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Investigation Of Intelligent Pid Controller Intended For Heat Exchanger

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Abstract

This article discusses the implementation of the FLC-PID controller and standard PID controller for the control of the output temperature of a Heat Exchanger (HE). Mathematical modeling of Heat Exchanger is designed and the performance system is evaluated using different controller. The utilization of water is increasing whenever there is an increase in industries and startup companies which leads to scarcity of water worldwide. Indirectly there is a high rate of industrial effluents are rejected out and it pollutes the environment. To keep balance between the industrial growth, water scarcity and industrial effluents, proper treatment technologies for industrial effluents should be made. In this separation process, involves various stages of processing such as chemical and biological processes. In that heat exchanger is also playing a major role as a secondary treatment process. Maintaining the optimal output temperature in a HE is very important to obtain the absolute total dissolved solids (TDS). Based on TDS the wastewater treated and recycled. The simulation results obtained are compared and the performance comparisons like setting time and peak overshoot are outlined in this paper. The FLC-PID shows less setting time and overshoot.

Key words: *Temperature, Heat Exchanger, PID, FLC-PID*

Introduction

In most of the process industries, the transfer of heat from [1] one fluid to another is an essential activity. A device to transfer heat from one fluid to another is called Heat Exchanger (HE) and plays an important role [2] in many engineering processes in the process industries, steam generators in pressurized and water reactor plants, power plants as condensers, oil refining, environmental protection, energy generation, air processing and compressor cooling the refrigeration.

The shell and tube heat exchangers (STHE) were widely used in many industries compared to other types of heat exchangers. 35-40 percent of HE is shell and tube heat exchanger for easy construction and less maintenance [3]. It consists of number tubes in construction, i.e., it has number passes which tend to increase the rate of heat transfer [4]. The design of the heat exchanger controller is a very challenging process due to aspects such as measuring noise, uncertainty and robustness of the system.

Various control methodologies have been proposed, such as; in [5] Artificial Neural Network and CFD and fin and elliptical tube HE were studied. For increased heat transfer analysis, multi objective optimization is used. This [6] presents designing a model predictive controller of HE. In this analysis 4 separate robust MPC models have been used. State space model of water to air, surface HE is built and dynamic behavior is studied [7]. The liquid–liquid HE system is analyzed by parametric system identification and various models implemented in this system [8]. The SOPDT heat exchanger model was studied in paper [9] and stability methods were also investigated. For tubular heat exchanger fuzzy adaptive Kalman filter approaches designed in [10]. In paper [11], four various Artificial intelligence techniques are analyzed for shell and tube heat exchanger and finned tube heat exchanger. Dynamic

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behavior of plate HE was analyzed using state space model and H infinity controller is used to increase the response of the system [12]. The model [13] result ensures that the development of HE increases the rate of heat transfer and decreases the pressure drop by PSO. In paper [14] fuzzy controller along with a conventional controller to maintain the output temperature of STHE. In this paper, the performance FLC is analyzed to control a temperature of HE [15].

1. Heat Exchanger

Heat transfer devices are generally referred to as heat exchangers used to transfer heat from one medium to another. Figure 1 depicts the basic working of heat exchanger.

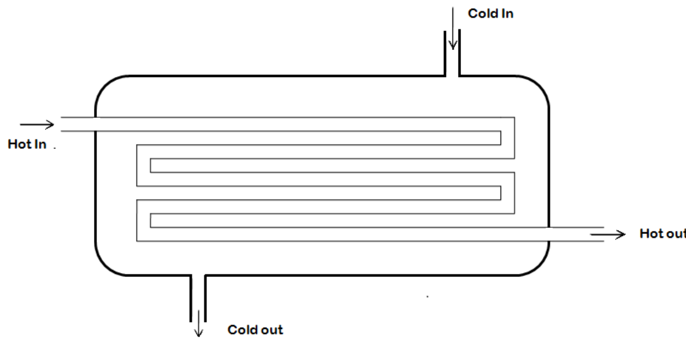

Figure 1 Working of heat exchanger

1.1 Types of heat exchangers

Heat Exchanger (Based on heat transfer surface)

Single Tube

Shell and tube

Cross flow

U - tube	Straight - tube

Compare to all the types of HE the shell and tube heat exchanger (STHE) used in many of the industries. Shell, Tubing. Baffles, Header are the essential elements of the shell and tube heat exchanger. The additional components will be added depending on the specification.

1.2 Process parameters

Process variables

Thermal design

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- Flow rates
- Input / output temperature of hot liquid
- Input / output temperature of cold liquid
- Pressure drop

Total number of tubes
Length and diameter of tubes
Heat transfer area
Number of shell and tube passes
Baffles, its type and size

TEMA (Tubular Exchanger Manufacturers Association) is an organization that offers specification for all the categories of heat exchanger. The operating parameters to monitor the output of the HE include input / output temperature of hot/cold liquid, flow rates. These parameters most influence the output of the process.

2. Experimental setup

Figure 2 depicts the experimental setup of a STHE. The heater supplies the boiling water to the heat exchanger tube and the temperature sensor (RTD) tests the heat of the boiling water supplied to the tube. Similarly RTD was located the entrance of a cold water supply side (shell side). The output of the temperature transmitter is given to the DAQ (VDPID-03) card and is represented in figure 3. The analog output is converted to digital signals and then fed to a personal computer.
The control action taken by the controller is given to DAQ card again. Now it converts the digital signals from the computer into analog signals for further processing. The 15 minutes data obtained from the DAQ with a sampling interval of 1 second are reported on the computer.

Figure 2 Shell and tube Type heat exchanger

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Figure 3 Shell and tube type Heat exchanger with DAQ set up

3. Mathematical modeling

Mathematical modeling of the system is important to design a controller. Naturally real time industrial process is non linear one, the performance of those systems are estimated with the help of standard first and second order plus time delay equations. The standard first order plus time delay (FOPTD) process equation is

$$G_p(s) = \frac{K_p e^{\tau_D s}}{\tau s + 1}$$

The standard SOPTD (second order plus time delay) process equation is,

$$G_p(s) = \frac{K_p e^{\tau_D s}}{(\tau_1 s + 1)(\tau_2 s + 1)}$$

Where K_p is the process gain, τ_D is the process dead time and τ, τ_1 and τ_2 are process time constant for FOPTS and SOPTD respectively. The experimental data collected from DAQ are used to design the transfer function of HE system. The derived process transfer function is

$$G_p(s) = \frac{8.262}{75.37s^2 + 14.3921s + 4.66}$$

which is in the form of SOPTD using system identification tool.

4. Control Methodologies

The control of the output temperature of the STHE device which can be accomplished by the controller is necessary. The paper [14] investigates the use of PI fuzzy controller to control the output temperature of a compact heat exchanger. In this paper conventional PID and Fuzzy PID controllers are designed and investigated.

4.1 PID controller design

The majority of industries still use the proportional Integral and Derivative (PID) action to regulate the process. The gains of PID controller are determined when the device transfer function is available. PID

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control is a good way to move the device towards a target temperature control. It is almost ubiquitous as a way of regulating temperature, chemical and scientific processes as well as automation. The PID controller is a combination of P, I and D term. The proportional control output is directly proportional to the error input of the system. High proportional control gives the system oscillation and results in an offset error. The integral control provides the response based on an integral of the error of the system. It reduces the oscillation of the system and also minimizes the offset. The derivative term purpose is to decrease the overshoot and reduce the error. So the derivative action is trying to mitigate the error by adjusting the output of the controller. In many circumstances, performance will take a long time, and perhaps even a variable time, to respond to input changes. The few PID tuning methods are open loop, closed loop and modified Z-N method, Chien - Hrones - Reswick method for open loop, Cohen and Coon method for open loop system and Damped oscillation method for closed loop system.

The Z-N approach offers better efficiency and is a very simple method when compared to other methods. This approach provides excellent tuning behavior for calculating the gain of K_P, K_I, K_D. Figure 4 illustrates the design of the PID controller block diagram. Once the process transfer function $G_p(s)$ is obtained (using system identification tool) from the data collected by the DAQ, the gains of controller is determined using Z-N equation. Based on the error value, the controller gives the control action and the system response meets the change of set point. Yet it takes a long time for the controller to take direct action.

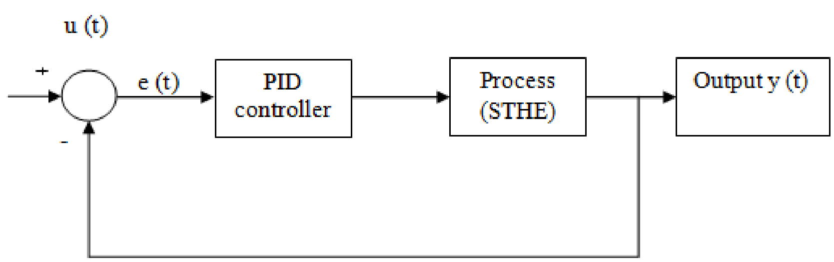

Figure 4 Block diagram of PID controller

4.2 Fuzzy logic controller

Figure 5 shows the basic building block diagram of FLC. FLC consist of four key blocks such as

i) Fuzzificaion: It is the process of changing the crisp value into a fuzzy value.
ii) Rule base: Set of logic rules in the form of an IF-THEN argument.
iii) Inference engine: Inference engine is the decision maker dependent on the systems input and output mapping and it is the main component of fuzzy logic system.
iv) Defuzzification: It is the method of generating a quantifiable result in the logic of Crisp.

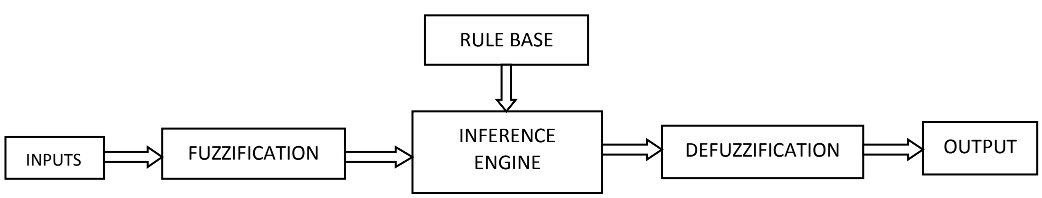

Figure 5 Basic building block diagram of FLC

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4.3 FLC-PID Controller

A fuzzy PID controller is used to control the temperature distribution of the heat exchanger. In the study of Artificial Intelligence, Fuzzy logic is a specific field of emphasis and is focused on the meaning of the knowledge, which is neither true nor false. Fuzzy logic involves changing the point to control the oscillation below the critical level [15]. Figure 6 demonstrates the Fuzzy logic PID controller block diagram approach. The FLC knowledge base includes two elements such as the rule base and the data base. Rule base having if –then rules and a data base have membership function of fuzzy sets used in fuzzy rules [16]. The core component of the FLC is the rule – base. The rule – base is used to define the control of the goals and to control the strategy of deciding the linguistic element of the control of the rules. The rules that connect the input and output variables are given here [17]. It consists of a number of rules that provide a connecting between the input error (e), change in error (de/dt) and the output y(t) of the controller [18]. The different shapes of the membership roles would have a different effect on the control efficiency [19]. In this system triangular membership functions are used. For the FLC, the two inputs (error, change in error) and output are divided into 5 fuzzy membership function such as NL, NS, ZE, PS and PL. Figures 7 and 8 shows the input and output membership function. On the basis of linguistic variables there are 25 rules are formed and the figure 9 represents the rule viewer. The output is defuzzified by using the centroid method. The surface viewer displays the full view of the relationship between inputs and output is depicted in figure 10.

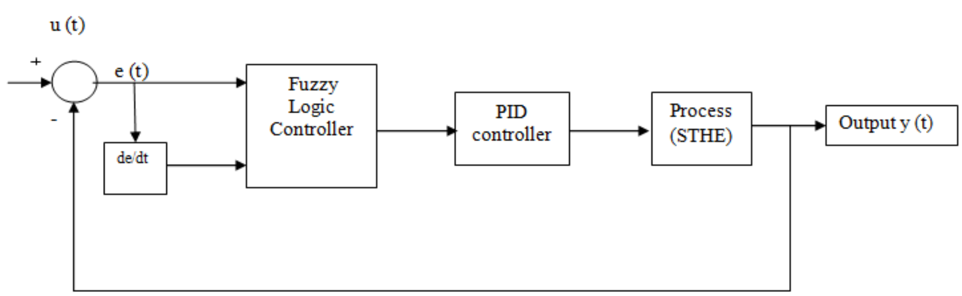

Figure 6 Block diagram of FLC-PID controller

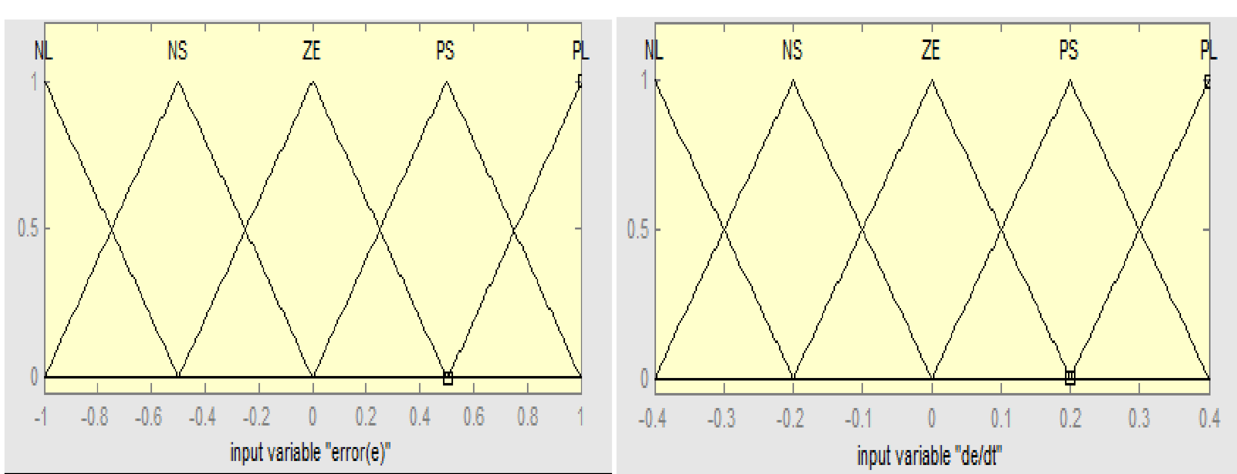

Figure 7 Input 1(error (e)) and Input 2(change in error (de/dt))

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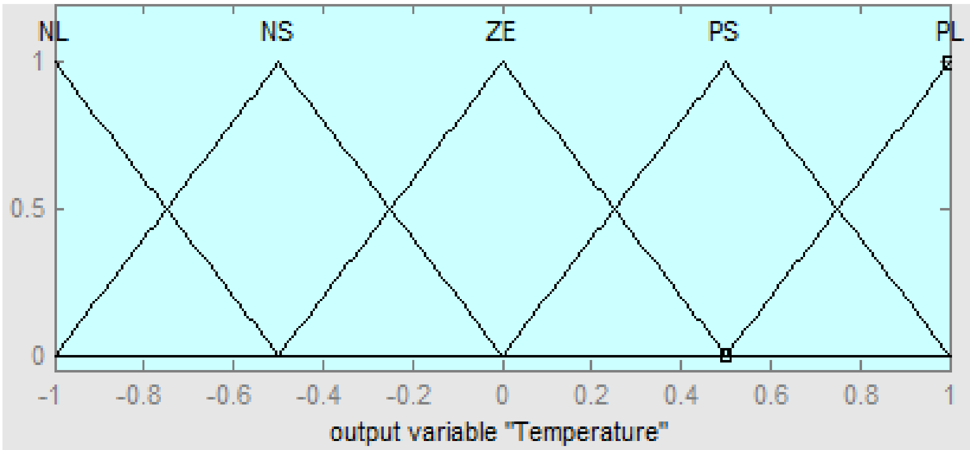

Figure 8 Output membership functions (Temperature)

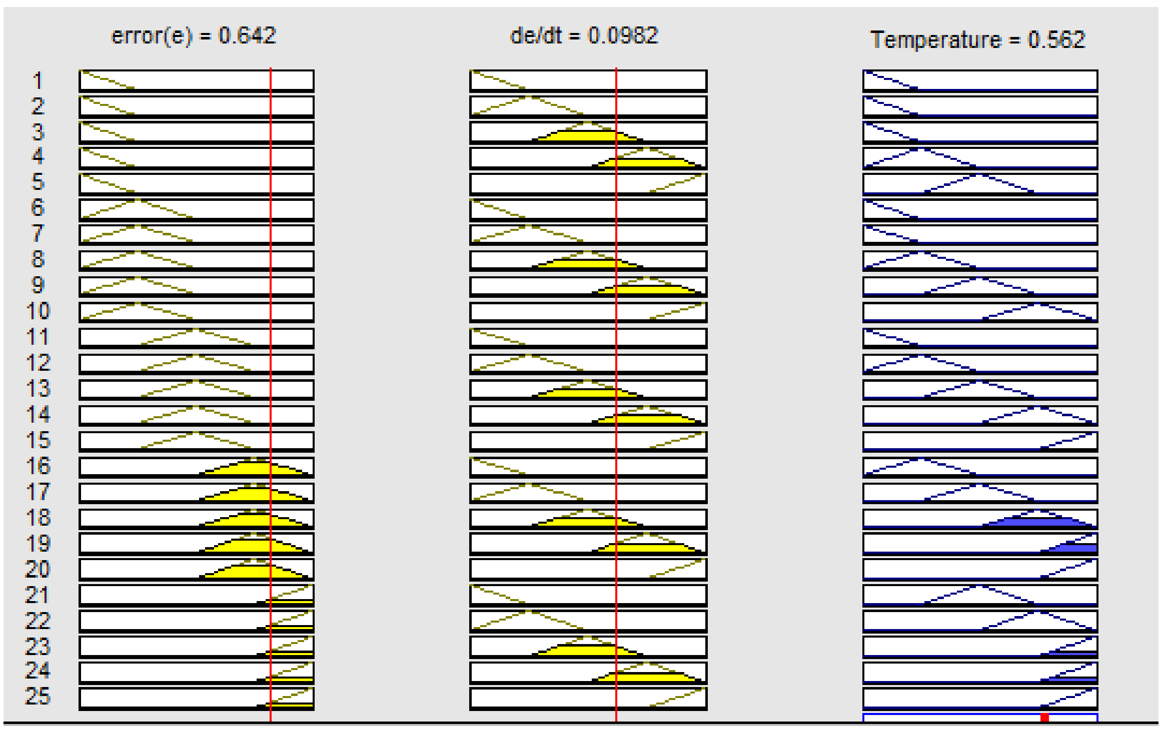

Figure 9 Rule viewer

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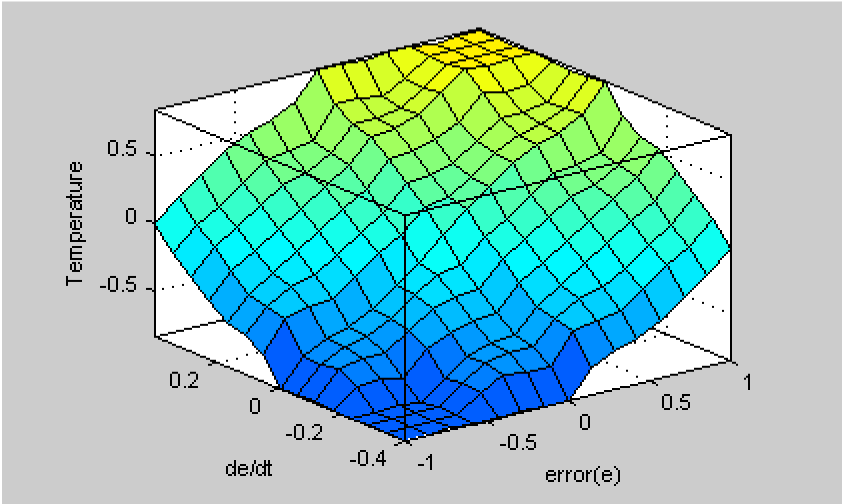

Figure 10 Surface plot

5. Results and discussion

5.1 Linearization

The acquired data from STHE with and without linearization is shown in figures 11 and 12. In order to eliminate offset error Piecewise linearization is done. In piecewise linearization entire system is linearized into linear models by considering different operating points.

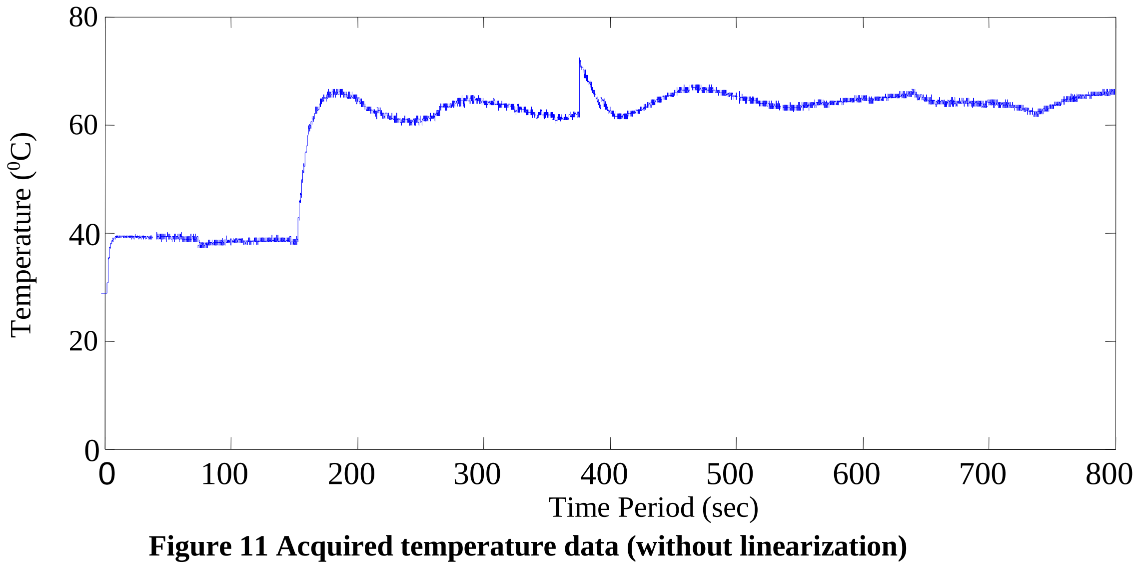

Figure 11 Acquired temperature data (without linearization)

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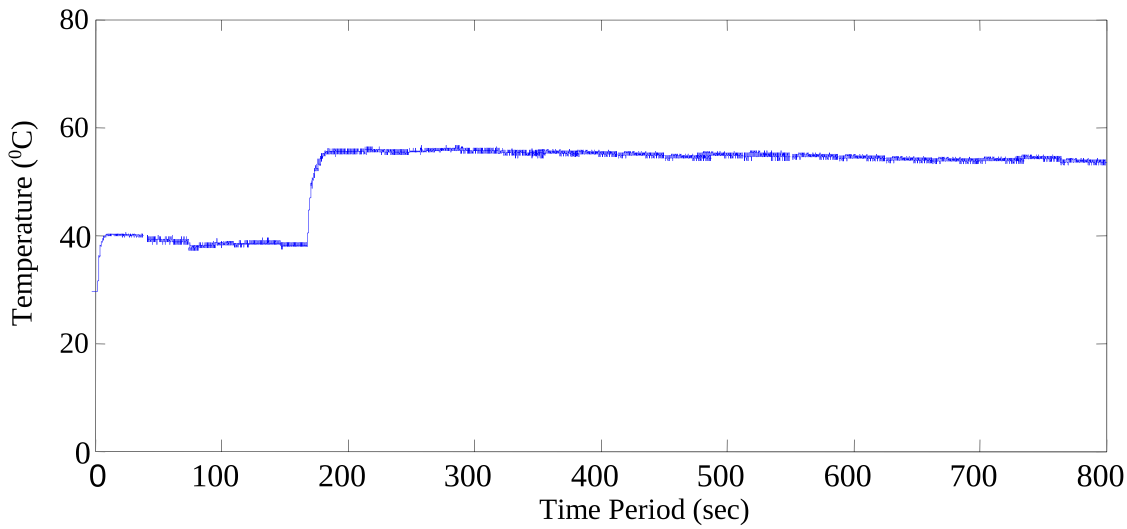

Figure 12 Acquired temperature data (without linearization)

5.2 system identification

This is an experimental approach certain experiments are conducted on the system with input and output signals. This approach can be used to estimate the unknown parameter. In this proposed system, the input and output data are collected from the STHE. Here the input (tube input hot fluid temperature) and output temperature (shell side) data are collected from the DAQ for the duration of 15 minutes. The collected data are used to find the transfer function of the system using a system identification tool. The final process transfer function of the open loop system is

$$G_p(s) = \frac{8.262}{75.37s^2 + 14.3921s + 4.66}$$

5.3 Stability analysis

Routh Hurwitz method

Routh –Hurwitz criteria approach used to determine whether or not the system is stable. It is a mathematical analysis that consists of two conditions which are both necessary and sufficient. The test is an expert method to find whether all the poles of a system positioned on the negative side of the s-plane. For the stability analysis of the HE system is performed by Routh criterion. The Routh array is

S^2	75.37	4.66
S^1	14.3921	-
S^0	4.66	

The necessary condition and sufficient conditions are satisfied. So the heat exchanger system is stable.

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Bode diagram

Bode diagram is the graphical method for the system's frequency response. It is consists of two plot magnitude plot (Frequency Vs log magnitude) and phase plot (Frequency Vs phase angle). Bode plots are found the stability of the system. Figure 13 depicts the bode plot of the system and it demonstrates the stability of the system. After stability review, the system is able to control using traditional PIDs and FLC-PIDs.

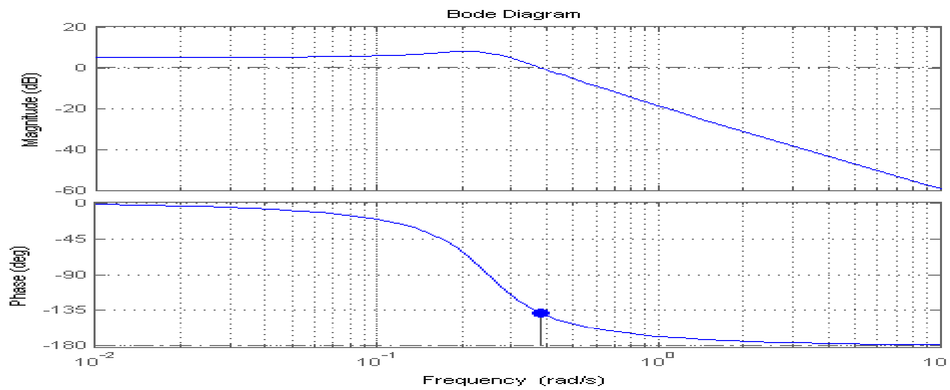

Figure 13 Bode plot

The resulting graph for the conventional PID controller and FLC-PID is shown in figures 14 and 15. The Z-N approach is used to determine the PID controller gain values. Figure 14 shows that high overshoot and higher settling time values are achieved in the system with PID controller. Further improvement in the characteristic response of the system the FLC-PID used. Figure 15 shows that the system's response has improved significantly with the aid FLC. The overshoot of the system using FLC has been reduced; the settling time, the peak amplitude of the system also appreciable reduction as analyzed.

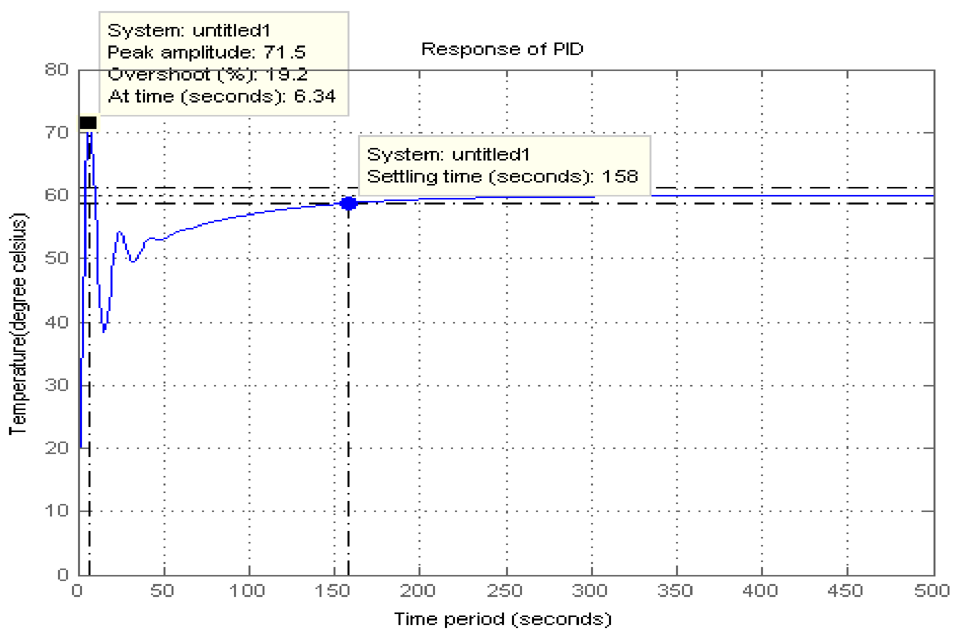

Figure 14.PID response

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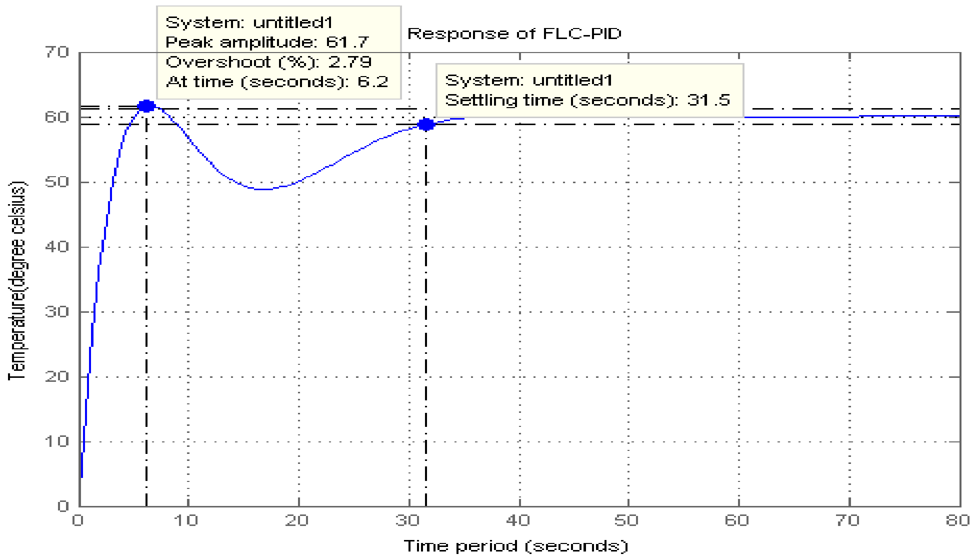

Figure 15 FLC-PID response

Table 1, reveals that the overshoot and settling time with the FLC-PID controller was substantially reduced compared to standard PID.

Table 1 Time domain performance of PID controller and FLC-PID

Characteristics	PID controller	FLC-PID controller
Settling time	158 seconds	31.5 seconds
Peak Overshoot	19.2 seconds	2.79

Conclusion

The output temperature of the STHE is regulated in this paper using an FLC-PID controller and traditional Proportional Integral Derivative controller. MATLAB is used to give the simulation results of both the conventional PID controller and FLC-PID controller. The time domain results of peak overshoot (2.79) and settling time (19.2 seconds) reduced with FLC and also control performance has been significantly enhanced. The proposed fuzzy logic controller has more benefits, such as greater flexibility, control, better dynamic and static performance compared with conventional controller. As a result, FLC-PID controller design introduced and implemented.

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