Kp)(t/Θ) = (0.9/0.3725) (11.235/2.247) = **12.08**	= (1.2/Kp)(t/Θ) = (1.2/0.3725) (11.235/2.247) = **16.12**
Ti	= 3.3 Θ = 3.3 (2.247) = **7.4151**	= 2 Θ = 2 (2.247) = **4.494**
Td	NA	= 0.5 Θ = 0.5 (2.247) = **1.1235**

4.1.2 Ciancone Correlation Tuning Method

Ciancone Correlation method is another tuning method based on the open loop analysis. The values of gain, transport delay and time constant from the process model is used to provide the Kc, Ti and Td. The calculation is based on the Ciancone correlation for dimensionless tuning constant, PID algorithm chart (Appendix 4).

Every process responds with a different "speed", which can be characterized by the time for a step response to achieve 63% of its final value. For a first order with dead time process, this time is (Θ + t). Dividing the time by this value "scale" all processes to the same speed, so that one general correlation equation can be developed [1]. The resulting equation is called fraction dead time which is:

$$\frac{t}{(\Theta + t)} = 0.2$$

Table 4.3: PID Controller Parameters for Ciancone Correlation Method

Controller/ Parameter	PI Controller	PID Controller
Kc	KcKp = 2.5 Kc = 2.5/0.3625 = **6.897**	KcKp = 2.5 Kc = 2.5/0.3625 = **6.897**
Ti	Ti/(Θ + t) = 0.95 Ti = 0.95 x 13.54 = **12.86**	Ti/(Θ + t) = 0.95 Ti = 0.95 x 13.54 = **12.86**
Td	NA	Td/(Θ + t) = 0.02 Td = 0.02 x 13.54 = **0.2708**

4.1.3 Cohen & Coon Correlation Method

Cohen & Coon Correlation Method is also another method based on the empirical Method. The calculation of the PID parameters is determined from the process model obtained from the process reaction curve. Below is the calculation of the PID controller parameters:

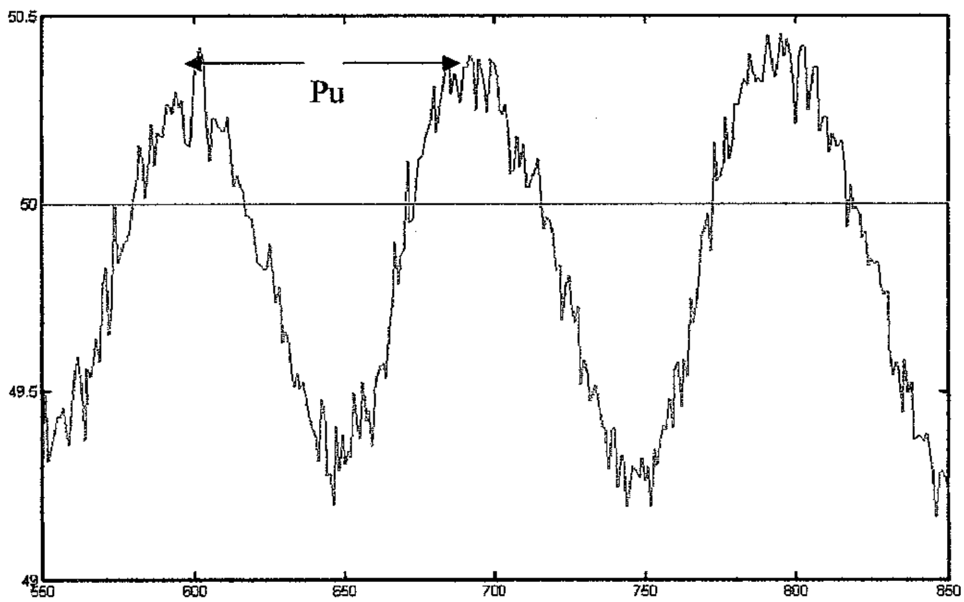
Table 4.4: PID Controller Parameters for Cohen & Coon Correlation Method

Controller/ Parameter	PI Controller	PID Controller
Kc	= (1/R.Kp) (9/10 + R/12) = (1/0.2x0.3625)(9/10+0.2/12) = **8.359**	= (1/R.Kp) (4/3 + R/4) = (1/0.2x0.3625)(4/3+0.2/4) = **19.08**
Ti	$= \Theta.\frac{(30+3R)}{(9+20R)}$ $= 2.2575 . \frac{(30+3.0.2)}{(9+20.0.2)}$ = **5.3138**	$= \Theta.\frac{(32+6R)}{(13+8R)}$ $= 2.2575 . \frac{(32+6.0.2)}{(13+8.0.2)}$ = **5.133**
Td	NA	$T_D = \Theta. \frac{4}{(11+2R)}$ $= 2.2575 . \frac{4}{(11+2.0.2)}$ = **0.792**

4.2 Closed Loop Analysis

The second method used in this project is the closed loop method. This method is better compare to the open loop method. It represents the real process of the plant because it involves the real time simulation. The process model from the open loop method is suitable for the computer simulation or offline simulation.

The PID controller parameters are calculated by using Ziegler Nichols equations. The value of proportional gain, Gu and period of oscillation, Pu, is obtained from the continuous oscillation with constant amplitude wave (Appendix 6).



Parameter	Value
Gu	160
Pu	100 s

Figure 4.3: Continuous Oscillation with Constant Amplitude

Table 4.5 shows the PID controller parameter calculated using the Ziegler-Nichols Closed Loop Method:

Table 4.5: PID Controller Parameters for Closed Loop Analysis

Controller/ Parameter	Kc	Ti	Td
PI Controller	= 0.45 Gu = 0.45 (160) = 72	= Pu / 1.2 = 1.667/1.2 = 1.389	NA
PID Controller	= 0.6 Gu = 0.6 (160) = 96	= Pu / 2 = 1.667 min / 2 = 0.8335	= Pu/8 = 1.667/8 = 0.2084

4.3 Performance Evaluation

The performance check is done to compare the controller performance based on the calculated values. The purpose of the performance check is to have the feedback control loop that maintains a small deviation between the controlled variable and the set point by adjusting the manipulated variable. The system of the Gaseous Pilot Plant is stable if all bounded inputs to the system result in bounded outputs [5].

The performance of the controller is evaluated based on the value of important control performance; rise time, settling time, decay ratio and offset. Control performance is the ability of a control system to achieve the desired dynamic response, as indicated by the control performance measure, over an expected range of operating condition [1]. The rise time is the time from the step change in the set point until the controlled variable first reaches the new set point [1]. The settling time is the time the system takes to attain a nearly constant value, usually +-5% of final value. This measurement is related to the rise time and decay ratio. Usually the short rise time and settling time are as desired. Decay ratio is the ratio of neighboring peaks in an under damped controlled variable response. The small decay ratio is as desired and an overdamped response is as desired. Offset is the difference between final, steady state values of the set point and of the controlled variable. A zero steady state offset is desired because the control system should achieve the desired value, at least after a very long time [1]..

4.3.1 Computer Simulation

The PID controller performance of the open loop analysis is evaluated using the computer simulation. The Matlab/Simulink block diagram is used for this purpose. The calculated value of PID parameter is inserted into the PID controller block, the process model is inserted in the transfer function block and transport delay, the step is given and the result is shown in the scope. The recorded data also can be view in the Matlab workspace. Matlab/Simulink block diagram is as follow:

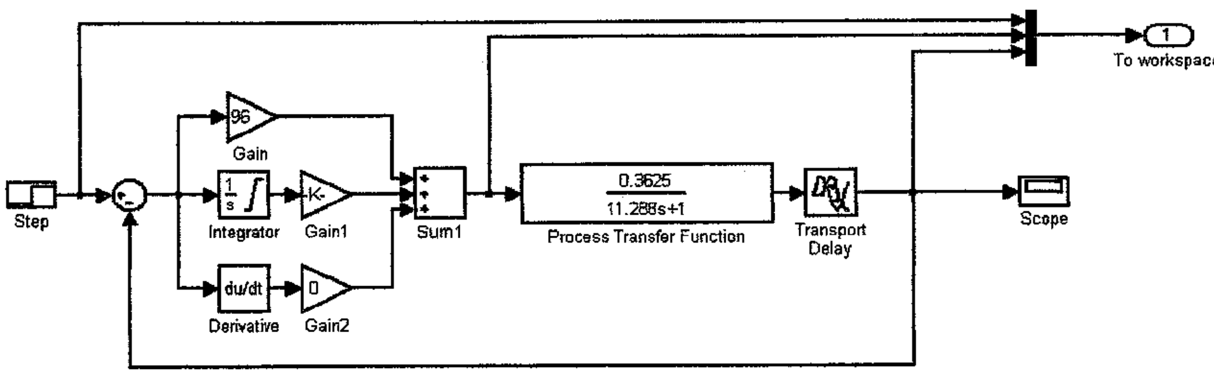


Figure 4.4: Matlab/Simulink Block Diagram

The first performance evaluation is the PI controller of Ziegler-Nichols Open Loop method. From the result, it shows that the system is not stable. The controlled variable and manipulated variable keep on oscillating when the step input is given. The controlled variable never settles at the setpoint which is 30.

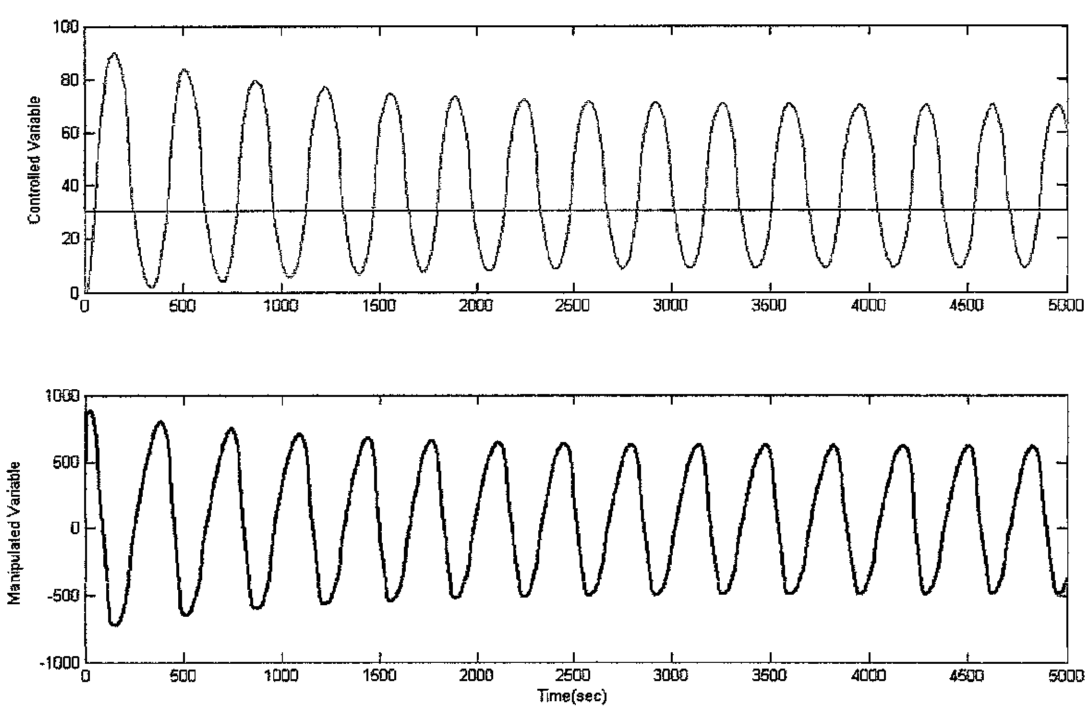


Figure 4.5: The Response using PI Controller of Z-N Open Loop Method

The second performance evaluation is the PID controller of Ziegler-Nichols Open Loop method. From the result, it shows that the system is also not stable. The controlled variable and manipulated variable keep on oscillating when the step input is given. Eventhough the oscillatory response is decreasing at the end of the simulation, the controlled variable never settles at the setpoint which is 30.

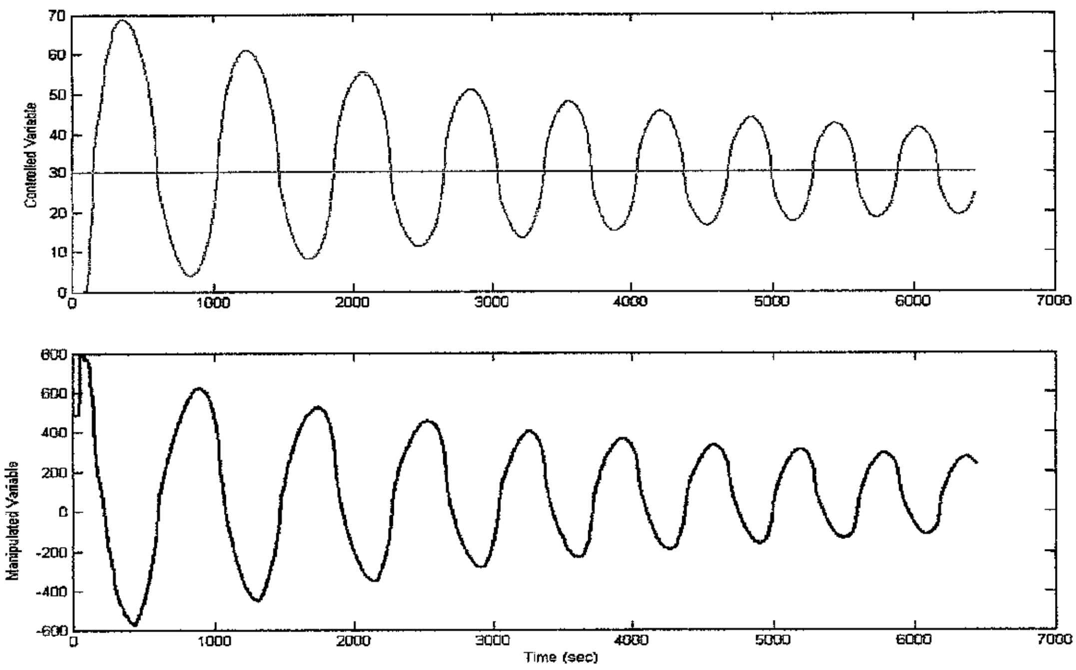


Figure 4.6: The Response using PID Controller of Z-N Open Loop Method

By observation of Ziegler-Nichols Open Loop Method performance evaluation, both PI and PID controller have the unstable response while controlling the controlled variable. The controlled variable has never settles at the setpoint. From the result, the important control performance value is difficult to be calculated. The unstable system always gives the poor performance. As a conclusion, the PID controller parameters from Ziegler-Nichols Open Loop Method are not suitable to use for controlling the temperature in the Gaseous Pilot Plant.

The parameters from Ciancone Correlation also been tested using the computer simulation. Below is the PI controller of Ciancone Correlation method performance result:

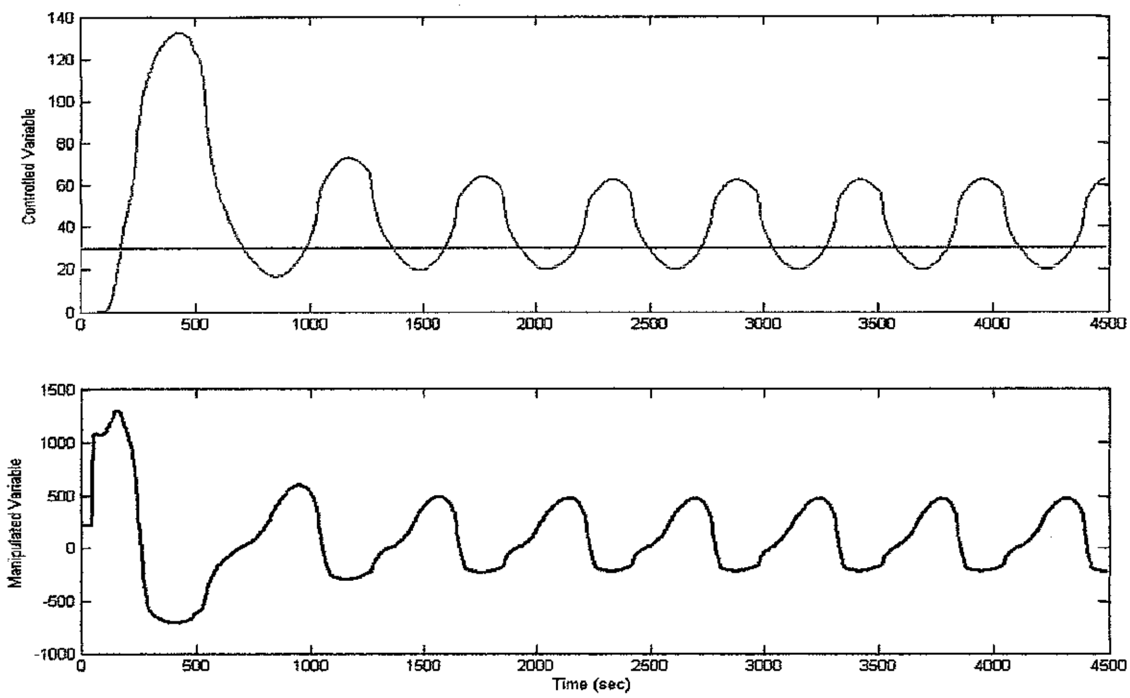


Figure 4.7: The Response using PI Controller of Ciancone Correlation Method

Again, the controlled variable and manipulated variable keep on oscillating when the step input is given. Even though the oscillatory response is decreasing at the end of the simulation, the controlled variable never settles at the setpoint which is 30. Below is the control performance value of this controller:

Table 4.6: Control Performance for PI Controller using Ciancone Correlation Method

Control Performance	Value
Rise Time	2.96 min
Settling Time	NA
Decay Ratio	2.35
Offset	9.93 °C

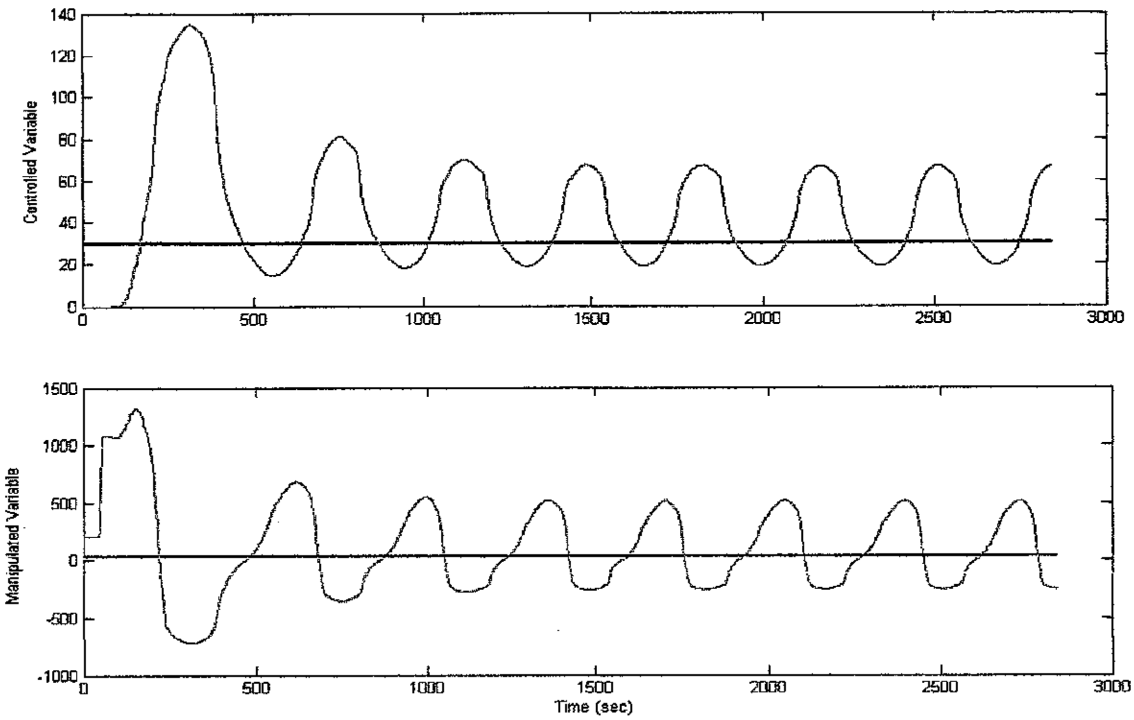


Figure 4.8: The Response using PID Controller of Ciancone Correlation Method

Table 4.7: Control Performance for PID Controller using Ciancone Correlation Method

Control Performance	Value
Rise Time	2.83 min
Settling Time	NA
Decay Ratio	1.27
Offset	10.89 °C

For the Ciancone Correlation method, there is some control performance that has been identified. For the rise time and decay ratio, the PID controller has the smaller value compared to the PI controller. But for the offset the PID controller has bigger value than PI controller. The settling time for both controllers is not achieved until the end of the experiment. As a conclusion for the Ciancone Correlation method, the PID controller performance is better than the PI controller.

The PID controller calculated parameters using the Cohen & Coon Correlation method are tested to see the performance. The result for PI controller is as follow:

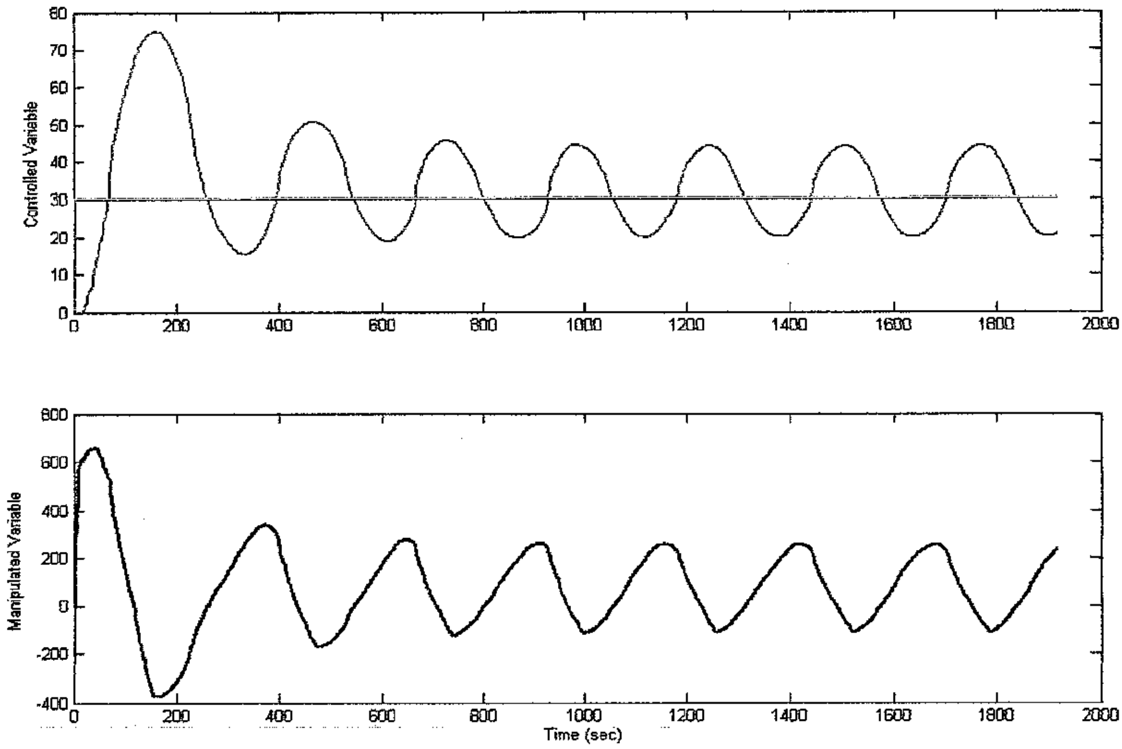


Figure 4.9: The Response using PI Controller of Cohen & Coon Correlation Method

The controlled variable and manipulated variable keep oscillating when the step input is given. Even though the oscillatory response is decreasing at the end of the simulation, the controlled variable never settles at the setpoint which is 30. Below is the control performance value for this controller:

Table 4.8: Control Performance for PID Controller using Ciancone Correlation Method

Control Performance	Value
Rise Time	1.15 min
Settling Time	NA
Decay Ratio	2.15
Offset	9.91 °C

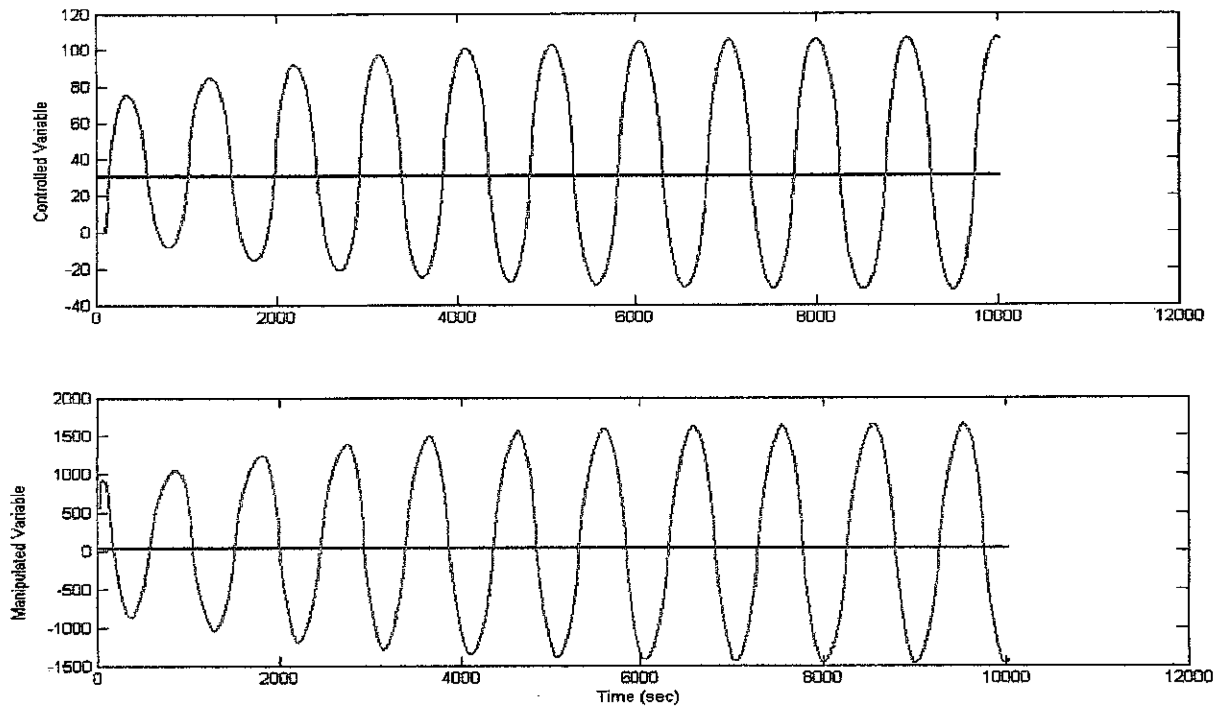


Figure 4.10: The Response using PID Controller of Cohen & Coon Correlation Method

The above result shows the performance of the PID controller from Cohen & Coon correlation method. It shows that the system is unstable. The controlled and manipulated variable is oscillating when the step change is given. The oscillatory response is increasing and never settles at the setpoint until the end of the simulation time. This controller is not suitable to be implementing in the Gaseous Pilot Plant.

As a summary, in the Open Loop Analysis, the controllers cannot control the controlled variable to maintain at the setpoint. They gave the oscillatory response and never settles at the setpoint, has big decay ratio and give higher offset which is not desired even though the rise time between one minutes to two minutes is acceptable, in general, all of the controllers gave the poor performance and need the fine tuning before implementing at the Gaseous Pilot Plant.

4.3.2 Online Simulation

The online performance check is conducted using the PID controller values from the Closed Loop Analysis. From the online experiment, the real process response can be seen. In the Matlab/Simulink block diagram (Appendix 5), the controller mode is set to '1' which is for automatic controller.

Below is the result for PI controller using Ziegler-Nichols Closed Loop Method:

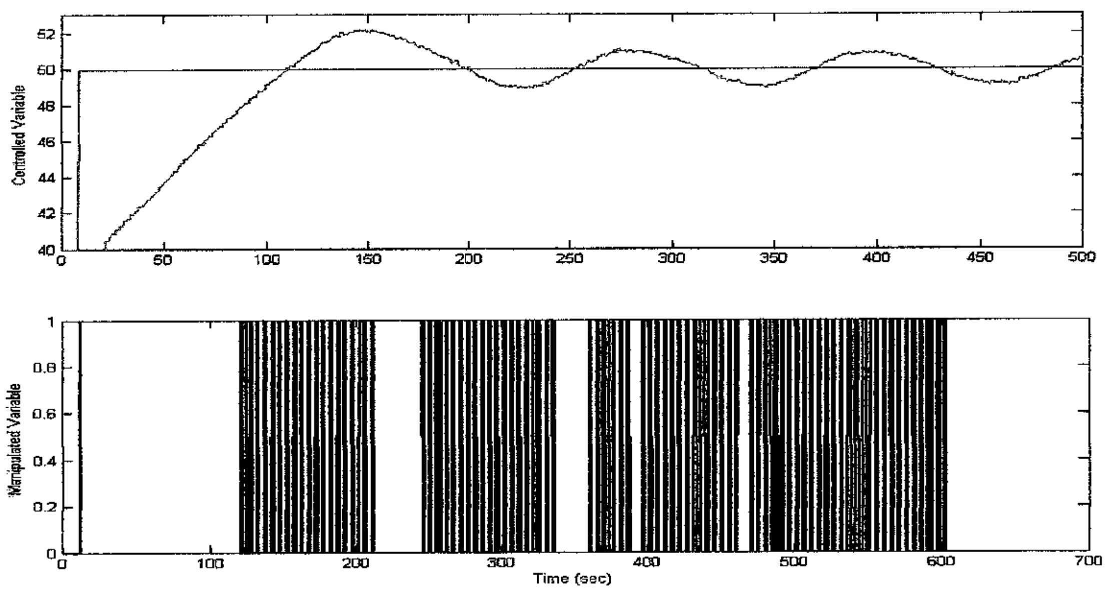


Figure 4.11: The Response using PI Controller of Z-N Closed Loop Method

Table 4.9: Control Performance for PI Controller using Z-N Closed Loop Method

Control Performance	Value
Rise Time	1.68 min
Settling Time	6.5 min
Decay Ratio	0.45
Offset	0.83 °C
Peak to Peak	1.72

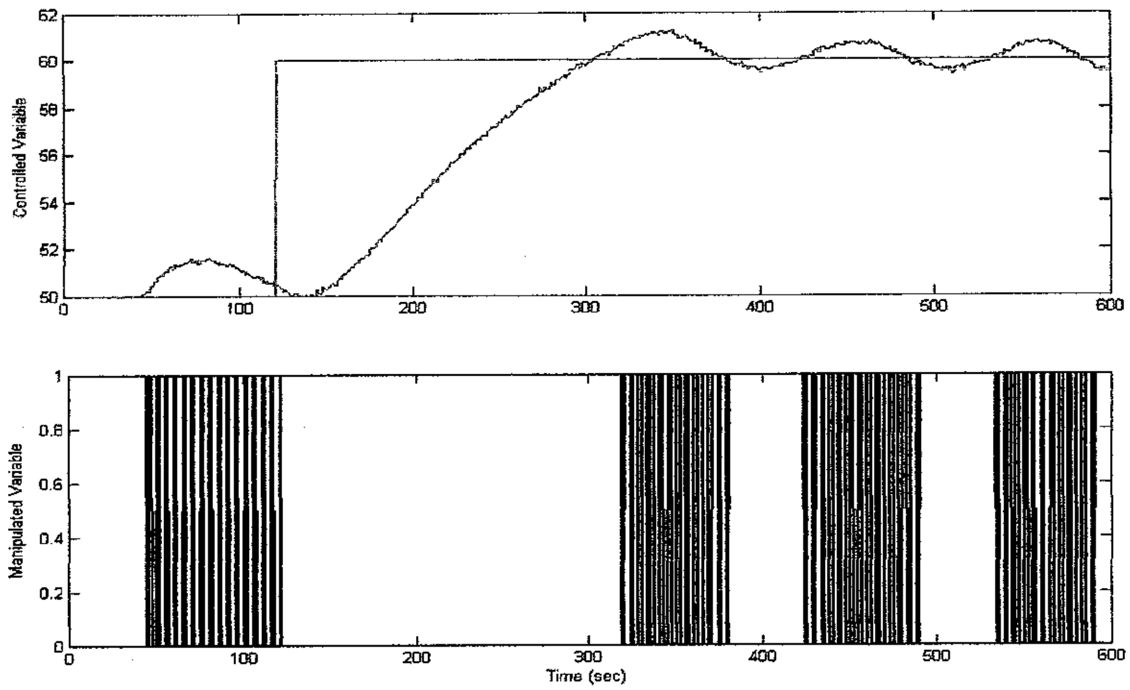


Figure 4.12: The Response using PID Controller of Z-N Closed Loop Method

Table 4.10: Control Performance for PID Controller using Z-N Closed Loop Method

Control Performance	Value
Rise Time	3.03 min
Settling Time	5.68 min
Decay Ratio	0.63
Offset	0.6 °C
Peak to Peak	1.24

By running the experiment online, the real response of ON/OF heating element can be observed. The controlled variable is not maintained at the setpoint because it uses the ON/OFF heating element, hence the above response is acceptable as long as the peak to peak temperature is ±5% of the overall operating range. For this case the value is 5 °C. The settling time is identified at the first time the controlled variable reach ±5% of its final value which is 1 °C from setpoint. The offset is considered to be at the last peak value of the response since the response will not be maintained at the setpoint.

From the Closed Loop Analysis, it shows that both PI and PID controllers are able to control the temperature to the desired value. The PI controller gives a lower rise time compared to the PID controller which is 1.68 min. This value indicates that the controller is performing well even though the temperature always gives the slow response. Both controllers take 5 to 7 minutes to settle at the ±5% of the final value. The maximum peak to peak values of both controllers meet the requirement of ON/OFF heating element condition which is below than 5 °C. In general, the performance of the controller can be improved by fine tuning of the parameters from Closed Loop Analysis.

4.3.3 Fine Tuning

The temperature controller for Gaseous Pilot Plant is fine tuned based on the PI and PID controller parameters obtained in Closed Loop Analysis. The goal of this step is to achieve the best control performance values. The desired control performance value is as below:

Table 4.11: The Required Control Performance

Control Performance	Value
Rise Time	< 1 min
Settling Time	< 5 min
Decay Ratio	< 0.25
Offset	< 0.5 °C
Peak to Peak	< 1

By using the trial and error method, the initial values are varied to the difference value that can work best for Gaseous Pilot Plant. This method need a lot of effort since temperature is a slow response and only 1 parameter is allowed to be change in each experiment. This is to see the effect of varying each parameter on the process. The final values for the temperature controller at Gaseous Pilot Plant are as in Table 4.2:

Table 4.12: Values of PID Controller after Fine Tuning

Parameters	Values
Kp	72
Ti	0.72
Td	0

The temperature response using the PID controller parameters when the step change from 40 °C to 50 °C is given is shown below:

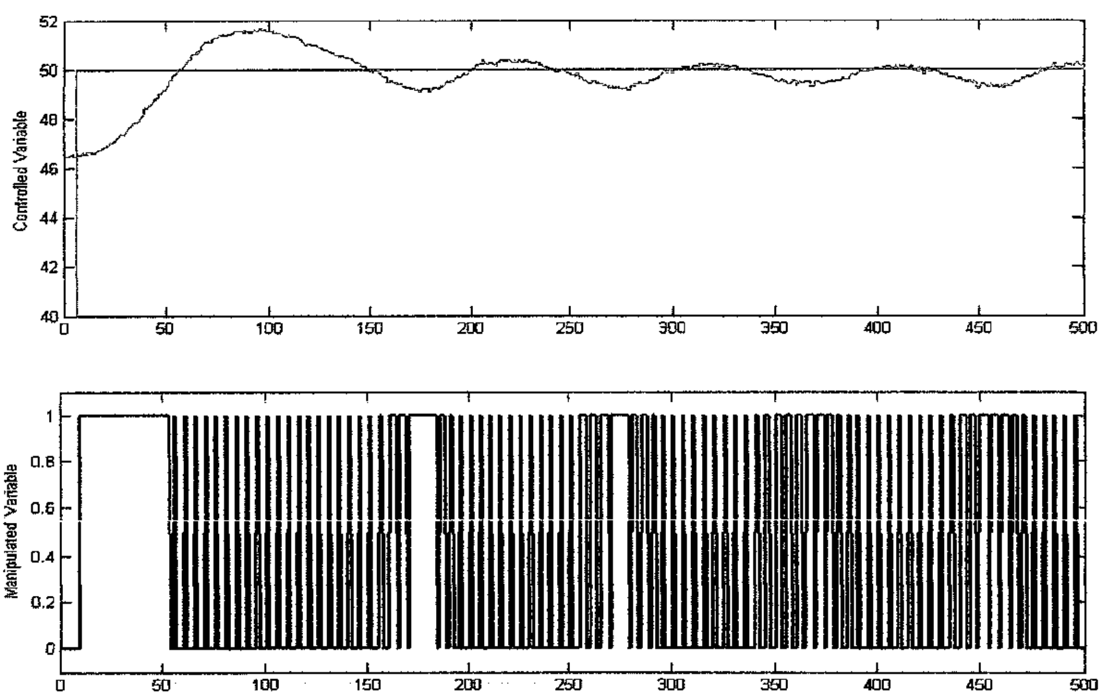


Figure 4.13: The Response after Fine Tuning

Table 4.13: The Control Performance Value after Fine Tuning

Control Performance	Value
Rise Time	0.85 min
Settling Time	4.55 min
Decay Ratio	0.24
Offset	0.48 °C
Peak to Peak	0.61

The response of the controlled and manipulated variable after fine tuning meet the control performance requirement and using PI controller to give the best performance.

4.4 Input and Disturbance Variation

In the real plant, the control system is considering the two sources of external input changes which are the set point changes and disturbance in input variables. In this project, the time functions of these sources are the step, sine changes and ramp input. The combination for each disturbance-function is also considered.

4.4.1 Set Point Change

Set point is the desired value for the operating variable. The set point is changed when the step change is applied. Most of the set point of the process variable remains constant for a very long time especially when it involves the continuous production with same condition. But for the batch operation, the temperature usually needs to be changed during the batch. Below is the step change input that apply to the system:

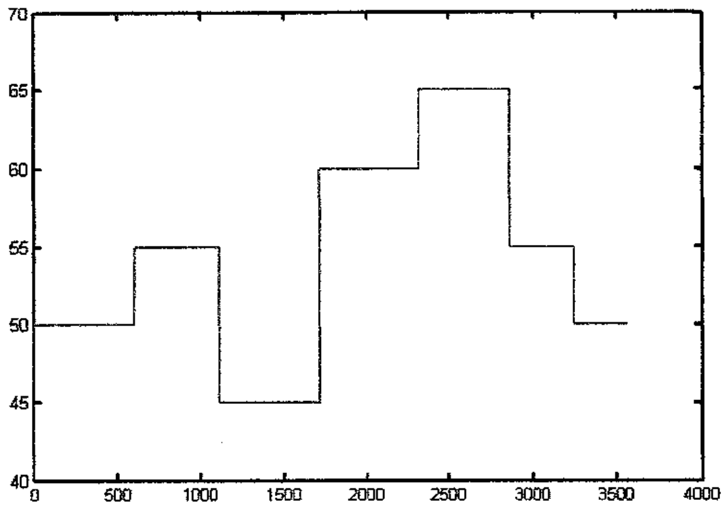


Figure 4.14: Step Change Input for the System

The step change input is increased or decreased between 5 °C to 20 °C from the steady state value. By applying the step change input, the controlled variable should response accordingly to the set point. Below is the response of the controlled variable:

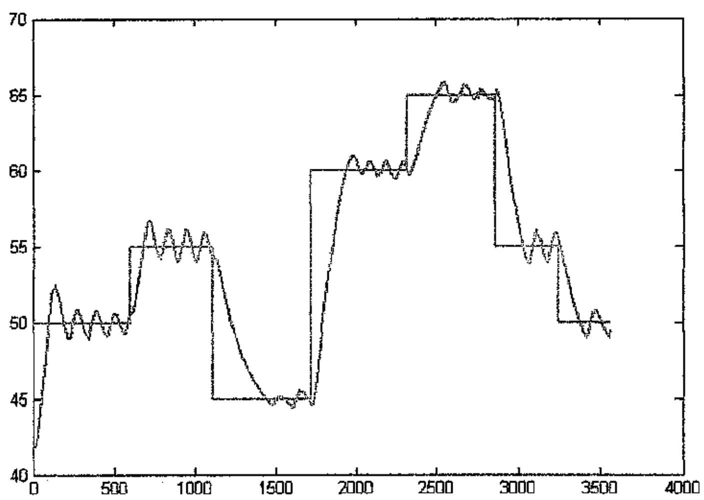


Figure 4.15: The Controlled Variable Response

Based on the result, the controlled variable is responses to each set point. The range of the working condition is 20 °C in the range of 45 °C to 65 °C.

4.4.2 Sine Input

The sine wave is one of the input that can be found in the real industrial plant. The sine wave can come with difference amplitudes and frequencies. It can be generated using the signal generator block. The block is combined with the previous Matlab block diagram at the input connection. The setting is as below:

Waveform: Sine
Amplitude: 20
Frequency: 0.1
Unit: rad/sec
Time: Simulation time, 100sec

Y(t) = amp*waveform(freq, t)

Y(t) = 20*sine(0.1, 100)

The generated sine wave shows below:

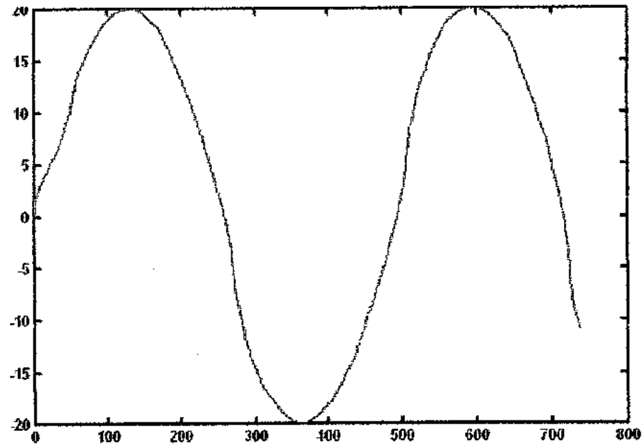


Figure 4.16: Sine Input

By introducing the sine input, the controlled variable will be expected to response to the changes. A good controller will controlled the manipulated variable so that the controlled variable is at the desired values. The temperature response after the sine input is introduced is as below:

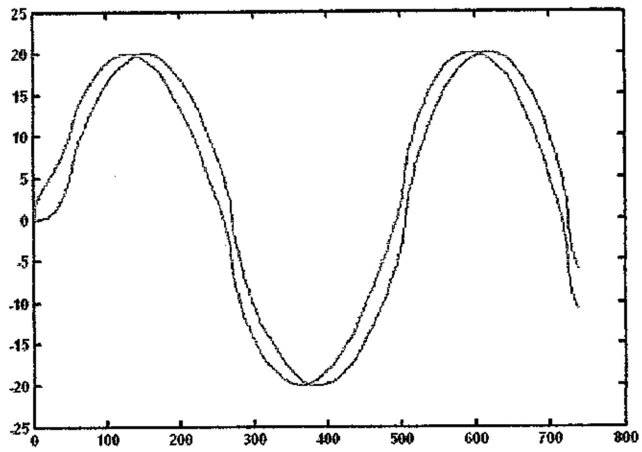


Figure 4.17: Temperature Response with the Sine Input

From the observation, the controller is responding very well. The controlled variable follows the input sine value. But there is a slight difference where there is delay which occurred for 10 seconds.

4.4.3 Ramp Input

Another type of input is the ramp input. The ramp input can be linear with the equation of $y = mx + C$. For this project, the linear input is replaced by the change of 2 °C in every two minutes. The resulting input is shown below:

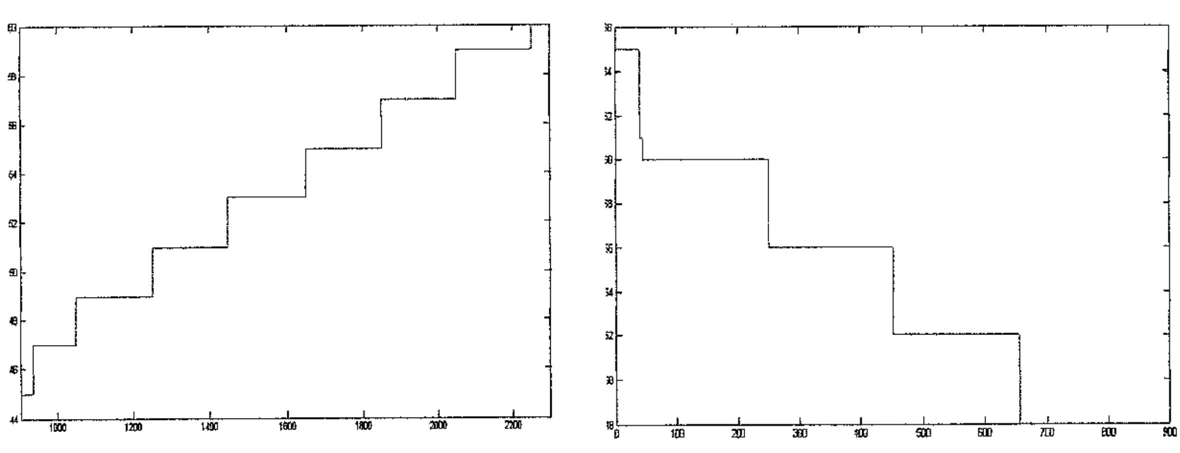


Figure 4.18: Ramp Input

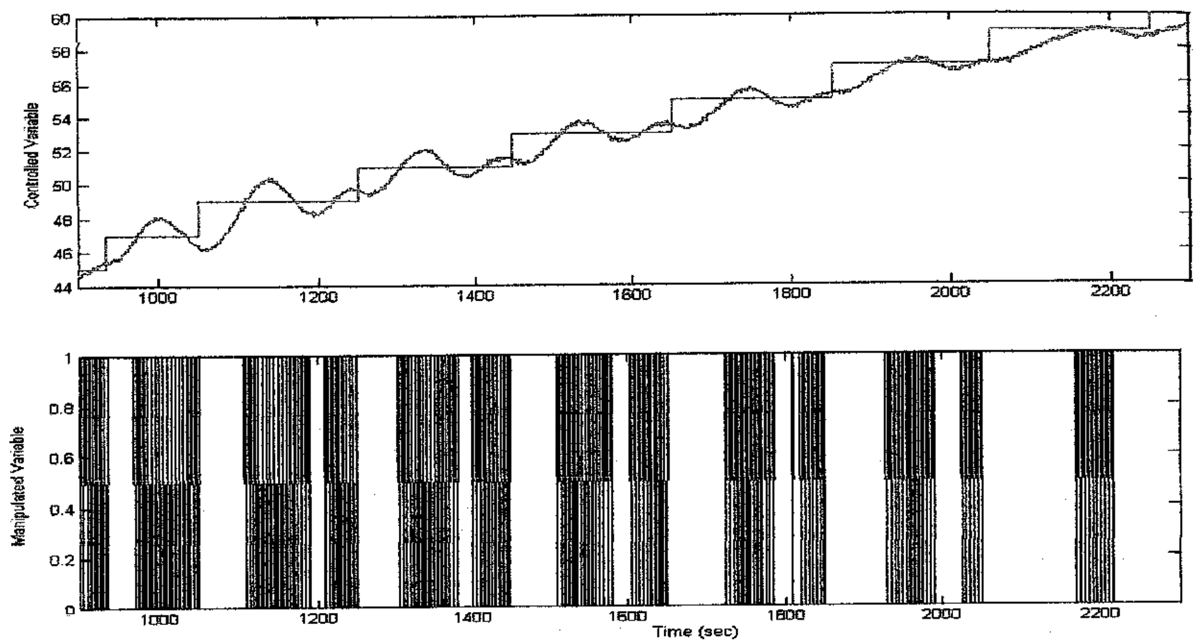


Figure 4.19: Temperature Response with the Increasing Ramp Input

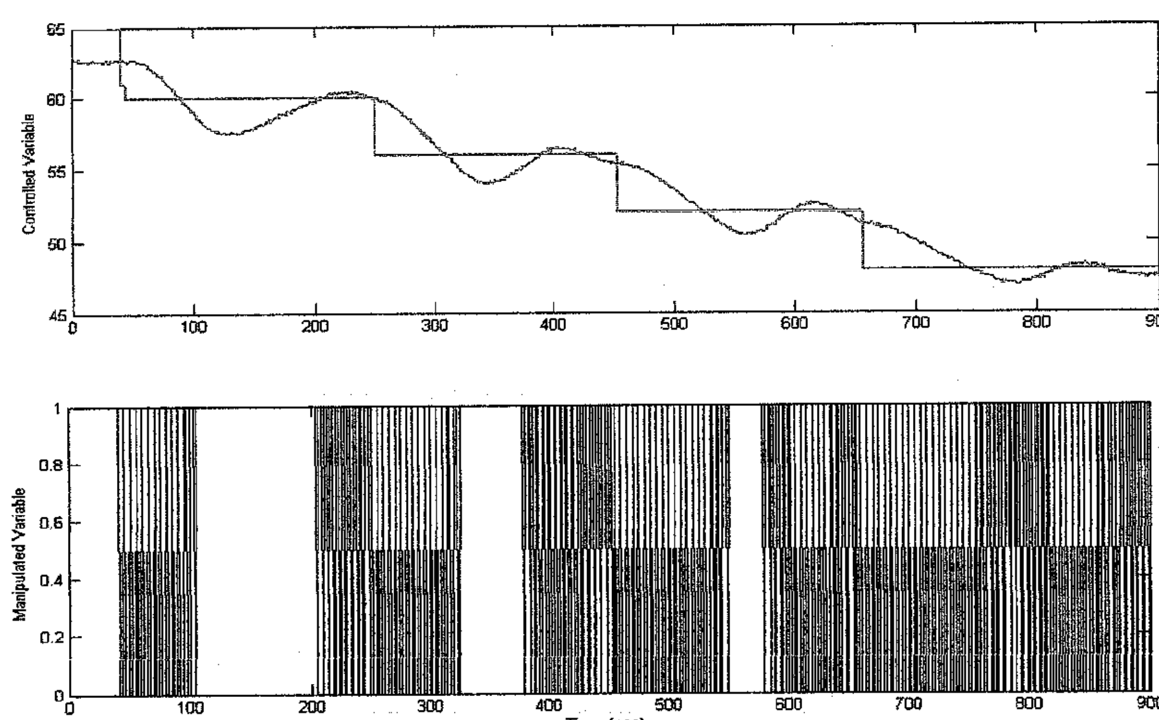


Figure 4.20: Temperature Response with the Decreasing Ramp Input

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

The PID controller is chosen as the controller for the temperature control of the Gaseous Pilot Plant. Basically, it is a very common controller used in industrial control. The PID controller is designed based on the calculation of process model and parameter obtained from the experiment. There are three stages to complete this project. First, the research and literature review stage where useful information was obtained during the stage. The information is very useful because it gives better understanding of the project and for the project execution. The computer simulation is conducted to obtain the PID controller parameters and to understand how the controller will performed. The data from plant experimentation is used for tuning, testing and performance check. The PID controller shows to perform well in controlling the temperature of Gaseous Pilot Plant. The design PID controller characteristics are:

- The PID controller is designed based on analysis of Open Loop and Closed Loop method.
- The PID controller can be used for temperature control at Gaseous Pilot Plant.
- The control variable response to the difference type of input which are step point change, sinusoidal and ramp input
- The online PID controller at Gaseous Pilot Plant can work best for the temperature response within 20 °C range (45 °C to 65 °C)
- The temperature response can be monitored through LabVIEW (Appendix 6) and recorded through Matlab at the Process Laboratory Workstation 2 for one hour continuously.

5.2 Recommendation

There are further problems to be considered both in the development of the model in Matlab/Simulink and the experimental design:

- Analyze the effect of disturbances from the variable at the Gaseous Pilot Plant itself such as flow and pressure of the medium.
- Calculate the PID controller parameters that can work in a wide temperature range.
- Expand the monitoring and recording period for the process.

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[8] http://en.wikipedia.org/wiki/PID_controller

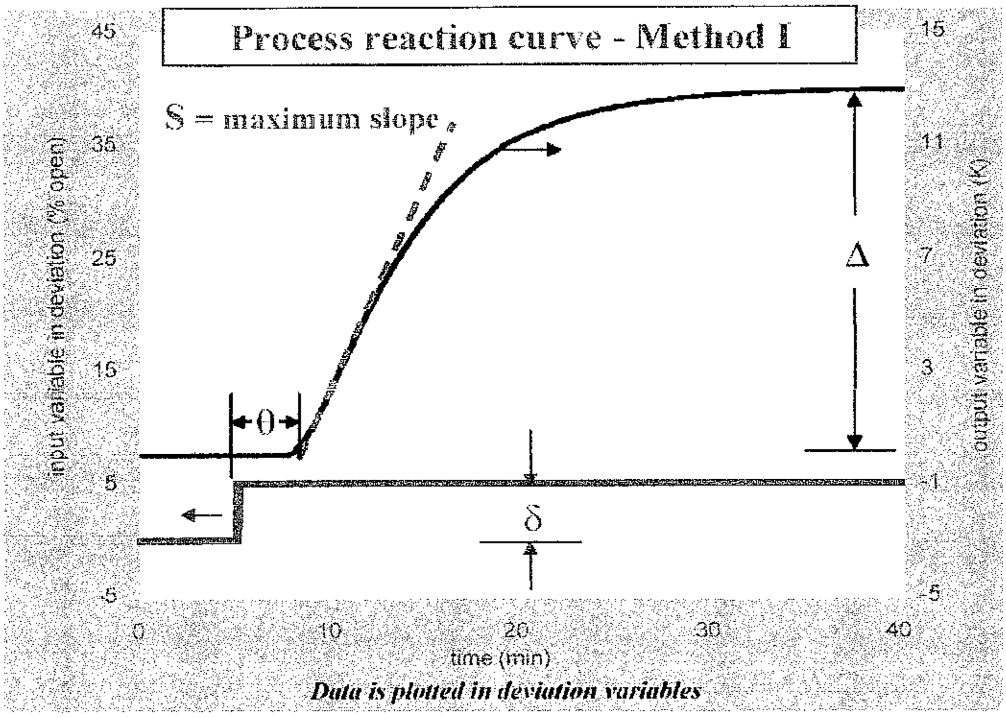
[9] http://en.wikipedia.org/wiki/Temperature

[10] http://en.wikipedia.org/wiki/Control_system

APPENDICES

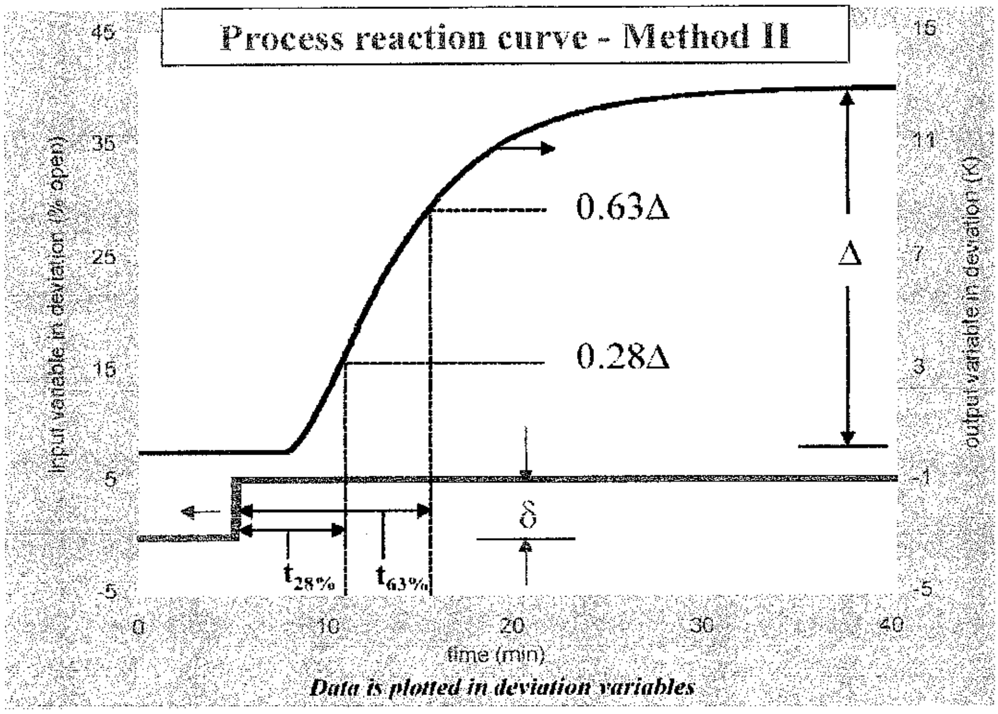
Appendix 1

Empirical Method I



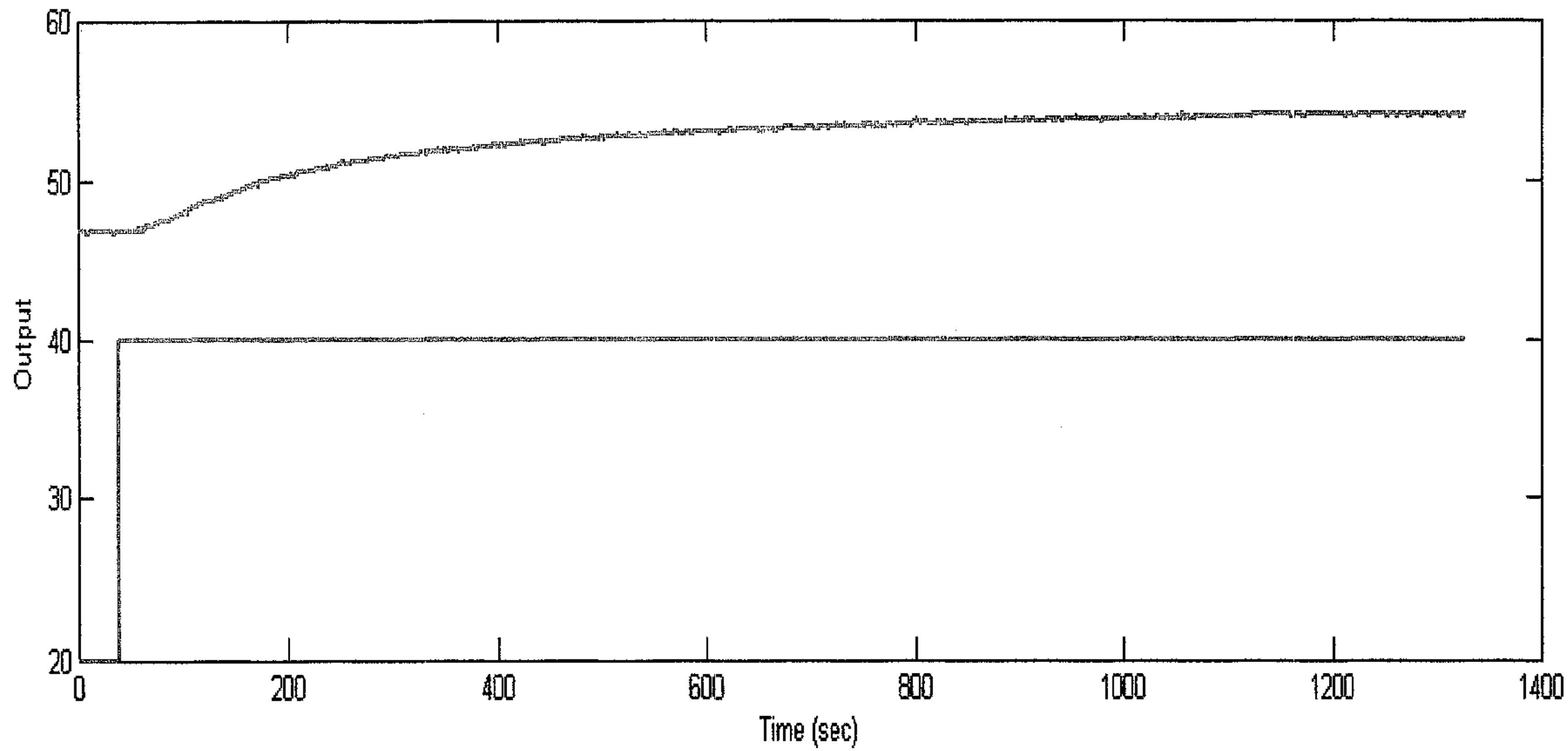
Appendix 2

Empirical Method II



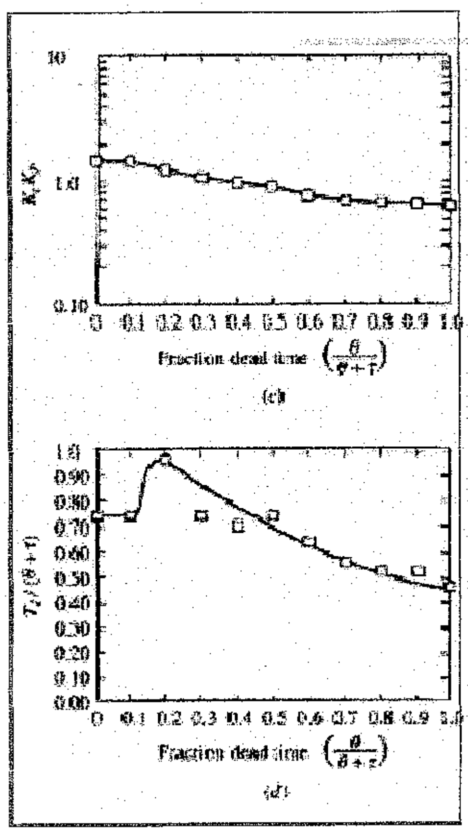
Appendix 3

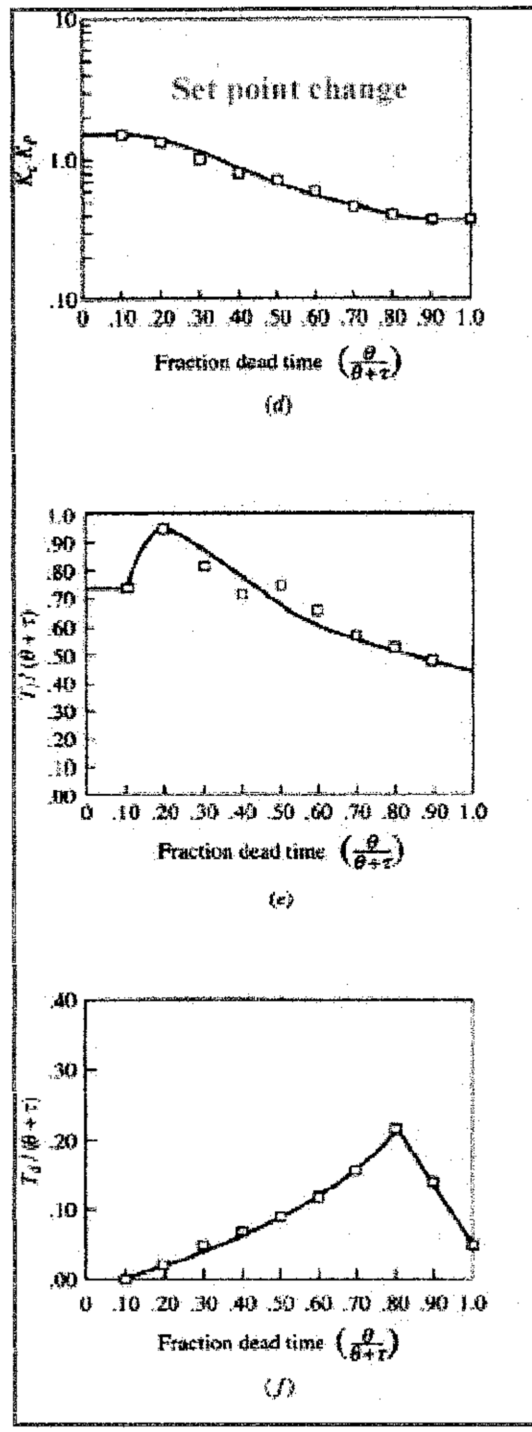
Process Reaction Curve



Appendix 4

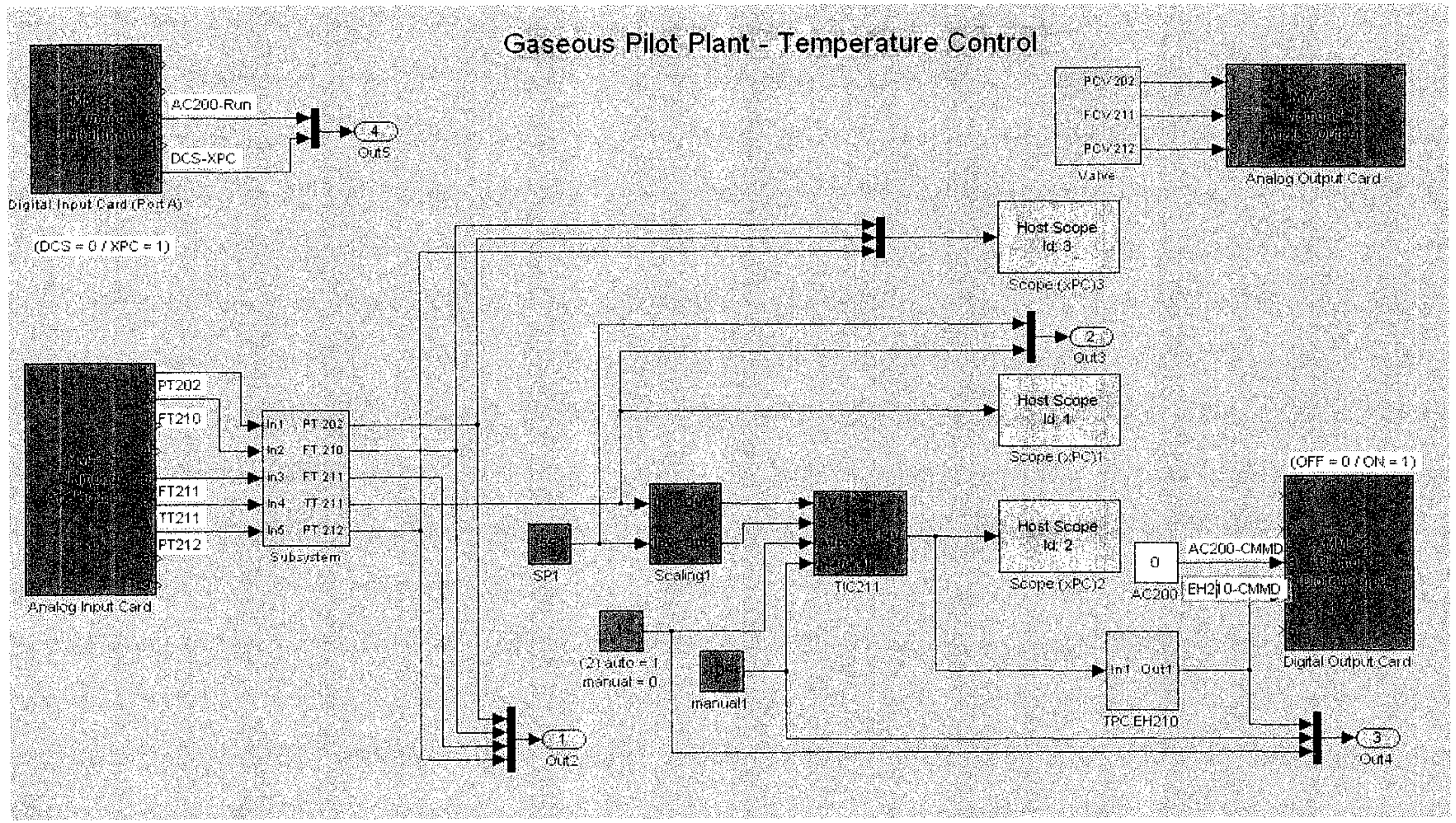
Ciancone Correlation Tuning Mode for PI and PID controller





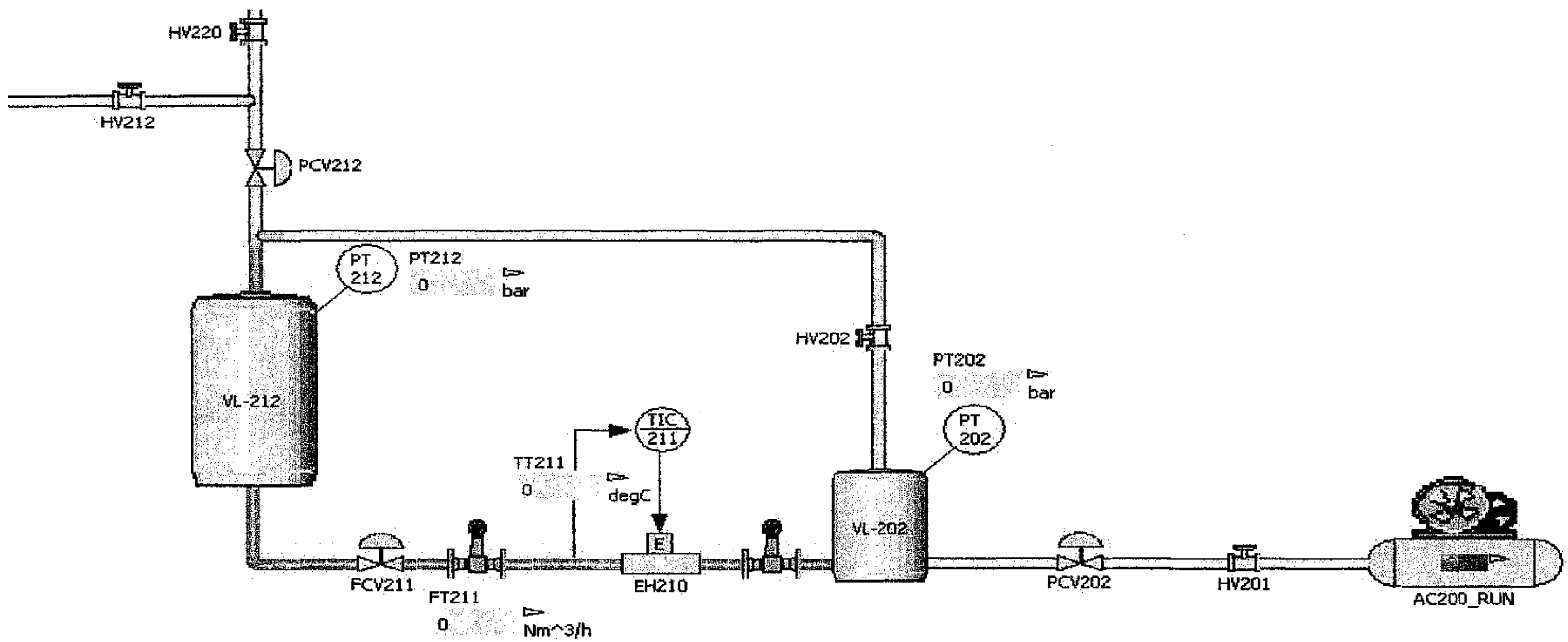
Appendix 5

Matlab/Simulink Block Diagram



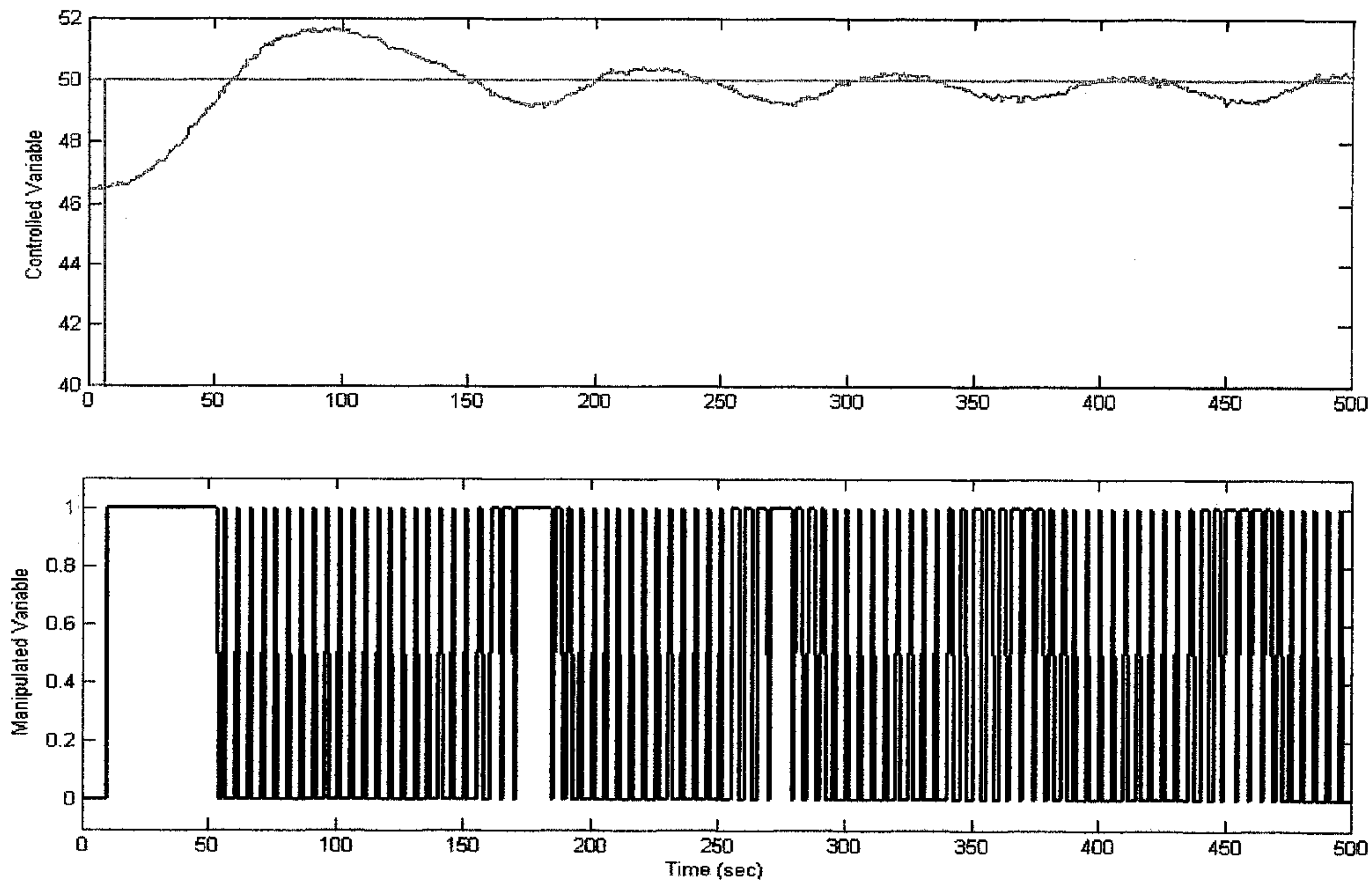
Appendix 6

LabVIEW Block Diagram for Realtime Monitoring



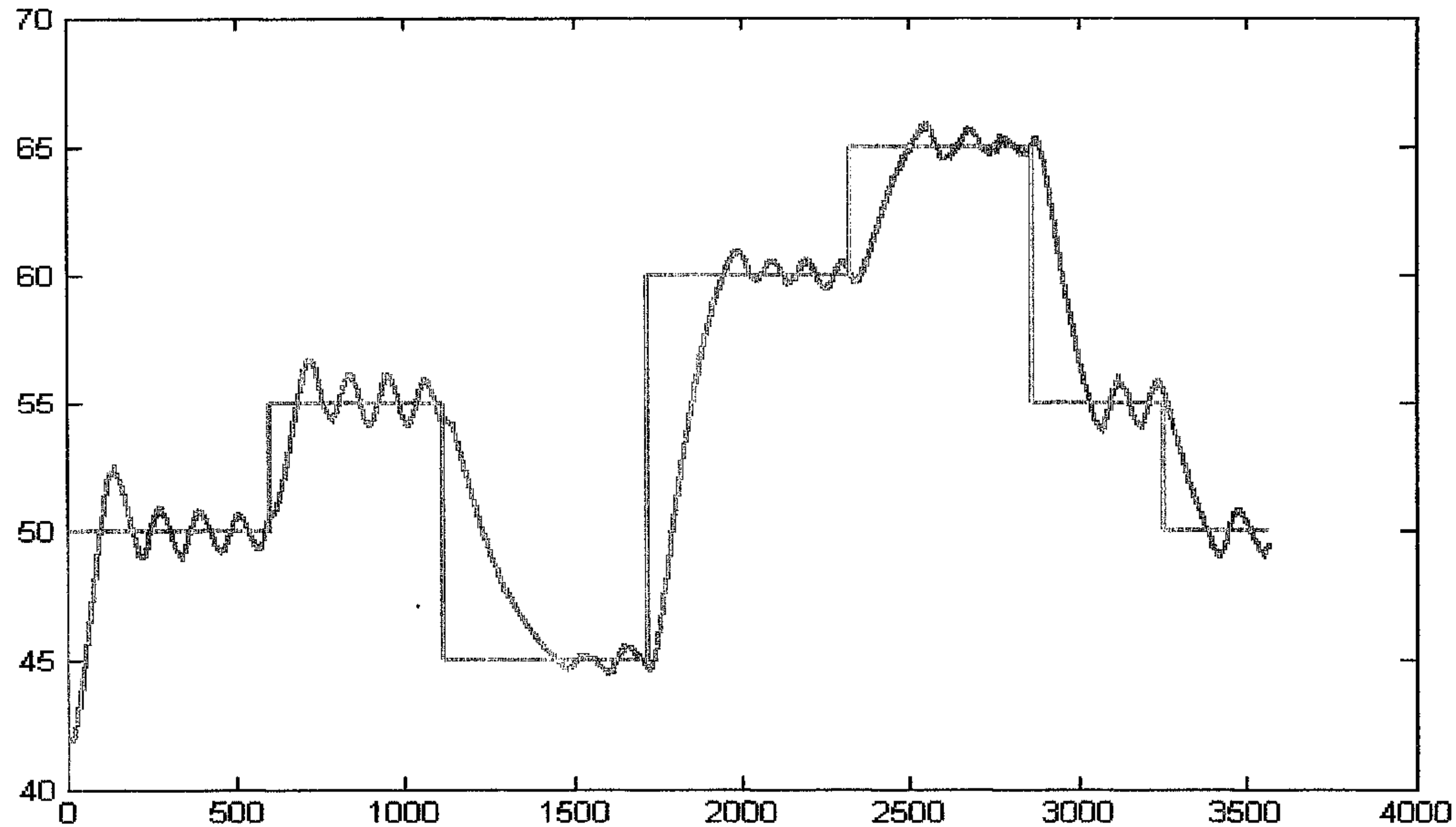
Appendix 7

Response after Fine Tuning



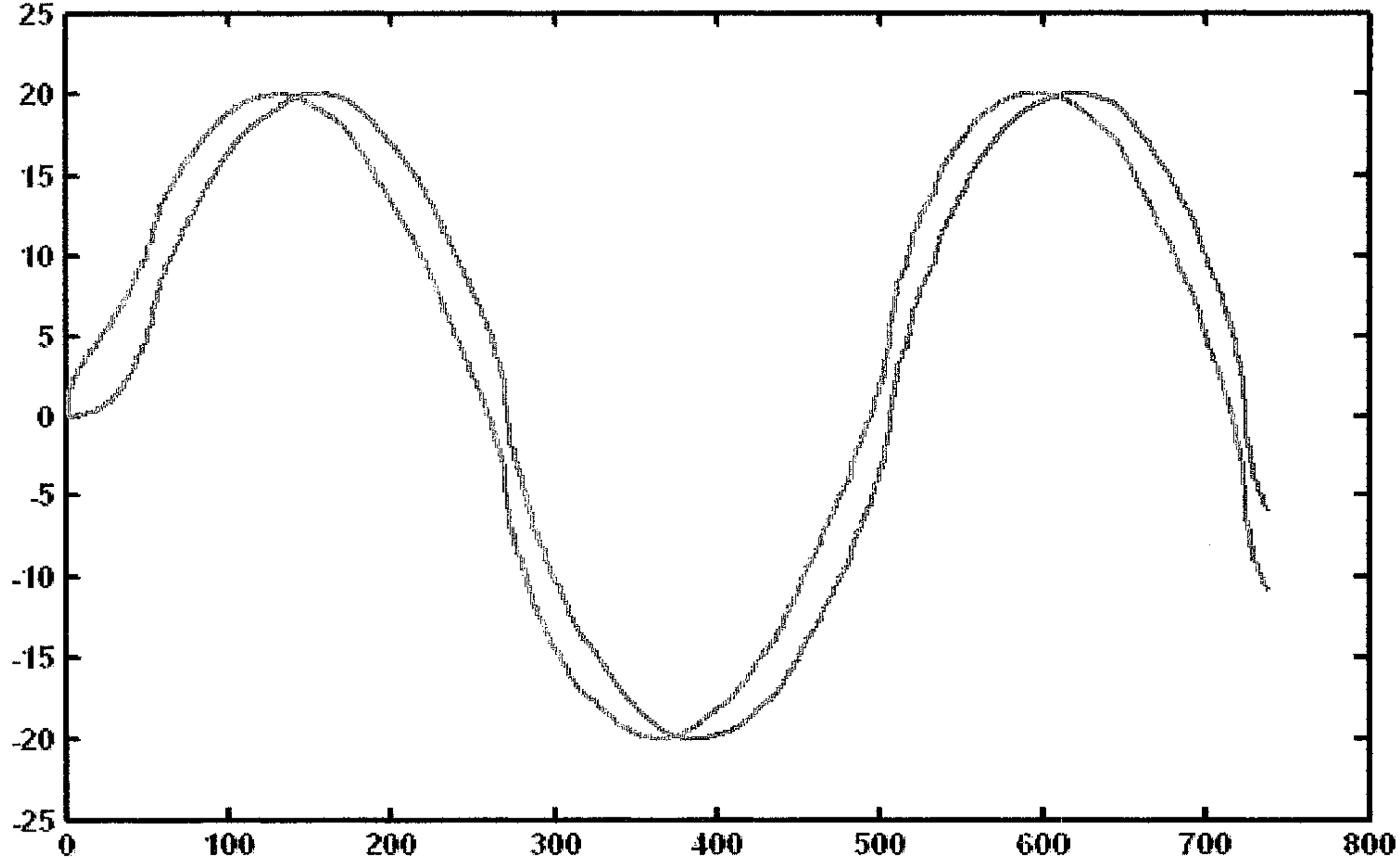
Appendix 8

The PID Controller Temperature Range



Appendix 9

Temperature Response with the Sine Input



Appendix 10

Temperature Response with the Ramp Input