PRACTICAL MODELLING AND ADVANCED CONTROL SIMULATION STUDIES ON A HEAT EXCHANGER PILOT PLANT

by

Muhammad Muzamir Bin Bharum

Final report submitted in partial fulfilment of

the requirement for the

Bachelor of Engineering (Hons)

(Electrical and Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

(Dr. Rosdiazli Ibrahim)

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 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 expect as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(MUHAMMAD MUZAMIR BIN BHARUM)

ABSTRACT

Heat exchanger is a device that uses to thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and fluid, at different temperatures and in thermal contact. A variety of heat exchanger are used in industry and it classified according to transfer process, number of fluids, degree of surface compactness, construction features, flow arrangements, and heat exchanger mechanisms. One example of the application that used heat exchanger is a pilot plant, which provides design and operating information before construction of a large chemical plant. This heat exchanger usually will be controlled by PID controller. PID controller also known as conventional controller and can achieve good control performance with the proper choice of tuning parameters. However, the control performance can perform poorly and even become unstable, if improper values of the controller parameters are used. The main objective of this project is to design and simulate an advanced control strategy of heat exchanger pilot plant by using Fuzzy Logic Controller (FLC). The development of the plant model will be based on a pilot plant at Universiti Teknologi PETRONAS (UTP). While the development of the controller and all simulation work will be based on MATLAB simulation. The aim is to improve the controller performance of pilot plant to become more smoothly, efficient, and optimize the product yield. The expected result for this project is to get the smooth process operation when using FLC compared to conventional method (PID controller).

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

PID	Proportional, Integral and Derivative
FLC	Fuzzy Logic Controller
DCS	Distributed Control System

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The importance of heat exchanger has increased immensely over the past quarter century from the viewpoint of energy conservation, conversion, recovery, and successful implementation of new energy sources. Its importance is also increasing from the standpoint of environmental concern such as thermal pollution, air pollution, water pollution, and waste disposal [6].

Heat exchangers are widely used in transportation, heat recovery, alternate fuel, space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, and sewage treatment [16]. Typical applications involve heating or cooling of a fluid stream of concern and evaporation or condensation of single or multi component fluid stream [6].

In most of heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. In many of heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or leak. Common examples of heat exchangers are shell-and tube exchanger, automobile radiators, condensers, evaporators, air pre-heaters, and cooling towers [6].

The process industries, which operate equipment at high pressure and temperatures with potentially hazardous materials, needed reliable process control many decades before digital computers became available. As a result, the control methods developed many decades ago were tailored to the limited computing equipment available at that time. The controller that they used in many decades ago until today is PID controller. This controller also known as conventional controller because it has been used in process industries since 1940s and remains the most often used controller today [13].

The heat exchanger of pilot plant also will controlled by PID controller since this controller have integral controller that can give zero steady state error for a step input and derivative control that make the process response become faster. However, it takes longer time to get the best tuning of PID parameters.

Other type of controller that can be used to control the heat exchanger of pilot plant is fuzzy logic controller (FLC). Fuzzy logic is the logic on which fuzzy control is based, is much closer in spirit to human thinking and natural language than the traditional logical systems.

Experience shows that the FLC yields results superior to those obtained by conventional control algorithms [3]. Thus, fuzzy logic control may be viewed as a step toward a rapprochement between conventional precise mathematical control and human-like decision making.

1.2 Problem Statement

PID controller may be tuned in variety of ways such as Ziegler Nichols tuning, Cohen Coon tuning, manual tuning and by using software. All of these methods have their own advantages and disadvantages. For example the advantage of manual tuning is that a process engineer can use the procedure right away, online and develop a feel for how the closed loop system behaves. While the disadvantage is that it may take a long time to develop this feel and it is difficult to sense whether the final settings are optimal [10].

A few examples have demonstrated that the PID controller can achieve good control performance with the proper choice of tuning constant. However, the control system can perform poorly and even become unstable, if improper values of the controller tuning constant are used [18]. This problem will affect the process time become longer and it will potentially costly.

1.2.1 Significant of the Project

The idea of this project is to design, develop and simulate an advanced control strategy for a heat exchanger pilot plant by using Fuzzy Logic Controller (FLC). The aim of the project is to improve the efficiency of the process plant.

Some of the advantages of Fuzzy Logic are it can provide an intuitive way to design function blocks for intelligent control system, can control complex process and it also can mathematically emulates human reasoning. Control systems deploying Fuzzy Logic also can improve the management of uncertain variables, such as temperature fluctuations [12]. All of these advantages will make the process plant more efficient and productive.

1.3 Objectives and Scopes of the Study

The objectives of this project are:

a) To obtain the model for a heat exchanger pilot plant by experimental work.
b) To design, develop and simulate an advanced control strategy for heat exchanger pilot plant.
c) To observe and analyze the control performance of the proposed controller as compared to PID controller.

While the scope of study are as follow:

a) Plant development based on the pilot plant located at UTP laboratory.
b) The development of the controller and all simulation work will be based on MATLAB software.

CHAPTER 2

LITERATURE REVIEW

2.1 The Heat Exchanger

Heat exchanger is a device that is used to thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and fluid, at different temperatures and in thermal contact [6]. The heat exchanger is widely used in air conditioning, refrigeration, space heating, power production and chemical processing [16].

The heat exchanger also is frequently characterized by construction features. Four major construction types are tubular, plate-type, extend surface and regenerative exchangers. This project will focus only on tubular heat exchanger; shell-and-tube. This exchanger is generally built of a bundle of round tubes mounted in a cylindrical shell with tube axis parallel to that of the shell. One fluid flows inside the tubes, the other flows across and along the tubes [6].

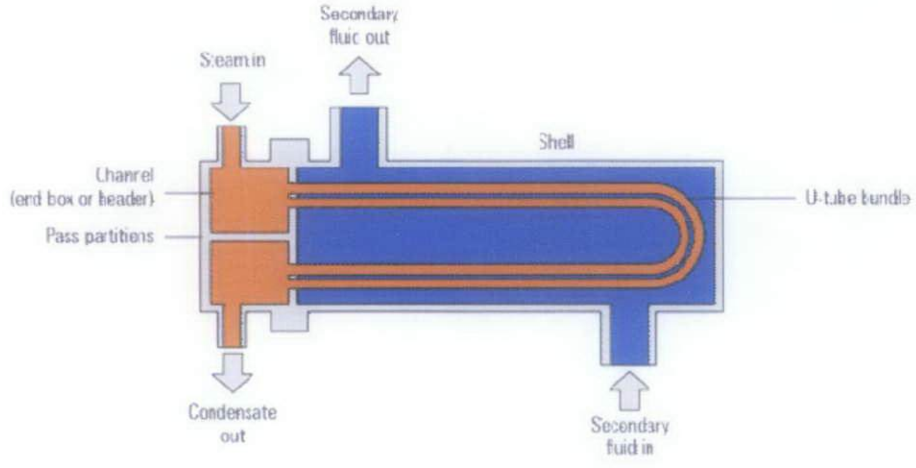

Figure 1: Shell-and-Tube Heat Exchanger

Figure 1 show the example of common design for a steam to water non-storage calorifier heat exchanger used in process plant. The hot water will flow through U-tube bundle and cold water will flows across the tubes. This heat exchanger also known as a 'one shell pass two tube pass' type of shell and tube heat exchanger and consists of a U-tube bundle fitted into a fixed tube sheet.

It is said to have 'one shell pass' because the secondary fluid inlet and outlet connections are at different ends of the heat exchanger, consequently the shell side fluid passes the length of the unit only once. It is said to have 'two tube passes' because the steam inlet and outlet connections are at the same end of the exchanger, so that the tube-side fluid passes the length of the unit twice [15].

2.2 Plant Process Description

The Heat Exchanger control pilot plant has been designed on how a temperature loops for an exchanger can be controlled using a microprocessor based controller. The control panel is connected to a Distributed Control System (DCS), which can remotely control the process plant using supervisory control mode (SCADA) or direct digital control mode (DDC). A selector located at the control panel is used to select between SCADA or DDC mode. In SCADA mode the DCS can monitor and control the process through the process controller and in DDC mode, the DDC can directly control the plant through the Field Control Station.

The heat exchanger control is a water process. Based on Heat Exchanger Module (refer APPENDIX A), 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 returns to hot water tank T-203. Cold water is circulated 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.

There are various types of instrumentations are installed in the process line. An RTD Temperature Transmitter, TT-221 monitors the product temperature and feeds the signal to a PID loop TIC-221 in the process controller. The output from TIC-221 is fed to the control valve TCV-221 which regulates the amount of heating energy into the heat exchanger.

There is another ON-OFF temperature controller TIC-203 that controls the temperature in the hot water tank T-203 according to a preset temperature. Another ON-OFF controller LIC-202 in used as the batching controller which controls LV-202 to batch a certain quantity of product in tank T-202. Solenoid valves have been installed for the purpose of fault simulation in various sections of the process line. Fault simulation switches have been installed to simulate these faults, which will create errors in the process line.

2.3 Empirical Modelling

In empirical model building, models are determined by making small changes in the input variable(s) about a nominal operating condition. The resulting dynamic response is used to determine the model. This general procedure is essentially an experimental linearization of the process that is valid for some region about the nominal conditions [13].

Empirical model building should be undertaken by using the six-step procedure as shown in Figure 2. This model identification is an iterative procedure that may involve several experiments and potential model structures before a satisfactory model has been determined. The procedure clearly demonstrates the requirement for a priori information about the process to design the experiment. Since this information may be inexact, the experimental procedure may have to be repeated, perhaps using a larger perturbation, to obtain useful data. Also, results of the analysis should be evaluated with diagnostic procedures to ensure that the model is accurate enough for control design [13].

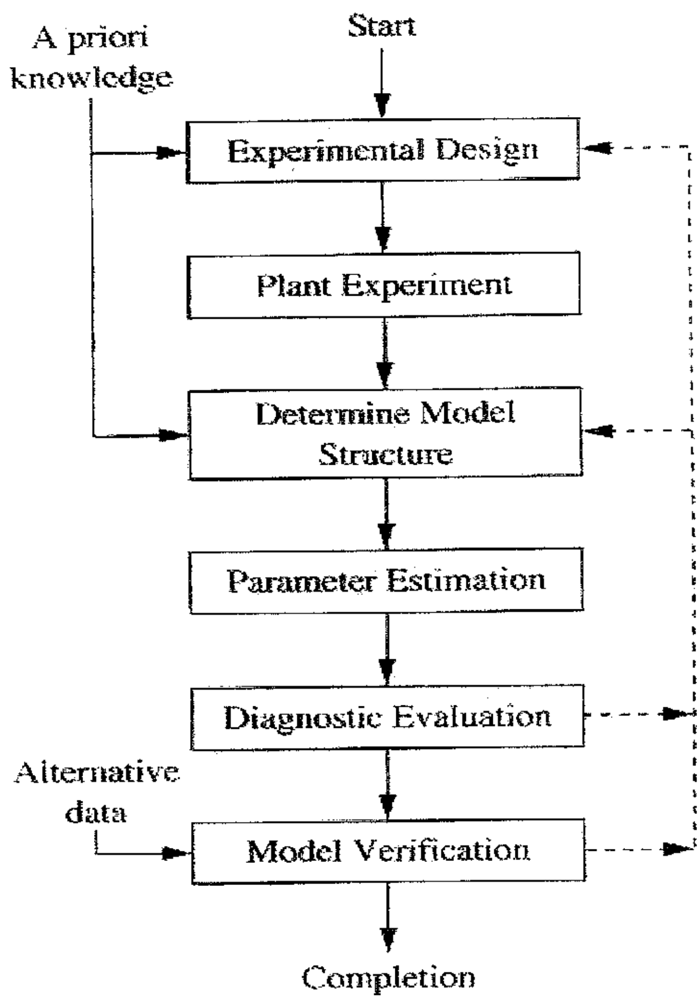

Figure 2: Six-step procedure for empirical transfer function model identification

2.4 PID Controller

PID is stand for Proportional-Integral-Derivative. This type of controller is widely used in industrial application since 1940s and remains the most often algorithm today [13]. It is because of their simplicity, robustness, and successful practical applications. A PID controller also calculates an "error" value as the difference between a measured process variable and a desired set point [17]. The time-domain controller algorithm for PID controller is given below:

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

This controller often provides acceptable control even in the absence of tuning, but performance can generally be improved by careful tuning, and performance may be unacceptable with poor tuning. The example methods for tuning a PID loop are;

a) Manual tuning
b) Ziegler-Nichols
c) Software tools
d) Cohen-Coon

2.5 Ziegler-Nichols Tuning

In 1942, Ziegler and Nichols, both employees of Taylor Instruments, described simple mathematical procedures, the first and second methods respectively, for tuning PID controllers. These procedures are now accepted as standard in control systems practice [8].

Both techniques make a priori assumptions on the system model, but do not require that these models be specifically known. Ziegler-Nichols formulae for specifying the controllers are based on plant step responses [8].

The first method is typical of a first order system with transportation delay, such as that induced by fluid flow from a tank along a pipe line. It is also typical of a plant made up of a series of first order systems. The plant model is therefore [8]:

$$G(s) = \frac{Kpe^{-\theta s}}{\tau s+1} \tag{2}$$

Ziegler and Nichols derived the following control parameters based on this model [8]:

Table 1: Ziegler-Nichols Recipe – First Method

PID Type	K_p	$T_i=K_p/K_i$	$T_d=K_d/K_p$
P	$\frac{\tau}{\theta}$	∞	0
PI	$0.9\frac{\tau}{\theta}$	$\frac{\theta}{0.3}$	0
PID	$1.2\frac{\tau}{\theta}$	$2\,\theta$	$0.5\,\theta$

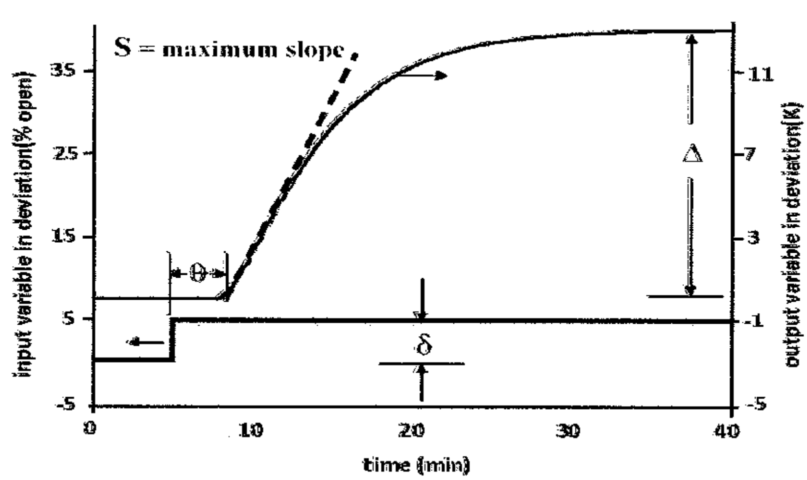

Figure 3: Response Curve for Ziegler-Nichols First Method

The second method targets plants that can be rendered unstable under proportional control. The technique is designed to result in a closed loop system with 25% overshoot. This is rarely achieved as Ziegler and Nichols determined the adjustments based on a specific plant model [8]. The controller gains are now specified as follows:

Table 2: Ziegler Nichols Recipe – Second Method

PID Type	K_p	$T_i=K_p/K_i$	$T_d=K_d/K_p$
P	$0.5Ku$	∞	0
PI	$0.45Ku$	$Pu/1.2$	0
PID	$0.6Ku$	$Pu/2$	$Pu/8$

2.6 The Process Reaction Curve

The process reaction curve is most widely used method for identifying dynamic models. It is simple to perform and provides adequate models for many applications. The graphical calculations determine the parameters for a first order dead time model. The form of the model is shown in Equation 2.

There are two different techniques in common use, First Method and Second Method. For the First Method, it is adapted from Ziegler and Nichols (1942), uses the graphical calculation shown in Figure 3. The intermediate values determined from the graph are the magnitude of the input change, δ; the magnitude of the steady state change in the output, Δ; and the maximum slope of the output versus time plot, S. The values from the plot can be related to the model parameters according to the following relationship for a first order with dead time model. The general model for a step in the input with $t \geq \theta$ is

$$Y'(t) = K_p\delta\,[1 - e^{-(t-\theta)/\tau}] \qquad (3)$$

The slope for this response at any time $t \geq \theta$ can be determined to be

$$\frac{dY'(t)}{dt} = \frac{d}{dt}\{K_p\delta\,[1 - e^{-(t-\theta)/\tau}]\} = \frac{\Delta}{\tau} e^{-(t-\theta)/\tau} \quad (4)$$

The maximum slope occurs at $t = \theta$, so $S = \Delta/\tau$. Thus the model parameters can be calculated as

$K_p = \Delta / \delta$

$\tau = \Delta / S$

θ = intercept of maximum slope with initial value (refer Figure 3) (5)

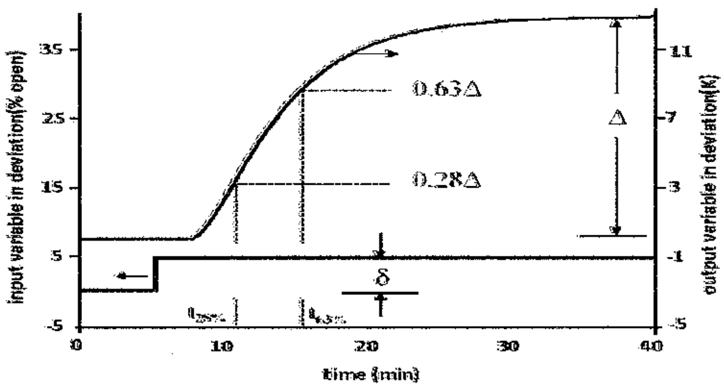

Figure 4: Process reaction curve, Second Method

For a Second Method, it uses the graphical calculations shown in Figure 4. The intermediate values determined from the graph are the magnitude of the input change, δ; the magnitude of the steady state change in the output, Δ; and the times at which the output reaches 28 and 63 percent of its final value. The value from the plot can be related to the model parameters using the general expression in equation (3). Any two values of times are selected where the transient response is charging rapidly so that the model parameters can be accurately determined in spite of measurement noise [13].

The expressions are:

$$Y(\theta + \tau) = \Delta\,(1 - e^{-1}) = 0.632\Delta$$

$$Y(\theta + \tau/3) = \Delta\,(1 - e^{-1/3}) = 0.283\Delta \quad (6)$$

Thus the values of time at which the output reaches 28.3 and 63.2 percent of its final value are used to calculate the model parameters.

$$t_{28\%} = \theta + \tau/3$$

$$t_{63\%} = \theta + \tau$$

$$\tau = 1.5\ (t_{28\%} - t_{63\%}) \qquad (7)$$

2.7 Fuzzy Logic Controller

Fuzzy Logic Controller (FLC) based on Fuzzy Logic provides a means of converting a linguistic strategy based on expert knowledge into an automatic control strategy [3]. Basically, the Fuzzy Logic is a form of conventional logic that has been extended to handle the concept of partial truth-truth values between completely true and completely false.

There have four main components in Fuzzy Logic controller: fuzzification, fuzzy rules, inference and defuzzification [14]. Fuzzification is related to the vagueness and imprecision in a natural language. Its plays an important role in dealing with uncertain information which might be objective or subjective in nature [3].

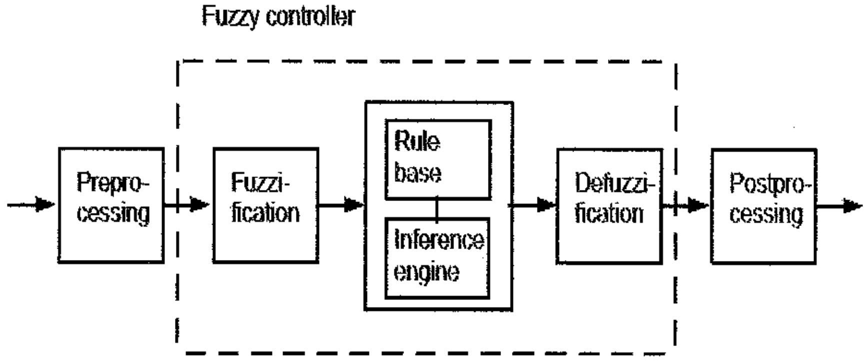

Figure 5: Blocks of a fuzzy controller

The collection of fuzzy control rules that are expressed as fuzzy conditional statement forms the rule base or the rule set of a FLC. In developing this design, it is necessary to initialize and declare what the inputs and the outputs variables, source and derivation, justification, types of fuzzy control rules, and properties of consistency, interactivity, and completeness.

The process of formulating the mapping from a given input to an output using fuzzy logic is called fuzzy inference. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves of the Membership Functions, Logical Operations, and If-Then Rules.

The resulting fuzzy set then will converted to a number that can be sent to the process as a control signal. This operation is called defuzzification [10]. There are several methods of defuzzification such as COG (centre of gravity), MOM (middle of maximum), EQM (extended quality method), BADD (basic defuzzification distributions, ICOG (indexed centre of gravity), FOM (first of maximum), and etc.

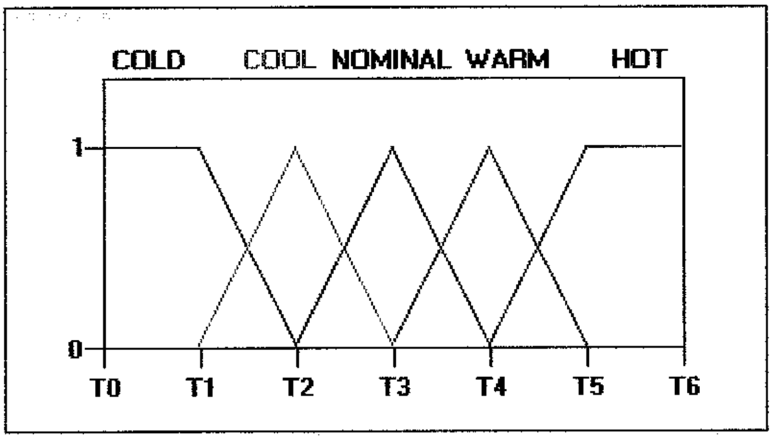

Figure 6: Diagrammatic representation of fuzzy temperature

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

Figure 7 and Table 3 shows the project work flow and description of the project research. The methodology has been designed to fully optimise the time frame provided in order to completely carry out the planned and anticipated project works.

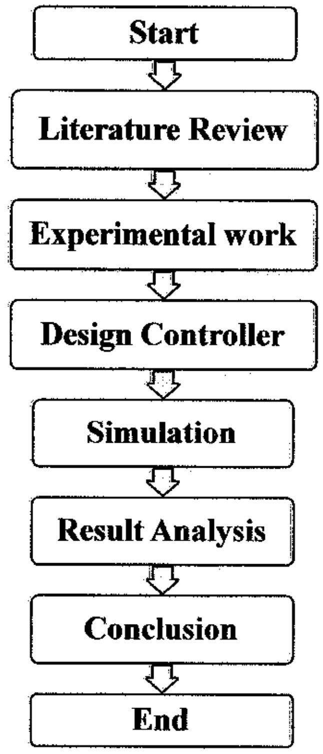

Figure 7: Project work flow

Table 3: Project work description

Methodology	Description
Literature Review	Perform a research on a heat exchanger pilot plant and several controllers that are been used from the past, present and followed by future technology to control the process plant. The research has been done by referring several resources from the books, conference papers, journals, technical report and internet.
Experimental Work	Experimental work is a process to obtain the First Order with Dead Time (FODT) model from the pilot plant. This plant modelling is performed by using the Empirical modelling method.
Design Controller	At this stage, the plant will be modelled by using Simulink library browser in MATLAB. The Fuzzy Logic Controller will be used with PID Controller in order for it to mimic the PID responses.
Simulation	The simulation involves FIS which are developed using Fuzzy Logic Toolbox and the empirical model of the plant. This is done to compares the control performance of the Fuzzy Logic Controller and PID controller.
Result Analysis	The control performances of the Fuzzy Logic Controller and PID controller are compared to determine which one is the best.

3.2 Tools and Equipment Used

This project uses the liquid processing pilot plant and MATLAB software in order to develop and simulate advanced control strategy of heat exchanger. Below is the list of hardware and software used:

a) Liquid Processing Pilot Plant (Hardware)

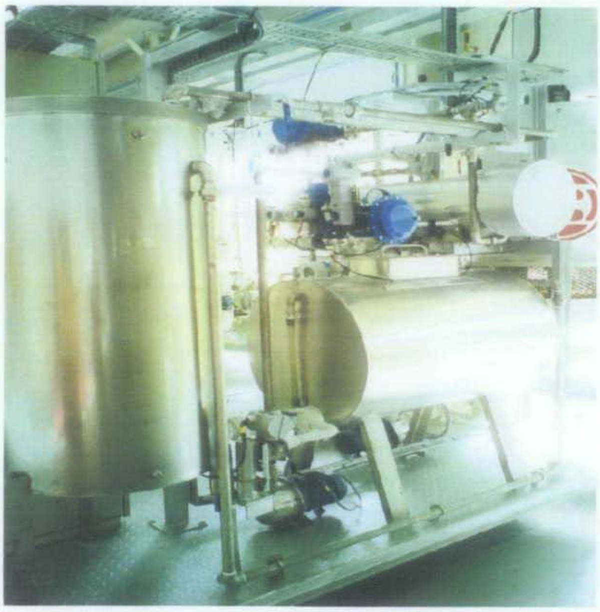

Figure 8: Liquid Processing Pilot Plant located at UTP laboratory

b) Distributed Control System, DCS (Software)
c) MATLAB simulation (Software)

The MathWorks

3.3 Project Activities

3.4.1 Experimental Work

In order to complete the analysis of PID controller, some of the procedures need to be done as shown below.

A. Start up procedure

1) Follow the start up procedure as given in the lab manual.
2) Set all the valves according to the initial valve position outlined as in Table 3 below:

Table 4: Initial Valve Positions

Open	Close
HV231	HV232
HV234	HV233
HV235	HV240
HV236	HV242
HV241	HV248
HV243	HV249
HV244	HV246
HV245	HV250
HV247	HV251
	HV252
	HV253
	HV237
	HV238
	HV239

3) Fill the cold water tank T-201 and hot water tank T-203 respectively.

4) Set the instrument air regulatory RG1 to 2.8 bar (40 psi). The RG1 pressure was checked and needed to adjust at 2.8 bar.
5) Switched ON the main panel.
6) Set the value of T-203 to 70 ^{0}C.
7) Then, switch ON pump P211 and adjustFI201 to 10LPM by using HV240.
8) Lastly, switch ON the pump P213.

B. Controller tuning using Ziegler-Nichols closed loop method

1) By using SV = 40 and MV = 50, turn the control loop to manual mode.
2) Enter the following values:
   P = 0.15; I = 9999; and D = 0
3) Observed the Process Value (PV) from the trend window and wait until it stabilized to a constant value.
4) After PV reach it stable value, turn the control loop to auto mode.
5) Change the value of SV to 50 and wait until it has stabilized to a constant value.
6) Observe the graph of PV and print the trend window.
7) Repeat the step (1) until (7) with the following values:
   P = 0.2, 0.5, 0.75

C. Tabulation and calculation of PID Controller parameter

1) Using the graph obtained in section B, note down the ultimate gain, Ku and determines the ultimate period, Pu.
2) Based on the Ziegler-Nichols closed loop tuning correlations in Table 2, calculates the controller tuning parameters for the following modes:
   - Proportional-only (P-only)
   - Proportional-Integral (PI)
   - Proportional-Integral-Derivative (PID)
3) Tabulate the tuning parameters and do the performance test for one controller mode at a time, test each mode in section D.

D. Control loop performance test

1) By using SV = 40 and MV = 50, turn the control loop to manual mode.
2) Enter the tuning parameter values for one controller mode at a time.
3) Observed the Process Value (PV) from the trend window and wait until it stabilized to a constant value.
4) After PV reach it stable value, turn the control loop to auto mode.
5) Then change the value of SV to 50.
6) Observed the graph of PV and print the trend window.
7) Compare and analyze the entire graph.

3.3.2 Simulation

The next step is to design and simulate the process by using MATLAB Simulink. The objective of doing this is to get the ideal process reaction curve without any disturbance from the pilot plant. By using this software, the user only needs to insert the PID modelling design that obtains from the experiment. Figure below show the example of Simulink library browser that we can get from MATLAB.

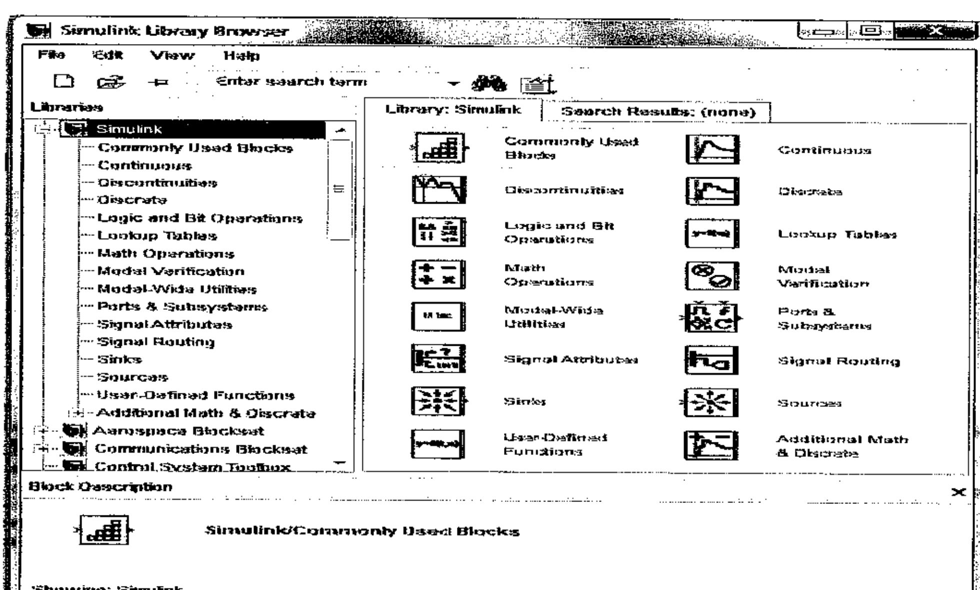

Figure 9: Simulink library browser

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Experimental Results

The Empirical Modelling is done through plant experimentation to obtain the Process Reaction Curve, and by using the Ziegler-Nichols tuning method, the PID Parameters were obtained:

Table 5: Result for PID tuning parameters

Control modes	K_C	T_I	T_D
P only	0.085	-	-
P + I	0.075	1.11	-
P + I + D	0.10	0.66	0.17

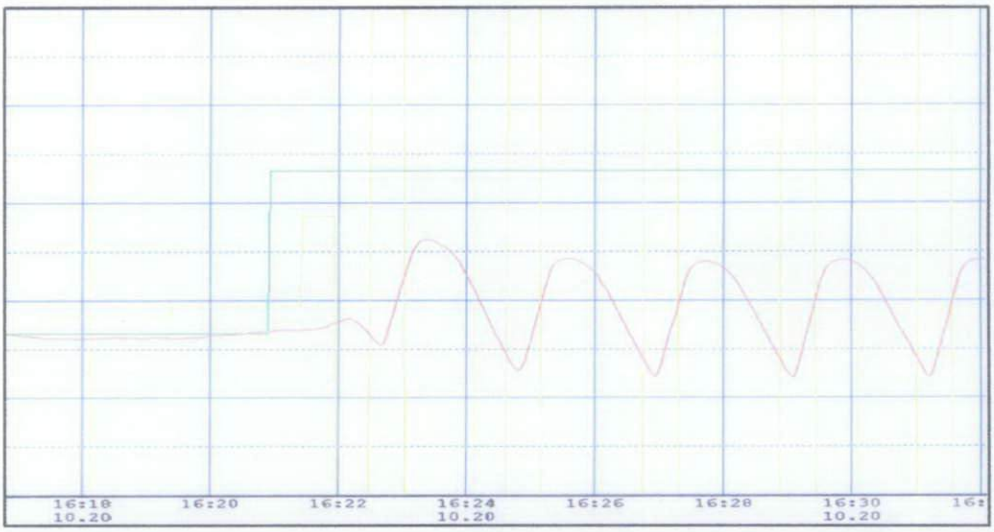

Figure 10: Process response graph for P controller (P=0.17; I=9999; D=0)

Ku = 0.17

Time for 3 oscillation period = 4.27 minutes

Pu = 4.27/3 = 1.42

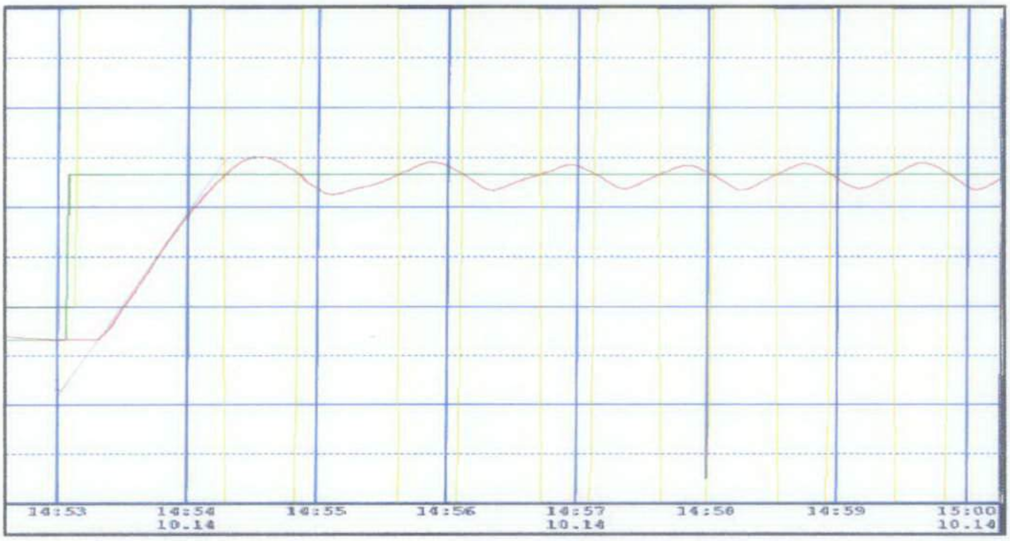

Figure 11: Process response graph for PI controller (P=0.075; I=1.11; D=0)

Slope = 11.15

θ = 14 sec

$$\Delta = 10$$

$$K_p = \Delta / \sigma = 10 / 60 = 0.17$$

$$\tau = \Delta / s = 10 / 11.15 = 0.90$$

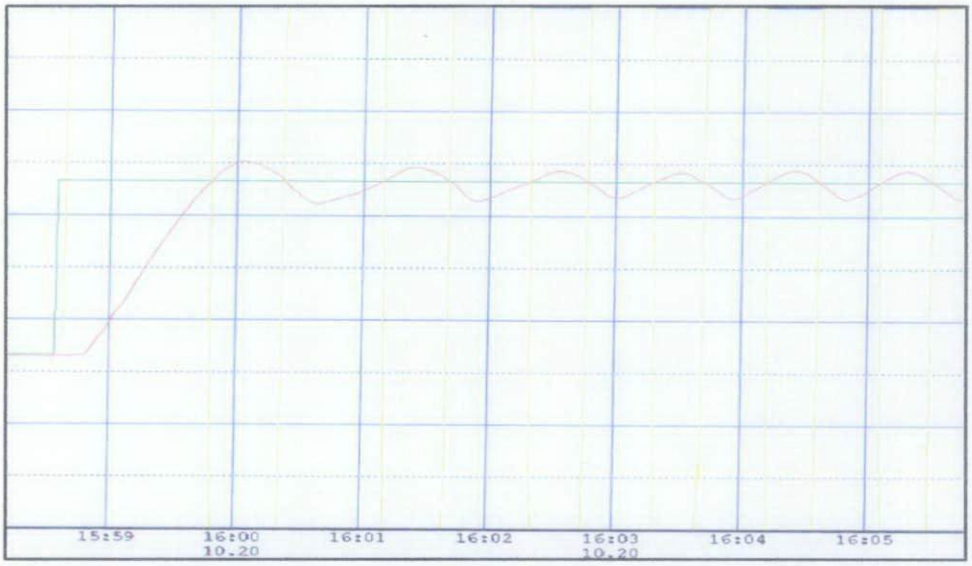

Figure 12: Process response graph for PID controller (P=0.1; I=0.66; D=0.17)

$$\text{Slope} = 11$$

$$\theta = 15 \text{ sec}$$

$$\Delta = 10$$

$$K_p = \Delta / \sigma = 10 / 63 = 0.16$$

$$\tau = \Delta / s = 10 / 11 = 0.91$$

From the process reaction curve, the First Order with Dead Time (FODT) model was obtained (PI controller has been chosen):

$$G(s) = \frac{0.17e^{-14s}}{0.9s+1}$$

4.2 Fuzzy Logic Controller Development and Simulation

Fuzzy Logic Toolbox in MATLAB was used to design the Fuzzy Logic Controller simulation. This software is a collection of functions built on the MATLAB technical computing environment. It provides tools to create and edit fuzzy inference systems within the framework of MATLAB and Simulink software. The Inference System (FIS) is designed to have two inputs (error and CE) and one output (valve) with seven membership functions for each variable.

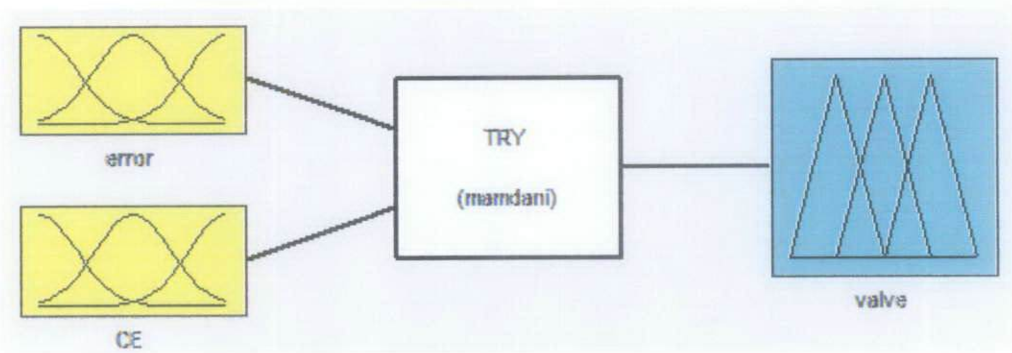

Figure 13: Inputs and output variable in FIS Editor

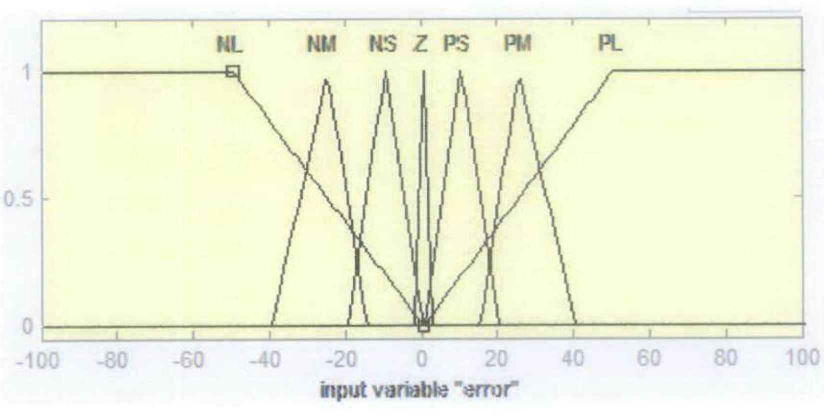

Figure 14: Membership Function for input variable (error)

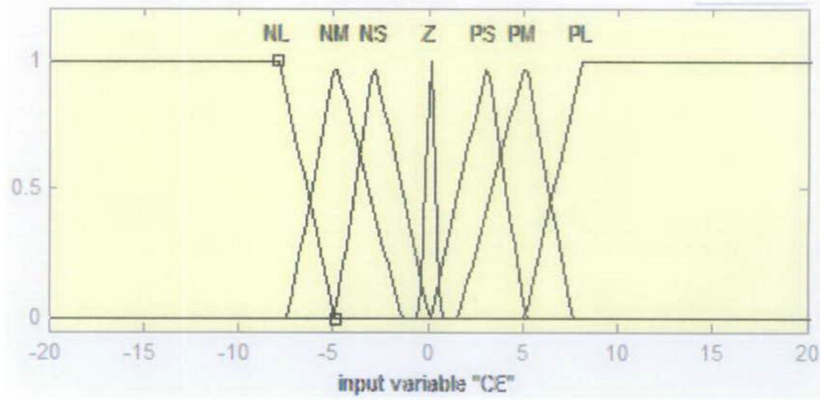

Figure 15: Membership Function for input variable (CE)

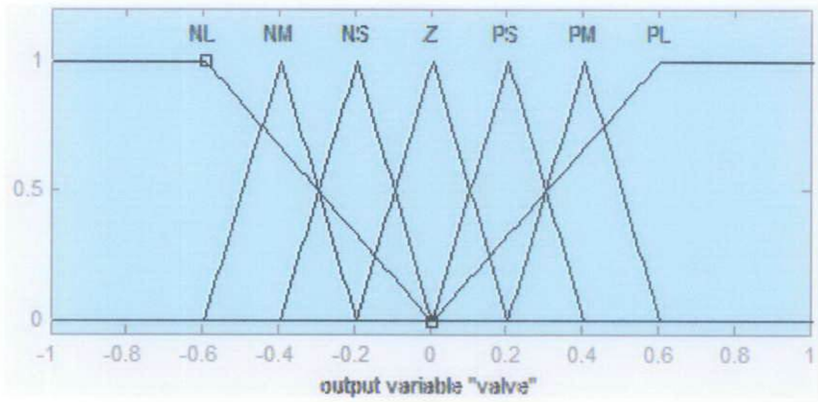

Figure 16: Membership Function for output variable

A total of forty nine IF-THEN rules for FIS have been developed in Rule Editor. The reason of using seven membership functions for each variable is because to ensure better control performance and accuracy at small errors. The rules are set based on a few key ideas, explained below:

- If E and CE are large then the percentage of valve opening must be big.
- If E and CE are moderate then the percentage of valve opening must be moderate / maintain at the middle.
- If E and CE are small then the percentage of valve opening must be small.

Table 6: Relationship between inputs and output

CE \ ERROR	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	PL	PL	PL	PL
NM	NL	NL	NL	PM	PL	PL	PL
NS	NL	NL	NL	Z	PL	PL	PL
Z	NL	NM	NS	Z	PS	PM	PL
PS	NL	NL	NL	Z	PL	PL	PL
PM	NL	NL	NL	NM	PL	PL	PL
PL	NL	NL	NL	NL	PL	PL	PL

Table 6 shows the relationship between the inputs and output. The two inputs name as Error and CE while the output is a valve. Each of them has seven membership functions; negative large (NL), negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM), and positive large (PL).

The surface viewer (Figure 17) shows the relationships between the two inputs and output. It can also be looked at as a graphic representation of the above rules (Table 6).

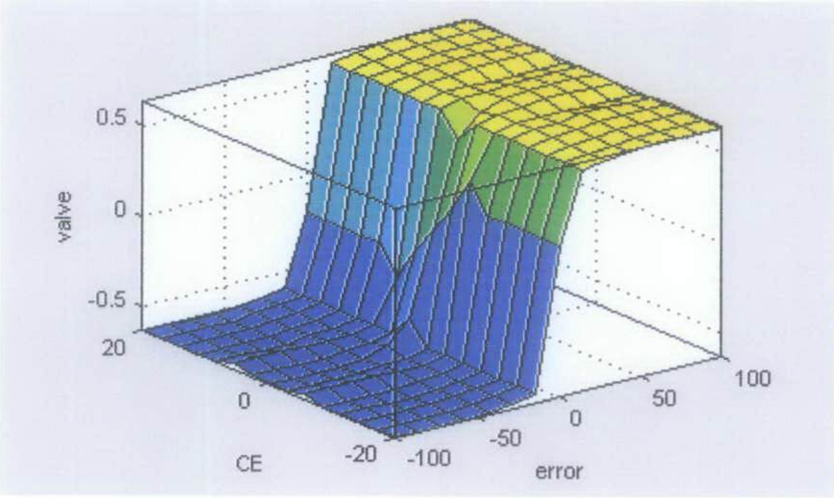

Figure 17: Surface viewer for inputs and output variable

4.3 Simulation Results

By using First Order with Dead Time (FODT) model that was obtained before, several simulations have been conducted using MATLAB and Simulink. The steps to develop the PID and Fuzzy Logic Controller in MATLAB are as follows:

i. Develop control model using PI Controller
ii. Implement the FIS in the Fuzzy Logic Controller block
iii. Compare results from both controllers.

4.3.1 PI Controller simulation

Figure 18 shows the plant model using PI controller. This is the control model and represents the heat exchanger of pilot plant. This model also have two input; step input and random number input in order to check the robustness of the system.

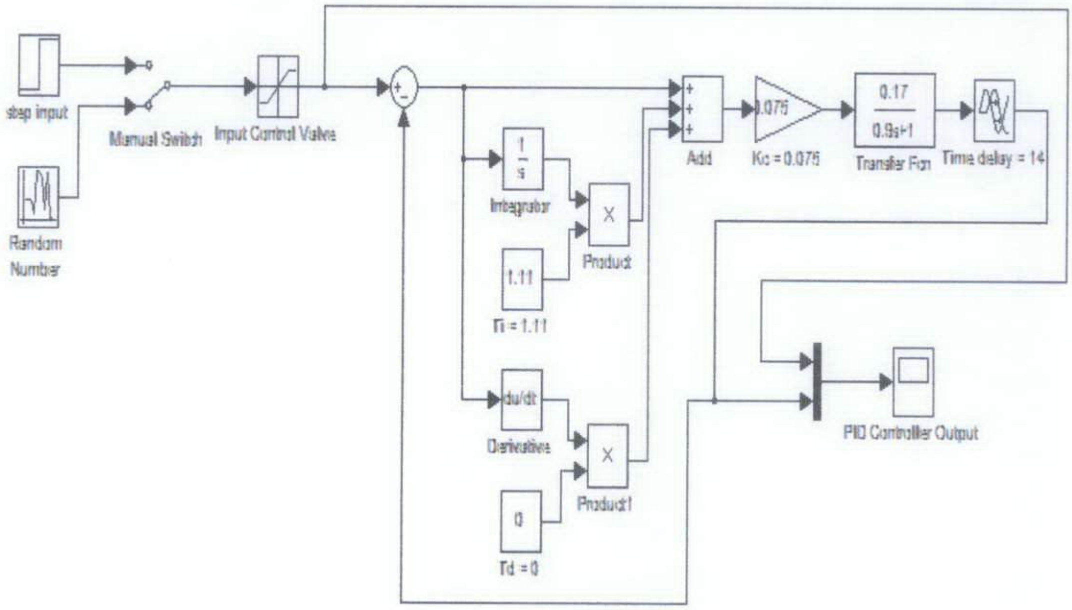

Figure 18: Plant model using PI controller

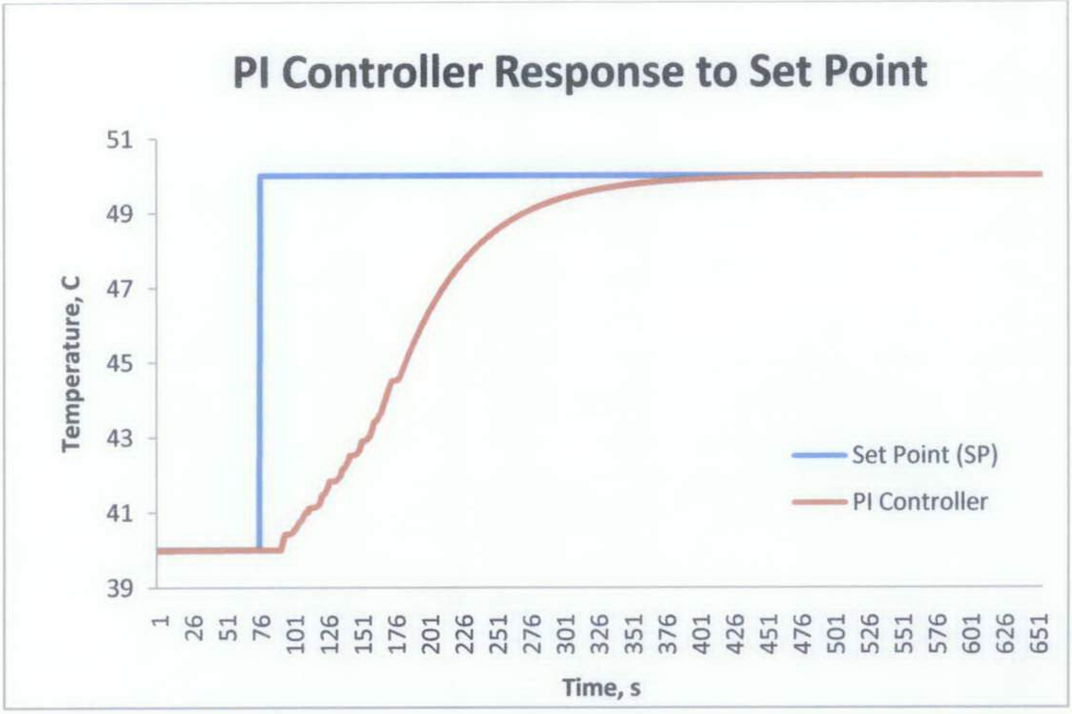

Figure 19: PI Controller Response to Step Input

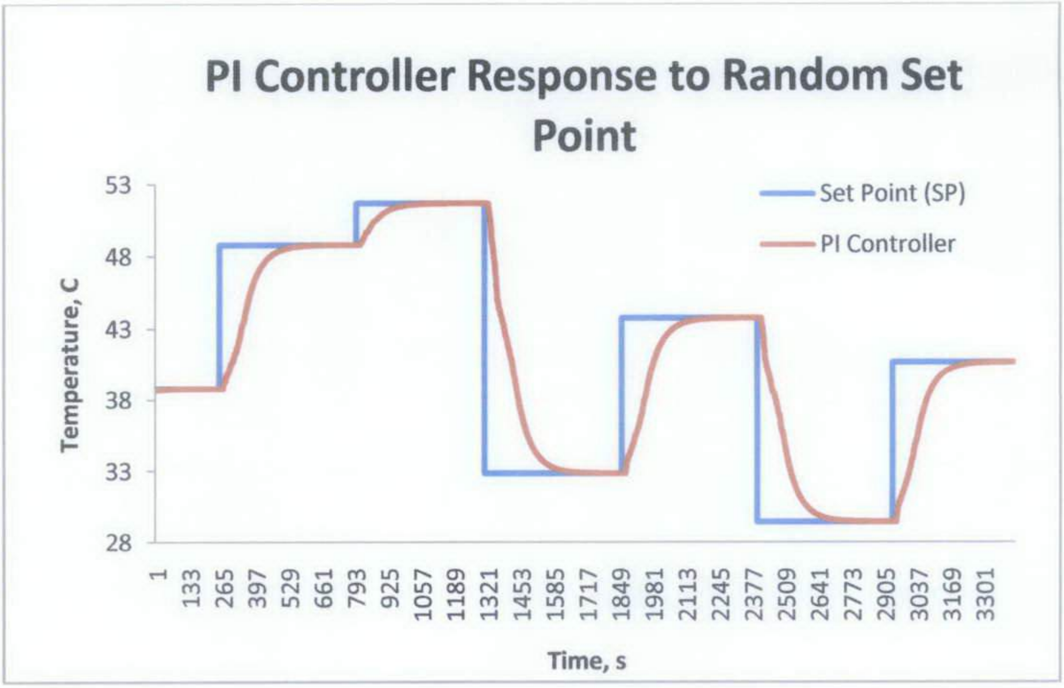

Figure 20: PI Controller Response to Random Set Point

4.3.2 Fuzzy Logic Controller simulation

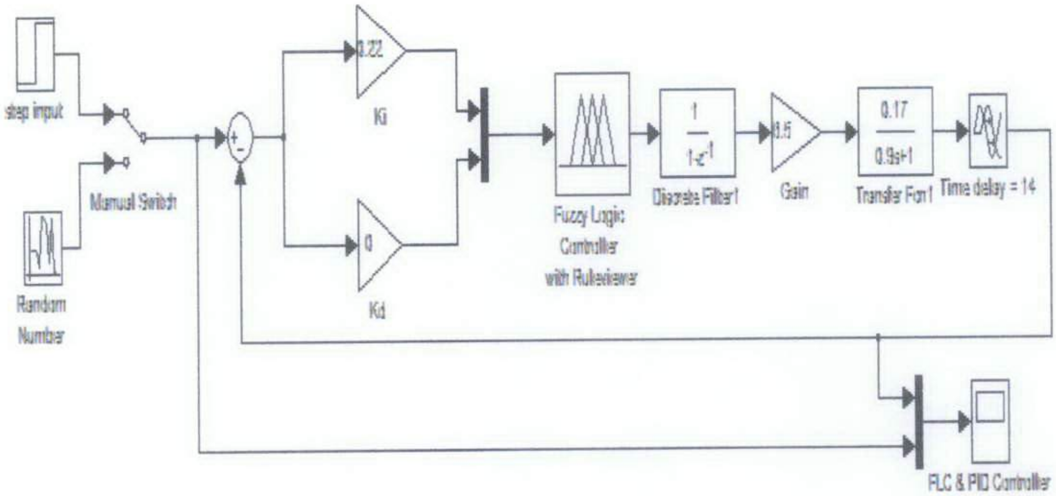

Figure 21: Plant model using Fuzzy Logic Controller

Three different number of membership function (three, five, and seven) are used in order to get the best control performance of the Fuzzy Logic Controller. The different number of membership function will affect the range and rules of the inputs and output. Besides that, these controllers also have been subjected to random set point changes in order to evaluate the robustness. Below are the results for Fuzzy Logic Controller performance.

A. Three membership function

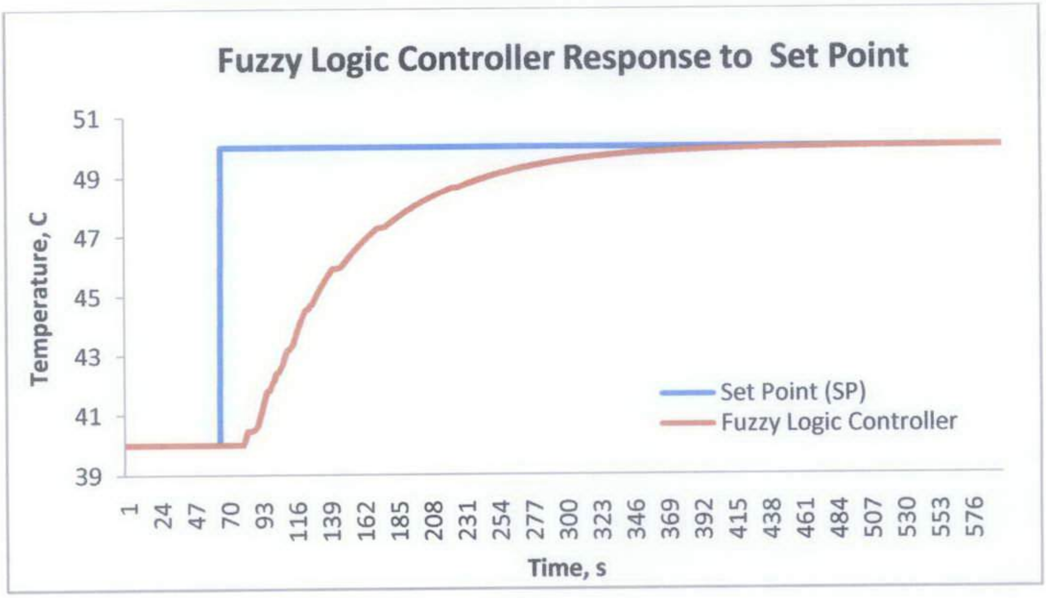

Figure 22: FLC Response to Step Input (3 membership function)

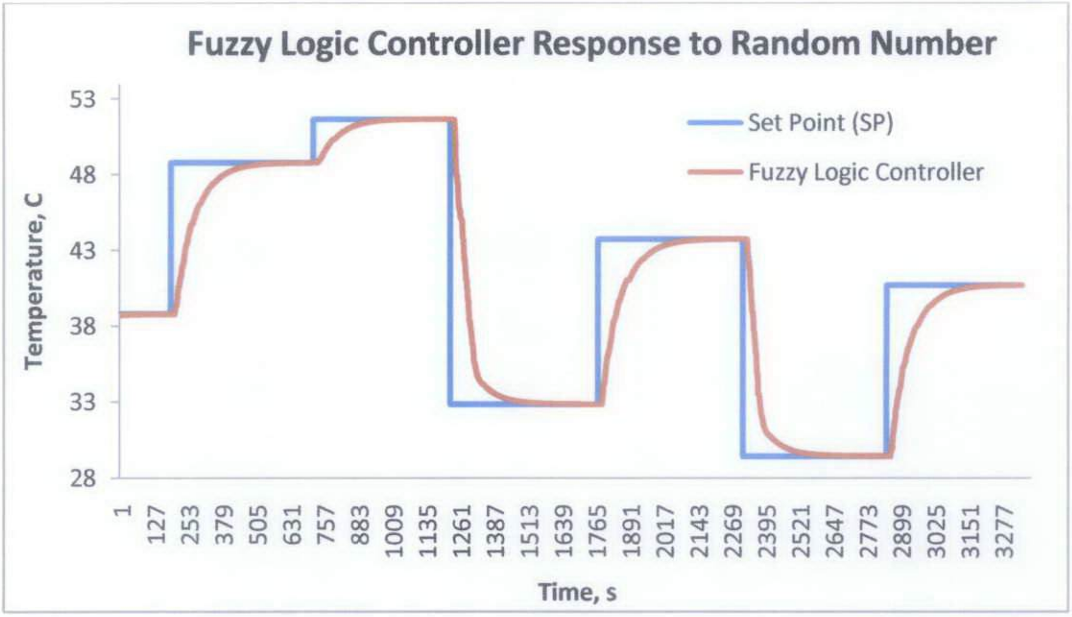

Figure 23: FLC Response to Random Number (3 membership function)

The result for FLC with three membership function is slightly same as PI controller performance. The different between these two controllers is the response of the curve (slope) for FLC is faster than PI controller, others criteria are same. So, it can conclude that FLC with three membership function is not suitable to become the best controller.

B. Five membership function

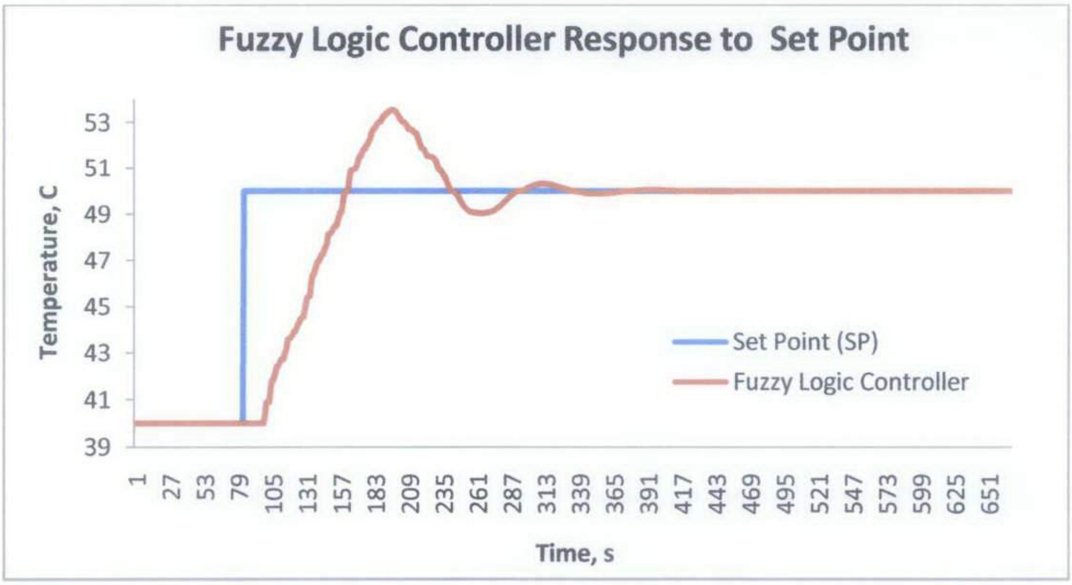

Figure 24: FLC Response to Step Input (5 membership function)

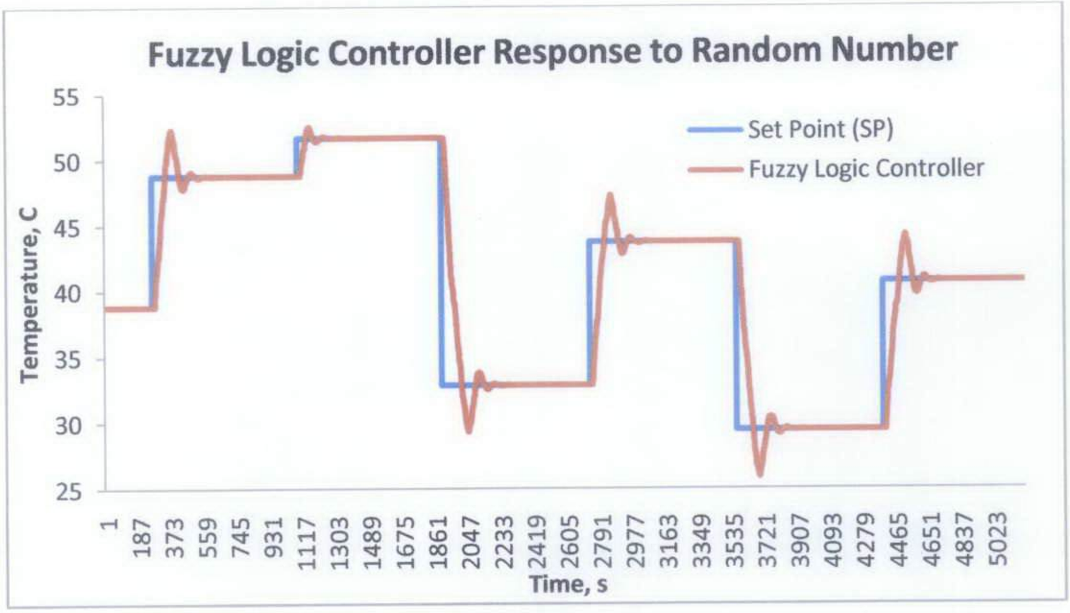

Figure 25: FLC Response to Random Number (5 membership function)

Based on the reaction curve obtain, FLC with five membership function has better control performance as compared to PI controller. However, this controller has overshoot and it takes time to settle down. The response of this controller also is too fast for temperature reaction. So, the third FLC simulation has been done to get the best controller among the best.

C. Seven membership function

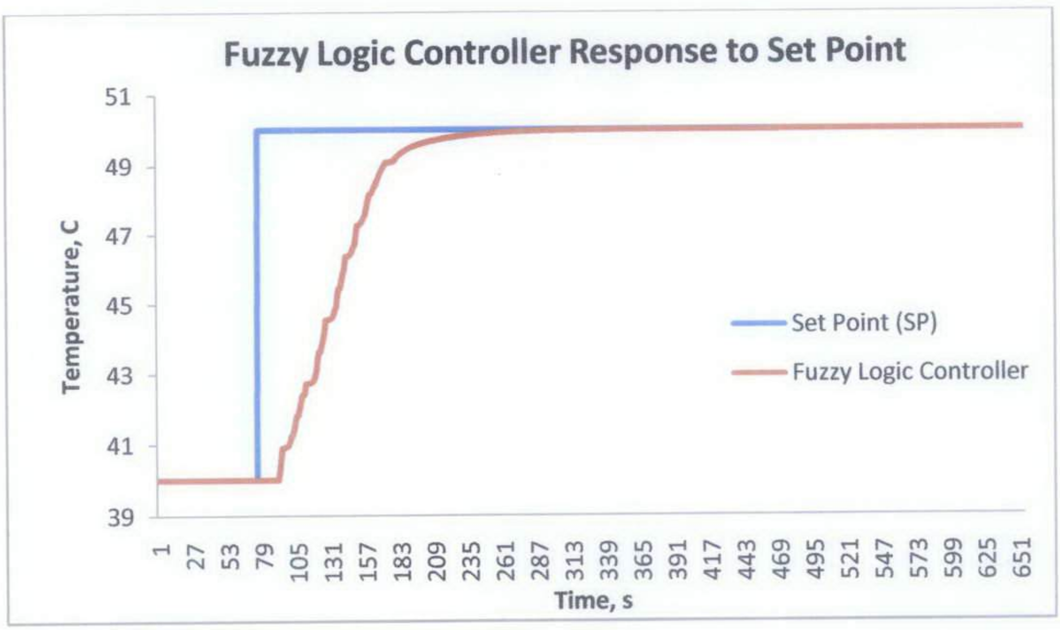

Figure 26: FLC Response to Step Input (7 membership function)

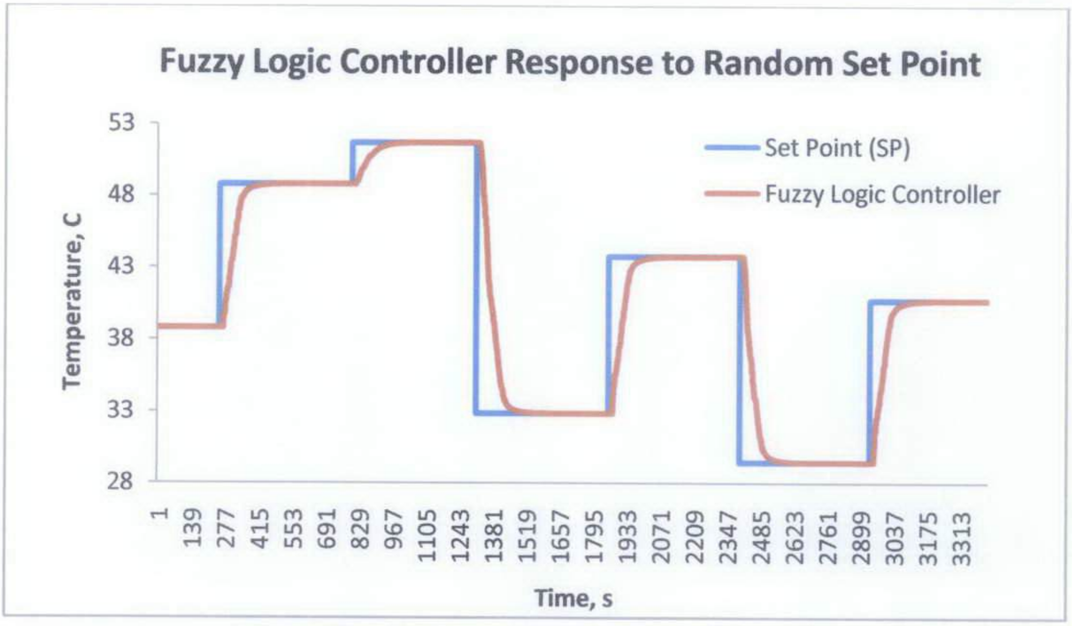

Figure 27: FLC Response to Random Number (7 membership function)

From the entire simulation process reaction curves above, the control performance can be studied. It can be concluded that the FLC with 7 membership function response is more favourable compared to others. This is due to better control performance of the FLC where it gives a zero offset, smaller rise time, very small IAE, zero decay ratio and overshoot, smaller settling time, and also fast response (refer to Table 7).

Table 7: Control performance comparison between PI Controller and FLC

Control performance	PI Controller	Fuzzy Logic Controller		
		3 membership function	5 membership function	7 membership function
Offset	Zero	Zero	Zero	Zero
Rise Time, Tr	5.39 min	5.39 min	**1.3 min**	2.95 min
IAE	Large	Large	Medium	**Small**
Decay Ratio	0	0	0.09	**0**
% Overshoot	0 %	0 %	35 %	**0 %**
Settling Time, Ts	8 min	7.9 min	4.85 min	**4.13 min**
Slope, s	0.07	0.09	**0.15**	0.12

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As a conclusion, the entire objectives have been done and from the result obtained, the Fuzzy Logic Controller with seven membership function has better control performance as compared to conventional method – PID controller. So, by using this type of controller in pilot plant / process plant, the process rate will become higher and increase the profit of the company. Fuzzy logic also is easy to understand because the mathematical concepts behind fuzzy reasoning are very simple. Besides that, this controller also based on human decision making hence developing and tuning of the FIS is more intuitive than the conventional controller. Therefore, the fuzzy logic controller could be used to replace the conventional controllers in the industry to increase the product quality, profit, production rate and also make the operation become smooth and faster.

5.2 Recommendation

In the future, the performance of heat exchanger by using Adaptive-Network-Based Fuzzy Inference System (ANFIS) will be compared. So that, it can be prove the advance control strategy is better than conventional method.

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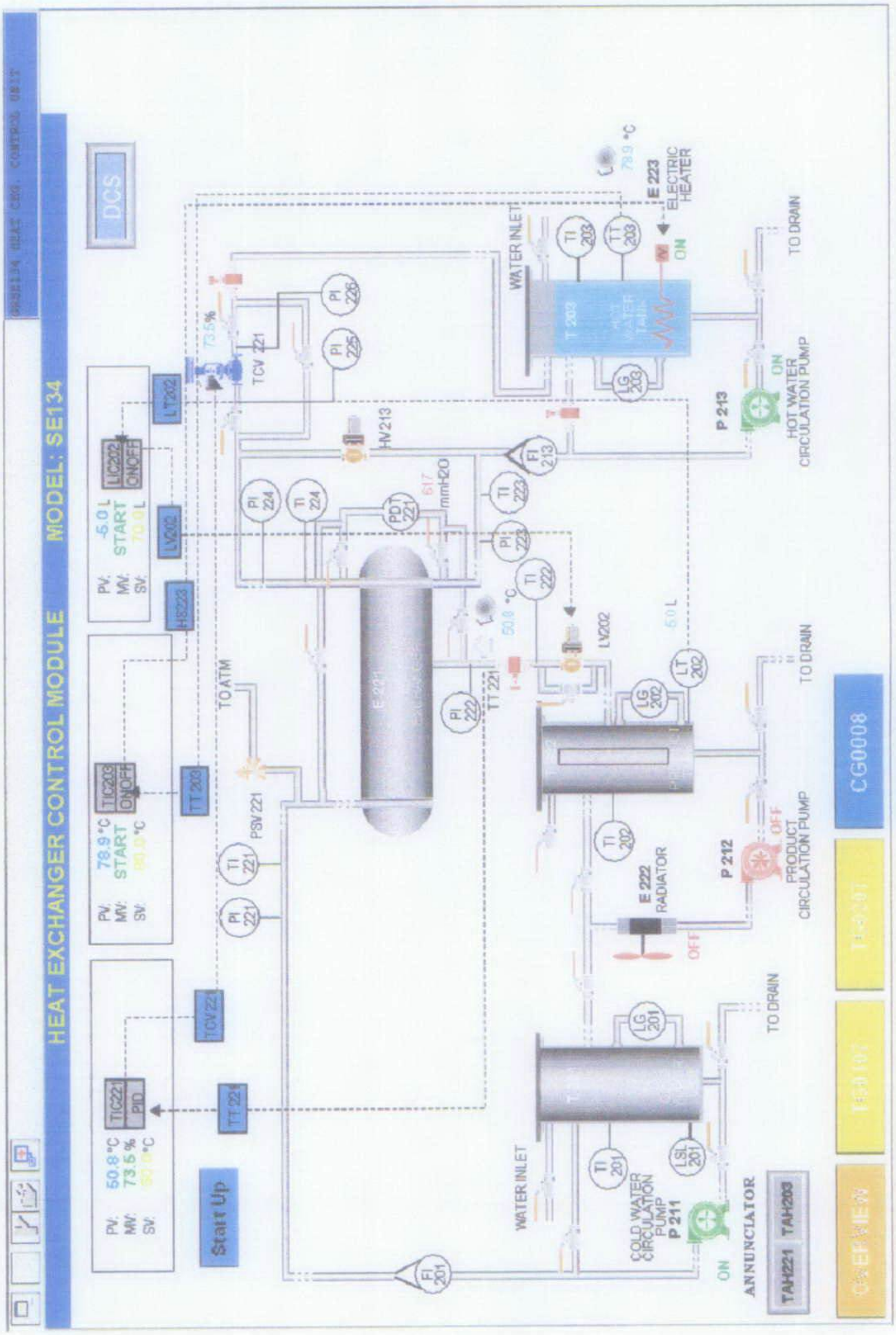
APPENDIX A

Heat Exchanger Control Module



APPENDIX B

Gantt chart for Final Year Project I (Semester July 2010)

Week number / activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of Project Topic	26 July													
Confirmation of Project Topic	29 July													
Meeting with Supervisor		3 Aug												
Preliminary Research Work			5 Aug – 17 Aug											
Submission of Preliminary Report				19 Aug										
Pilot Plant Familiarization				19 Aug										
Experimental Work					20 Aug – 21 Sept									
Submission of Progress Report								22 Sept						
Seminar										6 Oct				
Analysis & Comparison										4 Oct – 11 Oct				
Submission of Interim Report												18 Oct		
Oral Presentation														TBA

APPENDIX C

Gantt chart for Final Year Project II (Semester Jan 2011)

Week number / activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PID Controller Simulation	24 Jan – 11 Feb													
Fuzzy Logic Controller Simulation				14 Feb – 11 Mar										
Submission of Progress Report								14 Mar						
Fuzzy Logic Controller Simulation (cont.)									15 Mar – 5 Apr					
Poster Exhibition											6 Apr			
Seminar (Electrex)											6 Apr			
Submission of Draft Report													18 Apr	
Submission of Dissertation (soft cover)														28 Apr
Submission of Technical Paper														28 Apr
Viva														5 May
Submission of Dissertation (hard bound)														20 May