Fuzzy Logic for Heat Exchanger Dynamics

by

Suhaimi Bin Abdul Hamid

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

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Chemical Engineering Programme
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Approved by,

(Mr. Nasser M Ramli)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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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.

SUHAIMI BIN ABDUL HAMID

ABSTRACT

Variations of temperature in heat exchanger are very complex in terms of control and analysis. Therefore, due to its complexity, it's crucial to develop an advanced process control schemes simulation for regulatory control of a heat exchanger's operating temperature. Thus, it's proposed that in this project the development of advanced process control schemes simulation will be based on fuzzy logic concept. Modeling of systems is a very essential concept in developing an effective control system in which will reflect the simulation of the physical processes. Fuzzy logic concept is a very distinct idea in developing models of physical processes as the fuzzy models themselves are less complex, easy to understand and easy to be executed. Furthermore, fuzzy models also are very suitable to be deployed for non-linear processes for which models with fewer rules are more advantageous. The process chosen for this project is about the heat exchanger dynamics problem, specifically regarding the variation of cold and hot temperature in heat exchanger. The fuzzy model was developed by using the Fuzzy Toolbox provided by MATLAB 7.1. The Fuzzy Logic Control is one of the alternatives that can be employed to overcome this as it has the ability to cover wider range of processes because it uses human-like techniques to define the process. Based on this project, the Fuzzy Logic Control should be considered as a new solution approach in the process control field and it also can be applied in the larger scale in the industry.

ACKNOWLEDGEMENT

First and foremost, I am very grateful to Allah s.w.t. because I have been given the ability to finish my task on time. I also would like to express my gratitude to my Final Year Project (ECB 5034) supervisor, Mr. Nasser M Ramli for his guidance and mentoring in this course of completing the report on Fuzzy Logic for Thermal Dynamics.

Special thanks to the Universiti Teknologi PETRONAS Resource Center staffs and also the Computer Lab Technicians who had helped me in locating the much needed reading materials and also provides assistance in the computer laboratory during the development of this project.

Finally, I would like to express my thanks and appreciation to everyone who has given a helping hand and wish to remain anonymous.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

The process chosen for this project is about the Heat Exchanger dynamics problem, specifically regarding the variation of temperature, between hot and cold temperature. Heat Exchanger dynamics problem is very complex and tedious in terms of control and also analysis. Thus, by developing fuzzy model, it can provide the alternative solution towards analyzing and control of Heat Exchanger dynamics problem. The fuzzy model was developed by using the Fuzzy Toolbox provided by MATLAB 7.1.

1.2 PROBLEM STATEMENT

Varying temperature in the reactor when the reaction process is undergo could make problem to the reaction yield, thus fail the process. Therefore, it is important to have a better control strategy such that the variation of temperature can be minimized and controlled. Nowadays, many of controllers are designed and used for the process. Thus, this project are mainly about to find most suitable controller for heat exchanger, and proved Fuzzy Logic is best controller among others.

1.3 OBJECTIVE AND SCOPE OF STUDY

1.3.1 Objective

- To model advanced regulatory control scheme to control the operating temperature of a reactor using SIMULINK in MATLAB
- To get the suitable tuning formula for PI and PID controllers that best fits with each advanced control scheme and provide the desired response of temperature versus time
- To design a Fuzzy Logic Control (FLC) as an alternative approach in process control of a reactor's operation
- To assist in a process optimization

1.3.2 Scope of study

The scope of study for modeling an Advanced Regulatory of a Heat Exchanger project covers:

- Model an advanced control schemes which are as Feedback Feed Forward control, Cascade Control, Feed Forward Control, Adaptive Control and Inferential Control, Fuzzy Logic Control using SIMULINK in MATLAB.
- Selection for best tuning formulas for PI and PID controllers that best fits with each advanced control scheme and give desired result for temperature control
- Designing the Fuzzy Logic Control with its specific controller as an alternative approach to control the heat exchanger's operating temperature.
- Proving Fuzzy Logic Control is more advantageous compared to other controller.

CHAPTER 2

LITERATURE REVIEW

2.1 HEAT EXCHANGER

A heat exchanger is a device built for efficient heat transfer from one medium to another, whether the media are separated by a solid wall so that they never mix, or the media are in direct contact. They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, and natural gas processing. One common example of a heat exchanger is the radiator in a car, in which a hot engine-cooling fluid, like antifreeze, transfers heat to air flowing through the radiator.

2.2 CONTROL STRATEGY: CLOSE LOOP CONCEPT

Any systems that utilize feedback are called closed-loop control systems. The feedback is used to make decisions about changes to the control signal that drives the process. By contrast, an open-loop control system doesn't have or doesn't use feedback.

A closed-loop control system is one in which an input forcing function is determined in part by the system response. The measured response of a physical system is compared with a desired response. The difference between these two responses initiates actions that will result in the actual response of the system to approach the desired response. This in turn drives the difference signal toward zero. Typically the difference signal is processed by another physical system, which is called a compensator, controller, or filter for real-time control system applications. A basic closed-loop control system can be represented by the general block diagram shown in the Figure 1.

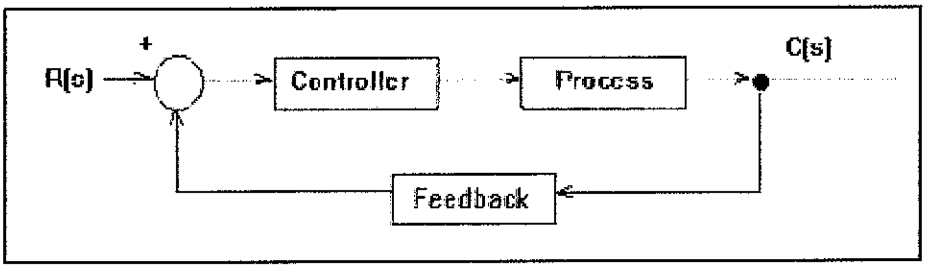


Figure 1: The concept of the feedback loop to control the dynamic behavior of the output of the process.

In this configuration a feedback component is applied together with the input R. The difference between the input and feedback signals is applied to the controller. In responding to this difference, the controller acts on the process forcing C to change in the direction that will reduce the difference between the input signal and the feedback component. This, in turn, will reduce the input to the process and result in a smaller change in C. This chain of events continues until a time is reached when C approximately equals R.

A closed-loop system is able to regulate itself in the presence of disturbance or variations in its own characteristics. In this aspect, a closed-loop system has a distinct advantage over an open-loop system.

2.3 ADVANCED PROCESS CONTROL

Several of control strategies are involved in this project, such as adaptive, cascade, feedback, feed forward, feedback-feedforward, inferential and smith.

2.3.1 Feed Forward Control

Since control action can only occur if a deviation occurs between the set point and the measured variable, perfect control is not possible. Therefore, feedback control fails to provide predictive control action to compensate for the effects of known disturbances. Feed forward control was developed to counter some of these limitations. Its basic premise is to measure the important disturbance variables and then take corrective compensatory action based on a process model. The basic concept is to measure important disturbance variables and take corrective action before they upset the processes. Feed forward control theoretically can become a perfect control and it will not affect the stability of the system.

2.3.2 Cascade Control

Cascade control is also widely used in the chemical process industries and especially in cases where there may be nonlinear behavior in the dynamics of the control loop. It also addresses the main drawback of conventional feedback control namely the fact that control action only occurs where the controlled variable deviates from the set point. Cascade control implementation is a familiar task because the architecture is comprised of two ordinary controllers from the PID family. Cascade is specifically designed for improved disturbance rejection. In a traditional feedback loop, a controller adjusts a manipulated variable so the measured process variable remains at set point. The cascade design requires that you identify a secondary process variable (call the main process variable associated with original control objective the primary variable). This secondary process variable must meet certain criteria

- It must be measurable with a sensor,
- The same valve used to manipulate the primary variable must also manipulate the secondary variable,
- The same disturbances that disrupt the primary variable must also disrupt the secondary variable,
- The secondary variable must be inside the primary process variable, which means it responds well before the primary variable to disturbances and final control element manipulations.

A cascade requires two sensors and two controllers but only one final control element because the output of the primary controller, rather than going to a valve, becomes the set point of the secondary controller. With this nested architecture, success in a cascade implementation requires that the settling time of the(inner) secondary loop is significantly faster than the settling time of the primary (outer) loop.

2.3.3 Feedback Feed Forward Control

Feedback and feed forward controllers can be combined in several different ways. In a typical control configuration, outputs of feed forward and feed back controllers are added together and the sum is the signal that is sent to the final control element.

An alternative configuration for Feedback Feed Forward control action is its control loop to have the feedback controller output serves as the set point for the feed forward controller. It is convenient especially when the Feed Forward control law is designed using steady state material and energy balances. Furthermore, the powerful combination of Feed Forward and feedback control utilize the best of both approaches since Feed Forward control works by reducing the effects of measured disturbances and feedback control provides the necessary compensation for the effects of model and measurement inaccuracies as well as unmeasured disturbances

2.3.4 Adaptive Control

An adaptive control is one in which the controller parameters are adjusted automatically to compensate for changing process conditions. Examples of changing process conditions that may require controller retuning are:

- changes in equipment characteristics – heat exchanger fouling, catalyst deactivation
- Unusual operational status – start up, shutdown, failures
- Inherent nonlinear behavior
- Changes in product specifications or product flow rates

When the process changes can be anticipated or measured directly, and the process is reasonably well understood, the gain scheduling approach (programmed adaptation) can be employed. The adaptive controller is also known as self tuning controller where the parameters in the process model are updated as new data are acquired (using on line estimation methods), and the control calculations are based on updated model. Three set computations are employed in adaptive controls which are estimation of the model parameters, calculation of the controller settings and implementation of the controller output in a feedback loop.

2.3.5 Inferential

Inferential control is employed where process measurements that can be obtained more rapidly are used with mathematical model sometimes called of a soft sensor to infer the value of the controlled variable. This control scheme is used at the situation where the measurements of controlled variable may no be available frequently enough or quickly enough to be used for feedback control. The concept of inferential control can be employed for operation such as in chemical reactors where composition is normally the controlled variable. Selected temperature measurements can be used to estimate the outlet composition if in can not be measured on line.

2.3.6 Fuzzy Logic Control

Fuzzy logic is derived from fuzzy set theory dealing with reasoning that is approximate rather than precisely deduced from classical predicate logic. It can be thought of as the application side of fuzzy set theory dealing with well thought out real world expert values for a complex problem. Degrees of truth are often confused with probabilities. However, they are conceptually distinct; fuzzy truth represents membership in vaguely defined sets, not likelihood of some event or condition. This activity is aimed to investigate the application of the fuzzy logic paradigm for the control of dynamic system. Fuzzy logic in control has been successful used to capture heuristic control laws obtained from human experience or engineering practice in automated algorithm. These control laws are defined by means of linguistic rule, for example "if the pressure is high, then decrease the pump power". The heuristic approach in the controller design can be appealing for its simplicity, but formal design method can be mandatory in some cases. There are two fuzzy methods which are Surgeno and Mamdani. Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. Mamdani-type inference, as we have defined it for the Fuzzy Logic Toolbox, expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It is possible, and in many cases much more efficient, to use a single spike as the output membership functions rather than a distributed fuzzy set. This is sometimes known as a singleton output membership function, and it can be thought of as a pre-defuzzified fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required by the more general Mamdani method, which finds the centroid of a two-dimensional function. Rather than integrating across the two-dimensional function to find the centroid, we use the weighted average of a few data points.

CHAPTER 3

METHODOLOGY

3.1 Flow of Methodology

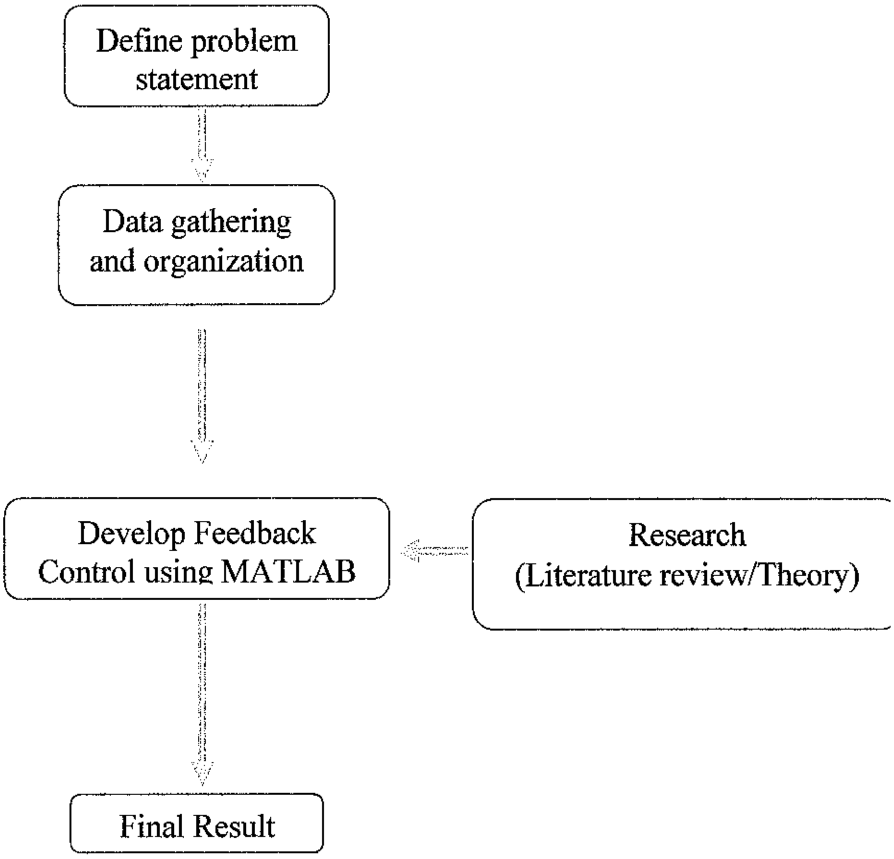


Figure 2: Flow Chart of FYP Methodology

CHAPTER 4

RESULT AND DISCUSSION

4.1 DATA GATHERED

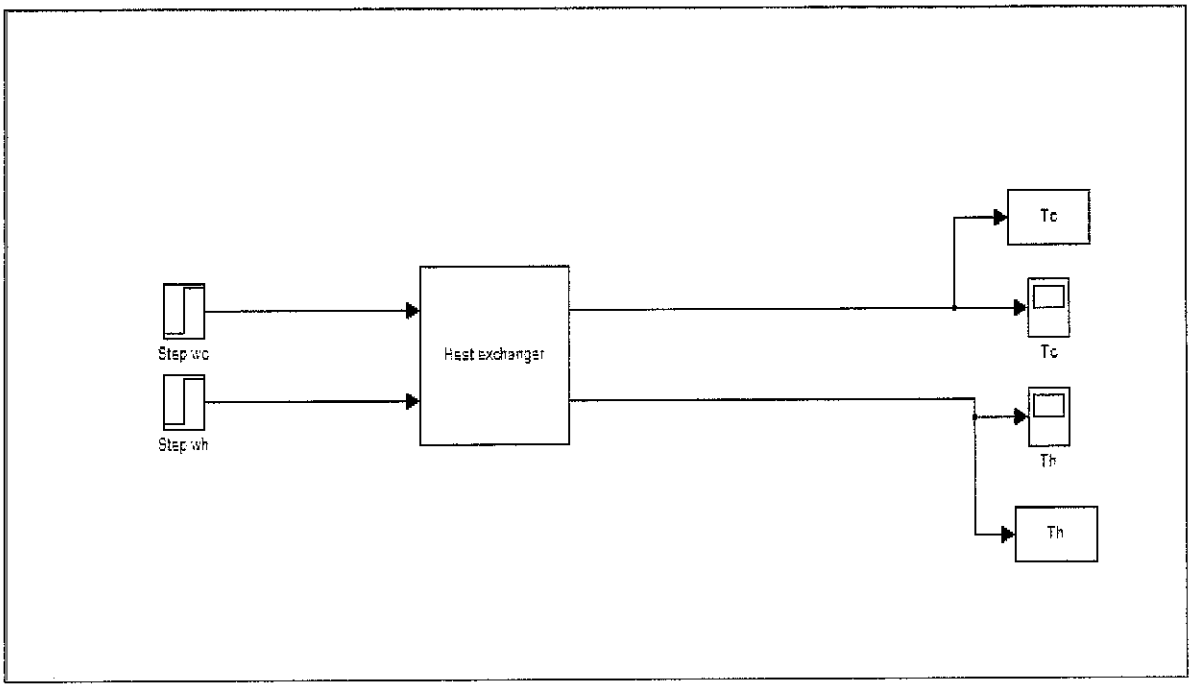


Figure 3: Process Model of Heat Exchanger Dynamics

From the process model of Heat Exchanger Dynamics, several equation and relation are designed.

For cold temperature;

$UA / Wc.Cpc\ (T2 - T1) = dT1 / dT$

For hot temperature;

$UA / Wh.Cpc\ (T2 - T1) = dT2 / dT$

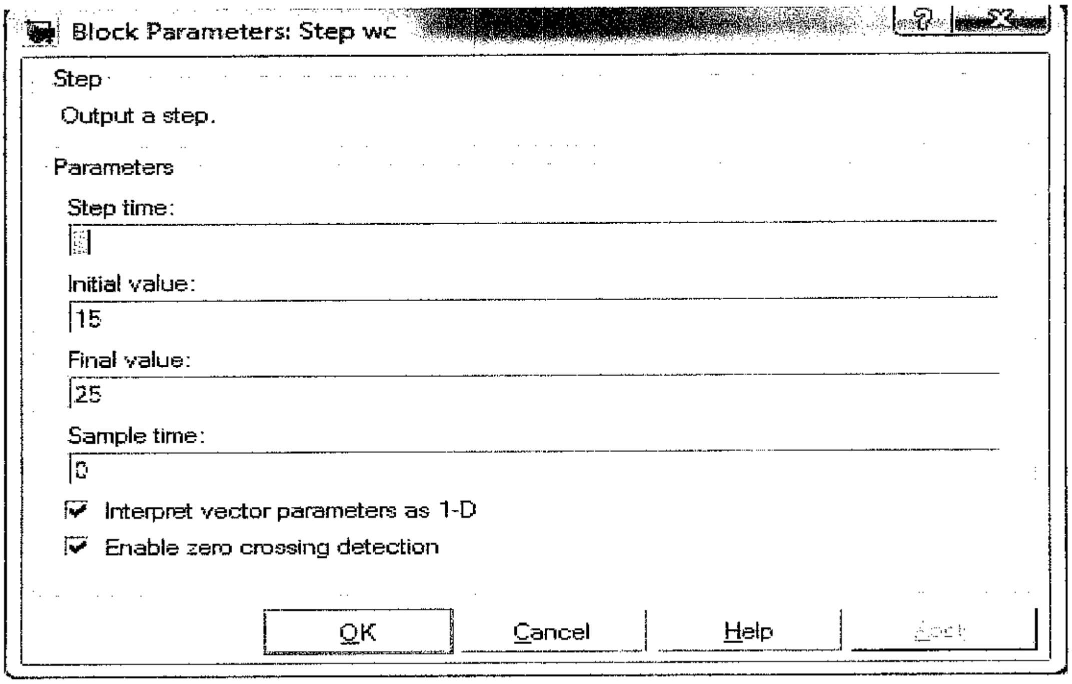
Where;

$Wc = \Delta MV = 10$ $\qquad$ $Wh = \Delta MV = 10$

$K = \Delta PV / (\Delta time / \Delta MV)$

$G(s) = K.\ \square / (5s + 1)$ $\qquad$ K = process gain

$\square$ = time delay



Step

Output a step.

Parameters

Step time: [illegible]

Initial value: 15

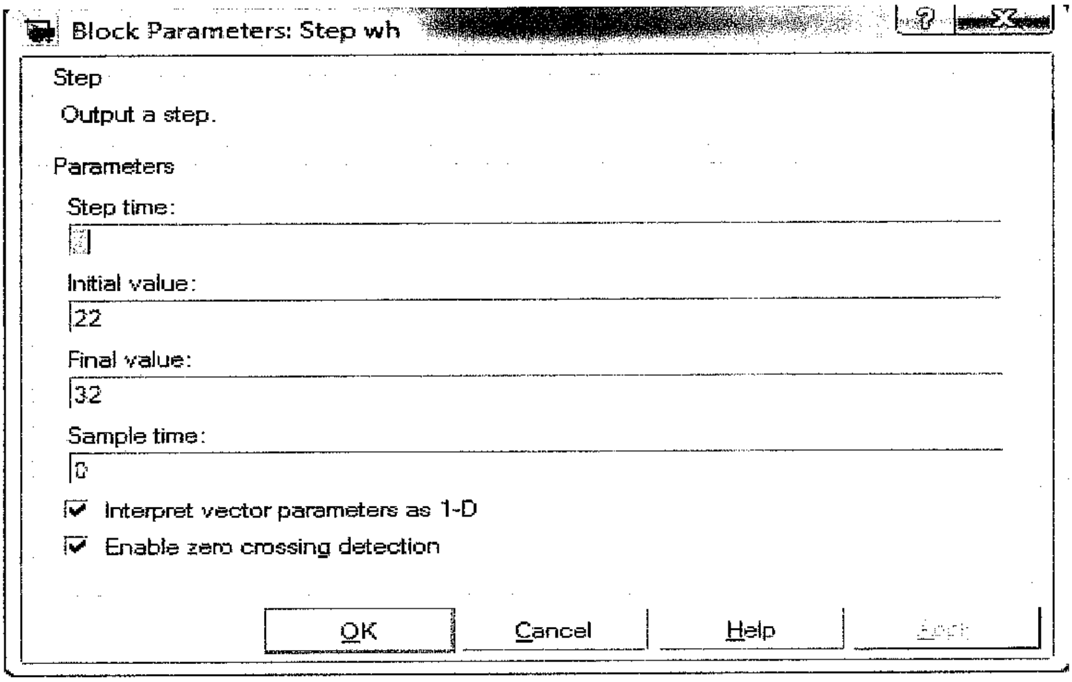
Final value: 25

Sample time: 0

☑ Interpret vector parameters as 1-D

☑ Enable zero crossing detection

Figure 4: Parameters for Cold Temperature



Step

Output a step.

Parameters

Step time: [illegible]

Initial value: 22

Final value: 32

Sample time: 0

☑ Interpret vector parameters as 1-D

☑ Enable zero crossing detection

Figure 5: Parameters for Hot Temperature

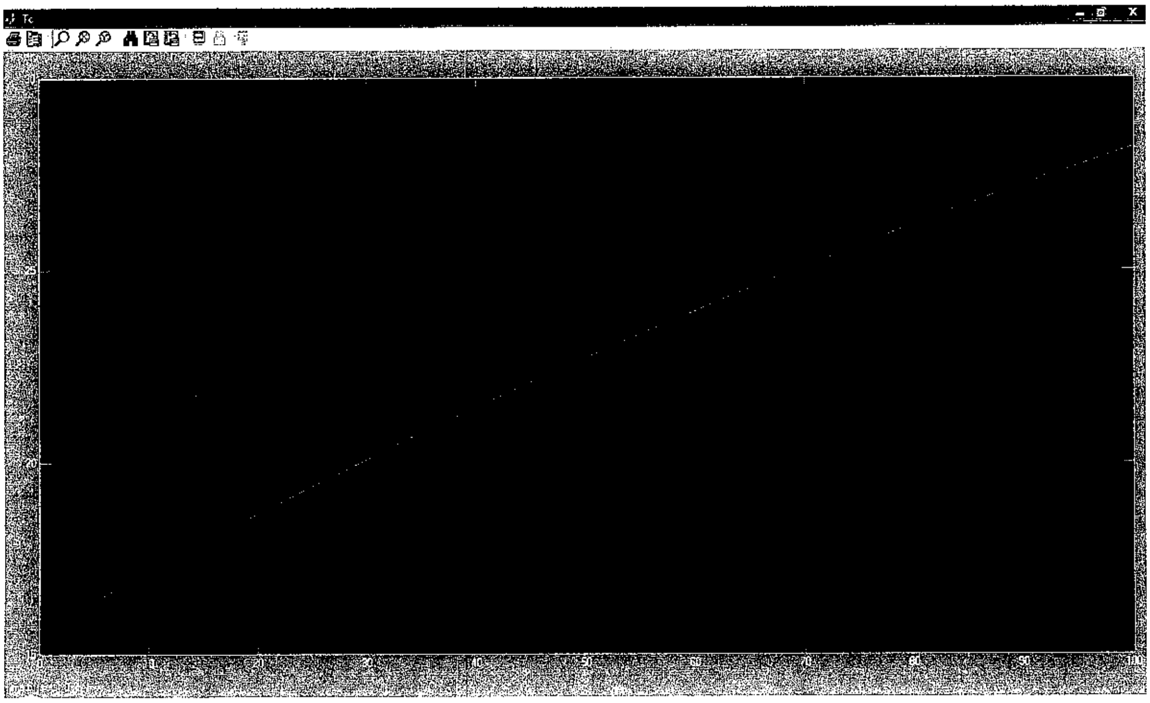


Figure 6: Graph for Cold Temperature

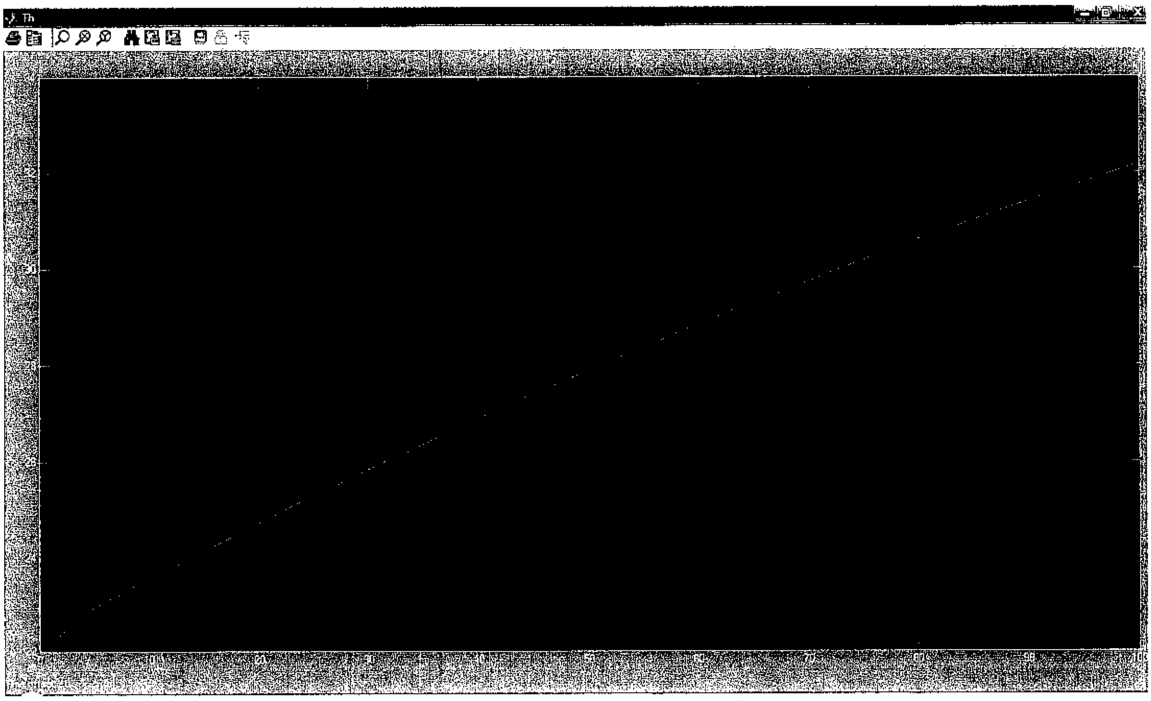


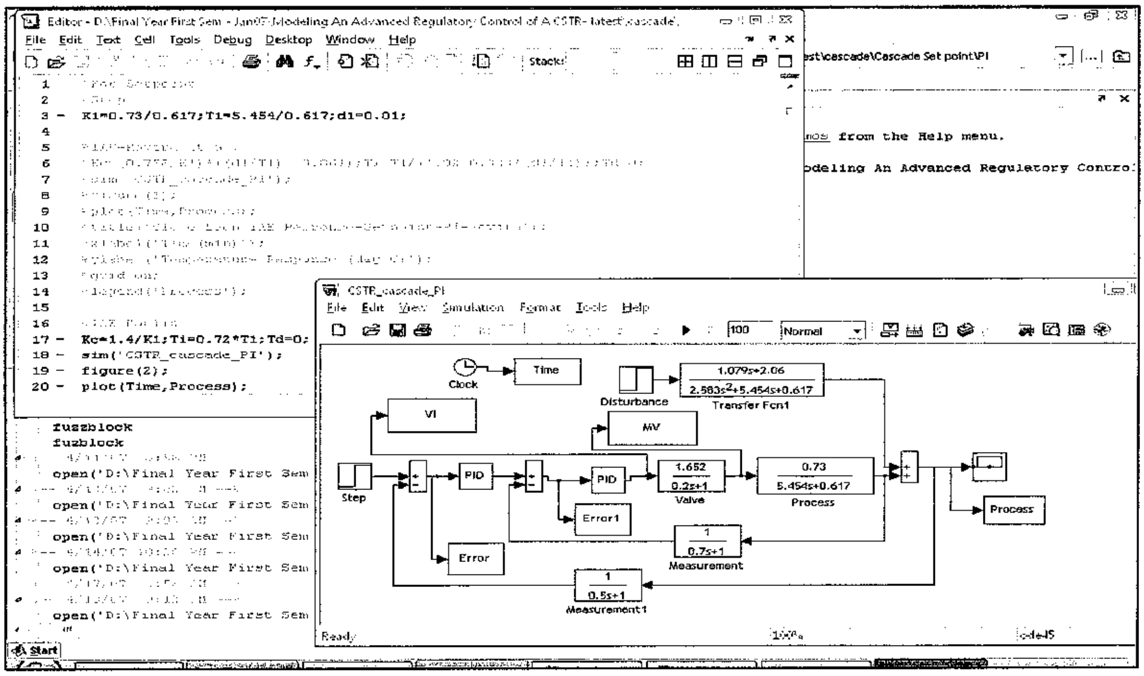
Figure 7: Graph for Hot Temperature

4.2 CONTROLLER TUNING

From process model and data gathered, the process control schemes are constructed in the SIMULINK by arranging and link the different types of blocks.
The process control schemes that involved in this project are:

i. Adaptive
ii. Cascade
iii. Feedback
iv. Feedforward
v. Feedback-Feedforward
vi. Inferential
vii. Smith

Each control scheme in SIMULINK is evaluated by using PI and PID controllers and the temperature response versus time then is analyzed. The purpose of controller tuning is to determine the tuning formula for that best suit with controllers in every control scheme. The tuning process is done by using the SIMULINK and M-File.



```
K1=0.73/0.617;T1=5.454/0.617;d1=0.01;

Kc=1.4/K1;Ti=0.72*T1;Td=0;
sim('CSTR_cascade_PI');
figure(2);
plot(Time,Process);
```

```
fuzzblock
fuzblock
open('D:\Final Year First Sem
open('D:\Final Year First Sem
open('D:\Final Year First Sem
open('D:\Final Year First Sem
open('D:\Final Year First Sem
```

Figure 8 : The relationship between M-File and SIMULINK

4.3 DATA ANALYSIS

There are a number of tuning formulas for controllers in each control scheme for each control problem that have been evaluated using SIMULINK and M-File. After the analyzing process, only one tuning formula in each control scheme that give best control performance of heat exchanger's operating temperature is chosen.

These are the list of the graph on temperature response versus time for selected tuning formulas:

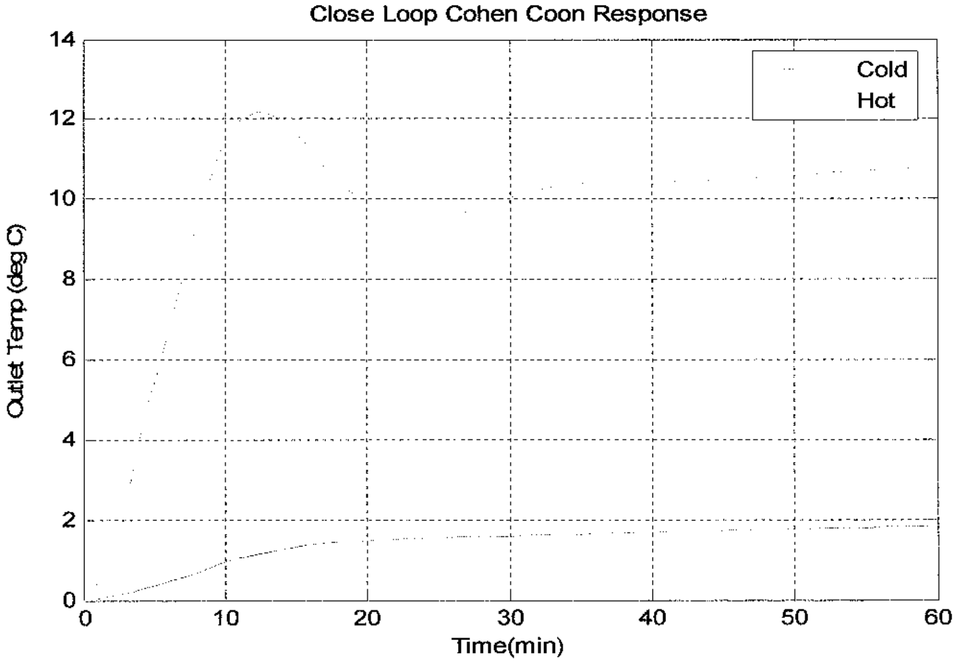


Figure 9: Graph on temperature response for Adaptive Control Set Point Change

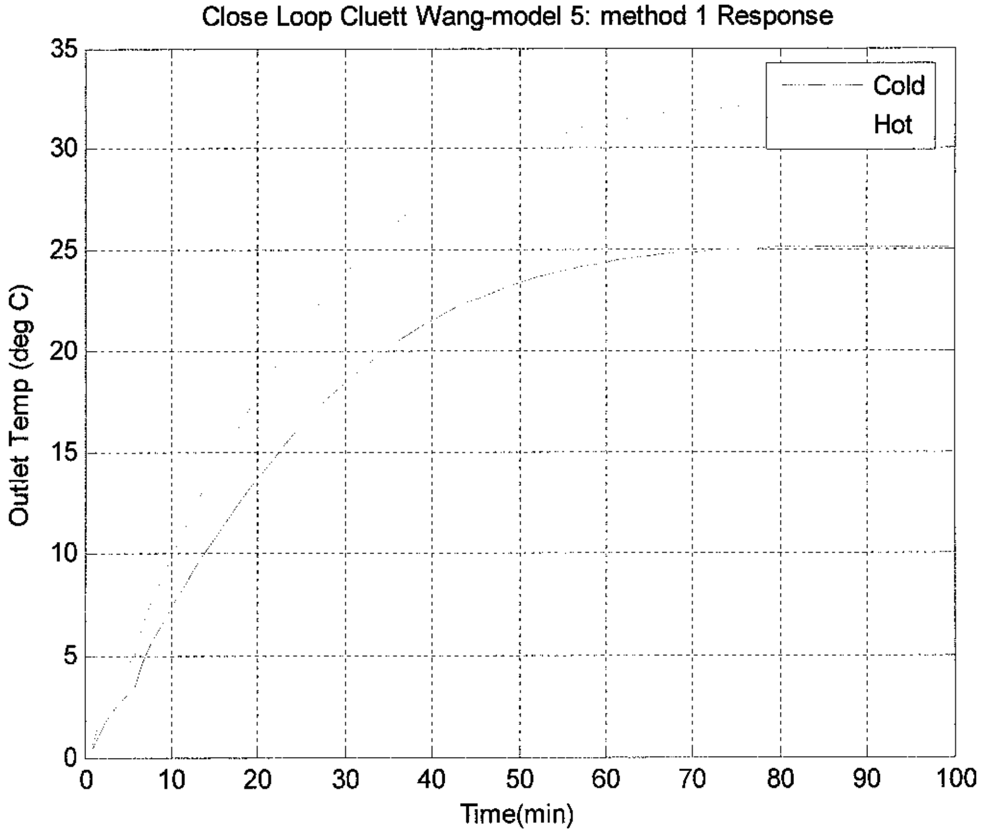


Figure 10: Graph on temperature response for Cascade Control for Set Point Change

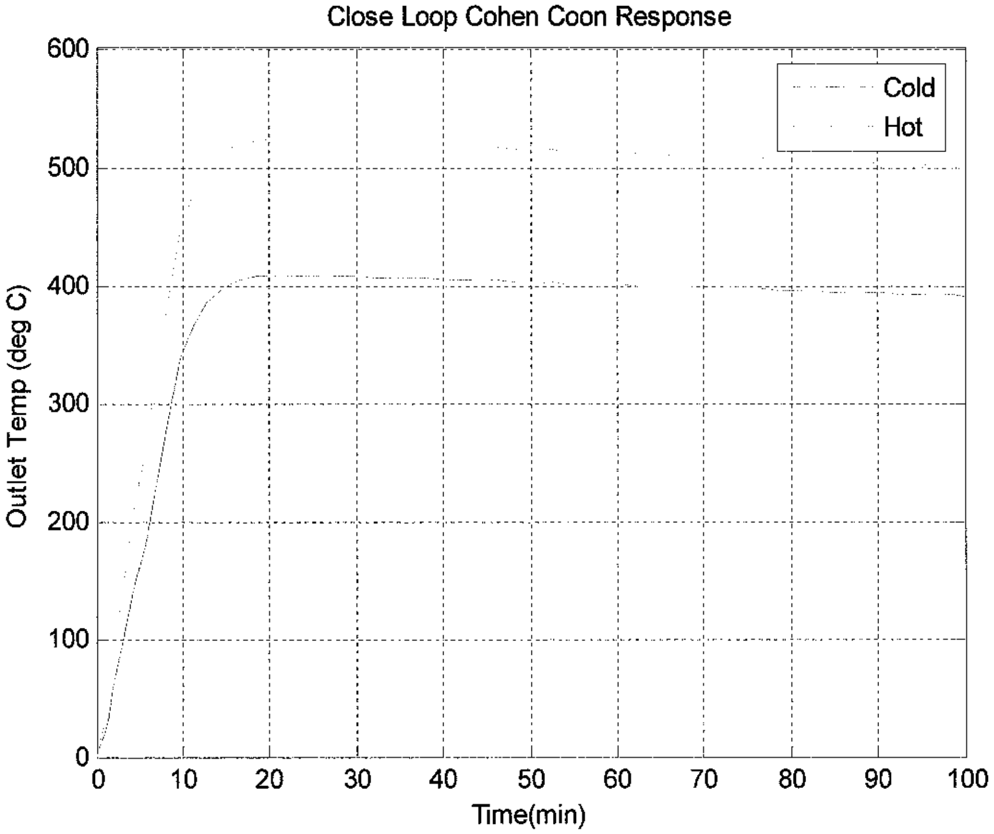


Figure 11: Graph on temperature response for Cascade Control for Disturbance

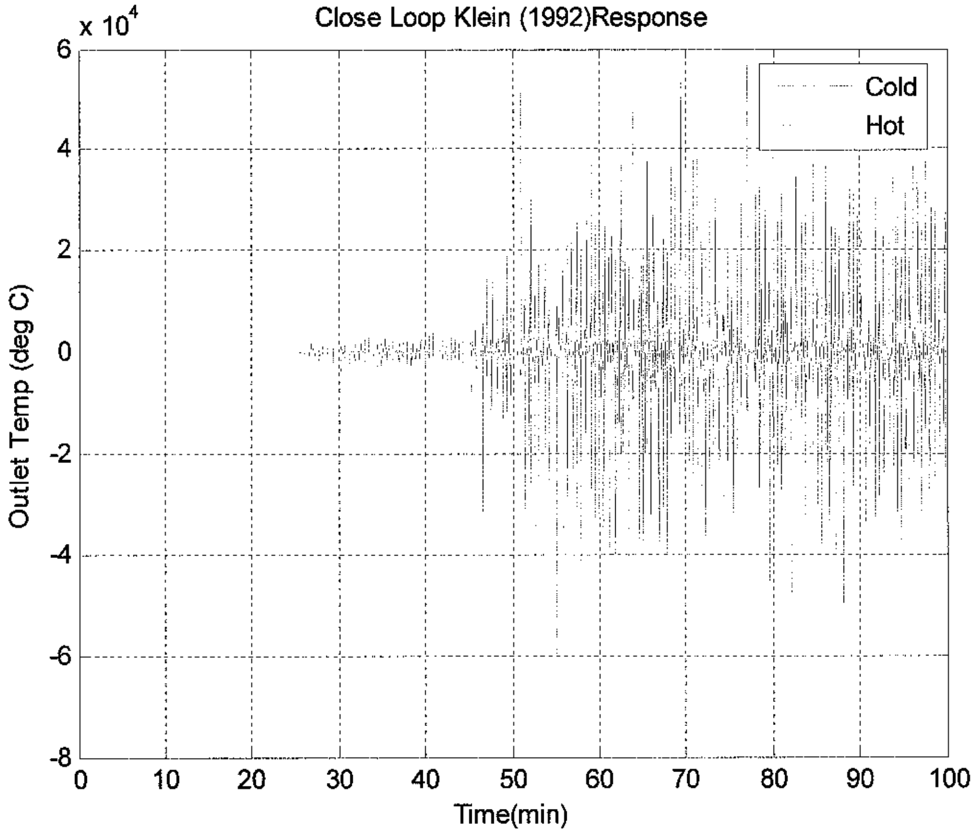


Figure 12: Graph on temperature response for Classical Control for Set Point Change

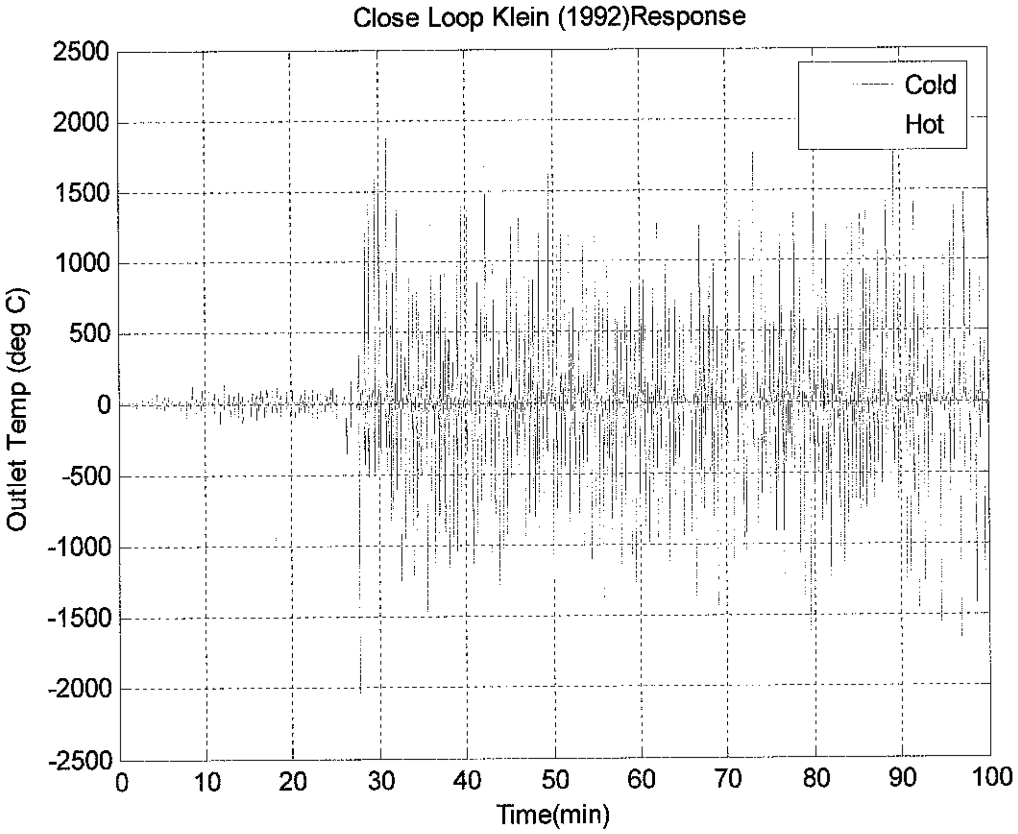


Figure 13: Graph on temperature response for Classical Control for Disturbance

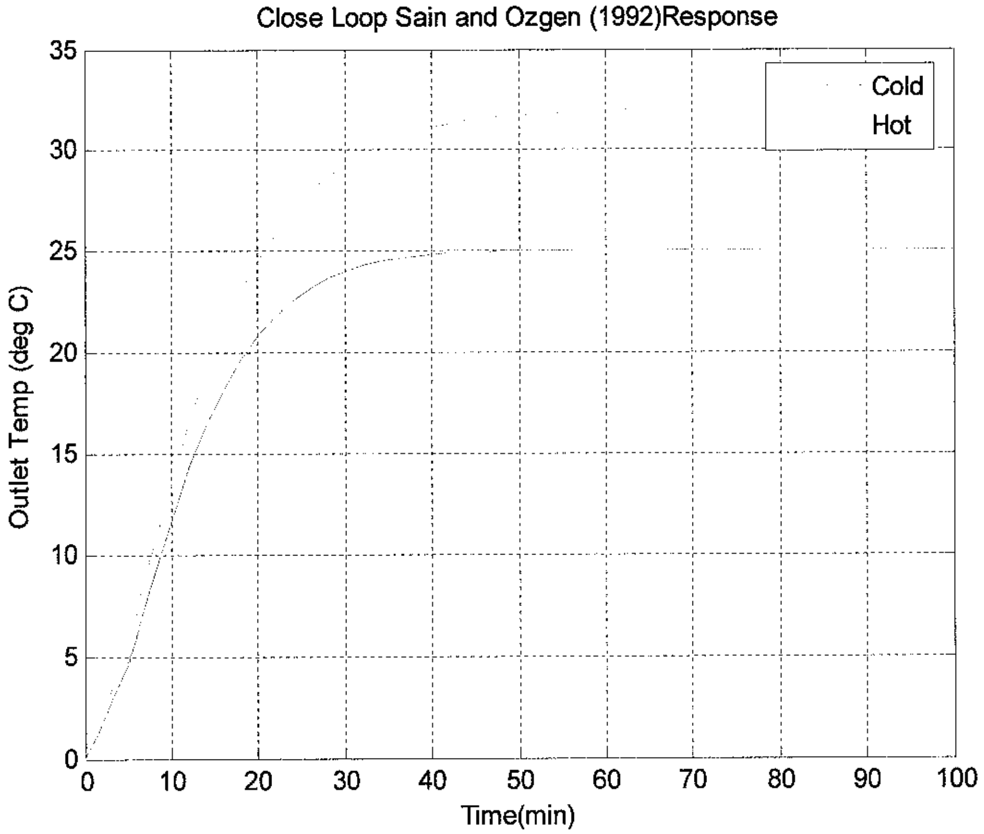


Figure 14: Graph on temperature response for Feedback Control for Set Point Change

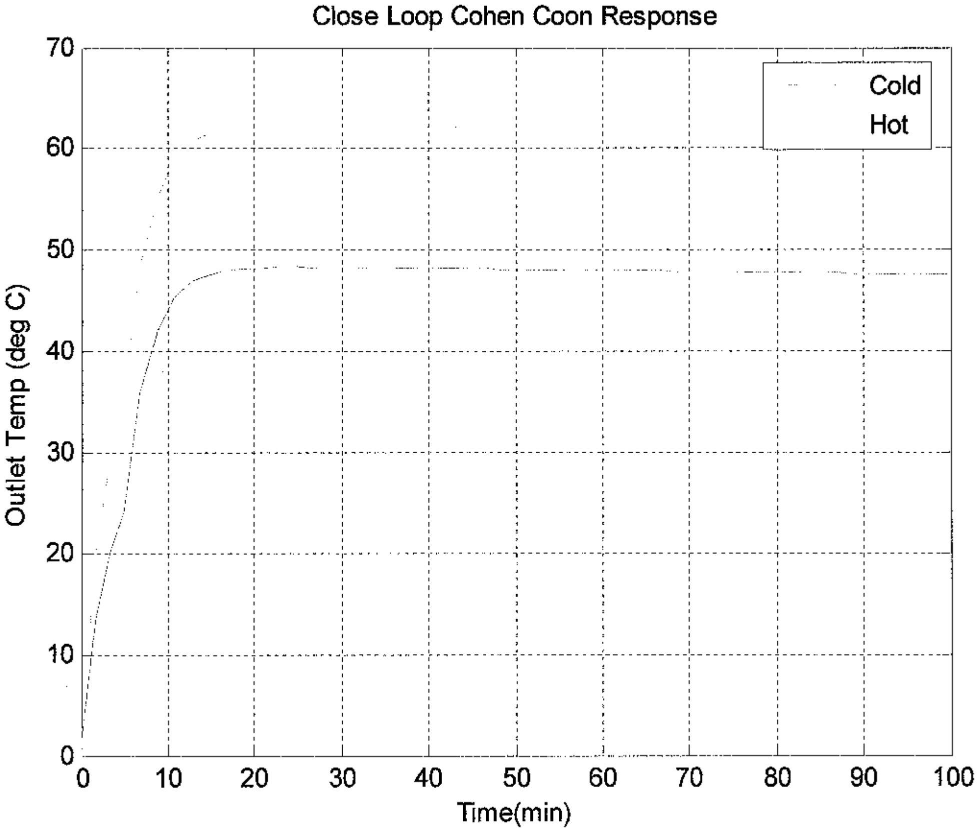


Figure 15: Graph on temperature response for Feedback Control for Disturbance

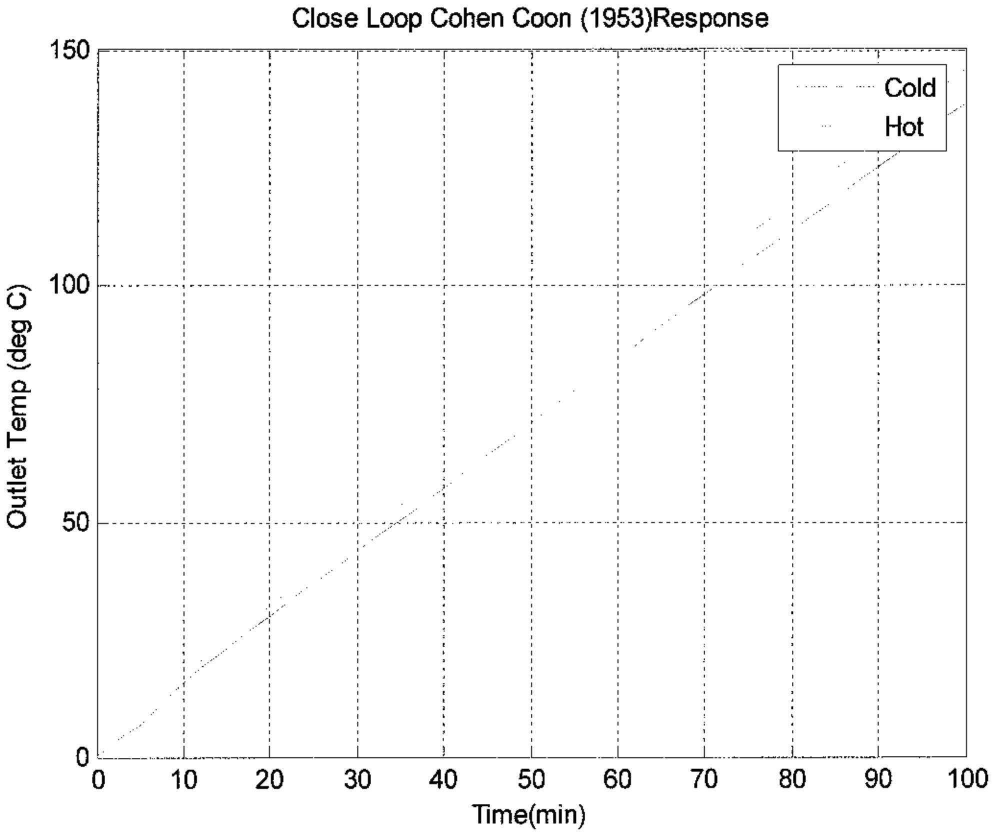


Figure 16: Graph on temperature response for Feedforward Control for Set Point Change

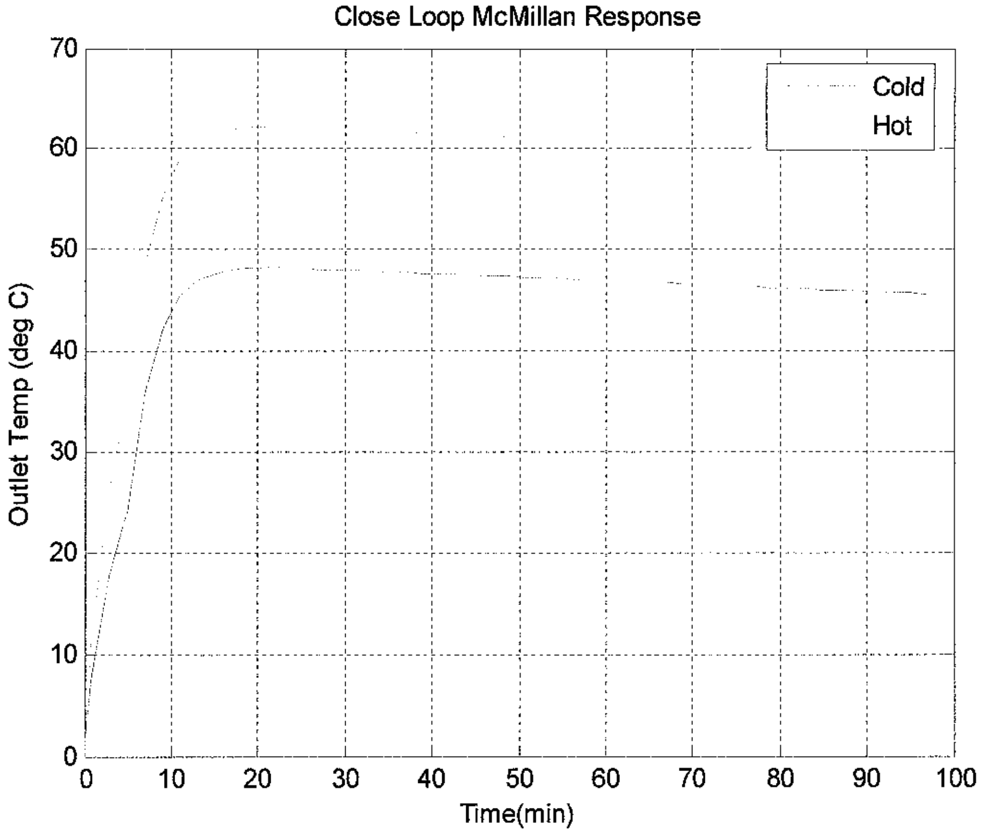


Figure 17: Graph on temperature response for Feedforward Control for Disturbance

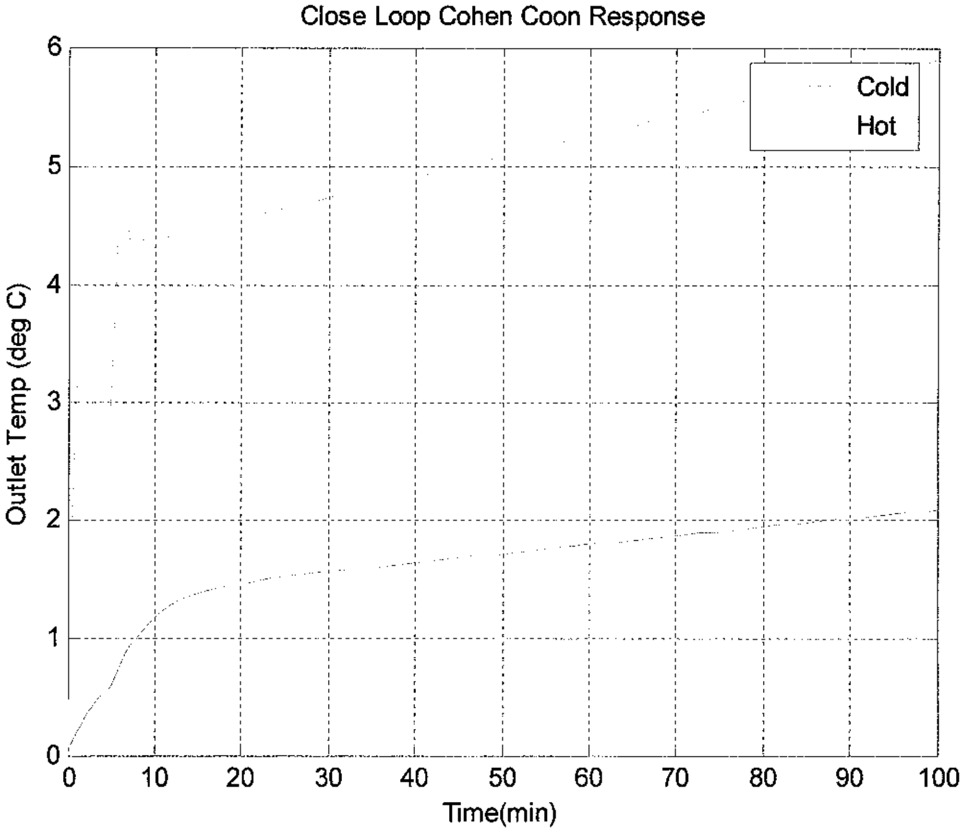


Figure 18: Graph on temperature response for Feedback Feedforward Control for Set Point Change

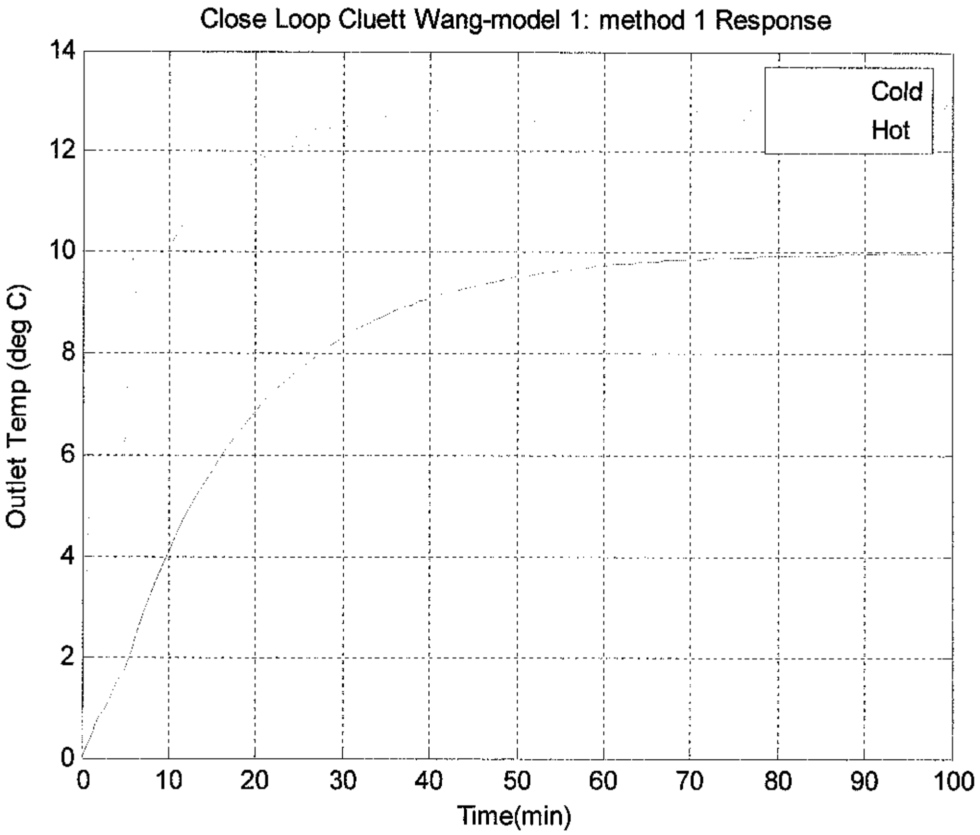


Figure 19: Graph on temperature response for Feedback Feedforward Control for Disturbance

4.4 SELECTION FOR THE BEST CONTROLLER TUNING FORMULAS

Based on the simulation that has been done, observed that only two controller are chosen in each control scheme.

- Close Loop Sain and Ozgen, Feedback Controller
- Close Loop Mcmillan Response, Feedforward Controller

Characteristics	Control Scheme	
	Feedback Control	Feedforward Control
Settling Time	5 minutes for set point change, and 8 minutes for disturbance change	Faster with 10 minutes for set point change and 12 minutes for disturbance change
Oscillation	No oscillation for set point change but has oscillations for disturbance change	No oscillation for set point change but has oscillation for disturbance change

Table 1 : Comparison between Feedback with Feed Forward Control

From the observation, it is noticed that Feedback Controller provides a better response than the Feed Forward in term of settling time and oscillation.

Comparison between Feedback Controller and Fuzzy Logic:

Characteristics	Control Scheme	
	Feedback Control	Fuzzy Logic Control
Settling Time	5 minutes for set point change, and 8 minutes for disturbance change	Faster than 5 minutes for set point change and 8 minutes for disturbance change
Oscillation	No oscillation for set point change but has oscillations for disturbance change	No oscillation for set point change but has oscillation for disturbance change

Table 2 : Comparison between Feedback Control with FLC

From the observation, it is noticed that Fuzzy Logic Controller provides a better response than the Feedback in term of settling time and oscillation.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

As a conclusion, Fuzzy Logic Controller is the best controller to control variation of temperature in Heat Exchanger.

5.2 RECOMMENDATION

After completing this Final Year Research Project, the author would like to make a note of a few recommendations for improvement in the future.

Give more information regarding the topic to the student.

Give more opportunity to student to study about the topic by providing adjunct lecture regarding the topic.

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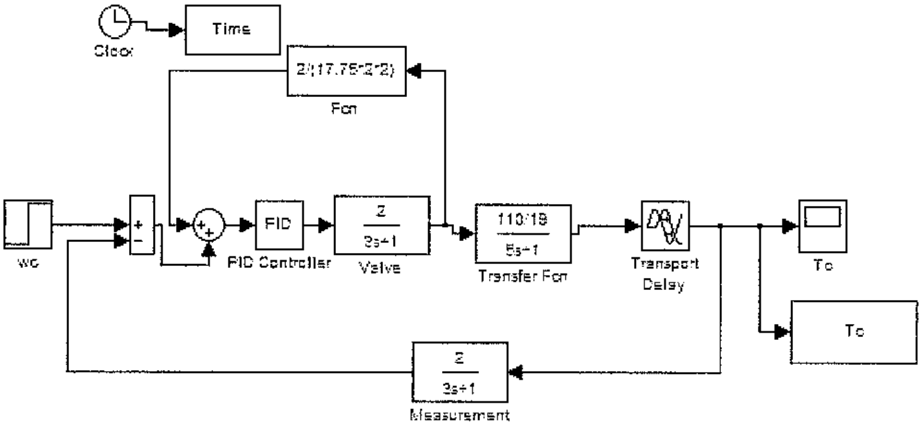
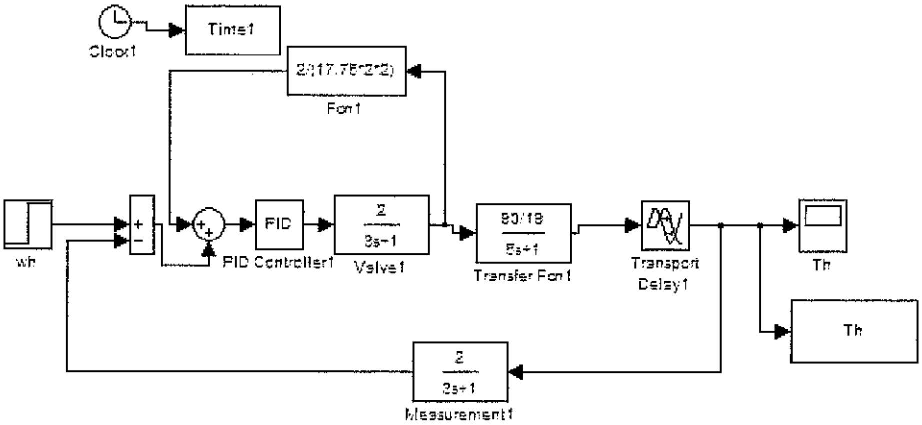
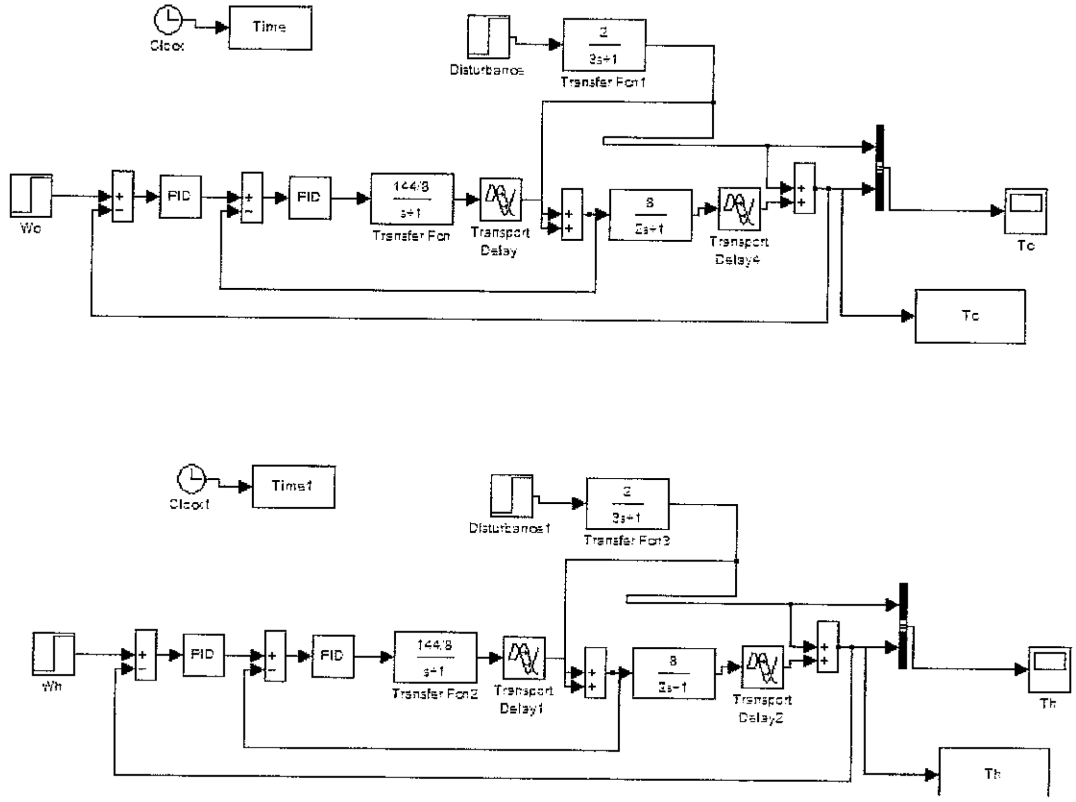
APPENDICES

Simulink block of control scheme

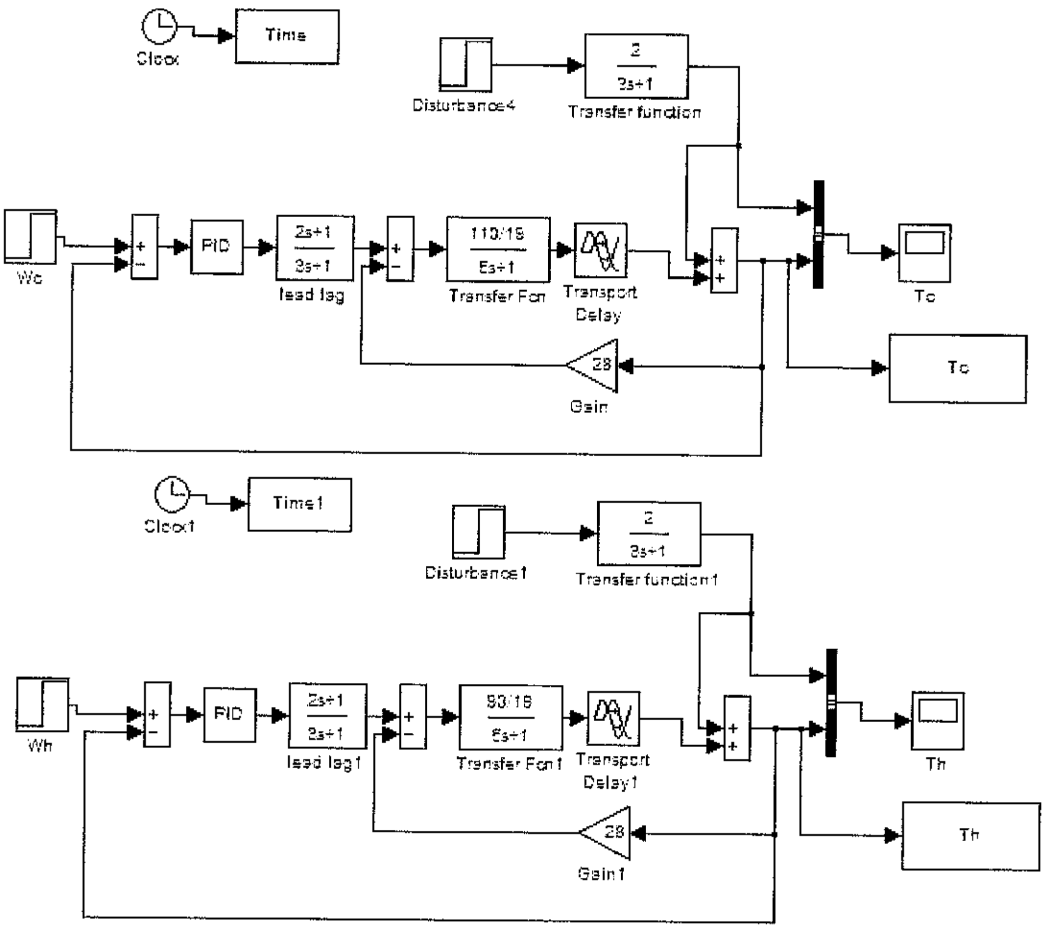




Adaptive Control Scheme



Cascade Control Scheme



Classical Control Scheme

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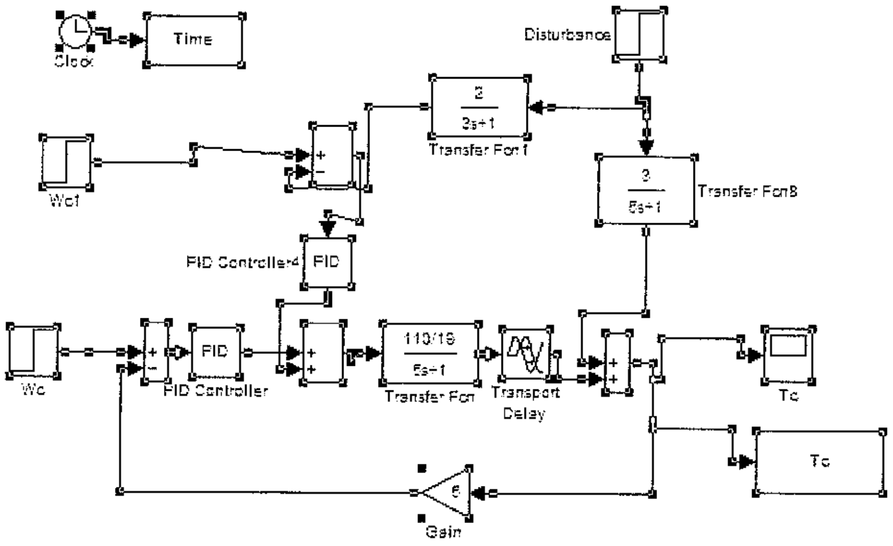
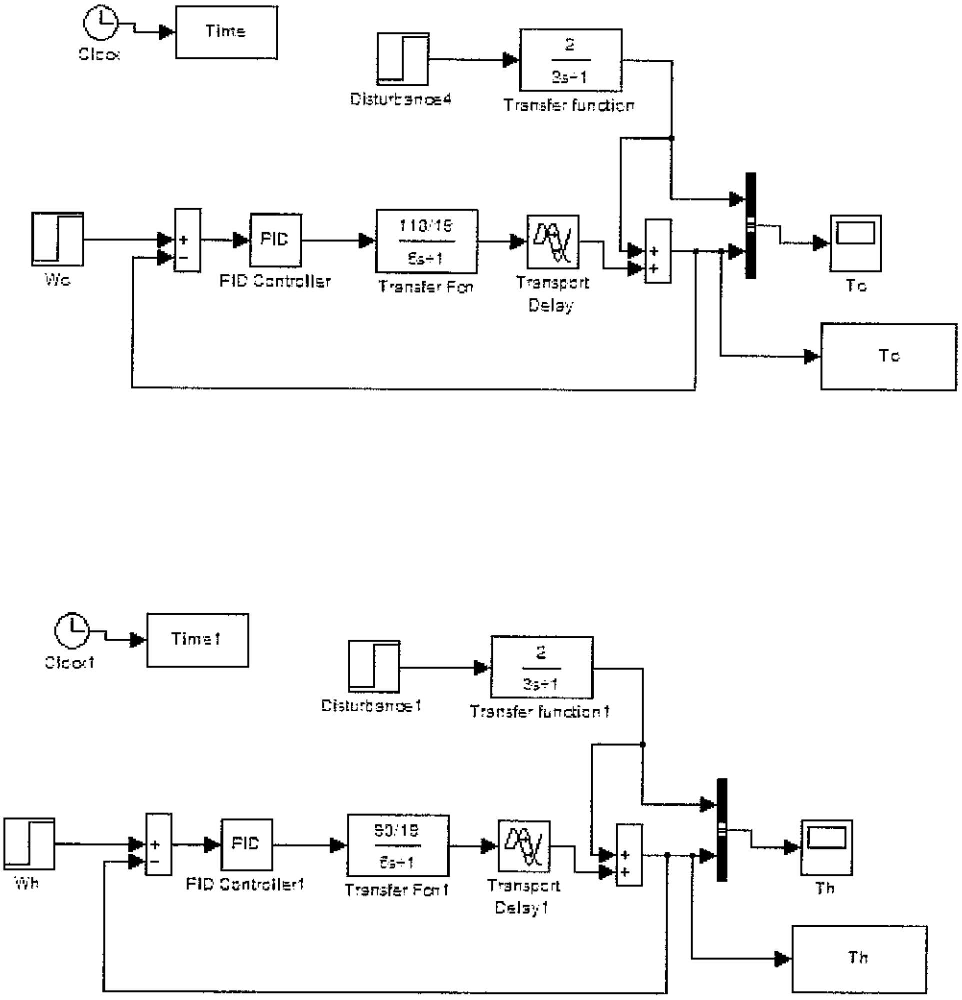
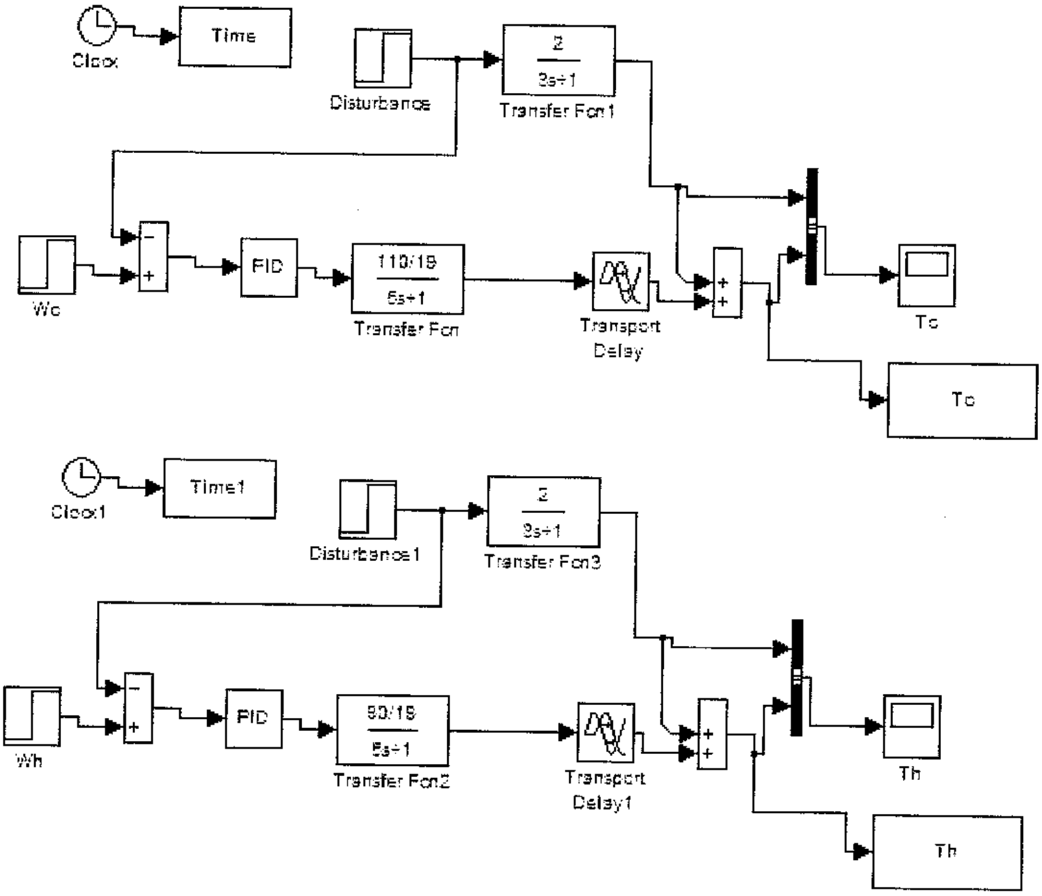


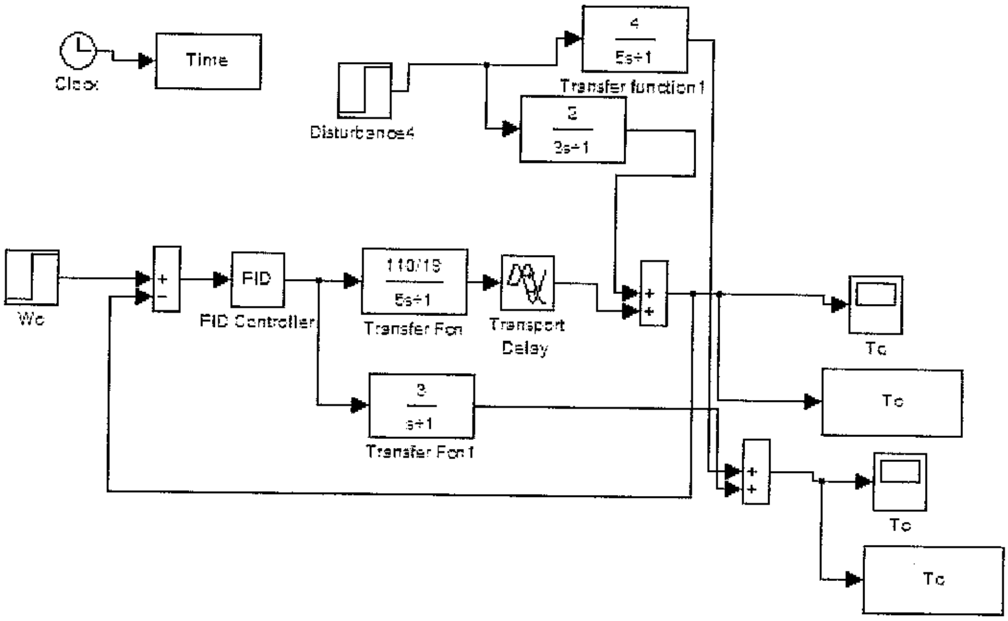
Feedback Feed Forward Control Scheme



Feedback Control Scheme



Feedforward control Scheme



Inferential Control Scheme