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B. ENGINEERING (HONS) CHEMICAL ENGINEERING

SEPTEMBER 2015

MODELLING FOR TEMPERATURE NON-ISOTHERMAL CONTINUOUS STIRRED TANK REACTOR USING FUZZY LOGIC

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Mohamad Syafiq Bin Mohamad

15563

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

SEPTEMBER 2015

University Teknologi PETRONAS,
32610, Bandar Seri Iskandar,
Perak

CERTIFICATION OF APPROVAL

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Approved by,

(NASSER BIN M. RAMLI)

UNIVERSITY TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

September 2015

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.

(MOHAMAD SYAFIQ BIN MOHAMAD)

ABSTRACT

As we study chemical engineering and in process engineering, we come across the importance of a Continuous Stirred Tank Reactor, CSTR. Many types of controllers have been applied on the CSTR process to control the reactor temperature. In this research paper, an analysis of the response of the conventional Proportional-Integral-Derivative, PID controller and multi types of Fuzzy Logic controller for temperature control of CSTR and to design a control system of a non-isothermal temperature control of a CSTR in order to produce the most theoretically stable response curve. A mathematical model of a CSTR using the most general operating condition was developed through a set of differential equations which were later then converted into S-function using MATLAB (Matrix Laboratory) editor. After developing the S-function of the defined CSTR model was used in SIMULINK (a graphical programming environment from MATLAB), model by using a path called User-Defined functions which allows us to apply a M.file system that was created prior to the simulation as for this project we used a system block of the S-function or S-function builder. Later, the introduction of the most basic proportional-integral-derivative controller (PID controller) to the system will be shown and an activity plot or response curve can be shown to explain the behaviour of the system with and without controller. We then later can start to add the fuzzy logic controller from the fuzzy logic toolbox and compare the results that is obtained from both experiments and the temperature control is found better with Fuzzy logic control as compared to PID control schemes respectively.

ACKNOWLEDGEMENT

I would like to take this opportunity to acknowledge and extent my heartfelt gratitude to the following persons who have made the completion of this Final Year Project possible. First and foremost, I would like to extent my gratitude to my beloved parents who has always supported my welfare in my undergraduate studies.

I would also like to express my biggest gratitude to my respected supervisor, Nasser Bin M. Ramli who gave me the most through support and guidance towards completing this project. Special Thanks to the examiners for the proposal defence and poster presentation who were being very supportive and always show guidance throughout this semester. Also to our coordinator Dr. Nurul Ekmi and Dr Sintayehu, for their continuous monitoring and guidance throughout our Final Year Project I and Final Year Project II course. Last but not least, a thousand of gratitude to all of my friend who assisted me directly or indirectly and in helping and supporting me to complete this project.

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LIST OF ABBREVIATION

CSTR	Continuous Stirred Tank Reactor
MATLAB	Matrix Laboratory
PID	Proportional-Integral-Derivative
FLC	Fuzzy Logic Controller
NB	Negative Big
NM	Negative Medium
NS	Negative Small
ZE	Zero
PS	Positive Small
PM	Positive Medium
PB	Positive Big

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

In the industry of chemical processes, a reactor is the main basis of equipment in which the raw materials to undergo a chemical reaction and changes to form desired products. The whole success of the industrial operation was due to the design and operation of chemical reactors. Reactors can be classified into various form depending on the nature of the process, feed raw materials and the products. The understanding of non-steady behaviour of process equipment is necessary for the design and operation of automatic control systems. One main type of the process reactor is the continuous stirred tank reactor (CSTR). The continuous flow stirred-tank reactor (CSTR), is one of the many reactor design that is used in chemical engineering and it is to be said as a common ideal reactor type. A CSTR regularly refers to a model used to evaluate the key unit operation variables when using a continuous agitated-tank reactor to reach a specified output.

When dealing with chemical reactions and reactor designing, there are various parameters that is needed to be taken into deep consideration and needed to be controlled properly in order to avoid any faultiness to the process unit. Temperature is one of the main parameters that are needed to be controlled while running a reaction process. There are various types of controller that can be used to control the temperature in a process. One type of controller that is applicable to be used in various process unit is the Fuzzy controller system that is based on the fuzzy logic.

Fuzzy logic is a form of many-valued logic that deals with approximate, rather than fixed and exact reasoning. Fuzzy logic is widely used in machinery control. Theoretically, fuzzy logic is an approach to computing based on “degrees of truth” rather than the typical “true or false” or “1 or 0” Boolean logic which is the basis of the modern computer. Fuzzy logic was first introduced by Dr. Lotfi Zadeh from the University of California at Berkeley in the 1960’s. The best thing about fuzzy controlled systems model is it do not involve any specific model for implementation of system under consideration. The successful measurement of the fuzzy logic was based on approximate reasoning instead of modelling assumption which remark the robustness of this method in real live application. Fuzzy logic doesn’t need mathematical modelling which makes it more flexible in dealing with complex non-linear problem. [1]

1.2 Problem Statement

Nowadays many plant have been applying the conventional automatic process control replacing the classical manual control system. Continuous stirred tank reactor system (CSTR) is a typical chemical reactor system with complex nonlinear dynamic characteristics. There has been considerable interest in its state estimation and real time control based on mathematical modelling. However, the lack of understanding of the dynamics of the process, the highly sensitive and nonlinear behaviour of the reactor, has made difficult to develop a suitable control strategy.

A system that is classified by high nonlinearities is hard to be controlled by controllers which are derived from a linear model for example the classical PID controllers. Even if this type of controller can be tuned in order to take effect on certain conditions, they are not very strong and may destabilize the entire system if there is some parameter changes. In controlling the CSTR, the problem is considered as attractive and controversial issue mostly for control and instrumentation engineer due to its nonlinear nature. Most of the conventional controllers are restricted to a certain linear pattern of a system. But in reality we cannot neglect the non-ideal, or nonlinear characteristics of the system and their functional parameter changes that caused from wear and tear.

In this project, a fuzzy based PID controller is to be applied to control the reactant temperature of a CSTR. Fuzzy systems are universal approximates. Fuzzy controlled systems models do not require any certain model for implementation of system under consideration. Thus by applying this type of controller to a CSTR, it should be able to control its nonlinear or for a specific case, non-isothermal parameter. A simulation modelling is to be designed via MATLAB Simulink.

1.3 Objectives and scope of Study

The purpose of this project is to design a control system of a non-isothermal temperature control of a CSTR in order to produce the most theoretically stable response curve by comparing it with Fuzzy Logic Controller, FLC and Proportional-Integral-Derivative, PID controller.

To achieve the stated goals of the project, the sub-objectives of this project are to design a non-isothermal CSTR temperature and concentration model using S-function blocks in Simulink® in MATLAB using the normal operating conditions of a CSTR. After that, to develop a control system for the designed CSTR model by applying PID controller and fuzzy logic controller using simulation modelling in MATLAB. Finally is to compare the temperature response curve of a fuzzy control system with PID controller by showing the results of bode diagram obtained at the end of the experiment.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Continuous Stirred Tank Reactor, CSTR

In the majority of industrial chemical processes, a reactor is the key item of equipment in which raw materials undergo a chemical change to form desired products. The design and operation of chemical reactors is thus crucial to the whole success of the industrial operation. Reactors can take a widely varying form, depending on the nature of the feed materials and the products. Understanding non-steady behaviour of process equipment is necessary for the design and operation of automatic control systems. One particular type of process equipment is the continuous stirred tank reactor. In this reactor, it is important to determine the system response to a change in concentration. This response of concentration or temperature versus time is an indication of the ideality of the system.

In figure 2.1 we can see that a CSTR is basically assembled with a jacket or coil in order to maintain the reaction temperature in the reactor. When heat is developed caused by exothermic reaction, a coolant stream is needed to pass through the jacket coil to remove the excessive heat. On the contrary, if endothermic reaction occurs in the system, the flow of the heating medium is passing through the jacket or coil to maintain the desired reaction temperature. A reactor operates at a constant temperature, then that is called as the isothermal reactor. If any exothermic or endothermic reactions are involved in the reactor, the temperature of the reactions mixture varies with time and is needed to develop the energy balance equation for this non-isothermal reactor.

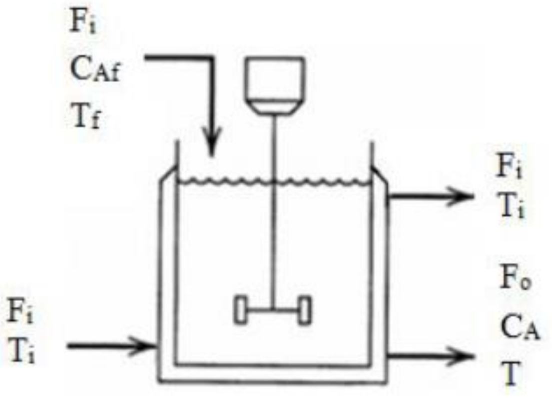


Figure 2.1 Schematic representation of CSTR

The examined reactor has real background and graphical diagram of the CSTR reactor as shown in below figure. The mathematical model of this reactor comes from balances inside the reactor. Notice that a jacket surrounding the reactor also has feed and exit streams. The jacket is assumed to be perfectly mixed and at lower temperature than the reactor. Energy passes through the reactor walls into jacket removing the heat generated by reaction. The control objective is to keep the temperature of the reacting mixture T, constant at desired value. The only manipulated variable is the coolant flow rate.

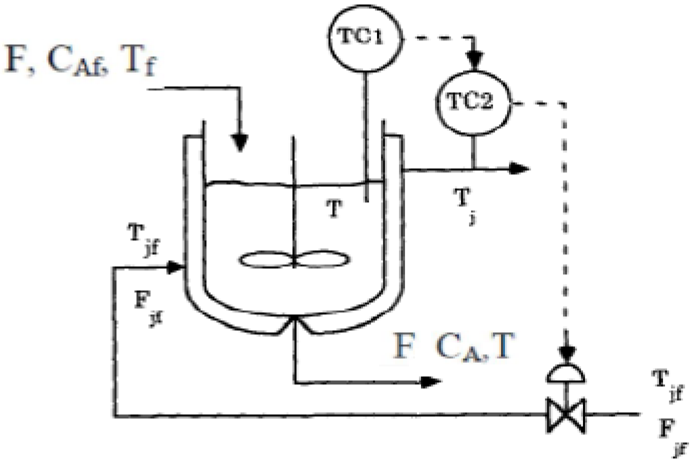


Figure 2.2 Continuous stirred tank reactor with cooling jacket

The temperature jacket, Tj is an input for this project, while Ca and T are concentration and temperature of the content as the output respectively. A model of CSTR is required for the process control system. The mathematical model equations are obtained by the components mass balance and energy balance principle in the reactor. Below we can see that equation (1) is the mathematical model for concentration while equation (2) is the temperature model of the CSTR.

$$\frac{dC_a}{dt} = \frac{F}{V}\left(C_{af} - C_a\right) - k_o exp[\frac{E_a}{R(T+460)}]C_a \tag{1}$$

$$\frac{dT}{dt} = \frac{F}{V}\left(T_f - T\right) - \frac{\Delta H}{\rho C_p} k_o \exp\left[\frac{E_a}{R(T+460)}\right] C_a - (\frac{UA}{\rho C_p V})(T - T_j) \tag{2}$$

2.2 Control Systems

2.2.1 Proportional-Integral-Derivative, PID Controller

A Proportional-Integral-Derivative (PID) type controller is mostly used in the industry because of simple control structure easiness in design and less expensive .PID controller cannot yield an efficient control performance if control object is nonlinear PID controller is a linear controller and is the most-used feedback controller. PID is an acronym for Proportional-Integra -Derivative, referring to the three terms operating on the error signal to produce a controlled signal. A PID controller continuously calculates an error value as the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error over time by adjustment of a control variable, such as the position of a control valve, a damper, or the power supplied to a heating element, to a new value determined by a weighted sum.

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de}{dt} \tag{3}$$

K_p, K_i, and K_d are all non-negative which resembles the coefficient for the proportional, integral and derivative terms. In the model P denotes for the present values of the error as an example if the error is large and positive, the control variable will be large and negative. While I accounts for past values of the error if the output is not sufficient to reduce the size of the error, the control variable will accumulate over time, causing the controller to apply a stronger action and D accounts for possible future values of the error, based on its current rate of change. [2]

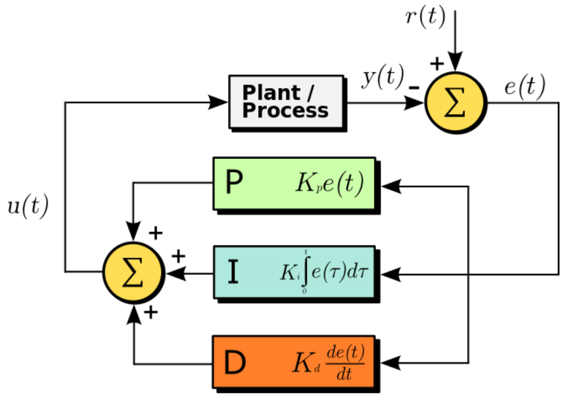


Figure 2.3 A block diagram of a PID controller in a feedback loop

2.2.2 Fuzzy Logic Controllers, FLC

Fuzzy logic is an extension of binary logic. It uses partial truth values instead of completely true or completely false .They have a value that shows the degree of truth in the range 0 to1.0 represents absolute false and 1 represents completely true. Fuzzy logic controller converts the intelligent knowledge into an automatic control action. It handles information in systematic way. Fuzzy logic is widely used in very complex and highly nonlinear system.

A. Farhad & K. Gagandeep (2011) designed a study on the Comparative Analysis of Conventional, P, PI, PID and Fuzzy Logic Controllers for the Efficient Control of Concentration in CSTR. They stated that an offset can be led by proportional controller between the actual output and the preferred set points. In their study the fuzzy control scheme helps to remove those delay times and the inverted response shown in graphs. Rise time and settling time are also reduced. The implementation of PID control in process overshoots and control delay time for problems in inverse response of over going process. The problems are tackled efficiently but inject instability in terms of setting and rise time [3]

Mosè Galluzzo, Bartolomeo Cosenza (2010) did a control system design on Type-2 fuzzy control of a fed-batch fermentation reactor with an aim to show the application of type-2 fuzzy logic controllers to the control of a fed-batch fermentation reactor in which the penicillin production is carried out. The performance of the control system using type-2 fuzzy logic controllers was compared by simulation with type-1 fuzzy logic controllers. In their study they used non-linear model for their simulation. From their findings it is confirmed that the robustness of the type-2 fuzzy controller.

S.Boobalan, K.Prabhu & V.Murali Bhaskaran (2013) did a paper on Fuzzy Based Temperature Controller for Continuous Stirred Tank Reactor. In their research, they found that he Fuzzy based PID controller provides performance comparable to that of Ziegler Nichols, ZN-PID controller. The servo response based on Fuzzy PID controller meet the desired set point but small overshoot present in it. [4]

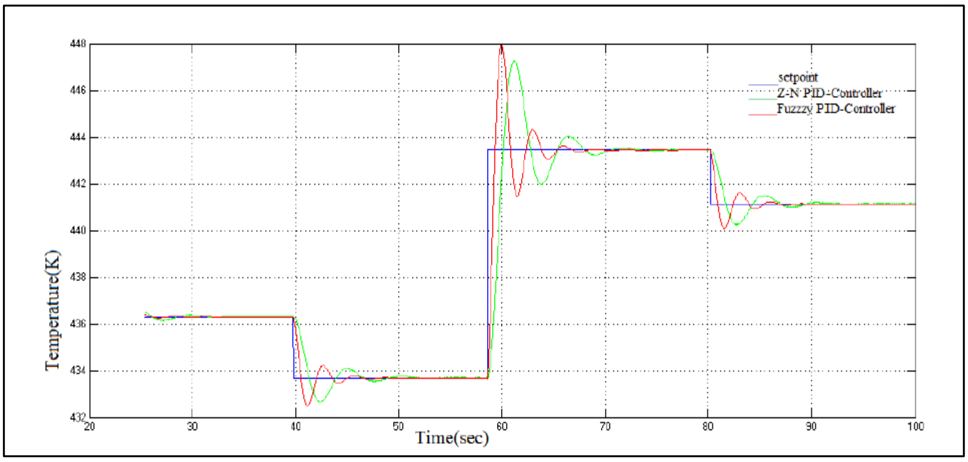


Figure 2.4 Servo Response Comparison of Ziegler-Nichols PID-Controller and Fuzzy PID-Controller (S.Boobalan, K.Prabhu & V.M Bhaskaran (2013)

CHAPTER 3

METHODOLOGY

3.1 Modelling for a Non-Isothermal CSTR System

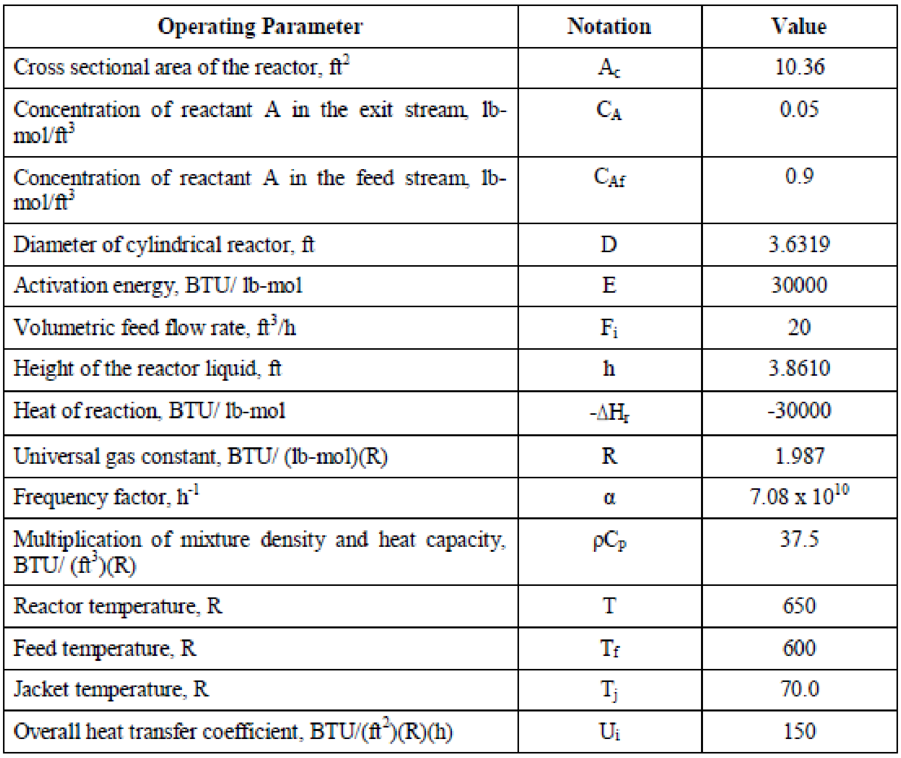
In a normal operation of a continuous flow stirred-tank reactor (CSTR), the contents are well stirred and it runs with continuous flow of reactants, as well as the products. The CSTR normally runs at a steady state condition, with a uniform distribution of concentration and temperature throughout the reactor. To model systems that do not obey the common assumptions for a CSTR, such as constant temperature or a single reaction, et cetera, additional dependent variables must be considered. If the system is considered to be in unsteady-state, a differential equation or a system of coupled differential equations must be solved. For this project, the CSTR system will be modelled using MATLAB Simulink software. This model is then used to generate a sample of baseline data (without faults) to be tested and used as benchmark later on, thus the following assumption are made:

1. Heat losses from the process are negligible (well insulated).
2. The mixture density and heat capacity are assumed constant.
3. There are no variations in concentration, temperature, or reaction rate throughout the reactor as it is perfectly mixed.
4. The exit stream has the same concentration and temperature as the entire reactor liquid.
5. The overall heat transfer coefficient is assumed constant.

6. No energy balance around the jacket is considered. This means that the jacket temperature can directly be manipulated in order to control the desired reactor temperature.

7. The reactor is a flat bottom vertical cylinder and the jacket is around the outside and the bottom.

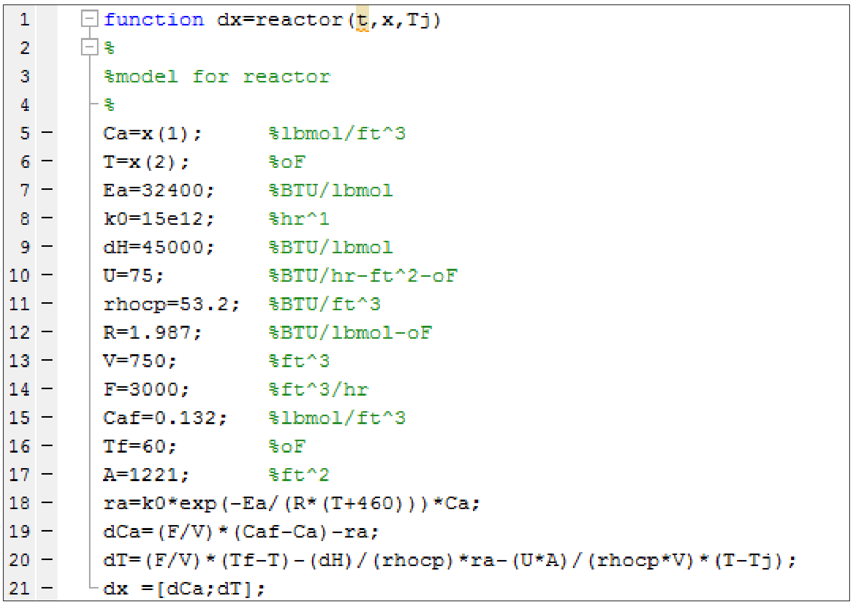
Table 3.1 Default operating parameters of a CSTR (Jana, 2011).



Operating Parameter	Notation	Value
Cross sectional area of the reactor, ft^2	A_c	10.36
Concentration of reactant A in the exit stream, lb-mol/ft^3	C_A	0.05
Concentration of reactant A in the feed stream, lb-mol/ft^3	C_{Af}	0.9
Diameter of cylindrical reactor, ft	D	3.6319
Activation energy, BTU/ lb-mol	E	30000
Volumetric feed flow rate, ft^3/h	F_i	20
Height of the reactor liquid, ft	h	3.8610
Heat of reaction, BTU/ lb-mol	$-\Delta H_r$	-30000
Universal gas constant, BTU/ (lb-mol)(R)	R	1.987
Frequency factor, h^{-1}	α	7.08×10^{10}
Multiplication of mixture density and heat capacity, BTU/ (ft^3)(R)	ρC_p	37.5
Reactor temperature, R	T	650
Feed temperature, R	T_f	600
Jacket temperature, R	T_j	70.0
Overall heat transfer coefficient, BTU/(ft^2)(R)(h)	U_i	150

For this project a design of CSTR for Temperature Control needed to be modelled in a simulation environment before we can proceed to designing the system control process. Before we model the CSTR a mathematical design needed to be done first using the equations above. Equation (1) is for the concentration modelling while equation (2) is for temperature modelling. I want to model this system in which the jacket temperature, T_j, will be treated as the input (i.e. manipulated variable) and also want to monitor concentration and temperature of the liquid in the CSTR as our outputs.

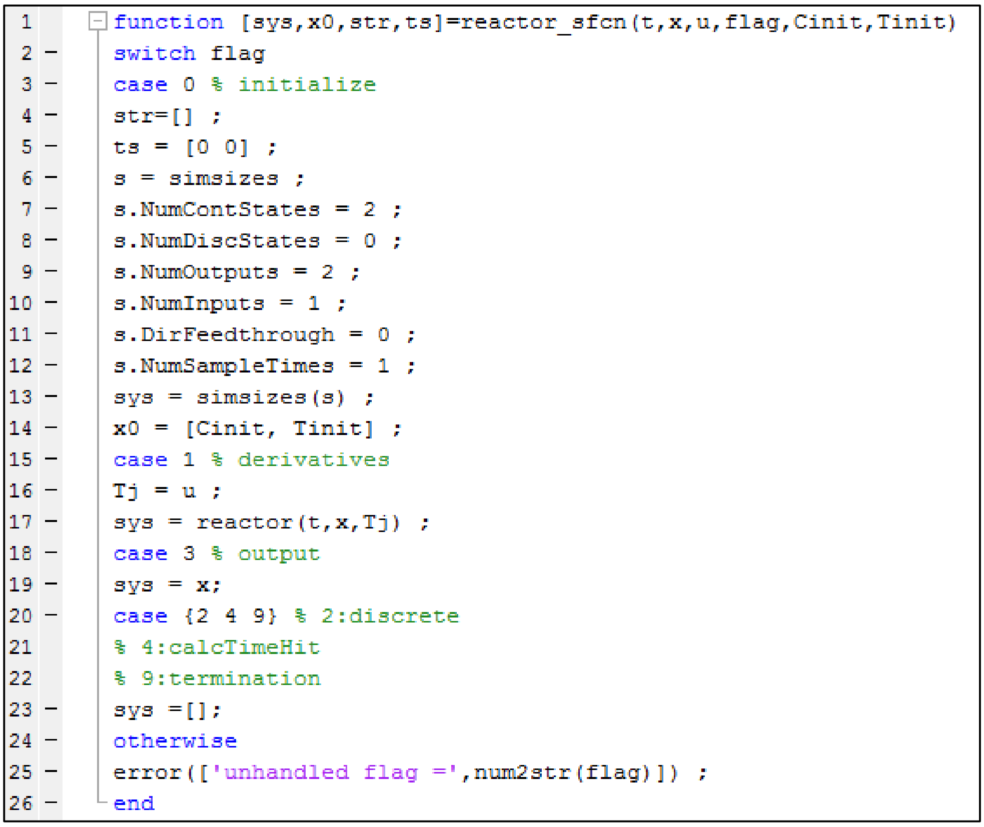
The next step is to write the M-File in Simulink MATLAB. The process can be modelled by writing an m-file to be used by MATLAB solvers such as ode45. The file which will named as reactor.m is shown in figure 3.1. We treat Tj as an argument/parameter. This is in anticipation that we will be varying Tj later as an input/manipulated variable. The arguments x and dx are column vectors for state and derivative, respectively. Writing a model first for direct ODE45 implementation is advisable, especially for complex processes. This way, one can check the validity of the model, prior to its incorporation to a Simulink model.



```
function dx=reactor(t,x,Tj)
%
%model for reactor
%
Ca=x(1);      %lbmol/ft^3
T=x(2);       %oF
Ea=32400;     %BTU/lbmol
k0=15e12;     %hr^1
dH=45000;     %BTU/lbmol
U=75;         %BTU/hr-ft^2-oF
rhocp=53.2;   %BTU/ft^3
R=1.987;      %BTU/lbmol-oF
V=750;        %ft^3
F=3000;       %ft^3/hr
Caf=0.132;    %lbmol/ft^3
Tf=60;        %oF
A=1221;       %ft^2
ra=k0*exp(-Ea/(R*(T+460)))*Ca;
dCa=(F/V)*(Caf-Ca)-ra;
dT=(F/V)*(Tf-T)-(dH)/(rhocp)*ra-(U*A)/(rhocp*V)*(T-Tj);
dx =[dCa;dT];
```

Figure 3.1 CSTR Model saved as reactor.m

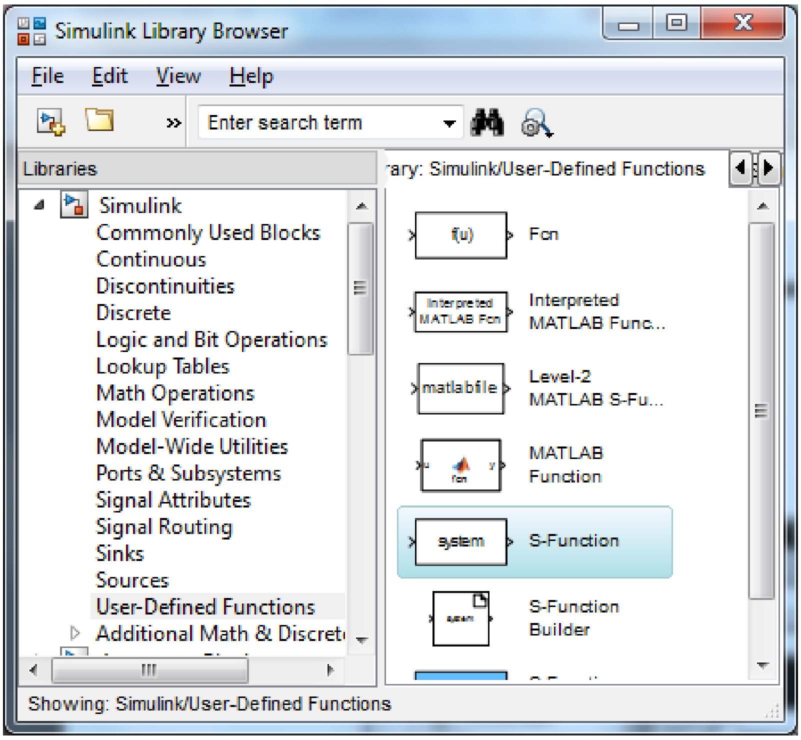
The next step is to write an S-function file which to be saved as an m-file. It contains the protocol in which Simulink can access information from MATLAB. For our example, we show one such S-function file in Figure 2. We will save this file as reactor_sfcn.m. This file will also be saved as an m-file. It contains the protocol in which Simulink can access information from MATLAB and the file is saved as reactor_sfcn.m



```
function [sys,x0,str,ts]=reactor_sfcn(t,x,u,flag,Cinit,Tinit)
switch flag
case 0 % initialize
str=[] ;
ts = [0 0] ;
s = simsizes ;
s.NumContStates = 2 ;
s.NumDiscStates = 0 ;
s.NumOutputs = 2 ;
s.NumInputs = 1 ;
s.DirFeedthrough = 0 ;
s.NumSampleTimes = 1 ;
sys = simsizes(s) ;
x0 = [Cinit, Tinit] ;
case 1 % derivatives
Tj = u ;
sys = reactor(t,x,Tj) ;
case 3 % output
sys = x;
case {2 4 9} % 2:discrete
% 4:calcTimeHit
% 9:termination
sys =[];
otherwise
error(['unhandled flag =',num2str(flag)]) ;
end
```

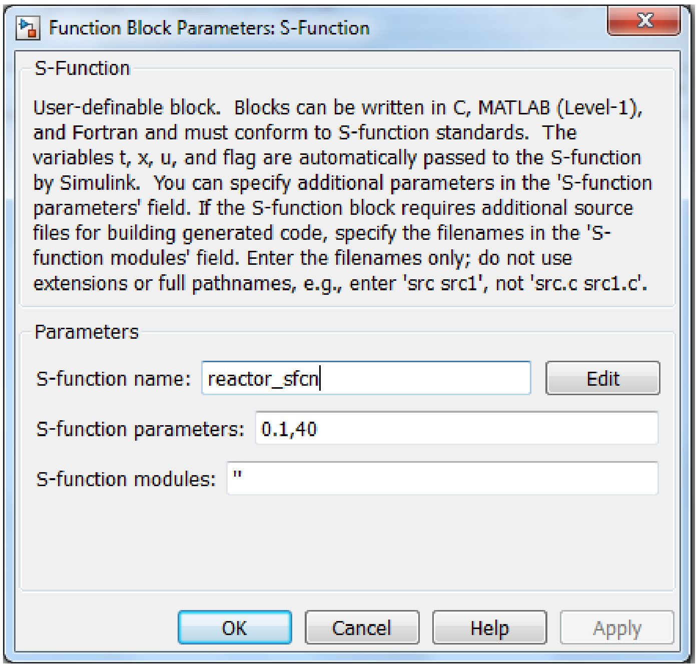
Figure 3.2 S-function file saved as reactor_sfcn.m

Next is to insert the S-Function block into the Simulink® model browser in order to turn these coding into a block function. In the Simulink® library browser, there is a group labelled as User-Defined Functions subdirectory and drag-drop the S-Function block as shown in figure 3.3. Double-click on the S-function block and fill in the parameters. Change the S-function name to reactor_sfcn. And fill in the parameters which is the value for Cinit and Tinit as shown in figure 3.4.



Showing: Simulink/User-Defined Functions

Figure 3.3 User-Defined Functions subdirectory that contains the S-Function block



User-definable block. Blocks can be written in C, MATLAB (Level-1), and Fortran and must conform to S-function standards. The variables t, x, u, and flag are automatically passed to the S-function by Simulink. You can specify additional parameters in the 'S-function parameters' field. If the S-function block requires additional source files for building generated code, specify the filenames in the 'S-function modules' field. Enter the filenames only; do not use extensions or full pathnames, e.g., enter 'src src1', not 'src.c src1.c'.

S-function name: reactor_sfcn

S-function parameters: 0.1,40

S-function modules: ''

Figure 3.4 S-Function block parameter editor

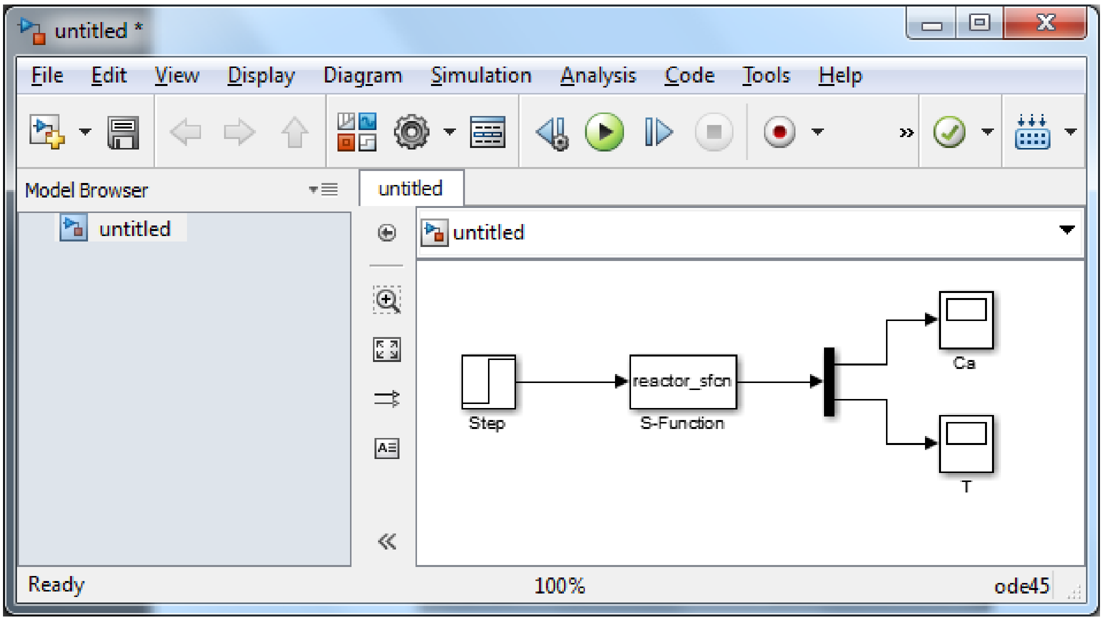


Figure 3.5 reactor_sfcn added with other Simulink blocks

In figure 3.5, we include a demux block (which stands for demultiplexer) to split the output vector to the 2 elements. In other applications where the input vectors has more than one element, we need a mux block (which stands for multiplexer). Both mux and demux blocks reside in the Signal Routing subdirectory of the Simulink Library browser.

3.2 PID Control Design

The PID control design is applying the feedback control strategy method where the output error is identified and the error signal is traced back into the feed to apply the change in the error so that the controller knows the value that is needed to be adjusted in order to reach the controlled target value.

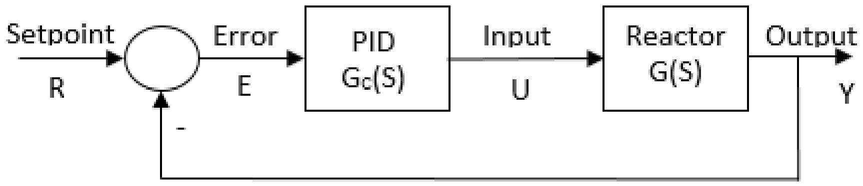


Figure 3.6 Block diagram of PID controller with G(S) reactor_sfcn

The trial and error tuning method is based on guess-and-check. In this method, the proportional action is the main control, while the integral and derivative actions refine it. The controller gain, K_c, is adjusted with the integral and derivative actions held at a minimum, until a desired output is obtained. The following tuning rule present in book titled "The Michigan chemical process dynamics and controls open text book" by prof. Peter Woolf, 2007.

Table 3.2: Trial and error method tuning rule

Gains	**Temperature process**
K_p	2-10
K_i	2-10
K_d	0-5

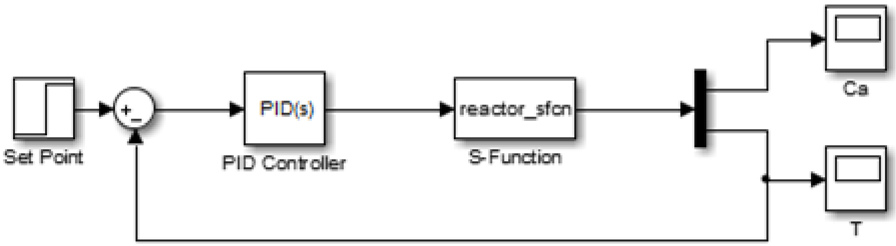


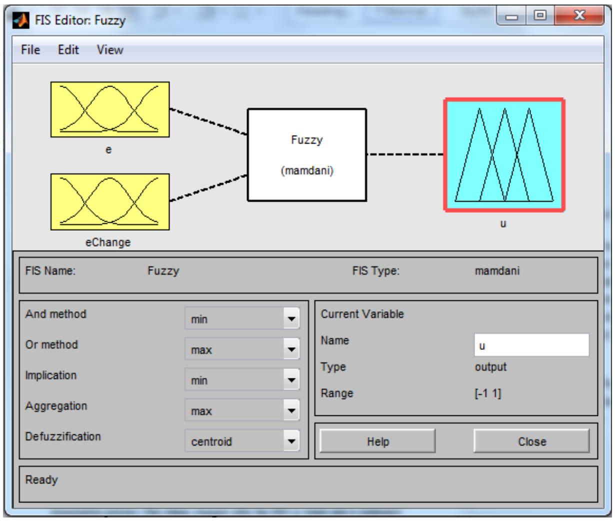
Figure 3.7 System reactor_sfcn with Tuned PID feedback control in Simulink

During the simulation, the initial values of K_c, K_i, and K_d was 8, 3 and 1 was used as the initial basis of the trial and error in the PID controller before the linearization process. The values changed after the PID is tuned and a controlled response was obtained in the simulation.

3.3 Fuzzy Logic Control Design

Fuzzy logic is extension of binary logic. It uses partial truth values instead of completely true or completely false .They have a value that shows the degree of truth in the range 0 to1.0 represents absolute false and 1 represents completely true. Fuzzy logic controller converts the intelligent knowledge into an automatic control action. It handles information in systematic way. Fuzzy logic is widely used in very complex and highly nonlinear system.

The first step to design the fuzzy logic control system is to decide on the rules that is going to be applied into the membership function in the fuzzy logic system. In this case there are two inputs which is control error labelled as e, while the change in the control error labelled as eChange. The output is the control action which is defined as u.



FIS Name: Fuzzy
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: u
Type: output
Range: [-1 1]
Ready

Figure 3.8 Fuzzy Inference System, FIS Editor in MATLAB

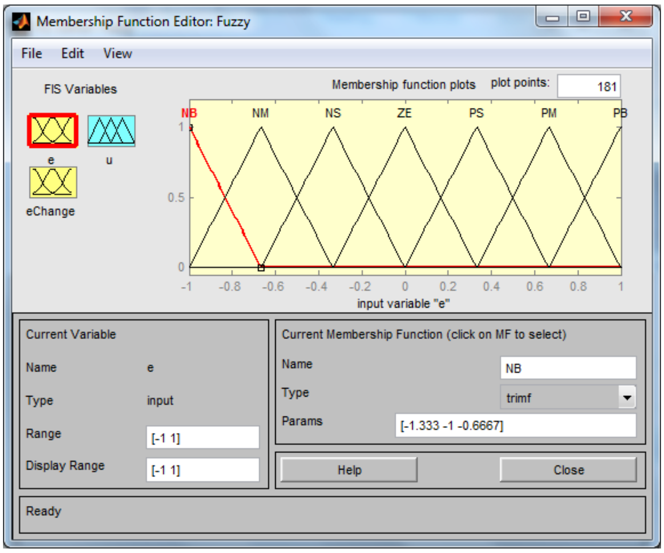
Using an interval Ttpe-2 Fuzzy Logic Controller for a non-linear CSTR plant the set of rules is described in table 3.3. These rules was added to the membership function in the FIS editor as set of rules for the FLC. The word definition for the membership variables is in the following table. The interface of the fuzzy membership function editor is shown in figure 3.9 and figure 3.10 while in figure 3.11 shows the Simulink model of the control system of the CSTR using FLC in the simulation. The simulation was run and the data and reading were obtained respectively via the scope block which shows the temperature response of the system.

Table 3.3 Interval Rules for Fuzzy Logic Controller

Controller Output u(t)		Error [e(t)]						
		NB	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
Error Change [Δe(t)]	**NB**	NB	NB	NB	NB	NM	NS	ZE
	NM	NB	NM	NM	NM	NS	ZE	PS
	NS	NB	NM	NS	NS	ZE	PS	PM
	ZE	NB	NM	NS	ZE	PS	PM	PB
	PS	NM	NS	ZE	PS	PS	PM	PB
	PM	NS	ZE	PS	PM	PM	PM	PB
	PB	ZE	PS	PM	PB	PB	PB	PB

Table 3.4 The linguistic variables used in the membership functions

NB	Negative Big	**PS**	Positive Small
NM	Negative Medium	**PM**	Positive Medium
NS	Negative Small	**PB**	Positive Big
ZE	Zero		



plot points: 181

Name e

Type input

Range [-1 1]

Display Range [-1 1]

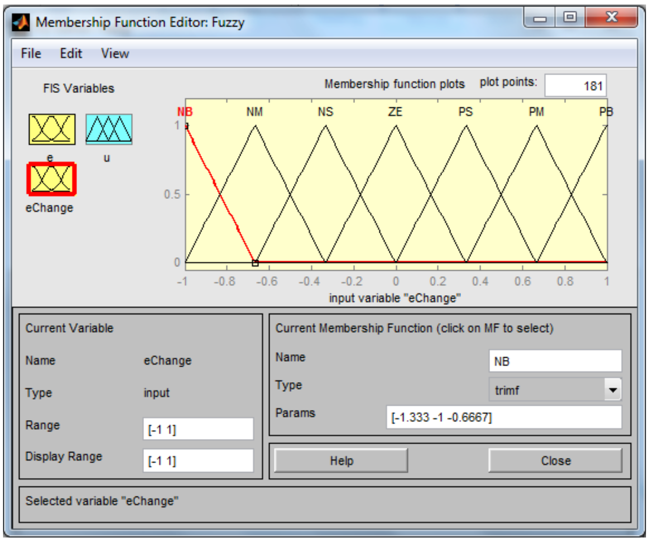
Name NB

Type trimf

Params [-1.333 -1 -0.6667]

Ready

Figure 3.9 Membership function for error (input 1)



plot points: 181

Name eChange

Type input

Range [-1 1]

Display Range [-1 1]

Name NB

Type trimf

Params [-1.333 -1 -0.6667]

Selected variable "eChange"

Figure 3.10 Membership function for error change (input 2)

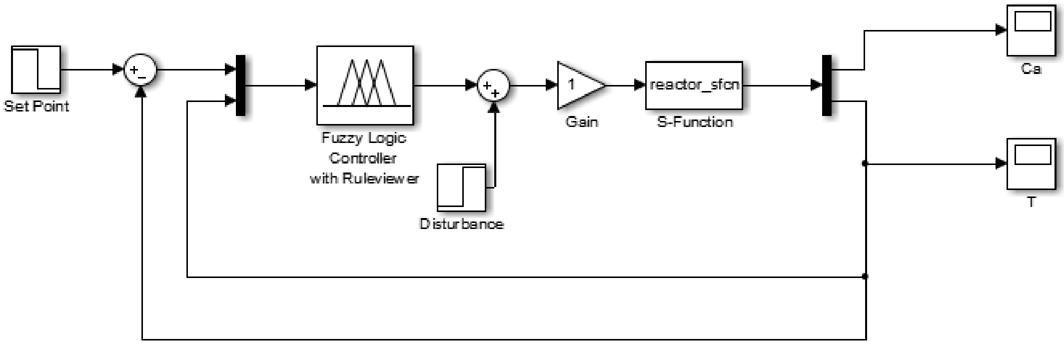
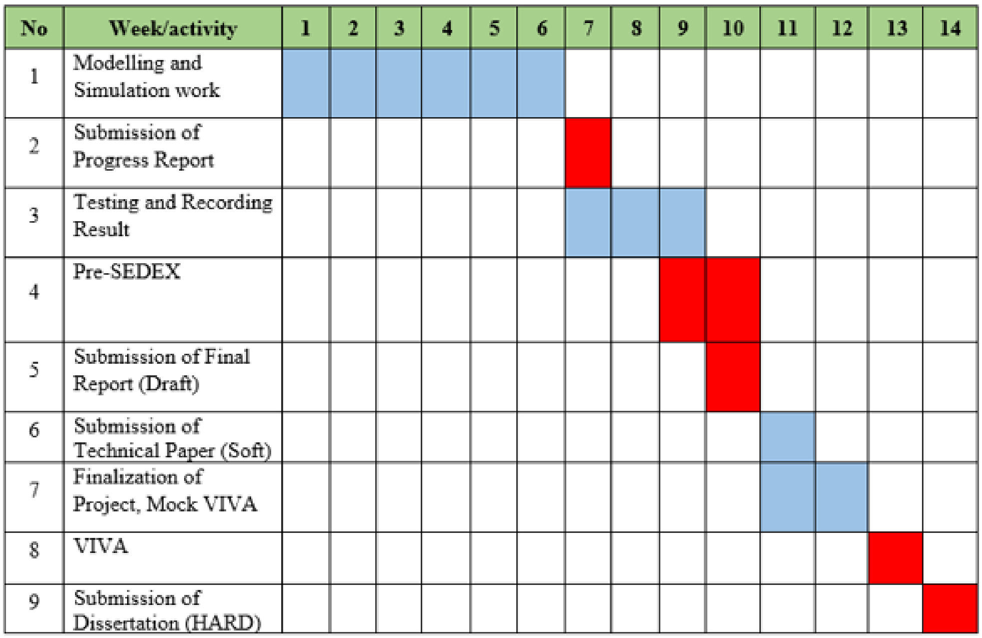


Figure 3.11 System reactor_sfcn with FLC in Simulink

3.4 Gantt chart and Key Milestones



No	Week/activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Modelling and Simulation work	🟦	🟦	🟦	🟦	🟦	🟦								
2	Submission of Progress Report							🟥							
3	Testing and Recording Result							🟦	🟦	🟦					
4	Pre-SEDEX									🟥	🟥				
5	Submission of Final Report (Draft)										🟥				
6	Submission of Technical Paper (Soft)											🟦			
7	Finalization of Project, Mock VIVA											🟦	🟦		
8	VIVA													🟥	
9	Submission of Dissertation (HARD)														🟥

🟦 **Gant chart**

🟥 **Key milestone**

CHAPTER 4

RESULTS AND DISCUSSION

4.1 PID Simulation Results

The temperature response that we obtained before applying any control system design can be seen in figure 4.1 below which is taken from the scope of the block designs in figure 3.5. In figure 4.1 we can see that there is that there is one peak that overshoots the valued set point. Initially the temperature was at 40°F and was set to reach a temperature of 36.7°F. The final output temperature shown was 37°F which vary from the set point value that needed to be attained.

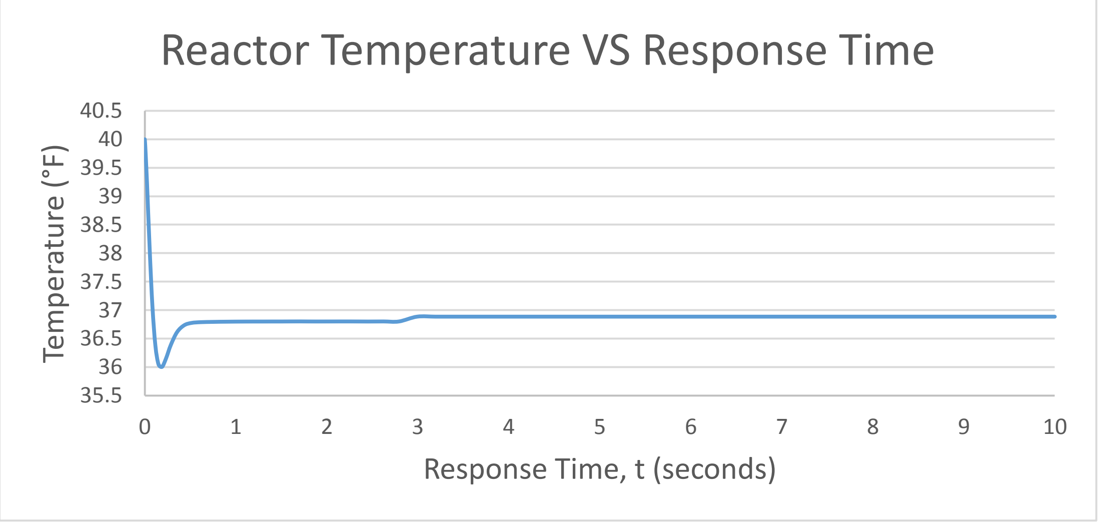


Figure 4.1 The temperature vs response time for an uncontrolled system.

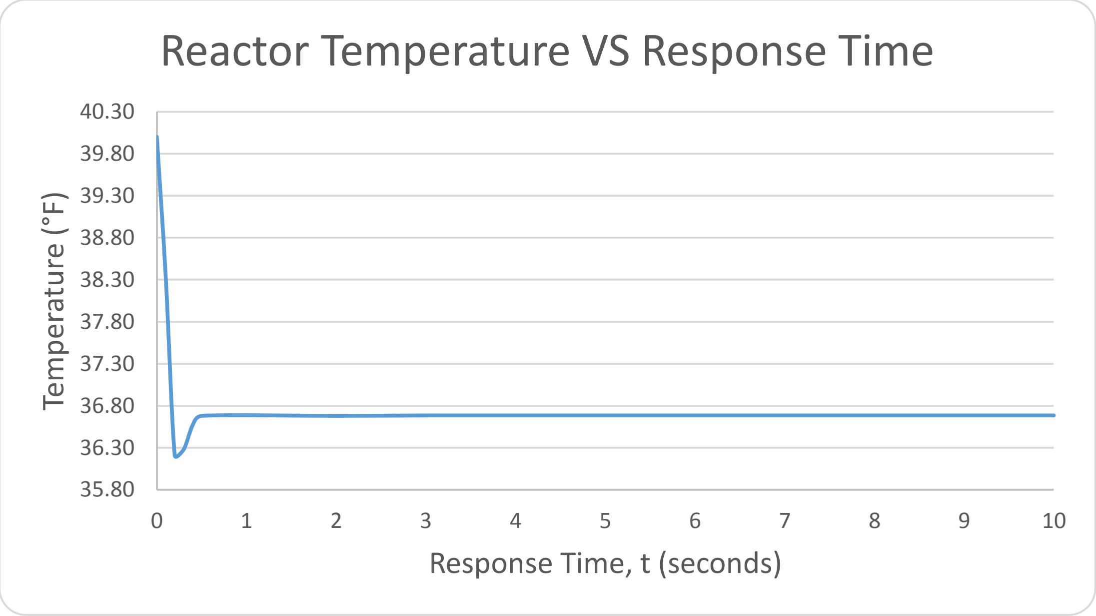


Figure 4.2 Temperature vs response time for PID controlled system

In the PID controlled CSTR system, the PID tuning coefficient is automatically generated using the tuner in the Function Block Parameters: PID Controller menu. The original coefficient that was input into the PID controller was $K_c = 8$ $K_i = 3$ and $K_d = 1$. After tuning, the coefficient values that was achieved was changed to $K_c = 4.11$ $K_i = 50.38$ and $K_d = -0.12$. In figure 4.2 we can see the temperature response of the CSTR system when applied PID tuned controller.

Initially the temperature falls quickly and settles in a split second to an intermediate temperature value which was at $T=37.5^oF$. When the response time reaches 1 second, it drops further to the set point value which is at $T=36.7^oF$. Comparing the PID controlled system with the uncontrolled CSTR system, we see that in a PID controlled environment there is no peak overshoot in the temperature response. In figure 4.3 we can see the PID step behaviour of the original CSTR response and the tuned response while in figure 4.4 shows the bode response both for block and tuned.

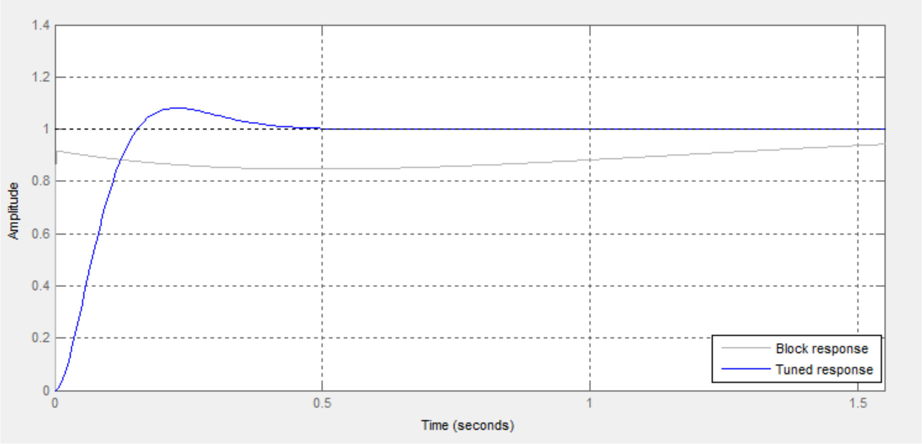


Figure 4.3 PID step amplitude against response time behaviour for block and tuned

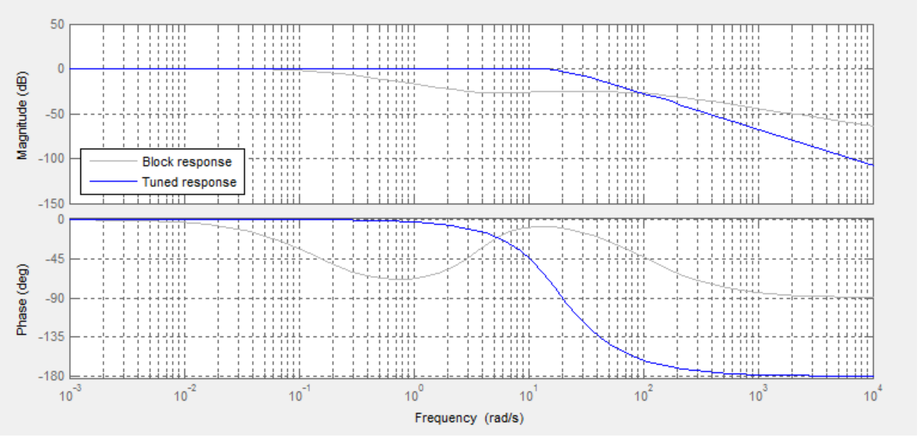


Figure 4.4 Bode Diagram for the PID control Phase and Magnitude against Frequency

4.2 FLC Simulation Results

In the FLC design of the CSTR system, we can see from figure 4.5 that the output temperature response of the reactor function is much more stable compare to the PID controlled system. We can observe that there is no peat overshooting while the setpoint temperature T=36.8°F value was reached in a smooth and steady manner. The time taken for the initial temperature to reach the setpoint value is approximately below 1 seconds while the temperature does not rest at any other temperature value.

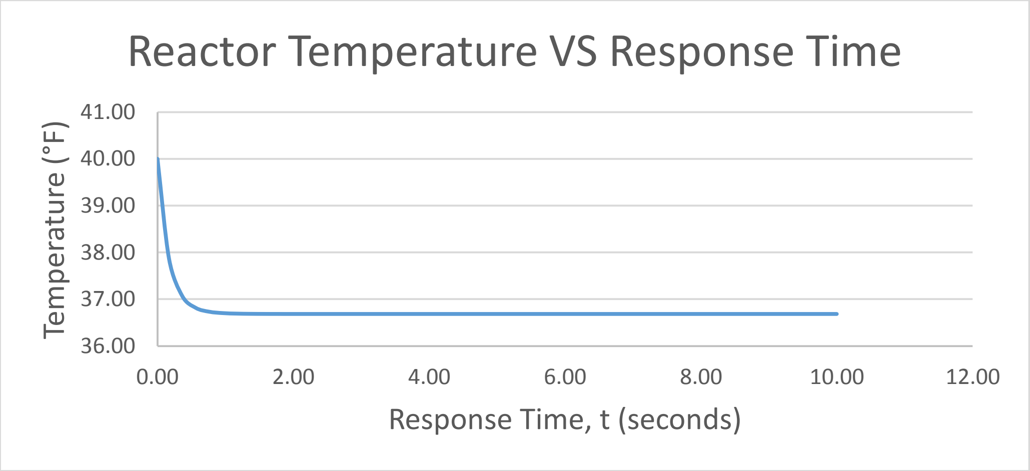


Figure 4.5 Temperature vs response time for FLC CSTR system

Comparing the PID and the FLC methods of controlling the non-isothermal CSTR model we can observe that the FLC is better at controlling a non-isothermal system comparing to the PID control system although that the tuning method of PID is very simple compared to the 49 rules relating membership functions of the Mamdani FLC design which finally gives the desired and most quickest response of a controlling parameters.

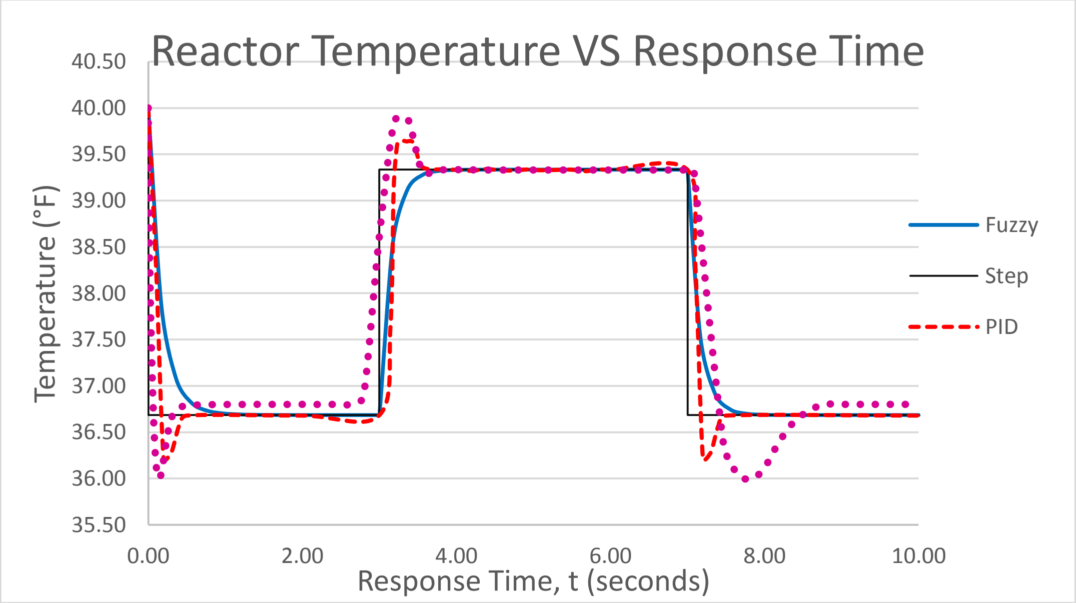


Figure 4.6 PID VS FLC with Pulse Generator

Table 4.1: Comparison between all types of controllers

Controller Types	Plot Behavior				
	Maximum Peak Temperature, °F	Settling Time (seconds)	Steady State Value	Steady State Error (%)	Peak Overshoot (%)
Uncontrolled System	36	0.78	36.79	0.30	1.85
PID Controlled System	36.21	0.5	36.68	0.00	1.28
Fuzzy Controlled System	36.68	1.15	36.68	0.00	0.00

From all of the results that was obtained in the experiment process, a comparative table showing the results and performance from all off the experiments in term of settling time, steady state value, percentage of steady state error, and percentage of peak overshoot. Similarly explained, the FLC gives the best performance in terms of steady state deviation and peak overshoots but when comparing the settling time, the FLC did not do well comparing to the PID System.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, this project was designed to develop a control system for a non-isothermal process in a CSTR which is theoretically hard to be controlled by the conventional PID controllers. The objective was to design a control system of a non-isothermal temperature control of a CSTR in order to produce the most theoretically stable response curve by comparing it with Fuzzy Logic Controller, FLC and Proportional-Integral-Derivative, PID controller.

The CSTR design was not designed into transfer function. Instead the application of S-Function block makes the modelling of a non-isothermal CSTR makes it easier and lesser time consumption compared using transfer function modelling which involves many mathematical equations and can be difficult to achieve an accurate model. The S-Function model was then later included in the Simulink block editor to be include with other block functions.

In the PID controller design it was initially specified that the tuning parameter was going to be achieved through trial and error method with a specific range of values to be applied and finally comes up with an initial guess of the parameter which are $K_c = 8$ $K_i = 3$ and $K_d = 1$. After tuning, the coefficient values that was achieved was changed to $K_c = 4.11$ $K_i = 50.38$ and $K_d = -0.12$. The results show that PID controller gives 0% peak overshoots but gives a response delay approximately 1 second until it reaches the desired temperature.

For the FLC design the defined type of FLC that was used in this project was the Mamdani type FLC. There are two input variables and one output variable where each of these variable was given 7 membership function labelled as in table 3.3 and the rules are as in table 3.4. The results of the FLC CSTR simulation is that there was also 0% peak overshoots and also there is no time delay for the temperature system. For CSTR system, the most required criterion is that the system has a no overshoot and zero steady-state error. Between these controllers, a comparison has been done to see which controller can meet the criterion. From the result and discussion section, the two controllers successfully designed were compared. The simulation results show that the FLC controller has the best performance because it has zero steady-state error at lowest time.

This project promises that it can give the process controlling industry an advantage and benefits in the future. Besides that, this project is considered to be feasible by taking into account the time constraint and the capability of final year student with the assist from the supervisor and coordinator.

5.2 Recommendation

For future study, we can include other ways or method in controlling the CSTR. One example is that we can change the control strategy from feedback to feedforward method. Besides that, we can also use a more complex control method such as Neuro-Fuzzy Design. The more complex the system, the more stable response it could achieve. The study of control system is unlimited, there are various ways to manipulate the methods and means to achieve the desired response of a system. Therefore, it is important that that there will be more studies and ecperiment of control and instrumentation design.

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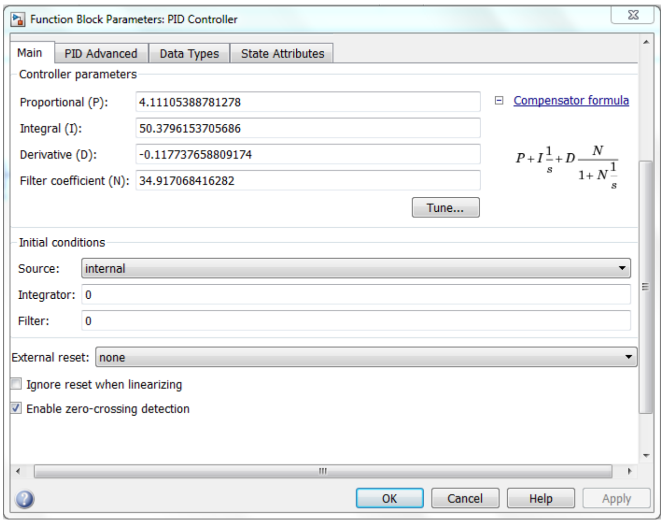
APPENDICES

a.PID tuning parameters from Simulink



Function Block Parameters: PID Controller

Controller parameters

Proportional (P): 4.11105388781278

Integral (I): 50.3796153705686

Derivative (D): -0.117737658809174

Filter coefficient (N): 34.917068416282

Compensator formula

$$P+I\frac{1}{s}+D\frac{N}{1+N\frac{1}{s}}$$

Initial conditions

Source: internal

Integrator: 0

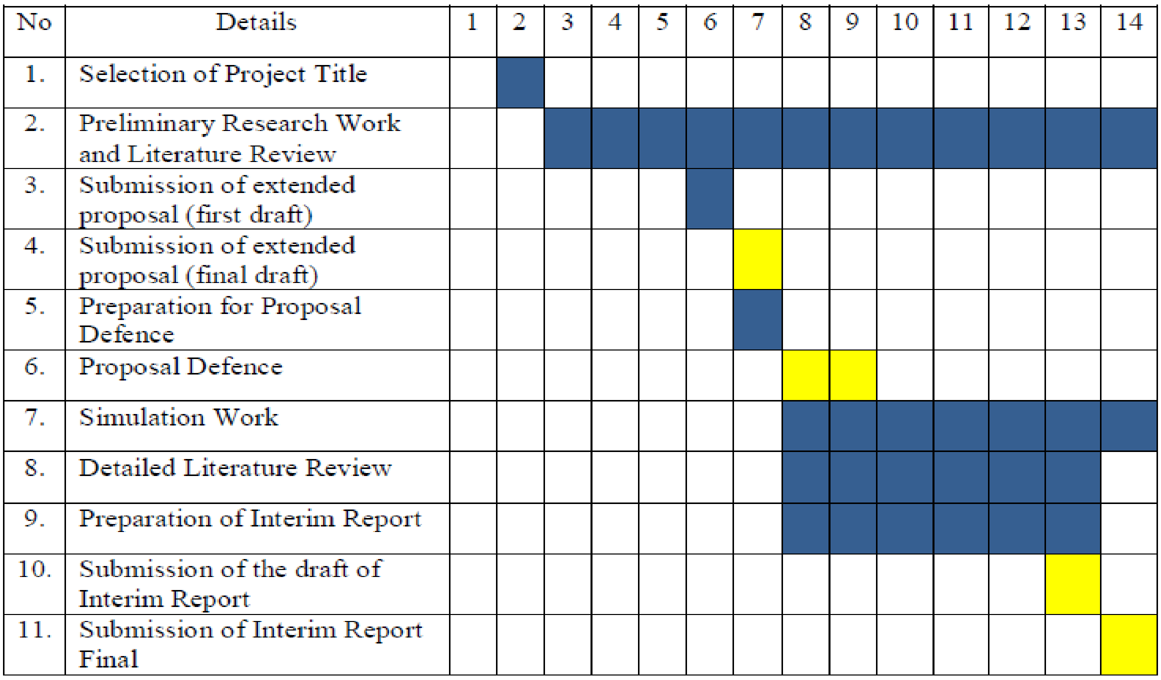
Filter: 0

External reset: none

☐ Ignore reset when linearizing

☑ Enable zero-crossing detection

b. Gant Chart for the initialization of the project.

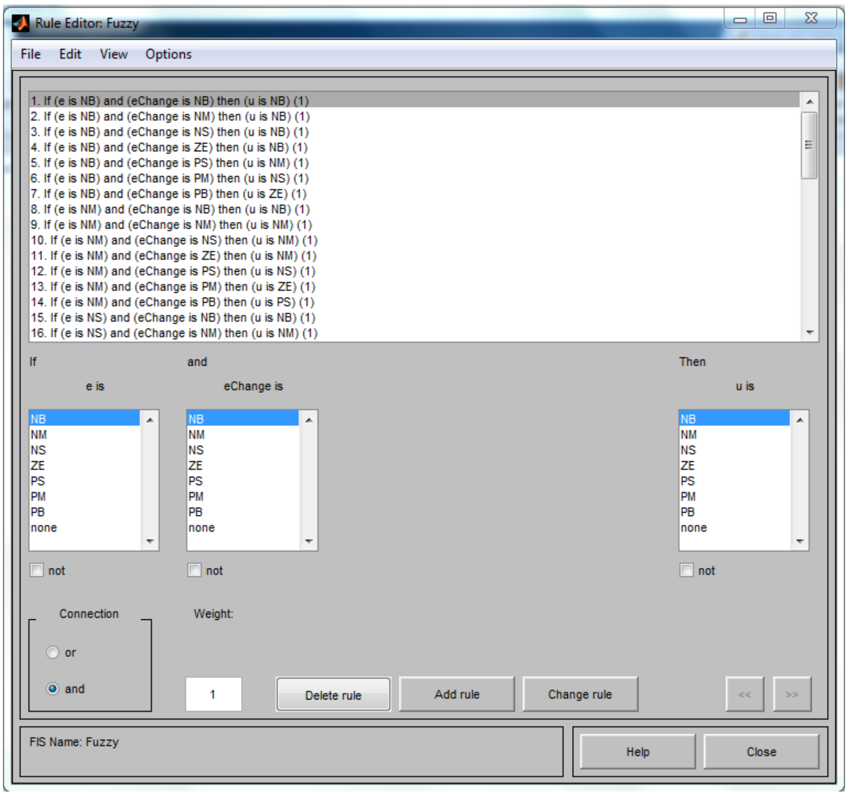


No	Details	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Selection of Project Title		🟦												
2.	Preliminary Research Work and Literature Review			🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
3.	Submission of extended proposal (first draft)						🟦								
4.	Submission of extended proposal (final draft)							🟨							
5.	Preparation for Proposal Defence							🟦							
6.	Proposal Defence								🟨	🟨					
7.	Simulation Work								🟦	🟦	🟦	🟦	🟦	🟦	🟦
8.	Detailed Literature Review								🟦	🟦	🟦	🟦	🟦	🟦	
9.	Preparation of Interim Report								🟦	🟦	🟦	🟦	🟦	🟦	
10.	Submission of the draft of Interim Report													🟨	
11.	Submission of Interim Report Final														🟨

🟦 Gantt chart

🟨 Key Milestone

c. Fuzzy Rules Editor containing the 49 inputs of rules.



```
1. If (e is NB) and (eChange is NB) then (u is NB) (1)
2. If (e is NB) and (eChange is NM) then (u is NB) (1)
3. If (e is NB) and (eChange is NS) then (u is NB) (1)
4. If (e is NB) and (eChange is ZE) then (u is NB) (1)
5. If (e is NB) and (eChange is PS) then (u is NM) (1)
6. If (e is NB) and (eChange is PM) then (u is NS) (1)
7. If (e is NB) and (eChange is PB) then (u is ZE) (1)
8. If (e is NM) and (eChange is NB) then (u is NB) (1)
9. If (e is NM) and (eChange is NM) then (u is NM) (1)
10. If (e is NM) and (eChange is NS) then (u is NM) (1)
11. If (e is NM) and (eChange is ZE) then (u is NM) (1)
12. If (e is NM) and (eChange is PS) then (u is NS) (1)
13. If (e is NM) and (eChange is PM) then (u is ZE) (1)
14. If (e is NM) and (eChange is PB) then (u is PS) (1)
15. If (e is NS) and (eChange is NB) then (u is NB) (1)
16. If (e is NS) and (eChange is NM) then (u is NM) (1)
```

○ or
● and

Weight: 1

FIS Name: Fuzzy

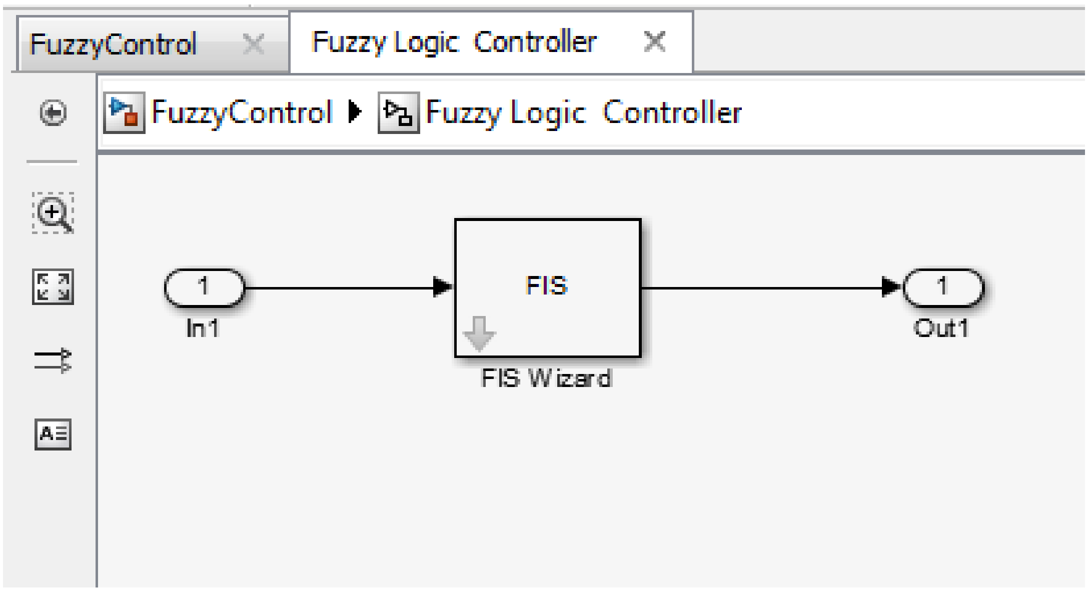
d. Working Data from MATLAB workspace

No Control		PID Controlled		Fuzzy Logic	
Time	Temperature	Time	Temperature	Time	Temperature
0	40	0	40.00	0.00	40.00
1.25E-06	39.99997442	0.1	38.32	0.17	37.86
7.48E-06	39.99984651	0.2	36.21	0.36	37.07
3.86E-05	39.9992062	0.3	36.28	0.56	36.82
0.000194	39.99598588	0.4	36.57	0.76	36.73
0.000974	39.97942113	0.5	36.68	0.96	36.70
0.004869	39.88579501	2	36.68	1.16	36.69
0.024345	39.23126708	3.00	36.68	1.36	36.69
0.053279	38.08316459	3.144667	37.64475678	1.56	36.69
0.083834	37.06647204	3.185968	39.13040324	1.76	36.69
0.116203	36.37933473	3.231661	39.60515462	1.96	36.69
0.1512	36.04462035	3.284567	39.64566703	2.16	36.69
0.189832	36.00252685	3.351086	39.63906617	2.36	36.68
0.233673	36.15262073	3.440654	39.62486604	2.56	36.68
0.285709	36.38624091	3.533307	39.3910617	2.76	36.68
0.354527	36.6128583	3.642689	39.33867097	2.96	36.68

0.432812	36.73349578	3.815365	39.33727838	3.00	36.68
0.5143	36.77471579	3.995848	39.33230304	3.18	38.56
0.614049	36.78765629	4.195848	39.32179089	3.37	39.12
0.752116	36.79302248	4.385834	39.34138	3.57	39.28
0.906308	36.79634747	4.558244	39.32674025	3.77	39.32
1.100575	36.79863147	4.758244	39.32507845	3.97	39.33
1.300575	36.79914779	4.917683	39.33578441	4.17	39.33
1.500575	36.79954328	5.077121	39.32792222	4.37	39.33
1.700575	36.8005775	5.277121	39.3303937	4.57	39.33
1.881971	36.79931261	5.477121	39.3347996	4.77	39.33
2.05247	36.80007749	5.677121	39.31786209	4.97	39.33
2.25247	36.80032397	5.85548	39.33715951	5.17	39.33
2.45247	36.79901477	6	39.33093603	5.37	39.33
2.623616	36.80047161	7.00	39.33	5.57	39.33
2.792707	36.80000739	7.10	38.32	5.77	39.33
2.992707	36.88	7.20	36.21	5.97	39.33
3.192707	38.56	7.30	36.28	6.17	39.33
3.369348	39.85	7.40	36.57	6.37	39.33
3.55461	39.88	7.50	36.68	6.57	39.33
3.75461	39.32	10.00	36.68	6.77	39.33
3.929259	39.33			6.97	39.33
4.092462	39.33			7.00	39.33
4.292462	39.33			7.17	37.53
4.492462	39.33			7.36	36.92
4.671914	39.33			7.56	36.75
4.848287	39.33			7.76	36.70
5.048287	39.33			7.96	36.69
5.239801	39.33			8.16	36.69
5.408062	39.33			8.36	36.69
5.591038	39.33			8.56	36.69
5.791038	39.33			8.76	36.68
5.978237	39.33			8.96	36.68
6.151181	39.33			9.16	36.68
6.351181	39.33			9.36	36.68
6.551181	39.33			9.56	36.68
7	39.33			9.76	36.68
7.01	39.33			9.96	36.68
7.080639	39.33			10.00	36.68
7.080639	39.33831646				
7.464482	39.33831646				
7.654877	36.37933473				

7.854877	36.04462035
8.024143	36.00252685
8.181205	36.15262073
8.381205	36.38624091
8.581205	36.6128583
8.76705	36.73349578
8.949273	36.8
9.149273	36.8
9.33338	36.8
9.495363	36.8
9.678889	36.8
9.878889	36.8
10	36.8

e. Fuzzy Logic Interface



f. Rule behaviour inside the FIS wizard