Advanced Control Studies on Heat Exchanger Pilot Plant

By

Awatif Binti Abdul Aziz

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

Electrical & Electronic Engineering

SEPTEMBER 2011

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Advanced Control Studies on Heat Exchanger Pilot Plant

by

Awatif Binti Abdul Aziz

A project dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Approved:

Dr Rosdiazli Bin Ibrahim
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2011

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.

Awatif Binti Abdul Aziz

ABSTRACT

Heat exchanger is a device that is widely used in engineering processes and often needed in a process plant. It is built for efficient heat transfer, from one fluid to the other and help in increasing or decreasing the temperature of medium that passes through the device. The application of heat exchanger can be seen in chemical plants, petrochemical plants, petroleum refineries, natural gas processing, power plants, and sewage treatment. Every process plant needs a reliable controller to control the system; therefore Proportional-Integral-Derivative (PID) controller was developed decades ago. In a heat exchanger device (and plant), normally PID controller is used. The conventional PID controller is very famous because of its simplicity and robustness. Although the controller is the most popular controller, its classic tuning suffers a few systematic design problems. It is difficult to adjust and get the best PID parameters. The objective of this project is to introduce alternative controller that uses advance control strategy. Designing the advance control strategy is based on the heat exchanger in a pilot plant in Universiti Teknologi PETRONAS (UTP). A pilot plant is a small chemical processing plant that is operated to generate information regarding the behavior of the real system used in a larger plant. The the development of new controller and the simulation of the controllers are through MATLAB. The aim is to improve the performance of pilot plant so that the operation will be smoother, more efficient and the product earn is improved by using the new control strategy. In the end of the project, the obtained model of the controller is Fuzzy Logic Controller (FLC). The developed FLC demonstrates better control performance than the conventional PID controller.

ACKNOWLEDGEMENTS

First and foremost, thanks to dear God for letting me live my life, now at least for 22 years.

This thesis would not have been possible unless Dr Rosdiazli guided me from the beginning till the final result. He assisted me, gave suggestions, solutions and recommendation through out the year for me to accomplish this project. Although I was sometimes, lost my focus, Dr Rosdi will be the one who will bring me back to the right path. I am totally grateful and proud to have him as my supervisor. He inspired me to do my very best for my thesis.

To my mother and father, who always give me support more than 100%, thank you so much. This thesis would not be completed if not because of support from my parents and family. They always be there whenever I need courage although most of them is not from engineering background.

I owe my deepest gratitude to my senior, Muhammad Muzamir who helped me in the beginning of the project for me to understand the topic better. Without him, I might not have the confidence to pursue the project. He made the Fuzzy Logic theory easy to understand and he also gave me advices on how to accomplish the project successfully.

Also, I would like to thank my classmate, Zulfadhli for helping me whenever I have problem with my project. He always remind me to focus and work on my thesis whenever he realized I was sitting back for too long. Also to Fadzielah, thanks for assisting me with MATLAB, although it was a small favour from you but it helped me a lot.

I am indebted to my housemates and friends who always be by my side and always supportive. Having all of you beside me makes me stronger. Those who help me directly and indirectly in accomplishing the thesis, thank you very much!

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CD-ROM	Compact Disc, Read-Only Memory
FGPI	Fuzzy Gain Scheduled PI Controller
FIS	Fuzzy Interference System
FLC	Fuzzy Logic Control
FODT	First Order with Dead Time
FYP	Final Year Project
IEEE	Institute of Electrical & Electronics Engineers
PD	Proportional Derivative
PDFLC	PD Fuzzy Logic Controller
PI	Proportional Integral
PID	Proportional Integral Derivative
PIDFLC	PID Fuzzy Logic Controller
PIFLC	PI Fuzzy Logic Controller
UTP	Universiti Teknologi PETRONAS

CHAPTER 1 : INTRODUCTION

1.1 Background of Study

Heat exchanger is one of the simplest and important units in process industries. It is used to transfer thermal energy between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperature and in thermal contact [1]. Typical applications of the device are to heat or cool a fluid stream that goes through the heat exchanger. The importance of a heat exchanger can be seen in refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, power plant and sewage treatment.

Heat exchanger plays an important role from the viewpoint of energy conservation, conversion, recovery and successful implementation of new energy resources. In most heat exchanger, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner [1]. Common examples of heat exchangers are shell-and-tube exchanger, automobile radiators, condensers, evaporators, air pre-heaters, and cooling towers.

The process industries which operate equipment at high pressure and temperatures with potential hazards need a dependable process control. That is why PID controller was invented back then, to equip the need of a controller in a plant. The control methods developed many decades ago were tailored to the limited computing equipment available at that time. PID controller is the most famous controller until present time. It is known to be used since 1940s when process control is developed and known as conventional controller.

The success of any plant depends on the performance of each and every unit of the plant. The heat exchanger performance can affect the total plant operation directly. Therefore, controller of a heat exchanger is important to ensure the process runs smoothly and efficiently. The heat exchanger is usually controlled by PID controller since the controller can give faster rise time as well as faster settling time. PID controller as well, compared to other method, is more effective and economical [2].

However, using this type of controller, more time is wasted in tuning the parameter to get the best values. The heat exchanger system has highly nonlinear features. When the operating point changes a little, the dynamic performance of the system may change a lot. For this reason, controller of a heat exchanger needs to respond accordingly and work well under different operating point [2].

The key to solve this is by inventing a new control strategy. There are several strategies in the market nowadays, such as Neural Network Controller, Model Predictive Controller, Genetic Algorithm and Fuzzy Logic Controller. In this project, the new controller that will be introduced is using Fuzzy Logic theory which is Fuzzy Logic Controller (FLC).

Fuzzy logic is the logic on which fuzzy control is based, and more users friendly. This is due to its environment that is closed to human thinking and natural language compare to the conservative control algorithms. Even if the users do not know the dynamic process underneath, one can design and operate the controller. Fuzzy control technique has been widely used in industrial processes, particularly in situations where conventional control design techniques are difficult to apply.

From experience, it shows that FLC yields results superior to those obtain by conventional control algorithms [3]. The main advantage of FLC is it can be applied to plants that are difficult to obtain the mathematical model and the controller can be designed to apply heuristic rules that reflect experiences of human experts [4].

1.2 Problem Statement

PID controller can be a controller with good performance if the correct tuning is being done and the right constant value is achieved. The controller can be tuned in several ways using Ziegler-Nichols method, Cohen Coon method, manual tuning and by using software.

The manual tuning allows engineer to tune straightaway online and understand how the closed system behaves but it may take long time to learn the behavior and difficult to sense whether the final setting is optimal or not.

The control system can perform poorly and become unstable if the constant values are not correct and improperly tuned. This problem will affect the plant process and give poor overall performance.

1.2.1 Significant and Feasibility of the Project

The notion of the project is to design and developed an advanced control strategy to the heat exchanger in a pilot plant using FLC. The aim is to improve the smoothness and efficiency of the process plant. FLC can be seen to be a reliable controller that provides an intuitive way to design function blocks for intelligent control system.

It can control complex processes and be applied to plant that is hard to obtain its mathematical model. The FLC can mathematically emulates human reasoning and improve the management of uncertain variable such as temperature variation. Successful FLC controller can improve the performance smoothness and efficiency of the process plant. Furthermore, it can increase product quality, profit and production rate. These reasons show that it is significant to continue the project.

This project is done within two semesters. In the end of the project, the new controller is seen to be giving better performance than conventional controller. The project is directed according to the methodology and milestone that has been planned, referring to Table 2.

1.3 Objectives and Scopes of Study

The objectives of the project:

i. To design and develop an advanced control strategy (FLC) for the use in heat exchanger pilot plant
ii. To observe, compare and analyze the control performance of the proposed controller with the conventional controller (PID controller).

The scope of study:

i. Plant based on the pilot plant located in Universiti Teknologi PETRONAS (UTP) laboratory
ii. Development and simulation of PID controller for heat exchanger model using MATLAB software
iii. Designing and development of new advanced control strategy of FLC using MATLAB software

CHAPTER 2 : LITERATURE REVIEW

2.1 Heat Exchanger

A wide range of industries use heat exchangers in continuous process and operations. It is often that a heat exchanger is part of a larger process and it became important over the past quarter century [9]. The importance of heat exchangers increased immensely from the viewpoint of energy conservation, conversion, recovery, and successful implementation of new energy sources [1].

Heat exchangers are used to bring the product to the specified temperature [3]. This device was built for efficient heat transfer from one fluid to another and is widely used in engineering processes, for example in air conditioning, refrigeration, space heating, power production and chemical processing [12].

There are many type of heat exchangers available; Liquid to Liquid Exchangers, Fired Exchangers, Steam Heaters, Condensers and Reboilers. The classification of heat exchangers can be made according to its transfer process, number of fluids, surface compactness, construction, flow arrangements, or heat transfer mechanisms [1]. All types of heat exchangers share a common objective which is to help in producing high quality products safely and efficiently.

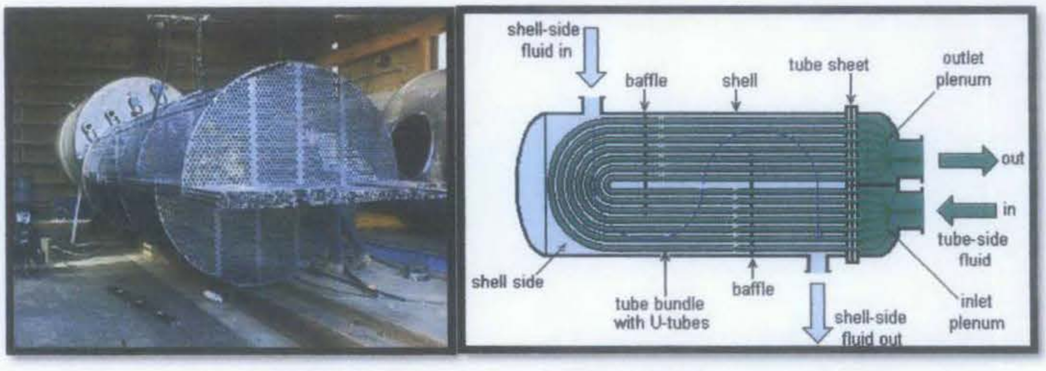

Figure 1 : Shell and Tube Heat Exchanger

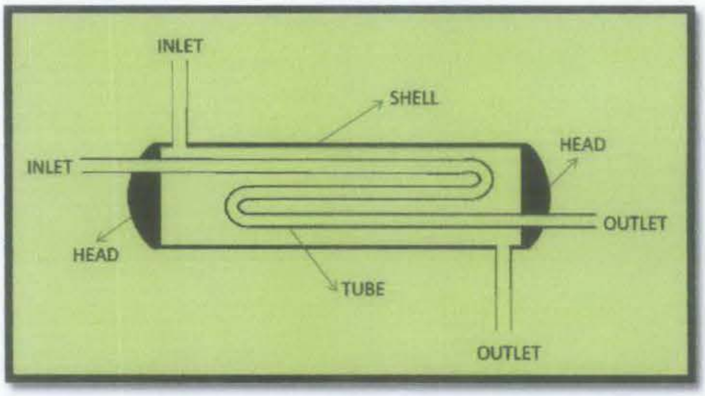

Figure 2 : Cross-Section of Shell-and-Tube Heat Exchanger

Figure 2 shows the shell-and-tube heat exchanger which is the most commonly used in process plant. It is widely used as power condensers, oil coolers, preheaters, and steam generators. It consists of many tubes, mounted parallel to each other in a cylindrical shell. Depends on the configuration of shell-and-tube heat exchanger, the flow may be parallel, counter, or cross flow. The heat transfer between the tube and shell is quite rapid and efficient. Shell-and-tube designs are fairly simple and most often designed according to the Tubular Exchanger Manufacturer's Association (TEMA) standards. There are two configurations of heat exchangers (shell-and-tube):

i. Product through tube while heating medium flows through the shells
ii. Product flows through the shell while the heat exchanger medium through the tube

2.2 Plant Process Description

The heat exchanger pilot plant is designed for the temperature loops for the exchanger can be controlled by microprocessor based controller. Distributed Control System (DCS) can control the process plant using supervisory control mode (SCADA) or direct digital control mode (DDC). The DCS can control the process through process controller, if using SCADA. While using DDC, it can directly control the plant through Field Control Station.

The heat exchanger medium used is liquid and based on Heat Exchanger module at the pilot plant, a double pass shell and tube exchanger E-221 is used for the study of process control. Hot water is circulated in the system by pump P-213 through the tube side of the heat exchanger and proceeds to hot water tank T-203. Cold water on the other hand, is distributed by pump P-211 from tank T-201 through the shell side and is collected as the heated product in tank T-202. The product can also be cooled down by an air-cooled radiator E-222 and re-circulated back to the cold water tank T-201.

To monitor the product temperatures, RTD Temperature Transmitter, TT-221 is used and it feeds the signal to a PID loop TIC-221. The output is fed into the control valve TCV-221 which regulates the amount of heating energy into the heat exchanger. The On-Off Temperature Controller, TIC-203 is use to control the temperature in the hot water tank T-203 according to a stated temperature. Another controller LIC-202 is use as a batching controller which controls LV-202 to group a certain quantity of product in tank T-202. Solenoid valves are used for the purpose of fault simulation in several segments of the process line.

2.3 Process Controller

In every plant and system in process industries, (including the heat exchanger) a reliable process control is needed. A control system is crucial as the variables need to be maintained at their desired readings even when disturbances occur and also to respond to changes in the targeted values [5]. The desired values are based on detailed analysis of the plant operation and objectives. These are the main objectives of the process control; safety, environmental protection, equipment protection, product quality, profit optimization, monitoring, diagnosis and smooth plant operation [5].

The control system works in feedback control where the desired value must be set and as the process goes, the sensor will sense the variable (eg: temperature). Controller will be responsible in adjusting the variable to achieve the desired value set in the beginning.

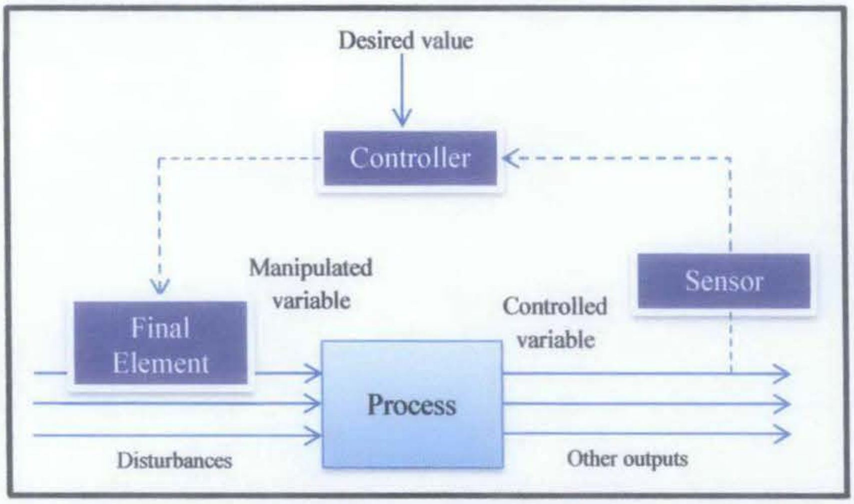

Figure 3 : Feedback System

2.4 Conventional Controller

As control system is needed, PID controller was developed many decades ago and being used as industrial controller until today. Proportional-Integral-Derivative Controller or known as PID Controller is the most common form of feedback and became the standard tool when process control was developed in 1940s. PID controllers have been utilized for control of diverse dynamical systems ranged from industrial process to aircraft and ship dynamics [13].

It is so popular that more than 95% of the control loops are of PID type in the process control nowadays, and most are actually PI controller. PID Controller remains the most often algorithm used today because of its simplicity, robustness, performance characteristics and successful practical applications [6].

It is as well, an important element of a Distributed Control System (DCS). Basically, all PID controllers made today are based on microprocessors. Therefore, the controller is given opportunities to provide additional features such as automatic tuning, gain scheduling, and continuous adaptation [7]. The controller operates by calculating the inaccurate value as the difference between a Measured Variable (MV) and a desired Set Point (SP). The controller will then try to minimize the error by adjusting the process control inputs [8].

Although PID controller is the most popular controller for the majority of control systems, the classic tuning methods involved in the controller suffers with a few systematic design problems [6]. It is difficult to adjust the PID parameters and once the parameters are adjusted, they remain unchanged during the control systems operation [13].

Linear fixed-gain PID controllers are often acceptable for controlling a minor physical process; however the requirements for high-performance control with changes in operating conditions or environmental parameters are usually beyond the capabilities of simple PID controllers [13]. Nevertheless the most difficult part of PID controllers is how to alter the three parameters with the change of operating conditions and environmental parameters. It takes longer time to tune and get the best tuning of PID parameters.

In order to improve the performance of linear PID controller, various approaches have been developed to enhance the flexibility and robustness. Several approaches that been adopted are the self-tuning method, general predictive control, fuzzy logic and neural networks strategy. It can be conclude that, the control system method has been developing and new approaches can replace the old conventional method. But as for now, a heat exchanger still uses the PID controller as its control system.

2.4.1 PID Controllers

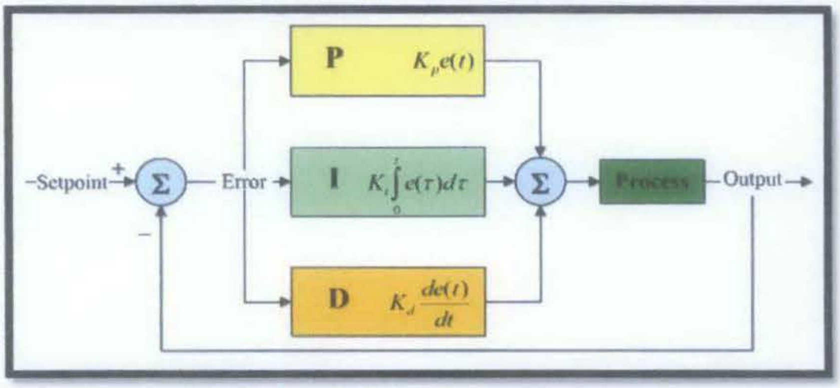

Figure 4 : PID Controller Block Diagram

PID Controller comprises of three separate controllers, which are *Proportional* (P), *Integral* (I) and the *Derivate* (D) controllers. The proportional term considers *how far* PV is from SP at any instant in time. Its influence to the controller output is based on the size of error ($e(t)$) only at time t. The effect of the proportional term grows or shrinks immediately and proportionally as $e(t)$ grows or shrinks.

As for the integral term, it shows *how long* PV has been away from SP. The integral term will continually summing the size of error. Even if it is a small error, it will take into account and influence of the integral term will similarly grow. The magnitude of integral term to the control action is expressed by the integral gain, K_i.

The derivative term on the other hand, describe how steep a curve is. The curve is which the slope or rate of change of a signal trace at a particular point of time. The derivate term magnitude is determined by derivative gain K_d.

$$P_{out} = K_p\, e(t);\;\; I_{out} = K_i \int_0^t e\,(\tau)\, d\tau;\;\; D_{out} = K_D\, \frac{de(t)}{dt}$$

Performance of PID controller can be improved through proper tuning. Tuning is the procedure of adjusting feedback controller parameters to obtain a specified closed-loop response. Poor tuning can lead to unacceptable performance. There are a few methods of PID controller tuning which are:

i. Manual tuning
ii. Ziegler-Nicholes Open-Loop/Closed-Loop
iii. Ciancone
iv. Cohen-Coon

2.5 Advanced Control Strategy

Currently, fuzzy logic emerged as a profitable tool for the controlling of complex industrial process and other application such as subway systems, household and entertainment electronics, and diagnostic system [10]. Fuzzy logic was invented in United States by Lotfi A. Zadeh, a professor for computer science at the University of California in Berkeley. Fuzzy-research is widely supported and emerged as one of the most active and fruitful areas for research in the application of fuzzy theory [3]. For example, the NASA space agency is engaged in applying Fuzzy Logic for complex docking-manoeuvres [10].

Recent applications of fuzzy logic controller (FLC) have appointed a way for an effective utilization of fuzzy control in the situation where the process is complex and unclear. Using FLC, system can be controlled by a skilled human operator without the knowledge of their underlying dynamics [3]. It can be said that fuzzy logic is much closer to human thinking and natural language, rather than the traditional logical systems. It provides an effective means of capturing the approximate nature of the real world.

The important part of the FLC is a set of linguistic control rules related by the dual concepts of fuzzy implication and the compositional rule of inference [3]. Fuzzy Logic is basically a multivalued logic that allows intermediate values to be defined between conventional evaluations like Yes or No, True or False, Black or White, etc. Conditions like rather warm or pretty cold can be formulated mathematically and processed by computers. In this way an attempt is made to apply a more human-like way of thinking in the programming of computers [10].

Therefore FLC provides an algorithm which can convert the linguistic control strategy based on expert knowledge into an automatic control strategy. From the experiments done by the researchers, FLC can yields results superior than those obtain from the conventional control algorithms. This shows that the methodology of FLC can be very useful when the process is complicated for analysis using conventional techniques or when the available data are interpreted uncertainly. Thus fuzzy logic control may be viewed as a step toward a rapprochement between conventional precise mathematical control and human-like decision making [11].

2.5.1 Fuzzy Logic System

There are two major parts involved in the process of developing a controller which are Fuzzification and Defuzzification.

- **Fuzzification**: Generation of membership values for the conditions and the output using the membership functions. These conditions are inferred to the fuzzy set with a certain degree of membership using the predetermined membership function
- **Defuzzification**: The conversion of a fuzzy quantity, represented by a membership function to a crisp value.

The overall process block diagram for a Fuzzy Logic Controller is shown as below. The Fuzzy Sets emulates the expert's decision making in interpreting and applying knowledge about how best to control the plant.

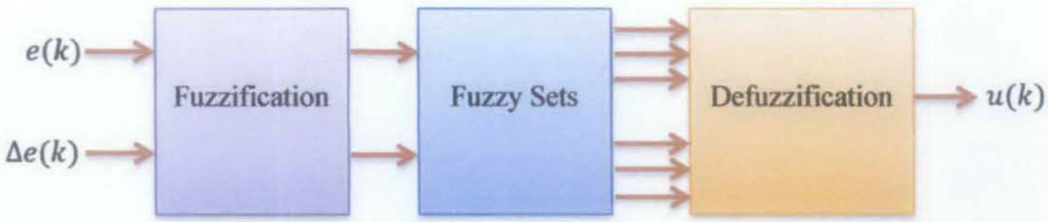

Figure 5 : FLC process block diagram

Where; $e(k)$= Error

$\Delta e(k)$ = Change in Error

$u(k)$ = Output

A fuzzy set is a set without a crisp and is a clearly defined boundary. It can contain elements with only a partial degree of membership [14]. A fuzzy set can be represented by a membership function, which is a possibility function (not a probability function). Fuzzy logic uses IF/THEN rules, for example:

IF temperature is very cold THEN hot water valve will be opened larger

IF temperature is cold THEN hot water valve will be opened medium

IF temperature is normal THEN hot water valve will be closed

All of the rules are evaluated and no "ELSE" statement because the temperature might be cold and normal at the same time to different degrees.

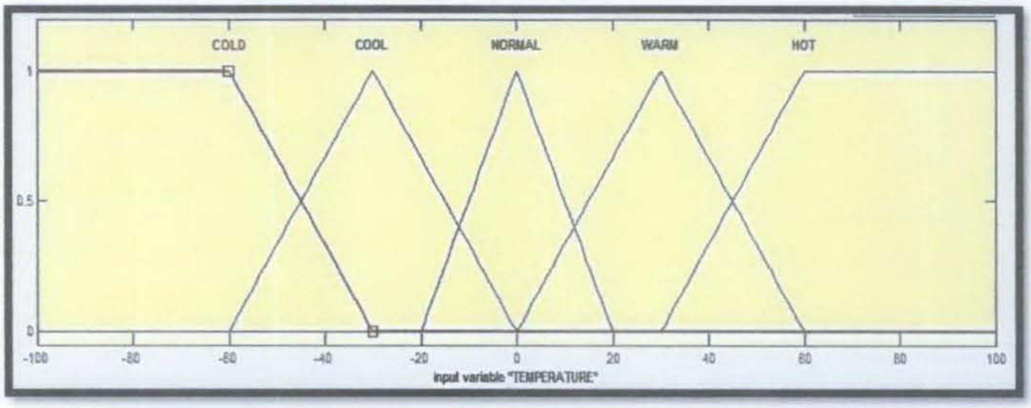

Figure 6 : Graphical Representation of Membership Function

This membership functions (MF) are the curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The input space is sometimes referred to as the universe of discourse [14]. After getting the membership function, there is a process called, Fuzzy Inference.

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made [14]. There are two types of fuzzy inference systems which are Mamdani and Sugeno. The difference between these two types is the process of Defuzzification. Mamdani approach shows the whole membership functions whereby Sugeno takes a spike of the output.

CHAPTER 3 : METHODOLOGY

3.1 Research Methodology

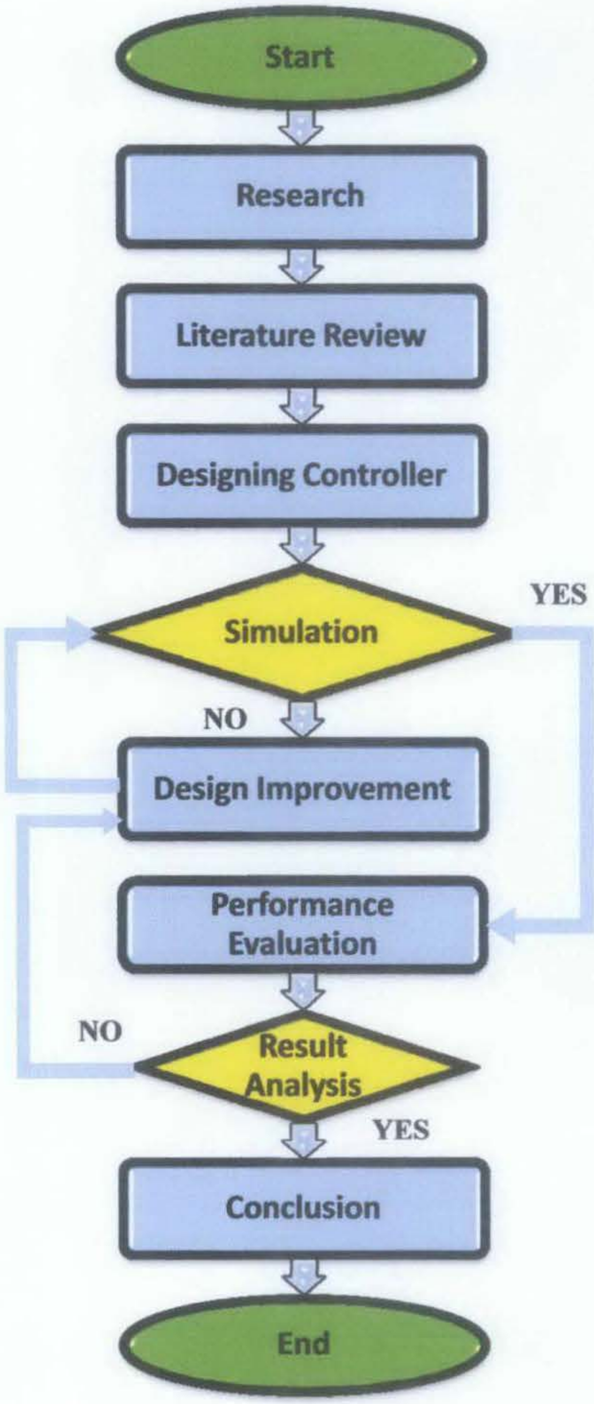

Figure 7 : Project Flow Diagram

The previous figure shows the flow chart of the project. From the flow diagram, the steps and direction of the project can be seen clearly. It has been designed to fully utilise the time frame given to complete the project. The flow chart helps in developing and making the project successful.

3.2 Project Activities

Table 1 : Project Work Description

Methodology	Description
Research	Conduct research on heat exchanger and plant process controller which are PID controller, Fuzzy Logic Controller and several other controllers. Research is done by referring journals, thesis, books, conference papers, technical reports, internet and interactive media (CD-ROM).
Literature Review	Making clear the objective of the project. Outlining the direction by referring to the research that has been done. Afford to understand what is the type of controllers been used in the past and what can be improved for the next controller designed. Expectation is clearly stated at this methodology.
Designing Controller	The plant will be modelled using Simulink in MATLAB. PI Fuzzy Logic Controller modelled is integrated with PID in order to characterise the PID responses. The new modelled will be giving better output compare to PID response. PID Controller will be designed using MATLAB as well.

Simulation	Simulation is done using MATLAB. It uses Fuzzy Interference System (FIS) which are developed using Fuzzy Logic Toolbox and Empirical model of the plant.
Design Improvement	If simulation does not give satisfy output, improvement should be carried out. Design improvement involves the changes of design modelled that is made earlier to get a better output.
Result Analysis	The performances of the advanced control strategy (FLC) will be analysed and the success will be determine by comparing to the output of PID controller. The new controller must give better performance compare to the conventional controller.

3.2.1 Designing Controller

PID controllers and the new control strategy are designed and been simulated using Simulink in MATLAB. By simulating using MATLAB, the controller's respond can be obtained without much hustles. Analysis can be done easier using this software.

The model of controller is created by connecting the block diagrams which can be attained from the Simulink Library. The construction of the controllers is based on technical knowledge and research.

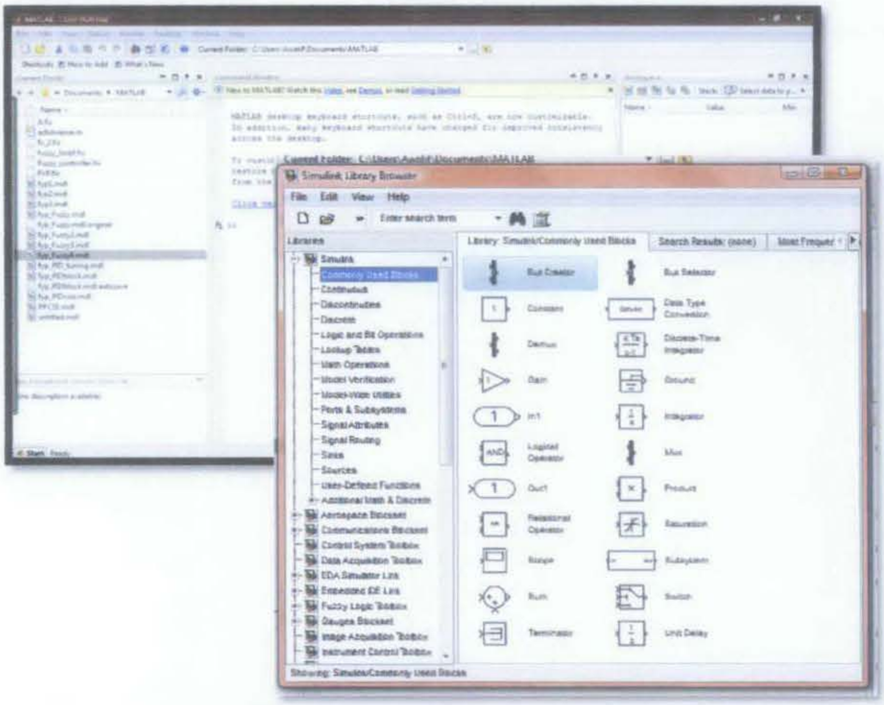

Figure 8 : Simulink Library Browser

3.3 Tools and Equipment Used

To carry out the project, the heat exchanger pilot plant was used to get the transfer function. MATLAB on the other hand is used to design and simulate controllers for the heat exchanger.

Figure 9 : Tools and Equipments Used

3.4 Gantt Chart

Table 2 : Gantt chart of Final Year Project (FYP) I

No	Details / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Topic Selection and Confirmation		1												
2.	Preliminary Research Work				2										
3.	Preparation of Extended Proposal						3								
4.	PID Controller Design							4							
5.	Familiarization with Fuzzy Logic Theory											5			
6.	Proposal Defence									6					
7.	Fuzzy Logic Controller Design and Simulation													7	
8.	Performance Evaluation														8
9.	Analysis and Improvement of design														
10.	Preparation of Interim Draft Report														
11.	Improvement of Interim Report														9

Process   Suggested Milestone

Table 3 : Gantt Chart of Final Year Project (FYP) II

No	Details / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.	Analysis and improvement of design	■	■	■	1											
2.	Performance Evaluation				■	■	2									
3.	Preparation of Progress Report						■	■	3							
4.	Analysis and Conclusion						■	■	■	■						
5.	Preparation for Pre-EDX									■	■	4				
6.	Preparation of Report									■	■	■				
7.	Submission of Draft Report												5			
8.	Submission of Dissertation													6		
9.	Submission of Technical Paper													7		
10.	Slide preparation and Oral Presentation													■	8	
11.	Submission of Project Dissertation (Hard bound)															9

■ Process   ✹ Suggested Milestone

3.5 The Milestones

The projects flow can be seen from the previous Gantt chart and there are a few milestones that been set in order to ensure that the project is completed within the time and scope. Gantt chart is very important to structured the project according to time allocated. This project successfully went according to the plan and meet all the milestones.

1
- Confirmation of the topic selection and submit the Form 02 to the FYP coordinatior

2
- Successfully gained and gather information on heat exchanger, conventional controllers and advanced control strategies
- Submission of Literature Review to FYP Supervisor

3
- Submission of Extended Proposal to the FYP coordinator

4
- Successfully obtained the parameters and PID controller design in MATLAB
- Sucessfully simulate the PID controller using MATLAB

5
- Fully understand the concept of Fuzzy Logic and ready to design a new controller, Fuzzy Logic Controller (FLC)

6
- Fully understand and familiar with the plant flows and operation

7
- Came out with a new design of FLC and simulate using MATLAB

8
- Evaluate the performance of the designs of FLC obtained

9
- Submission of Intertim Report to the FYP Supervisor

Figure 10 : The Milestones for FYP 1

Below are the milestones planned for Final Year Project (FYP) II.

1. Successfully analyze and improve the design to get better performance
2. Successfully evaluate the performance of the finalized design
3. Submission of Proress Report
4. Poster Presentation during Electrical & Electronic Exhibition (ELECTREX)
5. The Draft Report submission
6. Finalizing the Dissertation
7. Submission of Technical Paper
8. Sucessfully done Oral Presentation
9. Submission of Project Dissertation (hardbounded)

Figure 11 : The Milestones for FYP II

CHAPTER 4 : RESULT AND DISCUSSION

The achieved the objective, the control performance obtained from both conventional and new controller must give zero offset and zero overshoot.

4.0 Conventional Controller Design – PI Controller

The PID controller is designed based on the equation below whereby the parameters are obtained from the PID Tuning.

$$MV(t) = K_c \left(E(t) + \frac{1}{T_I}\int_0^t E(t')dt' + T_d \frac{dE(t)}{dt} \right) + I$$

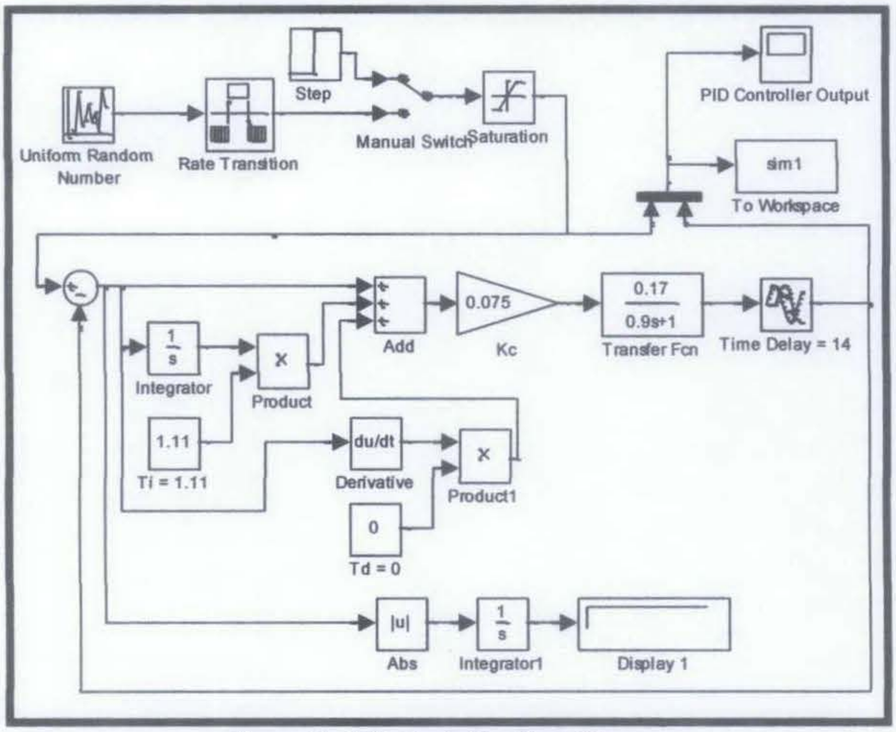

Figure 12 : PID Controller Block Diagram

The transfer function for the heat exchanger is $\frac{0.17e^{-14s}}{0.9s+1}$. This transfer functions has been obtained by experimental work and modelling from previous experiment in the heat exchanger pilot plant. From the transfer function, it is identified to be First Order Transfer Function. The PID controller parameters gained as displayed on the table below. The values received after the tuning process using Ziegler-Nichols method during experiment.

Table 4 : PI Controller Parameters

Parameter	Value
K_c	0.075
T_i	1.110
T_d	-

Result of the simulation is as seen below where the response has no overshoot and the IAE can be considered as large. The settling time and rise time is very slow. Observation is made for the response to a set point as well as to random set points.

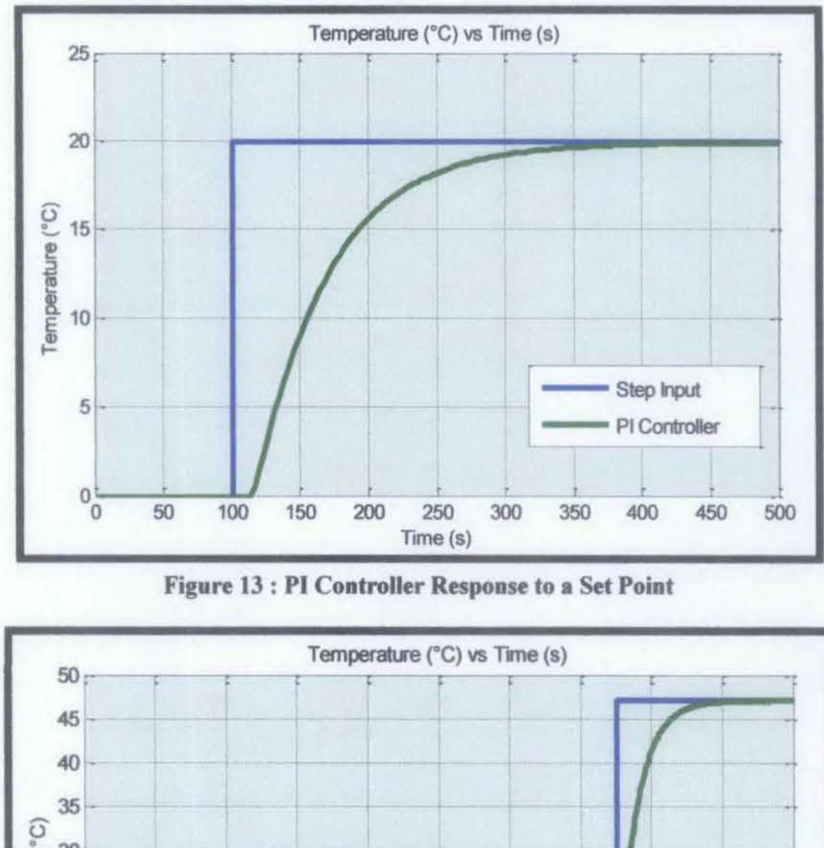

Figure 13 : PI Controller Response to a Set Point

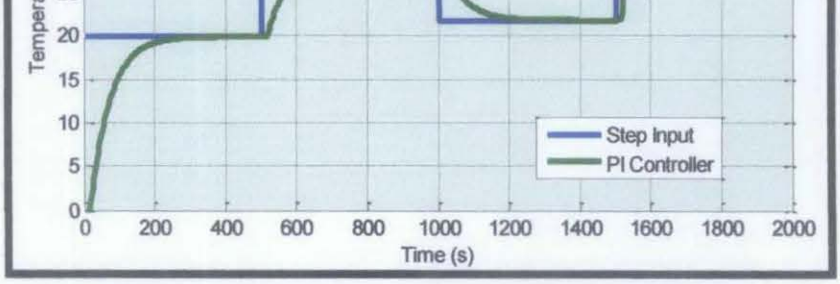

Figure 14 : PI Controller Response to Random Set Points

After observation and analysis, below are the results for the PI Controller. Result is obtained from the controller respond to one step change, which is from 0 to 20°C. This result is used as benchmark in designing the new controller where it must achieve better performance than this conventional controller.

Table 5 : PI Controller Performance

Control Performance	PI Controller
Offset	Zero
Integral Absolute Error (IAE)	1413
Decay Ratio	Zero
Rise Time, T_r	(450-14) = 436 seconds
Settling Time, T_s	450 seconds
Percentage Overshoot	0%
Slope, s	$\frac{10-0}{68-18} = 0.2$

4.1 New Controller Design –Fuzzy Controller

Analysing the past results is important in order to identify which factors need to be adjusted. Several attempts in designing new controller have been done. The aim is to get the best Fuzzy Controller and can perform better than the conventional PI Controller. The factors that need to be taken care of are :

i. Input and output of the fuzzy logic controller
ii. Number of membership functions
iii. Range of the input and output
iv. Relationship and rules

There is only one input which is the Error and one output which is the Valve Opening for the fuzzy logic controller.

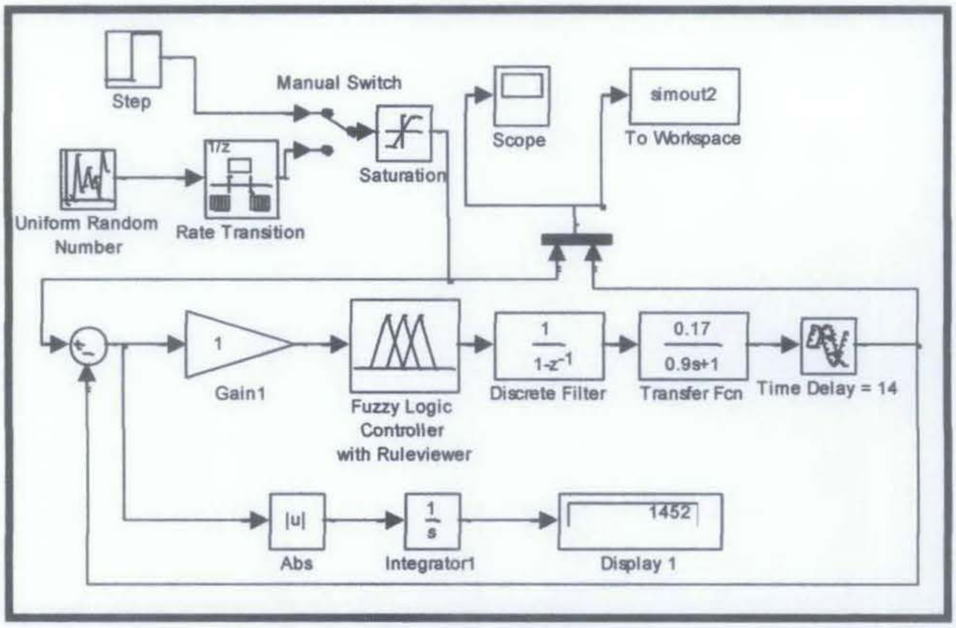

Figure 15 : Fuzzy Controller

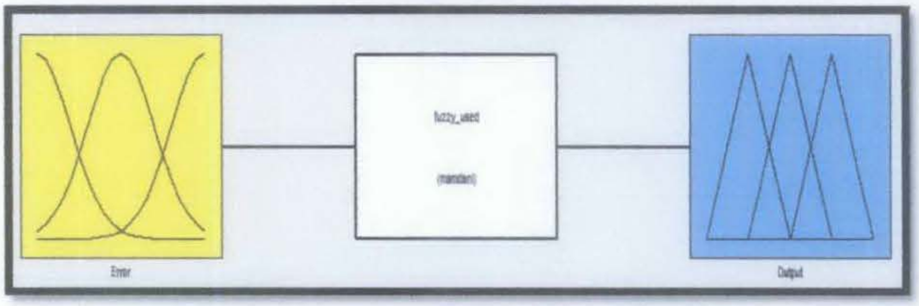

Figure 16 : Input and Output Variable in FIS Editor

By increasing the number of membership functions, it helps to improve the performance and minimize the rising time of the controller. Therefore, in this controller, 7 membership functions are used.

These the membership functions and the range can be seen from the graph;

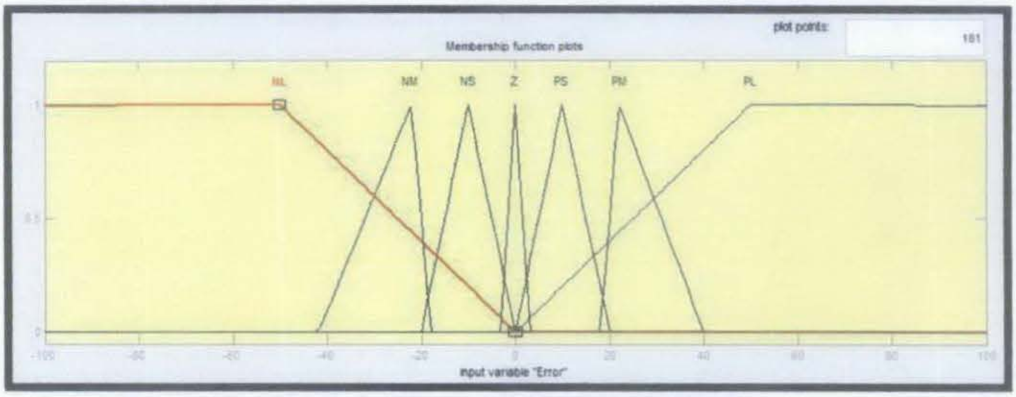

Figure 17 : Membership Functions for Error

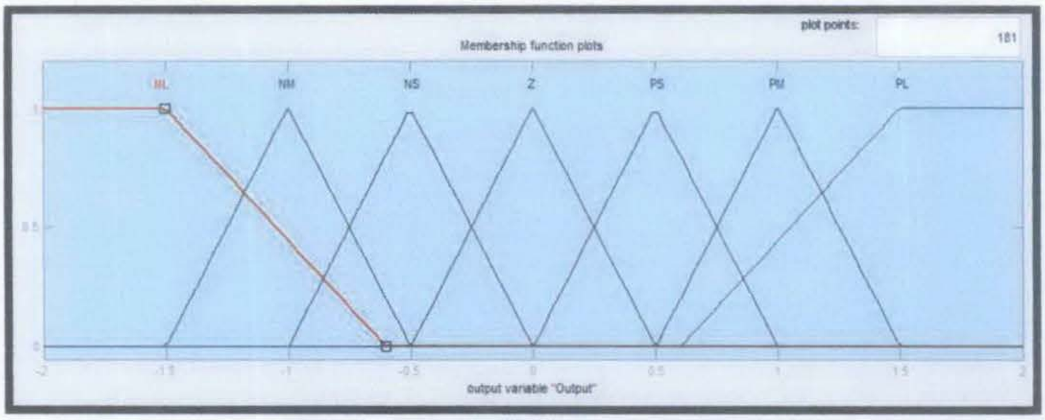

Figure 18 : Membership Functions for Output

The membership functions should cover the range effectively for the purpose of getting the smooth respond and minimum rising time. The smaller the range covered for each function, the respond will be better. The relationship of input and output is according to the table below. By referring to the table, it is understand that for example; "When the Error is Negative large, the Output will be Negative Large".

Table 6: Relationship between Inputs and Output

Input	Output
NL	NL
NM	NM
NS	NS
Z	Z
PS	PS
PM	PM
PL	PL

N = Negative; P = Positive; Z = Zero; S = Small; M = Medium; L = Large

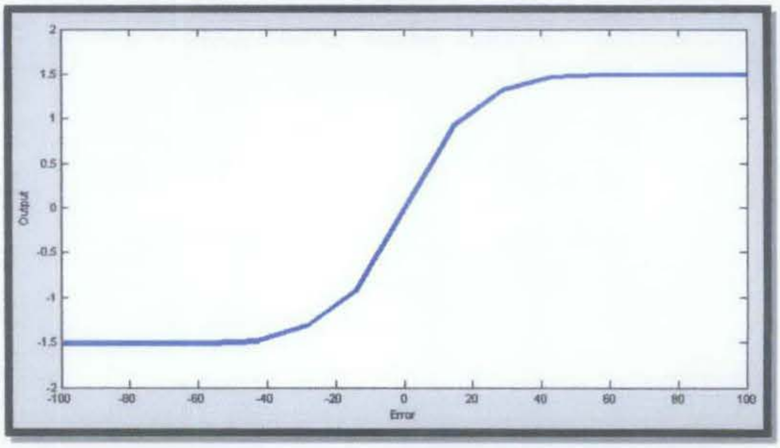

Figure 19 : Surface Viewer

Based on the result received, the functions for Medium and Large can be further adjusted and the idea of increasing the number of functions might be useful. This can improve the result obtained currently to get better performance.

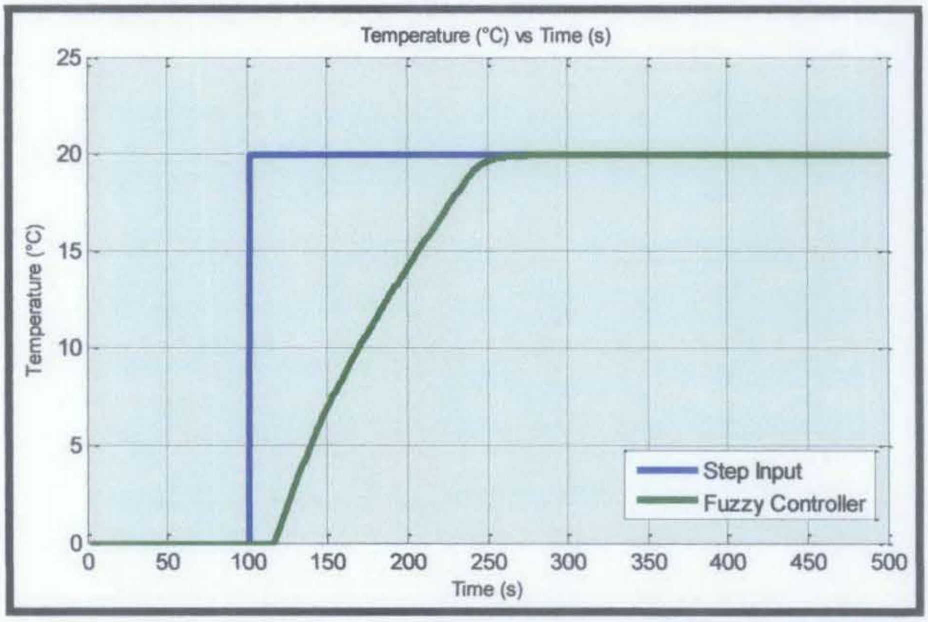

Figure 20 : Fuzzy Controller Response to a Set Point

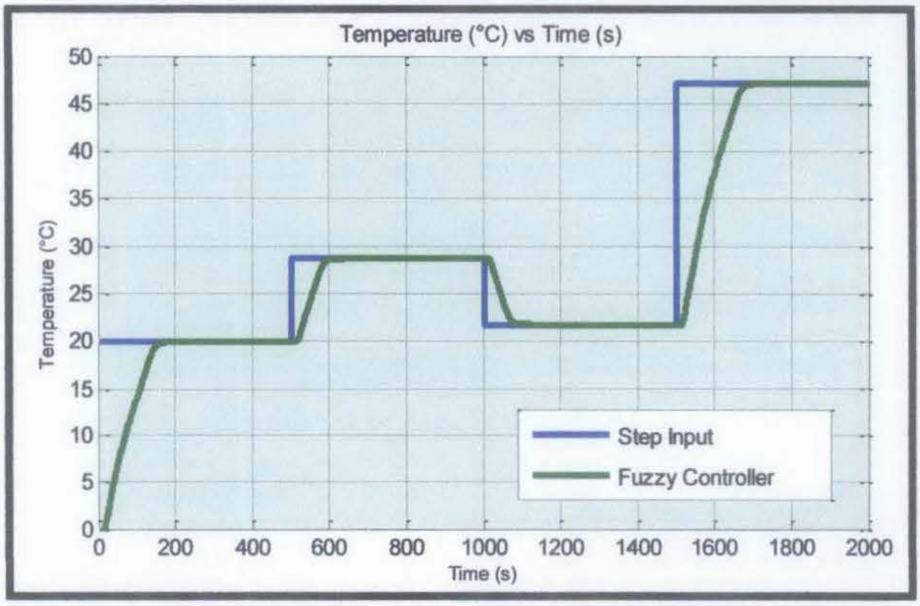

Figure 21 : Fuzzy Controller Response to Multiple Set Points

The result obtained is referring to the controller respond to step change from 0 to 20°C.

Table 7 : Fuzzy Controller Performance

Control Performance	Fuzzy Controller
Offset	Zero
Integral Absolute Error (IAE)	1452
Decay Ratio	Zero
Rise Time, T_r	(280-14) = 266 seconds
Settling Time, T_s	280 seconds
Percentage Overshoot	0%
Slope, s	$\frac{350-64}{40-0} = 7.15$

As seen at the graphs, the controller can respond to both positive and negative step inputs with minimum rise and settling time compare to the conventional controller. The slope is quite large means that it rises steeply. The rise time and settling time are both better and faster than the classic controller, PID Controller. Comparison can be easily seen from the figure and table below;

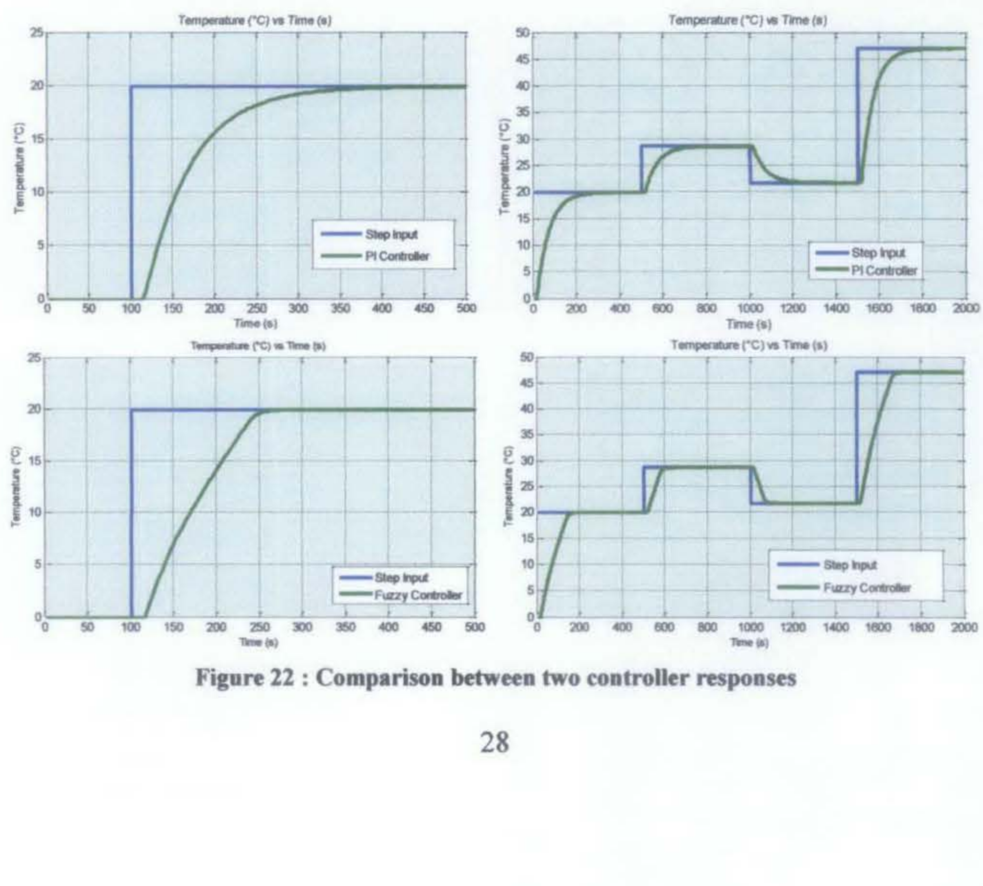

Figure 22 : Comparison between two controller responses

Table 8 : Comparison between PI Controller and Fuzzy Controller Performance

Control Performance	PI Controller	Fuzzy Controller
Offset	Zero	Zero
Integral Absolute Error (IAE)	1413	1452
Decay Ratio	Zero	Zero
Rise Time, T_r	(450-14) = 436 seconds	(280-14) = 266 seconds
Settling Time, T_s	450 seconds	280 seconds
Percentage Overshoot	0%	0%
Slope, s	$\frac{10-0}{68-18} = 0.2$	$\frac{350-64}{40-0} = 7.15$

CHAPTER 5 : CONCLUSION AND RECOMMENDATION

5.0 Conclusion

This project has been carried out for nearly 5 months and it resulted that the conventional controller has several disadvantages and can be replaced with the new control strategies. The Fuzzy Logic Controller is seen to be more users friendly and can give better performance.

The objective of the projects is to introduce an advance new controller which is based on Fuzzy Logic theory that gives better controller's respond. This objective is satisfied in the end of this semester with firm commitment towards the methodology and planning arranged. The project went smoothly according to the plan with few challenges that need to be faced.

The obtained controller in the end of the project is the new advanced controller which uses the application of Fuzzy Logic theory. The designed FLC gives better performance and smoother operation compared to classic PID controller. If the new controller is to be implemented at the heat exchanger, it would increase the product quality, profit and production rate. This is due to the faster respond given by the controller compare to the classic controller. The success and accomplishment of this project is important in proving that new advanced control strategy can be implemented on a heat exchanger. From the result obtained, it is seen that FLC gives faster rise time and settling time, with minimum Integral Absolute Error.

As a conclusion, it is proven that an advance control strategy, in this case, Fuzzy Logic Controller, provides better control performance as compared to the PID Controller. Based on the investigation, FLC also is user-friendly, easier to understand and the tuning of FIS can be done easily and intuitively.

5.2 Recommendation

The Fuzzy Logic Controller obtained in this project can be improved by increasing the number of membership functions to more than seven (currently). This is based on investigation done throughout the designing phase. Increase in membership functions can give better controller's respond if this action is done correctly.

Besides that, integration of PI controller with FLC also is a reputable action in order to improve the controller performance. Existence of hybrid controller has been proven as it has been establish that the application of PIDFLC results in lower energy input cost and shorter settling time for system output.

The integration of PI with FLC is to utilize the best attributes of the PI-type and fuzzy controllers to provide a controller which will produce better response than either the PI or the fuzzy logic controller.

REFERENCES

[1] Shah, R.K. and Sekulić, D.P. 2003, *Fundamentals of Heat Exchanger Design,* John Wiley & Sons Inc

[2] Gopalakrishna G., Sivakumaran N. and Sivashanmugam P., 2009, "Enhancement of Heat Exchanger Control Using Improved PID Controller," *Sensors & Transducers Journal:* 144

[3] Chuen, C. L. 1990, "Fuzzy Logic in Control Systems: Fuzzy Logic Controller-Part I," *IEEE Transactions On Systems, Man and Cybernetics:* 404

[4] Golob, M. and Tovornik, B. 2000. *Real Time Fuzzy PID Controller Structures.* 1-6, University of Maribor, Slovenia

[5] Marlin, Thomas E. 2000, *Process Control : Designing Processes and Control Systems For Dynamic Performance,* Singapore, McGraw-Hill

[6] Naik, K.A. and Srikanth, P., 2011, "Stability Enhancement of DC Motor using IMC Tuned PID Controller," *International Journal Of Advanced Engineering Sciences And Technologies:* 92

[7] Åström, K. J. 2002, "PID Control" in *Control System Design,* University of California, Santa Barbara

[8] Erives, H. (2011). *Motor Control* [Online]. Available: http://www.ee.nmt.edu/~erives/308_11/Lecture33.pdf

[9] The Instrumentation, Systems, and Automation Society, *Continuous Process Control Series: Applications of Heat Exchanger Control.* [CD-ROM]. Virginia Beach, Virginia. : Coastal Training Technologies Corporation, 2003

[10] Bauer, P., Nouak, S. and Winkler, R. (1996). *Fuzzy Logic – a powerful new technology* [Online]. Available: http://www.esru.strath.ac.uk/Reference/concepts/fuzzy/introduction.htm

[11] Mohanadas, K. P. and Shaik, K., 2001, "Fuzzy and Neuro-Fuzzy Modelling and Control of Nonlinear Systems," *Second International Conference on Electrical & Electronic, Bursa, Turkey:* 197-201

[12] Sadik, K. and Hongtan, L. 2002, *Classification of Heat Exchangers*, USA, CRC Press

[13] Xiaoping W., Yunliang Z. and Yuanqing L. 2011, "Dynamic Performance Analysis of PID Controller with one Memristor," *International Conference on Information Science and Technology:* 1234

[14] 2011, *Fuzzy Logic Toolbox User's Guide,* United States, The MathWorks, Inc.