CHAPTER 1
INTRODUCTION

1.1 Preamble

Designing a controller for any process is a very complicated and time taking challenge for control engineers. Many processes and chemical industries are using Continuous Stirred Tank Reactor (CSTR) for their operation. CSTR is a specialized chemical reactor with complex non-linear dynamic characteristics. Based on mathematical modeling, there is considerable interest in their state estimation and constant control. However, lack of understanding of process dynamic, compassionate and non-linear behavior of the reactor, have made it difficult to develop the accurate mathematical model of the system. An effective product concentration control in CSTR should be achieved through a specific mathematical model [1].

Different controllers are being used to keep the process in the desired situation. Therefore, more than one variable is measured to control each parameter in the process. The physical variable controller of this process can be implemented to design. In this dissertation, an attempt is made to find out the appropriate measures for controlling the CSTR, by comparing simultaneous controllers, dependency could be put to an end on the execution record and determination, given time area comes about. Each controller is run in its way to keep the process at the desired value.

A chemical reactor is one of the fundamental parts of the system used for the chemical reaction. There are two types of chemical reactors, the first is exothermic and the second is an endothermic reactor, which is used for more than one chemical reaction for heating and cooling process. In most of the chemical processes, chemical reactors are used in which chemical reactions that occur. To design the reactors, chemical engineers make sure that the response will be high efficiency and produce the highest performance of the product by sending the desired output. In all processes, the temperature for the isothermal term will be stable. The warmth does not evolve or is absorbed in the chemical reactor. CSTR concentration is an effective form of control exchange system [2]. Due to the large system control companies, control is used in this process; control specialists are very interested in soft computing control devices so that the selected results are completed. For the CSTR process, various conventional and intelligent controllers are used to implement the process such as PID Controller, Genetic Algorithm, and Fuzzy Logic Controller.

1.2 PID Controller

The PID Controller works for most of the control systems in the industry. It's been said that over 95% of controllers at intervals of commercial programs of technical management are PID. The PID controllers are used in a broad mixture of issues, the car type; the airfare handles, etc. because of its simplicity, cleanliness, practical, valuable and simple to use [3]. Although PID controller is simple to recognize still, the role of the machine requires exact parameters of PID. PID controller has three independent control actions namely as Proportional control (P), Integral control (I) and a Derivative control (D). These three independent control parameters expressed regarding proportional gain (K_p), integration gain (K_i) and a Derivative gain (K_d) [4]. Implementation of PID controllers requires proportional gains, integral gain and derivative gain to be adjusted as per the requirement. A conventional PID controller is used to determine the estimations of various performance analysis parameters.

1.3 Fuzzy Logic

Fuzzy Logic is an innovation used to create intelligent control systems and infromations. It doesn't show the true or false statement but assigns a value that represents the extension of the true or false statement. In these true or false values that show a number. The Fuzzy logic has the range between from 0 to 1. All things have been considered, 0 indicates the absolute falseness, and similarly, 1 indicates the absolute truth. It uses the expert knowledge to make decision. It has the benefits of better stability, flexibility and response time etc. [5].

1.4 Genetic Algorithm

The Genetic Algorithm (GA) is a stochastic overall research technique, which imitates the method of the natural evolution. John Holland formally started these techniques to the United States in 1970. GA is the search and the optimization influenced by the standards of the two biological methods: the procedures of "natural selection" along with the mechanics of "natural genetics." The Genetic Algorithm has been effectively actualized in the range of modern gadgets, such as identification of system parameters and automated control, form recognition, fuzzy logic controller, and programming. It has been an intelligent method that advances to the best possible outcomes. It deals with the three essential of genetic operators are Selection, Crossover, and Mutation [6].

In this thesis, GA's are used to determine the optimal values of the traditional PID controller parameters for enhancing the system's transient response.

1.5 Objective

The various objectives of this dissertation are:

- To study the mathematical model of an isothermal Continuous Stirred Tank Reactor (CSTR).
- Study and implementation the van-de-vusee reaction scheme for controlling the fluid and flow.
- To implement of conventional PID controller, Genetic Algorithm, fuzzy logic controller over the CSTR model.

1.6 Organization of the Dissertation

This dissertation is organized into six chapters. The chapters are organized as follows:

Chapter 1: This chapter presents a brief overview of the controllers.

Chapter 2: This chapter is titled as a review of the relevant literature. Here, a literature review has been done for the CSTR process.

Chapter 3: This chapter covers the Continuous Stirred Tank Reactor (CSTR) and its isothermal mathematical modeling.

Chapter 4: This chapter illustrates all the controllers (PID Controller, Fuzzy Logic controller, and Genetic Algorithm) and their soft computing techniques.

Chapter 5: This chapter discussed the details of the showing their results and the discussion and comparison of the results obtained with various methods.

Chapter 6: In this chapter the conclusion and future scope of the work has been discussed.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

In this chapter, a brief summary of the literature has been discussed.

2.2 Literature Survey

H.-P. Hong et al. (1992), proposed self-tuning PID controller using the fuzzy logic to overcome the drawbacks of existing self-tuning PID controllers. The proposed method depends on the settling time of the process. The benefit of using fuzzy logic is that it does not have to use test signals for modulation. Also fuzzy logic controller can be applied to an extensive variety of plants with robustness because it is not affected by the processes characteristics. The simulation results show that the proposed controller automatically sets the optimal PID parameters under the various operating conditions [7].

P. Wang et al. (1992), proposed self-tuning PID controller using the advanced genetic algorithms (GA). GA does not require analytical performance evaluation so they can use various settlement time together and also be knowledge-based performance index. When comparing the results obtained by Ziegler-Nichols and GA; the results are always better than ZN. GA techniques have several benefits, for example, robustness, simple mechanics, worldwide improvement, multi-objective [23].

M. Zhuang et al. (1993), studied, the PID controller with integral performance criteria. Ziegler-Nichols was used to determine the parameter of the PIDF controller. The performance criterion provides a good step response to the system and the best methods for setting parameters. Theoretical results are given for a simple plant with delay and used to verify the numerical calculations taken with a Pade approximation [19].

K. Åström et al. (2001), presented state of the art which reflects the PID controller and its future. In this paper, specific issues are mentioned that include the specifications, stability, design, application, and performance of the PID controller. This article also talks about other options to the PID controller and its future [4].

G. Mann et al. (2001), analyzed by several domains of time and analyzing PID tuning for the FOPID process design. The traditional PID controller that can handle actuator saturation, process linearity and the effective control action have also been discussed [42].

K. H. Ang et al. (2005), gave a complete description of modern PID controllers, various parameters in PID controller, commercial equipment module, and PID controller programming bundles. This article additionally examines the conventional PID controllers and reviews the future PID controller as a PID controller plug and play [8].

A. Khan et al. (2006), proposed the fuzzy PID controller by passing the PID controller domain tuning rules. The advantage of the proposed technique was its best performance regarding rising time and a small overshoot. The step response of the Fuzzy PID controller provides a small overshoot, less settling time, less rise time, and minimum absolute error as compared to the PID controller [18].

M. W. Iruthayarajan et al. (2007), proposed the optimization of PID parameters using the GA and PSO. The PID Controller has been tuned to minimize the different ISE, IAE, and ITAE execution measures for two linear systems. RGA and PSO implementation have been compared to the response times, calculation time, and performance statistics 20 independent analyses. The Performance measured as ISE, IAE, and ITAE considered the design of two different linear system of the PID controller. ITAE was preferable for a fast settling time [29].

B. W. Bequette (2008) presented the modulation design and control of simulation process; author has developed the mathematical model of the CSTR chemical reactor and described how to design the Simulink reactor model and its process control. It can also be described as a transient response of the PID controller by using the Ziegler-Nichols techniques [9].

Sanju Nanda (2008) designed bases reactors for chemical reactions, and such reactors can be according to the number of coexistence phases of these categories of homogeneous and heterogeneous reactors. A phase, such as gas or liquid, is in the reactor, i.e., a homogeneous reactor and two distinct reactants (or catalyst) phases, i.e. a heterogeneous reactor [2].

S. Kermiche et al. (2008), proposed the Fuzzy-PID controller parameters optimized by the GA. They have been adopted a fuzzy inference system to determine the weight values that multiply the set point by proportional action. This contribution has genetic algorithms to adjust the types of enrollment to the fuzzy controller to change its parameters. The benefits of the fuzzy logic controller were its simplicity, easy to adapt to the set point implementation operation process [38].

Jin-Sung Kim et al. (2008), introduced the control system that makes the auto-tuning by using a stochastic method that based on the improvement of GA. For a better Genetic Algorithm evaluation process, objective function defined to root mean square error has been used. Also, in order to obtain the better performance of genetic algorithm, greater purity and longer period of random numbers were desired [31].

L. Fan et al. (2009), have proposed the PID controller that based on GA. Ziegler-Nichols tuning method has been used to predict the range of gain GA-PID controller. Proposed strategy has been implemented to optimize PID controller gain coefficients, which have significantly increased the performance of the PID controller. Simulation evaluated the proposed controller in a second and third order control system. The simulation shows that the controller demonstrates Ziegler-Nichols technique based PID controllers and Fuzzy-PID controllers regarding dynamic and stable properties [27].

R. M. S. Malar et al. (2009), introduced the CSTR, which is a complex nonlinear system. However, lack of understanding of process dynamics, highly responsive and non-linear behaviour of the reactor, the development of a precise mathematical model of the scheme has been introduced. Effective product concentration control in CSTR must accomplish through an exact model. In this article, they proposed the use of Artificial Intelligence (AI), the neural network, fuzzy logic, and neuro-fuzzy to the model and to control the CSTR process [12].

C. Lu et al. (2010), discussed the parameter of the Fuzzy-PID controller. Fuzzy controller that based on the human language and mind habits belongs to the intelligent techniques. The Fuzzy logic has a static steady error. While PID may be neglect the static error and the principle is basic, simple to use as well as strong in nature, the PID has been acquainted in fuzzy control making it another controller. The simulation result shows that the parameters of the Fuzzy-PID controller compound improves the dynamic and static quality control system and has the more accurate control [43].

H.M. Asifa et al. (2010), proposed the PSO method to determine the optimal parameters of the PID controller to improve the step response by using the third order system. The result was compared with the perfomance of the PID controller using the conventional methods, for example, the Ziegler-Nichols, Tyreus-Luyben technique and the internal model control.

The proposed technique is better than traditional methods. The PSO based PID controller has a better result, for example, simple access, stable convergence, and high computational efficiency [10].

M. Tajjudin et al. (2011), have proposed optimum PID tuning introduced with PSO optimization, and it has been used to verify optimally K_p, K_i and K_d Minimize some of the typically IAE, ITSE objective functions. The proposed method presents the simulation results in a model reference input for the PSO tuned by using the PID controller for better output execution. The simulation was done in a basic original model for three reference model with various times constant. The proposed method has found better about the accuracy and stability in the results using the step response of reference signal [21].

S.-C. Gan et al. (2011), proposed the self-tuning PID controller that based on the fuzzy GA. The proposed method has been used to optimize the PID parameters of temperature control in a thermal furnace. After the genetic algorithm, 200 iterations performed, the preset temperature was set to 60 degrees in two intelligent nodes. The analysis has been shown that the PID controller based on the fuzzy genetic algorithm obtained less error and along with the less settling time [39].

A. H. Fathi et al. (2012), introduced the optimizing of the PID controller parameters and improved the performance by using the PSO and GA. Authors have described the PID controller and tune its parameter by using PSO and GA. They have also discussed the various error performance indices [6].

M. Geetha et al. (2012), have proposed optimum tuning of the PID controller for CSTR using the PSO technique. The proposed method has based on the virtual PID controller setting for CSTR control system using PSO technique for the minimum Integral Square Error configuration. The continuous stirred tank reactor control system PID parameter was obtained by the use of various Zeigler-Nichols methods, GA, and PSO. The results of the three adjustment strategies were compared. While comparing the three methods, it was found that the PSO technique was best executed [41].

R. Kumar et al. (2013), introduced a comparison of the some known as the various control schemes such as feedback, feedback plus feedforward, cascade and cascade plus feedforward by using the third order control system. The controller performnce in the different control plans i.e. the PID controller tuned to the Ziegler-Nichols technique and auto-tune relays method. A comparative analysis depends on the several performance measures, which is the rise time(t_r), settling time(t_s), the overshoot(M_p), constant error(e) along with the various performance indexes. The simulation result shows that the auto-tune relays method gives the better performance of the various control schemes [11].

A. Singh et al. (2013), studied that the concentration isothermal CSTR play a significant role in the chemical industries. Progress continues, and development in the sector has been increased and expanded the requirement for control with the intelligent methods. In this article, the outline of an ideal PID and FOPID has been discussed. The FOPID which is the GA and PSO controls the concentration of isothermal CSTR, independently of the disturbances introduced into the system. The transient response shows the operation of various standard controllers, and it observes that the FOPID controller with the particle swarm optimization approach achieves better results compared to other techniques [13].

V. Chopra et al. (2014), studied the PID controller that used in various industrial control loops due to their robustness, simplicity, ease of implementation. In traditional methods of tuning the PID controller have some limitations and it can be taken into account by tuning the PID controller using several computing techniques. The method optimized by the controller was utilized to control the concentration of CSTR. At last, it was shown that several soft computing methods give better performance than Zeigler-Nichols technique used for various performance indexes [20].

A. Jayachitra et al. (2014), discussed, the GA based PID controller has been proposed for tuning optimize the PID parameters in the CSTR process. Authors have utilized integral weighted combination of objective functions to regulate the PID parameters and its various performance indexes. A PID controller reduces the operating range of dynamic process with non-linearity. In this paper, the optimized parameters of the PID controller for CSTR system process all through the working extend to exceed the PID control boundaries [16].

H. Ahmed et al. (2014), compared the PID controller methods to improve the performance of the DC motor system. First, the PID controller has tuned to the traditional Zeigler-Nichols methods and after that it uses the Simulink/MATLAB response. The Fuzzy PID gain scheduling, where fuzzy rules have been used to optimize the PID controller parameter that based on the error and its derivatives. The result shows that for the DC motor position control system shows a better performance than different techniques [24].

D.S. Nagaraju et al. (2014), discussed the CSTR as one of the commonly used reactors in the chemical process. Such a specific concentration is obtained by mixing a full strength solution with water in the desired ratio. Authors have designed a controller to control the concentration of a chemical with the help of another. It affects the various models like PI, PID, FLC and GA. Authors concluded that the concentration control has better performance with the addition of genetic algorithm (GA) rather than the FLC and conventional PID controllers [15].

CHAPTER 3
CHEMICAL REACTOR

3.1 Introduction

A chemical reactor is one of the fundamental parts of the system used for chemical reaction process. There are two types of chemical reactors, the first is exothermic and the second is an endothermic reactor, used for the chemical reaction processes during heating and cooling. Before designing the reactors, chemical engineers make sure that the reaction will be effective and produce the highest performance of the product by sending the desired output and the maximum benefit at a least cost. For a chemical reaction, operational cost required, includes a form of energy in the type of heat, eliminating energy exchange, the cost of raw materials of workforce, etc [2]. Energy variations can come in the form of heating or cooling pumps to increase the pressure, stirring etc.

3.2 Types of Chemical Reactor

Chemical reactors can be classified as

1. Batch Reactor
2. Continuous Reactor (CSTR)
3. Semi-Batch Reactor

3.2.1 Batch Reactor

In the batch reaction process, each of the reagents are included at the start, and no additions or removal occurs while the reaction proceeds and output is obtained when the process stops. The method of the batch is appropriate for little production and processes for example, pigments, dyes, and polymers [2].

3.2.2 Continuous Reactor

Processes in which reactants are fed to the reactor and the products or by-products are removed in between proceed with the reaction. For example, Haber Process for Ammonia production. Continuous production usually reduces the production cost of the production batch, but restricts the flexibility of the production. Continuous reactors are preferred for mass production [2].

3.2.3 Semi-Batch Reactor

It is operated at both continuously going batch process at inputs and output. This process is often referred as semi-continuous. In such semi-batch reactors, some reagents may be added or withdrawn during the reaction process. These devices are designed by chemical engineers who are familiar with the requirements of chemical reactors and can be used in different ways. For specific applications, an engineer can design the special reactor to cater the needs of a particular application [12].

3.3 Continuous Stirred Tank Reactor (CSTR)

The Continuous Stirred Tank Reactor (CSTR) with single input and single output as shown in Figure 3.1. The CSTR is a primary tool in the field of chemical and biochemical, which provides different ranges of research in the areas of the chemical engineering. CSTR system has properties of time changing, non-linear system and time delays. In CSTR, the chemical reactor is either an exothermic i.e. energy release or endothermic which requires energy input, energy is required; it is possible that they are added or removed to the reactor for the steady temperature to be kept. CSTR is a complex non-linear system [13]. Because of its high nonlinear behavior, the identification of the problem and the CSTR control is always a difficult task for the control systems engineer. Modern reactors are controlled by adjusting the linear optimizations settings, and the PID control parameter is based on the linearization of reactor models in a small area around the stable operating points [14]. If this process needs to confront significant disturbances and more sensitivity is managed under the situation of the case, then the situation can vary greatly from the trajectory area, and therefore the controller performance gets spoiled. Despite the awareness that they are internally non-linear, most advanced processes, linear control design methods, offset the capabilities of PID controllers [15].

3.4 Types of Continuous Stirred Tank Reactors (CSTR)

There are two continuous stirred tank reactors:

1. Exothermal CSTR
2. Isothermal CSTR

3.4.1 Exothermal CSTR

It is a classic case study of non-linear systems. In fact, in dynamical behavior, there are many points of balancing the state-of-the-art facilities. So far, the correct behavior of the premises of the exothermic reactor has not been received. In energy-based balance control, the controller prepares the energy function of the system so that it has minimum limits at the desired change point. The controller provides the system with a limited amount of power to operate the system to the desired state [2]. This idea is associated with electromechanical systems and thermodynamic systems, which have entropy functions rather than energy accumulation.

3.4.2 Isothermal CSTR

It is a CSTR that works to keep the temperature and volume constant. The reaction design consists of set of irreversible reactions. In this dissertation, the CSTR isothermal model is taken [9].

3.5 Mathematical Model of Isothermal CSTR

For a CSTR product, the concentration in the instrument can be controlled by adding the rate of feed flow that changes the time of residence (for continuous reactor volume) [12]. The Isothermal CSTR as shown in Figure 3.1. In this case, there may be a CSTR isothermal series as well as a parallel reaction (note due to the reaction of Van-de-Vusse) [9].

$$A \xrightarrow{k1} B \xrightarrow{k2} C \text{ And}$$
$$2A \xrightarrow{k3} D$$

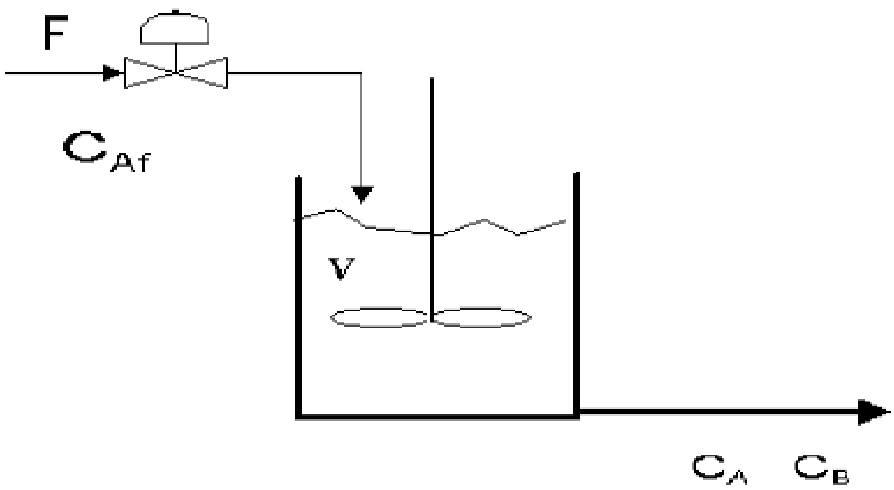

Figure 3.1 Isothermal CSTR system [13]

General physical balance equation is given as

$$\frac{d(V_p)}{dt} = F_i\rho - F\rho \quad (3.1)$$

Hence, $$F = F_i \quad (3.2)$$

Where, $$\rho = \text{liquid} - \text{ phase density}$$

$$V = \text{Volume}$$

$$F = \text{Volumetric flow rate}$$

For specific feedback under consideration, the rate constant is

$$k_1 = 50\ hr^{-1} = 0.8333\ min^{-1}$$

$$k_2 = 100\ hr^{-1} = 1.666\ min^{-1}$$

$$k_3 = 10\ \frac{mol}{liter.hr} = 0.1666\ \frac{mol}{liter.hr}$$

Furthermore, steady-state feed concentration is $C_{Afs} = 10\ \ gmol/liter$

Ideally, it is not hard to drive, conditions with a constant volume reactor:

Component can be shown as content

$$\frac{d(VC_A)}{dt} = F\,(C_{Af} - C_A) - Vk_1C_A - Vk_3C_A^2 \quad (3.3)$$

Using eq. (3) results in eq. (4),

$$\frac{dC_A}{dt} = \frac{F}{V}(C_{Af} - C_A) - k_1C_A - k_3C_A^2 \quad (3.4)$$

$$\frac{dC_B}{dt} = -\frac{F}{V}C_B + k_1C_A - k_2C_B \quad (3.5)$$

Where C_A and C_B are the molar concentration of A, B individually and k_1,k_2, k_3 are the reaction rate constant.

$$\frac{dC_C}{dt} = -\frac{F}{V}C_C + k_2C_B \quad (3.6)$$

$$\frac{dC_D}{dt} = -\frac{F}{V}C_D + \frac{1}{2}k_3C_A^2 \quad (3.7)$$

See that the first two equation components do not rely on the concentration of C or D. Since it is concerned about the concentration of components B, only initial two conditions are taken:

$$\frac{dC_A}{dt} = \frac{F}{V}(C_{Af} - C_A) - k_1C_A - k_3C_A^2 \quad (3.8)$$

$$\frac{dC_B}{dt} = -\frac{F}{V}C_B + k_1C_A - k_2C_B \quad (3.9)$$

The molar rate (per unit volume) of the structure of each element is

$$r_A = -k_1 C_A - k_3 C_A^2 \tag{3.10}$$

$$r_B = -k_1 C_A - k_2 C_B \tag{3.11}$$

$$r_C = k_2 C_B \tag{3.12}$$

$$r_D = \frac{1}{2} k_3 C_A^2 \tag{3.13}$$

To solve eq. (3.8) and eq. (3.9),

In a steady state, the balance of component A produces a quadratic expression,

$$k_3 C_{As}^2 + \left(- k_1 - \frac{F_s}{V}\right) C_{As} + \frac{F_s}{V} C_{Afs} = 0 \tag{3.14}$$

The manipulated input in this system is dilution rate. It is found by dealing with quadratic and positive root clearly there can not be a negative value consideration. By solving the equation (3.8) and (3.7) the stable-state concentration of A and B is defined as

$$C_{As} = \frac{-(k_1 + \frac{F_s}{V})}{2k_3} + \frac{\sqrt{(k_1 + \frac{F_s}{V})^2 + 4k_3 \frac{F_s}{V} C_{Afs}}}{2k_3} \tag{3.15}$$

And the solution of the stable-state concentration of B,

$$C_{Bs} = \frac{k_1 C_{As}}{\frac{F_s}{V} + k_2} \tag{3.16}$$

Using these two values, it is possible to detect the stable-state input-output curve related to C_{Bs} and F_s/V. Here the rate of dilution (F/V) is stated as controlled information. The capacity of reactor is equal to 1 or 10,000 liters. A similar rate of dilution will produce the same concentration as acknowledging the feed stream is the same structure [9].

State is represented as a linear model of space

$$\dot{x} = Ax + Bu$$

$$y = Cx + Du$$

Where the states, input and output sources are in deviation variable types, primary input i.e. dilution rate is controlled, along with secondary (A's feed concentration) can be input.

State represented as the space variable $x = \begin{bmatrix} C_A & -C_{As} \\ C_B & -C_{Bs} \end{bmatrix}$

Output variable is shown in this form $y = \begin{bmatrix} C_A & -C_{As} \\ C_B & -C_{Bs} \end{bmatrix}$

Input Variable is shown as $u = \begin{bmatrix} \frac{F}{V} & \frac{F_s}{V} \\ C_{Af} & -C_{Afs} \end{bmatrix}$

Two dynamic functional equations are shown in this form

$$\frac{dC_A}{dt} = f_1(C_A, C_B, \frac{F}{V}) = \frac{F}{V}(C_{Af} - C_A) - k_1 C_A - k_3 C_A^2 \quad (3.17)$$

$$\frac{dC_B}{dt} = f_1(C_A, C_B, \frac{F}{V}) = -\frac{F}{V} C_B + k_1 C_A - k_2 C_B \quad (3.18)$$

The state space of the matrix elements of A is found $A_{ij} = \left.\frac{\partial f_i}{\partial x_j}\right| x_s, u_s$

The state space of the matrix elements of B is found$B_{ij} = \left.\frac{\partial f_i}{\partial u_j}\right| x_s, u_s$

In the case of a stable position solution, two conditions should be linearized so that the state can get the space matrix.

$$A = \begin{bmatrix} -\frac{F_s}{V} - k_1 - 2k_3 C_{As} & 0 \\ k_1 & -\frac{F_s}{V} - k_2 \end{bmatrix}$$

$$B = \begin{bmatrix} C_{Afs} - C_{As} & \frac{F_s}{V} \\ C_{Bs} & 0 \end{bmatrix}$$

$$C = [0 \quad 1]$$

$$D = [0 \quad 0]$$

Based on the steady-space operating point $C_{As} = 3.0$ gmol/liter, $C_{Bs} = 1.117$ gmol/liter and $F_s/V = 0.5714$ $\min^{-1}$, is the state space model

$$A = \begin{bmatrix} -2.4 & 0 \\ 0.833 & -2.23 \end{bmatrix}$$

$$B = \begin{bmatrix} 7.0 & 0.5714 \\ -1.117 & 0 \end{bmatrix}$$

$$C = [0 \quad 1]$$

$$D = [0 \quad 0]$$

Transformation space models in the transfer function given below:

$$G(s) = C(sI - A)^{-1} B$$

Transfer function of the input-output process for the reactor is tampered with

$$g_p(s) = \frac{-1.117\,s + 3.1472}{s^2 + 4.6429\,s + 5.3821} \quad (3.19)$$

And the input-output is disturbance transfer function

$$g_d(s) = \frac{0.4762}{s^2 + 4.6429\,s + 5.3821} \quad (3.20)$$

Poles of the transfer function (-2.23 and -2.4) are equal to matrix A's eigenvalue. Also, the positive zero in the transfer function (1 / 0.3549) show the inverse reaction process.

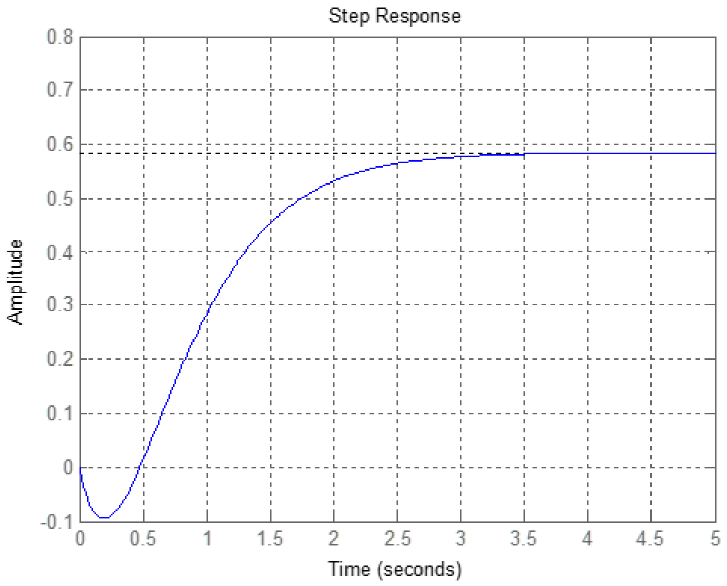

Figure 3.2: The concentration as a function of the response time

It is evident from the figure 3.2 that there is a non-linear connection among the steady-state dilution rate (F/V) and the steady-state concentration of B is available. A reactor can't be controlled at the most extreme conditions. The steady-state concentration of B is 1.117 g / liter can be obtained from Fs/V = 0.5714 min^{-1} or Fs/V = 2.8744 min^{-1}, which is demonstrating the presence of multiple input [12].

3.6 Features of the CSTR

The CSTR has the following features [16]:

- The Flow through CSTR, both input and output streams are continuous, however not really at a steady rate.
- The system inside CSTR is not necessary fixed.
- The fluid inside the CSTR is perfectly mixed, and therefore their property is uniform at any time, because of the reason for the efficient stirring.
- The density of the flowing system is not necessary; i.e. the density of the output stream may differ from the input stream
- The system can work both at steady state or unsteady state.
- Some heat transfer equipment can be accommodated for temperature control.

CHAPTER 4

CONTROLLER DESIGN AND SOFT COMPUTING TECHNIQUE

4.1 Introduction to PID Controller

Over the previous decades, control enterprises have made great progress. Many strategies has been developed utilized like adaptive control, neural network, fuzzy control, etc. The PID (proportional-integral-derivative) controller, which is broadly used in the industrial controllers, has a simple and robust performance in the broad field of the real time working conditions [3]. It was difficult to change the values of control variables of PID controller precisely because various industrial plants have regular loaded issues like higher-order system, delay, and non-linearity related to the systems used there. Apart from this, determining the ideal PID parameters or close typical adjustments for their parameters using the standard procedures for the same [8].

It was a necessary element of former authority and turned into the norm instrument when process control developed in the 1940s. In managing today's process, over 95% of the control loops are PID controller. The controllers are accessible in a wide range of the structures [4]. The PID controller is a central component of a distributed control scheme. In many special-purpose dedicated control systems and controllers are also implanted. The PID controller regularly associated with logic, sequential functions, selectors and simple work blocks, to create complex automation systems being used for production, transport and development [17].

The PID controller has three independent control actions, such as Proportional control(P), an Integral control (I) and a Derivative control(D). In these three parameters, independent control authority has been expressed in connection with the proportional gains(K_p), integration gain (K_i) and a Derivative gain(K_d). The success of any system, that based on the management of these parameters to control transient response such as maximum overshoot percentage (M_p %), the settling time (t_s) and the rise time (t_r) [18].

4.2 PID Control

The block diagram of the conventional PID controller is shown in Figure 4.1.The controller outputs in the time domain are given by [10]:

$$u(t) = K_p e(t) + K_d \frac{de(t)}{dt} + K_i \int_0^t e(t)dt \quad (4.1)$$

In the frequency domain, equation is written itself as,

$$U(s) = \left\{ K_p + \frac{K_i}{s} + K_d s \right\} E(s) \quad (4.2)$$

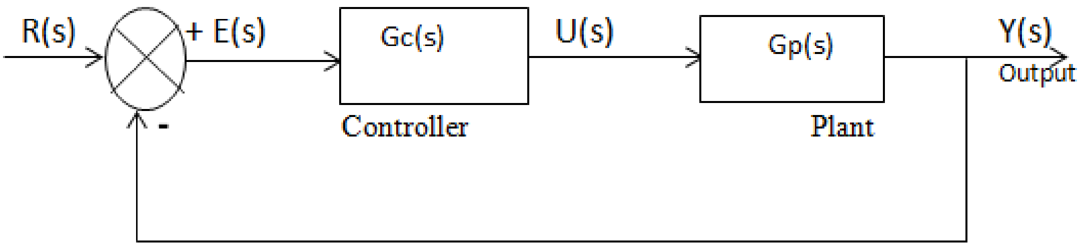

Figure 4.1: Block diagram PID Controller for plant [19]

A continuous PID controller output is written as below [7]:

$$G_{PID}(s) = K_p + \frac{K_i}{s} + K_d s \quad (4.3)$$

The structure of PID controller is given in Figure 4.2.

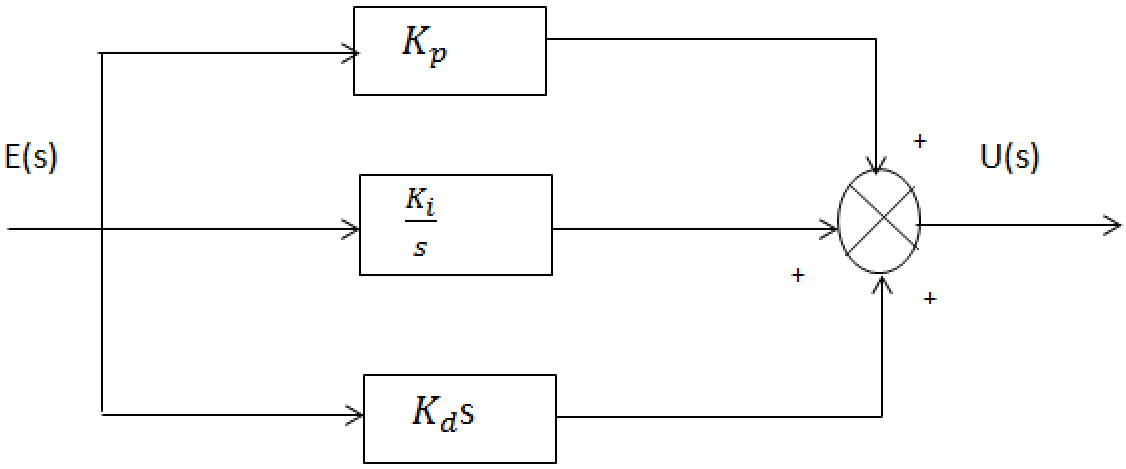

Figure 4.2: Structure of PID Controller [20]

Where K_P is the proportional gain, the integral gain is $K_i = \frac{K_p}{T_i s}$ i.e. T_i is the integral time constant and the derivative gain is $K_d = K_p T_d$ i.e. T_d is the derivative time constant [20].

Where error signal $e(t)$ and $u(t)$ are the input and output of the controller in the time domain individually.

4.3 The characteristics of P, I, and D controllers

Proportional Gain(K_p) affects the result of reducing the transient response time but not eliminated, from steady-state errors. An integral gain(K_i) will result in terminating a steady state error but it can make the transient response worse [21]. A derivative gain(K_d) affects the improvement of the stability by overshoot the percentage reduction of the time to the transients [22]. The effects of the each K_p, K_i and K_d are shown in following Table 4.1 for the closed loop system:

Table 4.1: Effects of each $\boldsymbol{K_p}$, $\boldsymbol{K_i}$ and $\boldsymbol{K_d}$ Controllers [22]

Closed Loop response	Rise time(T_r)	Overshoot (M_p)	Settling time(T_s)	Steady State Error (e_{ss})
K_p	Decrease	Increase	Small Increase	Decrease
K_i	Decrease	Increase	Increase	Eliminate
K_i	Minor Decrease	Decrease	Decrease	Minor Change

Take note that this connection can not be exactly accurate. In fact K_p, K_i and K_d depend on others, changing one of these variables can affect the outcome of the other two. Consequently, Table 4.1 can be utilized as the reference value when K_p, K_i and K_d are determined.

4.4 Transient Response of PID Controller

The following figure 4.3 indicates the transient response of the PID controller along with the step response of the second order system, varying the constant $\boldsymbol{K_i}$ and $\boldsymbol{K_d}$ values.

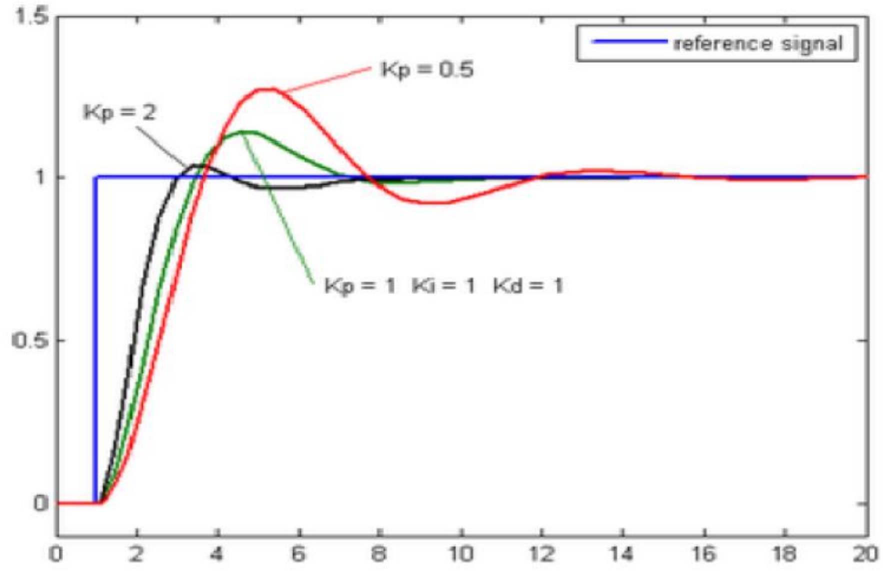

Figure 4.3 The effect of adding K_p i.e. K_d and K_i remains constant [22]

The following figure 4.4 indicates the transient response of the PID controller along with the step response of the second order system, varying the constant K_p and K_d values.

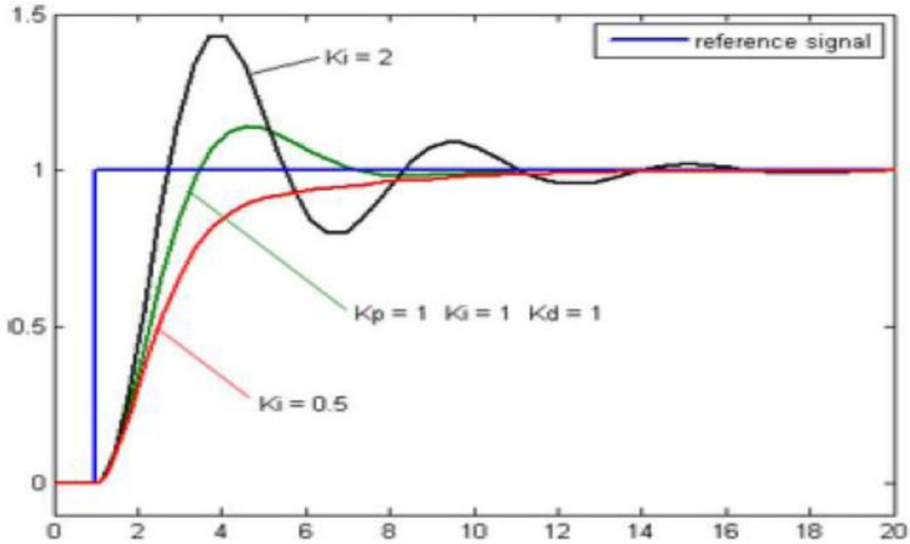

Figure 4.4 The effect of adding K_i i.e. K_p and K_d remains constant [22]

The following figure 4.5 indicates the transient response of the PID controller along with the step response of the second order system, varying the constant K_p and K_i values.

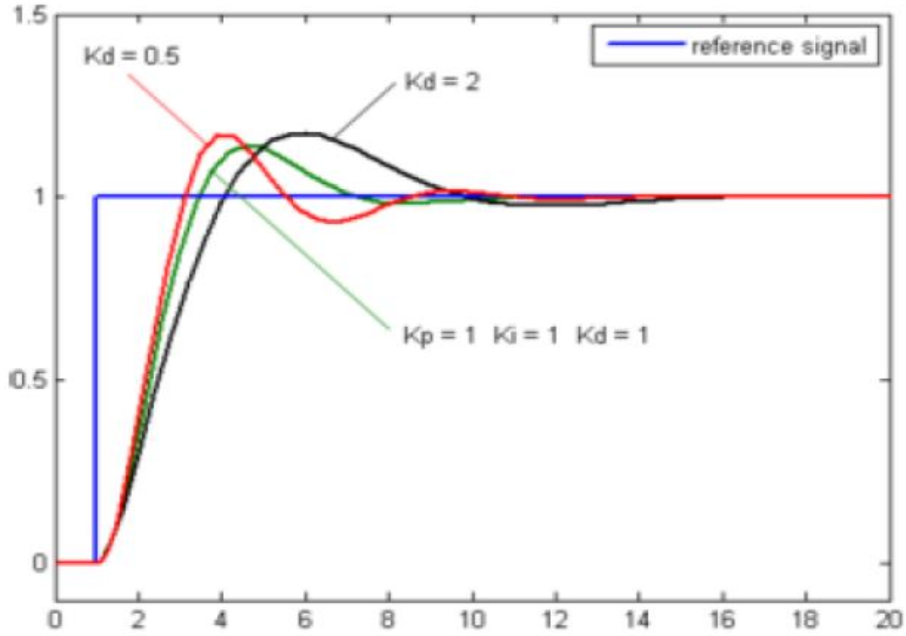

Figure 4.5 The effect of adding K_d i.e. K_p and K_i remains constant) [22]

4.5 Tuning of PID controller

All the typical design control techniques are useful for PID controllers. Some unique methods are also developed that are suitable for PID controllers, and these strategies are frequently called tuning techniques. In spite of the approach used, it is important to dependably consider the control components, sensor noise and the uncertainty of the process load disturbance and reference signals. The most famous tuning techniques are established by Ziegler and Nichols [23]. They have a lot of power over the follow of PID controller for over a century.

The PID tuning implies that selecting the numeric value for the PID coefficient. Many companies have manual industrial processes that regulate the PID tuning for process plant in particular. Therefore, it is usually possible to establish empirical rules and formulas to monitor the PID controller [11]. Some of these manuals base their events on the pro forma routines of the well-known Ziegler-Nichols techniques and variously related extensions of the associated rules (Ziegler and Nichols, 1942). Ziegler-Nichols experiment uses a line followed by the application of mathematical rules to calculate the PID coefficient values [19].

Method types include the trail method and method of tester setup and the reaction curve process. Most traditional methods of controlling optimization are Ziegler-Nicholls and Cohen-Koon. These strategies are often used when system numeric model is unavailable. In this way, the term closed loop systems are used for Ziegler-Nichols technique and, on the other hand, Cohen-Koon on is commonly utilized for open loop systems, with a control system closed with feedback control [24].

4.5.1 Ziegler-Nichols tuning method

Methods of Ziegler-Nichols have a simple mathematical derivative in the form of first and second methods for tuning the PID controller. These techniques are currently standard in the control system. These hypothesis techniques are a deductive model system, but these examples are not necessarily specifically acknowledged. This formula depends on the system model depending on the parameters of the plant design [4].

There are two approaches to change this Ziegler-Nichols tuning.

1. First method
2. Second method

First method

The first method is applied to plants in which there are step response systems, as shown in Figure 4.6. The plant made up of the series of first order systems. Two values characterize by this reaction, $\boldsymbol{L}$ is the delay time and $\boldsymbol{T}$ is the time steady. These have been created by tracing a tangent to the step response at its turning point and observing its intersections with the time range and constant value [11]. Plant model is

$$\boldsymbol{G(s)} = \frac{\boldsymbol{Ke^{-SL}}}{\boldsymbol{Ts+1}} \tag{4.4}$$

Where, $\mathrm{G(s)}$ = Transfer function of the process

K = Gain of the process

T = Time Constant of the process

Table 4.2 First Method of Zeigler-Nichols Technique [8]

PID parameter	K_p	$T_i = \frac{K_p}{K_i}$	$T_d = \frac{K_d}{K_p}$
P	T/L	Infinity	0
PI	0.9 T/L	$\frac{L}{0.3}$	0
PID	1.2 T/L	2L	0.5 L

In the above Table 4.2, various controllers type K_p, K_i and K_d have been achieved using the delay time and steady time using the Ziegler-Nichols First method.

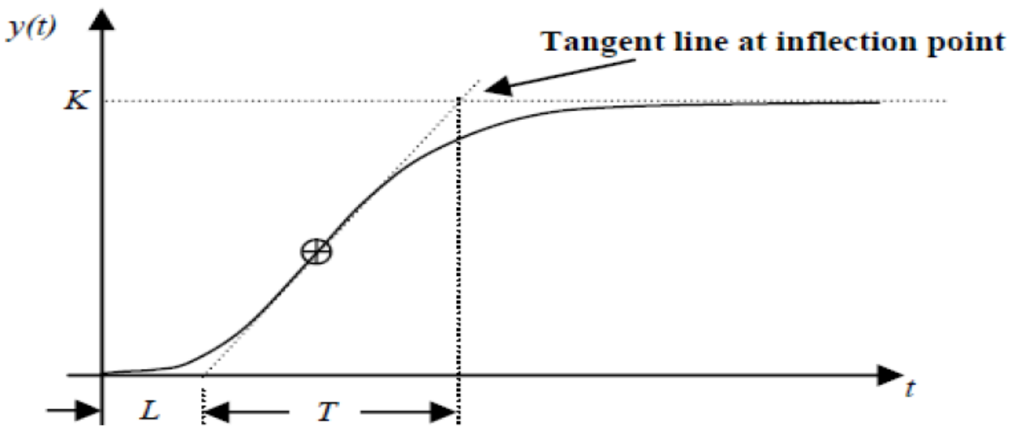

Figure 4.6 Response system for Zeigler-Nichols first method [22]

In the above figure, 4.6 show the response curve of over damped second order system.

Second method

In the second method that can be rendered unstable under the proportional control. This process is designed to create the closed loop system with more than 25% of overshoot. This outcome can be achieved by the Ziegler and Nichols specifically in particular model plant-based settings. The procedure for tuning a second PID controller is [8]:

Only the proportional feedback controller:

- Eliminate the integral and the derivative action. Set the integral time $(\boldsymbol{T_i})$ to ∞ or maximum value and the output controller $(\boldsymbol{T_d})$ to be zero.
- Set the proportional increase and decrease in gain, until the oscillations have constant amplitude.
- Notice the gain value $(\boldsymbol{K_{cr}})$ and the oscillation period$(\boldsymbol{P_{cr}})$.
- Link these values to closed loops of Ziegler-Nichols methods and determine the necessary changes to the loop controller.

The controller gains are presently indicated as follows:

Table 4.3 Second Method of Zeigler-Nichols technique [22]

PID type	K_p	$T_i = \frac{K_p}{K_i}$	$T_d = \frac{K_d}{K_p}$
P	0.5 K_{cr}	Infinity	0
PI	0.45 K_{cr}	$P_{cr}/1.2$	0
PID	0.6 K_{cr}	$P_{cr}/2$	$P_{cr}/8$

$$G_{PID}(s) = K_p\{1 + \frac{1}{T_i s} + T_d s\} \quad (4.5)$$

In the above Table 4.3, various controllers type K_p, K_i and K_d have been achieved by adjusting the gain value and oscillation period using the Ziegler-Nichols second method.

4.6 Introduction to Genetic Algorithm (GA)

The Genetic Algorithm (GA) is a stochastic research technique, which imitates the natural biological method of selection, crossover, and mutation [25]. GA is the random search technique and the optimization inspired by the standards of the two biological methods i.e. the processes of "natural selection" along with the mechanics of "natural genetics" [16]. It combines the survival of the fittest among string structures with the information exchange but structured to create a random search algorithm with some innovations in the field of human research. The GA has effectively actualized in the range of modern gadgets, such as identification of system parameters and automated control, form recognition and programming [26]. GA applies for various control strategies to improve overall system performance. The GA is an intelligent method that advances to the best possible outcomes.

In genetic algorithm, the string is a bit that represents the control parameter for a particular coding problem. Every parameter of the given issue is coded with a bit string. A bit is known as genes, and the contents of each gene are referred as alleles. An entire string of such genes of all the parameter written in an arrangement is known as the chromosome, for which there is a chromosome for every point in the space search [27]. In this way, a GA candidate arrangement appears as a linear string similar to a biological chromosome. The candidate solutions i.e. chromosomes created from the general view of starting a GAs population. Then each chromosome is evaluated and that value is given the objective corresponds to the fitness level in the workplace. In each generation, chromosomes are selected from their fitness.

Chromosomes with a high level of fitness stays, while others are left out. This procedure is known as selection. After selection, offspring chromosomes are developed from the parent chromosomes which use the same mutation mechanisms similar to the developmental science. The crossover operator, once referred to as recombination, creates a new offspring chromosome which combines partial sets of parent elements. The mutation operator randomly changes the point of a chromosome with a small probability [25].

4.7 Genetic Algorithm Philoshiphy

Genetic algorithm is one of many human inventions-creations which have been motivated by natural selection. It is based on the notion of survival of the fittest also known as the natural selection. In this, the individual who are better will survive for a longer time. Thus, in this way, it provides a better chance of producing offspring with genetic algorithm. Accordingly, the entire population includes a large number of genes from the good population than that of the wrong population. On the other hand, it can be said that .fittest candidates will survive and will not be disqualified. This force of nature is known as the natural selection [25]. The genetic algorithm uses this evolutionary to solve the optimizations problem.

4.8 Search Space of GA

A set of search points known as population, is a set of chromosomes selected for processing. The population is processed and evaluated by different operators of genetic algorithms to produce a new population. This process is done until the global optimum points are available [28].

4.8.1 Benefits of Genetic Algorithm

The various advantages of GA are

- It is basic algorithms that is simply known and resolve typical problems.
- It is robust.
- It is a non-linear process that is associated with most industrial processes with good outcomes.
- It looks for a population of points rather than a single solution.
- It doesn’t require system data, except for fitness function.
- Manages large search spaces and is easily understood.
- The problems must have the multi-objective function.

- Easily modified for various problems.

4.8.2 Applications of Genetic Algorithm

The Genetic algorithm has been used for several problems, to learn the machine, and also to evolve for simple programs. Few applications of genetic algorithms are [26]

- Non-linear unique systems: prediction, information investigation
- Robot trajectory planning
- Strategy planning
- TSP and sequential programming
- Functions for making pictures
- Design the semiconductor layout, keyboard layout, communication networks.
- Signal processing to design the filter.

4.8.3 Genetic Algorithm Versus Conventional Techniques

The Genetic algorithms are not the same as more conventional search, optimization methods, and their four major differences are [29]

- GAs search from the population of points in a parallel, as opposed to a single point.
- GAs use objective function information rather than derivatives or other auxiliary knowledge.
- GAs are used probabilistic transition rules, instead of deterministic rules.
- GAs work with a set of coding parameters and not the set of parameters themselves.

4.9 Stages in Genetic Algorithm

The Genetic Algorithms have initialization, evaluation and genetic operators as three stages.

4.9.1 Initialization

Genetic algorithms work with a set of string. This set of strings are put into the development process for the production of new strings. To get started, the first population is made up of chromosomes chosen randomly from selected strings. There should be different types of structures in the initial population [26].

The size and length of the string of the population of both parents is necessary. The size of the population represents the effective representation of the entire search space in a population. It affects the proficiency and execution of genetic algorithm.

4.9.2 Evaluation

The suitability of the solutions is determined by the initial set of solutions. It can be used a function which is known as a fitness function. This feature is taken from the objective function and used for genetic operator. The assessment function is a method for determining the suitability of each chromosome in the population and it is a high-oriented application [10].

4.9.3 Objective Function and Fitness Function

The Genetic algorithm (GA) shows the principle of the survival of the fittest, suitable for the nature of the search process. In this way, GA is appropriate to settle the maximum issue. Minimum issues are usually made to maximize every necessary change. The objective function is to get the fitness function $F(x)$, and it can later be used as a part of genetic operators [25]. For maximum issue, the fitness function can be treated as a purpose or function.

$$f(x) = F(x) \tag{4.6}$$

The minimum issue, a fitness function is similar to the optimum point, remains unchanged so that the maximum profit is released. The following fitness functions are often used as proposals.

$$f(x) = \frac{1}{(1+F(x))} \tag{4.7}$$

This is the $f(x)$ fitness function and $F(x)$ objective function.

4.10 Genetic Operators

In this part, There are basically three operator to use genetic operators to create a new population from the previous population.

i. Reproduction
ii. Crossover
iii. Mutation

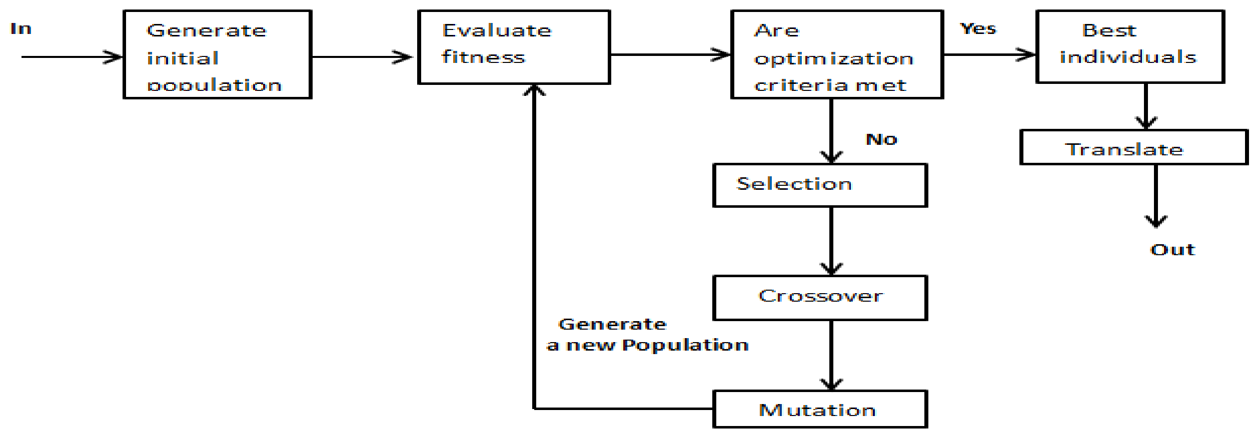

Figure 4.7 Genetic algorithm process flowchart [30]

Figure 4.7 shows, the genetic algorithm process flowcharts that have major blocks in the form of initial population, fitness function and optimization.Futhering detailing of all genetic operators (Reproduction, Crossover and Mutation) is discussed below.

4.10.1 Reproduction Operator

The Reproduction operator has been used to copy the old chromosome in the mating pool with the fittest value. Higher the fitness of the chromosome more is the number of copies in the next generation chromosome. Chromosomes have been selected from the initial population to be crossover parents and to produce offspring [26]. According to Darwin's Fittest theory, it is the best way to survive and to generate new offspring. Therefore, the operator is also called the selection operator. The population of the i^{th} the string is selected with a proportional probability F_i, where F_j the fitness value for that string. The probability of selected i^{th} term can be stated as [24]

$$P_j = \frac{F_i}{\sum_{i=1}^{n} F_j} \qquad (4.8)$$

Here, the population size is *n*.

The different techniques for choosing the chromosomes for parents to crossover are:

- Roulette-wheel selection
- Tournament selection
- Boltzmann selection
- Rank selection

The most common way to implement this is roulette wheel selection.

Roulette Wheel Selection

In the reproduction operator, commonly used is roulette-wheel selection method because, in this operator, the string has been selected from the mating pool, which has a proportional probability for its fitness. It is familiar that the roulette-wheel will perform f_i/fit_{avg} copies of i^{th} string of mating pool. Where the average fitness is given by

$$fit_{avg} = \sum_{j=1}^{n} \frac{f_i}{n} \quad (4.9)$$

4.10.2 Crossover Operator

The crossover operator performs crossover operation to make new chromosome. In this operation, information has been exchanged between the strings of the mating pool to make the new strings [26]. The purpose of the crossover operator is to find the parameter space. It is a recombination operator, which is in three steps. In the first place, the operator randomly selects the pair of two unique strings for mating so that it is randomly selected with the length of the string and the position values swap between two string after the cross site.

- Single point crossover
- Two-point crossover
- Multi-point crossover
- Uniform crossover

Single Point Crossover

In this, two separate strings are randomly selected from the mating pool. At that point, the crossover site is randomly selected with the length of the string along with the bits have been exchanged among the two strings on the crossover operator [30]. Understand that crossover site 5 is randomly selected. It implies that string bits from 6^{th} bit and onwards, bits of strings are exchanged for producing offsets shown in Figure 4.8.

Parent 1	1 0 1 1 0 0 1 0
Parent 2	1 0 1 0 1 1 1 1

Child 1	1 0 1 1 0 1 1 1
Child 2	1 0 1 01 0 1 0

Figure 4.8 Single point crossover [26]

Two Point Crossover

In addition to the single point crossover, two random crossover sites have been selected, and the contents between these points are exchanged by the two mated parents [30]. Cross site 1 is three and cross site 2 is six, then the exchange between three and six strings has been given in figure 4.9. In any case, the benefit of having a more crossover points is that the problem space can be searched more thoroughly.

Parent 1	1 1 0 1 1 0 1 0
Parent 2	0 1 1 0 1 1 0 0

Child 1	1 1 0 0 1 1 1 0
Child 2	0 1 1 1 1 0 0 0

Figure 4.9 Two point crossover [26]

4.10.3 Mutation Operator

In the general evolution, this is a random process in which an allele of a gene is placed at the second place to produce another genetic operator. It is the primary task because newly created individuals do not have any new legacy of data and the number of alleles has continuously declined. Diversity is a target of the learning algorithm for searching in various areas, which was not seen before. In this way, it is important to grow the information contained in the population. In mutation, the gen etic algorithms are associated with low probability in the range of 0.01 and 0.001, respectively, and changes the components in the chromosome [31].

4.11 Block diagram of optimal PID controller with GA

Optimal tuning of conventional PID controller with genetic algorithm for CSTR system is done. The block diagram of the optimal PID controller with GA is displayed in Figure 4.10.

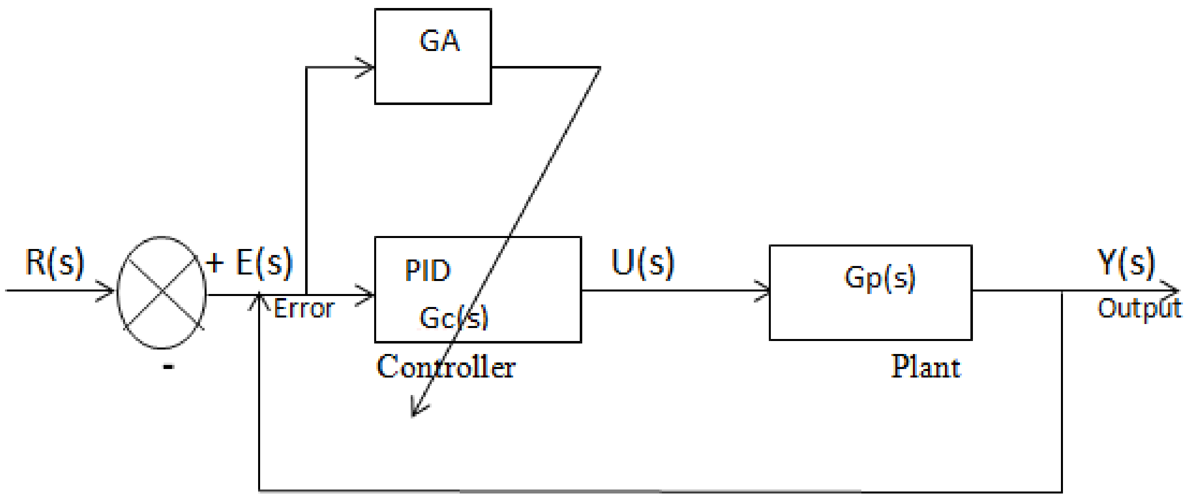

Figure 4.10 Block diagram of optimal PID controller with GA for CSTR system [32]

For each growth process, selection of the solver is important, as well as the design of the objective functions. Apart from this, it is important to note that in the case of genetic algorithm, the methods of coding are necessary, i.e. the functional parameters representation. Genetic algorithm implementation is accomplished using MATLAB/Simulink to achieve derived outcomes.

4.11.1 Flow chart of GA based PID Controller

Based on the conventional PID controller design with Genetic Algorithm for the CSTR system has been done as per the flow diagram shown in the Figure.4.11.

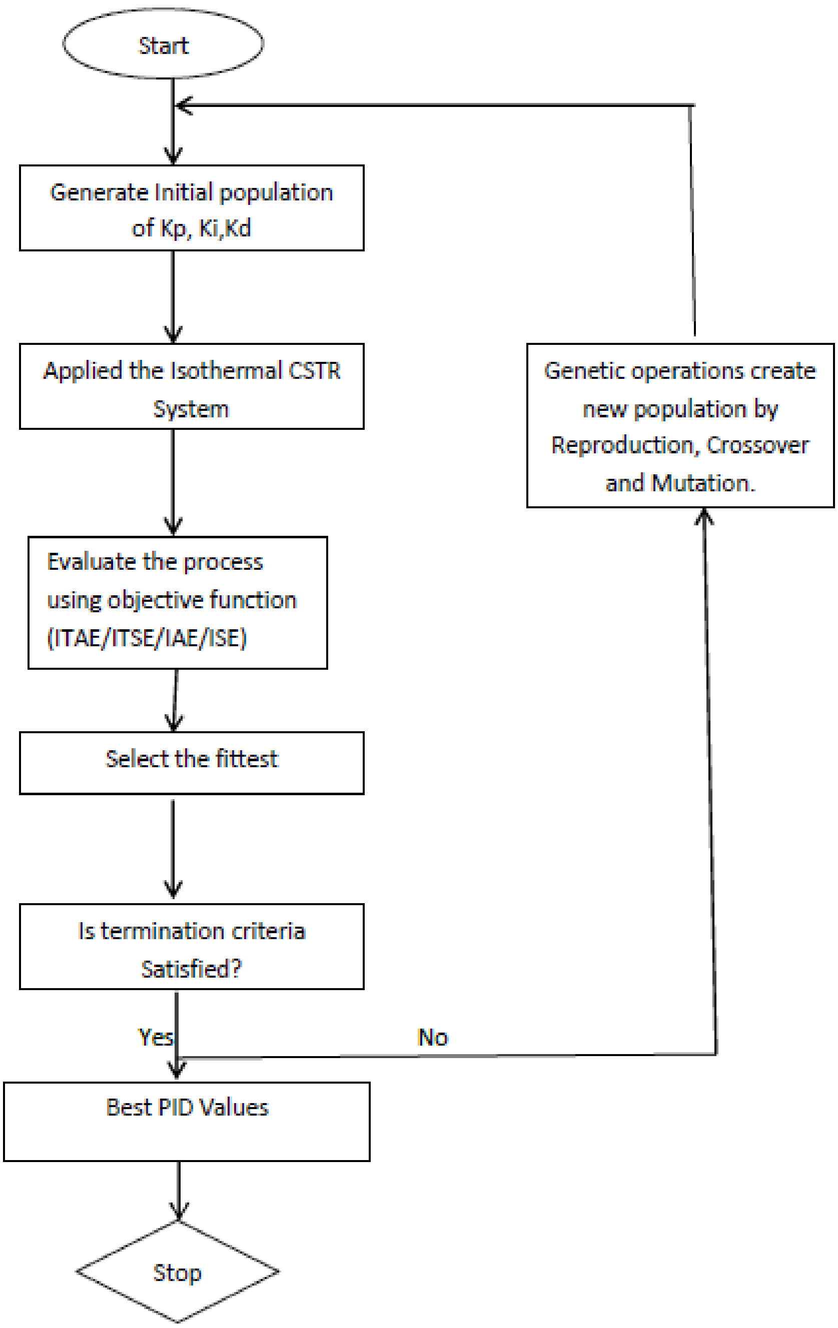

Figure 4.11 A Flowchart for the GA based PID Controller for isothermal CSTR system

4.11.2 Algorithm to use GA-PID controller

There are various steps need to create and execute the genetic algorithms are [32]:

1. Generating the initial random individual of the population for a fixed size i.e. relating to the traditional techniques K_p, K_i and K_d announced.
2. Evaluate the physical fitness for given system to reduce ISE / IAE / ITSE / ITAE.
3. Select the best individuals of the population

4. Recreate a probabilistic method to use for e.g, selection of roulette wheel.
5. The crossover chromosome operation is implemented.
6. Mutation operation is performed with a low probability.
7. Go to the step 2 until the predefined convergence criteria are completed.

4.12 Performance Index

It is a quantitative measure of the system's performance. To minimize the error value between the input and desired output, it is usually used in the research environment for the evaluation of performance [33].

Integral Absolute Error (IAE)

This is used for all those systems, that all of which require similar errors to be suppressed. The IAE is given by

$$IAE = \int_0^T |e(t)dt| \tag{4.10}$$

Integral Square Error (ISE)

This is suitable for reducing the initial small amount of errors. The ISE is given by

$$ISE = \int_0^T e^2\,(t)dt \tag{4.11}$$

Integral Time Absolute Error (ITAE)

This is used to reduce the initial amount of critical error and to reduce the error that occurs again in response over a period. The ITAE is given by

$$ITAE = \int_0^T t|e(t)dt| \tag{4.12}$$

Integral Time Square Error (ITSE)

This is used for the systems where there are initial value of errors is large. The ITSE is given by

$$ITSE = \int_0^T t\,e^2\,(t)dt \tag{4.13}$$

Here, t is the time and $e(t)$ is the difference between the reference value and the controlled variable (error signal). Finally, to see if GA process leads to a stable system, is confirmed by the poles of the controlled system and if found to be unstable then there is a pole on the right half of the s-plane. The error is assigned very big values to ensure that the chromosomes are not selected.

4.13 Introduction to Fuzzy Logic Controller

Fuzzy Logic is an innovation used to create intelligent control systems and information. Fuzzy logic does not show the true or false statement but assigns a value that represents the extension of truth or false statement. In the fuzzy logic, truth or false values that show a number. The Fuzzy logic has the range between from 0 to 1 [34]. All things considered, 0 must represent the absolute falseness, and similarly, 1 must represent the absolute truth. Fuzzy logic uses the expert knowledge to make decisions. Fuzzy logic allows computers to respond to some extent unlike Boolean logic solves one end or the other. PCs are allowed to think more like people. FL solves problems even if simple mathematical model does not exist [35].

The fuzzy logic control division has been making the fast progress in previous years. The fuzzy controller has been generally implemented for non-linear devices, and higher-order system [5]. The Intelligent fuzzy controller based on the fuzzy logic converts a linguistic control approach based on the expert acquaintance into a spontaneous control approach. It has the benefits of better stability, flexibility and response time etc [36].

Fuzzy logic helps in solving highly nonlinear processes. The fuzzy logic was first started as a representation scheme. It has argued in the machines by marking intermediate range such as true/false, hot/cold, etc. It is the critical thinking method. It has the range of applications in small, simple, microcontroller systems, multichannel, networked PCs or workstation based data acquisition of integrated control systems, information, etc. The Fuzzy logic can be executed in any software, hardware or in the combinations of both. It can provide an easy way to enter a clear conclusion that depends on ambiguous or vague, noisy, inaccurate or missing information. It is the way to deal with control issues simple as a human makes tough decisions much quicker [37].

The fuzzy logic, that gives a basic way to reach the complete determinations from vague, ambiguous or uncertain data. As it is, the fuzzy logic looks like human decision making with their capacity to work from the rough information and locate the exact solutions. The fuzzy logic enables to express this knowledge with subjective concepts, for example, very hot, bright red, and a long time, assigned to specific numerical intervals.

It has a pattern for an alternative design strategy, which can be applied in creating both linear and nonlinear systems. It gives an option answer for nonlinear control because of its closeness to practical problems. The process of fuzzy logic bring about enhanced execution, ease of distribution, reduced design costs and ability to handle non-linearity. By using this, designers can bring down the development costs, its superior features, and better end product execution. Besides, products can be brought to market quicker and more profitable [38]. The acceptance of fuzzy logic controller has been increased in past few years. Today it is used as a part of a single washing machine that is used in homes to an auto-focus system industry [39].

4.14 History of Fuzzy Logic

In 1965, Professor L.A. Zadeh of the University of California, Berkeley presented his article outlining the fuzzy theory in which he introduced the idea of fuzzy theory along with the operation, fuzzy based controller etc. In 1970, the theory of fuzzy logic started to produce results in Japan, Europe, and China. In the year 1987, 16 subway railway stations were built that worked with a fuzzy logic that based on the control system in the Sendai, at Japan. The ride is so smooth to the point that runners do not need to hold the straps, and the controller makes seventy percent less critical errors in accelerating and braking human operators. The fuzzy logic is the most capable troubleshooting technique with a host of the applications in the embedded control system and the information is processing [35].

4.15 Fuzzy Inference System (FIS)

Fuzzy Inference Systems (FIS) depend on the rules-based systems and that governed by fuzzy set. It enables the development of structures used to generate responses or results into the appropriate stimulation or inputs. The response of FIS depends on the knowledge or relationship between responses and simulations. Knowledge is stored as a database rule. The basic rule communicates relationships between the system input and output results.

The knowledge is obtained by removing the data from authorities called fuzzy expert systems. FIS is another name of the fuzzy system based on knowledge, or it is also known as data-driven fuzzy systems. They mainly divided into two classes. First is MIMO, Multiple Input Multiple Output Systems and other is MISO, and Multiple Inputs Single Outputs that offers some outputs depending on the received entries. MIMO are those in which only one output data have come back from the multiple inputs. Multiple Input Multiple Output Systems disintegrate into a set of MISO systems operating in the parallel. An FIS has two inference engines for process [35]:

1. Mamdani-type FIS

2. Takagi-Sugeno- Kang (TSK) type FIS

4.15.1 Mamdani Based FIS

Sources of inputs and outputs have the IF-THEN rules in the fuzzy inference system that based on the Mamdani. A typical rule in a Mamdani Fuzzy model is: if X is Positive Big Y, Y is small positive, Z is zero.

4.15.2 Sugeno Based FIS

This section examines the Sugeno, or Takagi-Sugeno-Kang, inference engine implementing a technique for fuzzy. Presented in 1985, it is like the Mamdani strategy in many regards. There are two regions of the fuzzy inference process that input fuzzifier and apply the fuzzy operator are precisely the same. The principle distinction amongst Mamdani and Sugeno is that the Sugeno output features are either linear or constant.

Both the Sugeno and Mamdani FIS can be used to perform the similar tasks. Defuzzifiers can be decided for FIS Mamdani, and defuzzifiers likewise cause similar results in a Sugeno FIS. There is an overlapping amongst the two accurately systems. It's intuitive and interpretable nature, so it is used to support decision support applications. Consequences of an FIS Sugeno rule are not direct semantic means. An FIS offers the greater flexibility. Sugeno FIS does exclude a complicated defuzzification process from a computational point of view. Likewise, a Sugeno FIS always begins with continuous surfaces. Any existence of discontinuities, it involves to the similar inputs originating from different outputs. A Sugeno FIS is most appropriate then a Mamdani FIS for analysis, as well as for the continuous structure of output functions.

4.16 Fuzzy Logic Controller (FLC)

Fuzzy Logic is widely used in various signal processing and control applications. The fuzzy logic system maps into crisp input and crisp output. Since it can be described as ‘computing with words instead of numbers’, it can be described as ‘control with sentence instead of equations’. It can be incorporate specific rules and is particularly helpful in plants that controlled by the operator. Therefore, some tasks need to be developed for fuzzy logic system and are discussed as follows [37]:

- Define the problem

- Define linguistic variables.
- Define the behavior of control surfaces or fuzzy rule
- Define the mechanism of reasoning or inference
- Build the system
- Test the system.
- Tuning and validating the system.

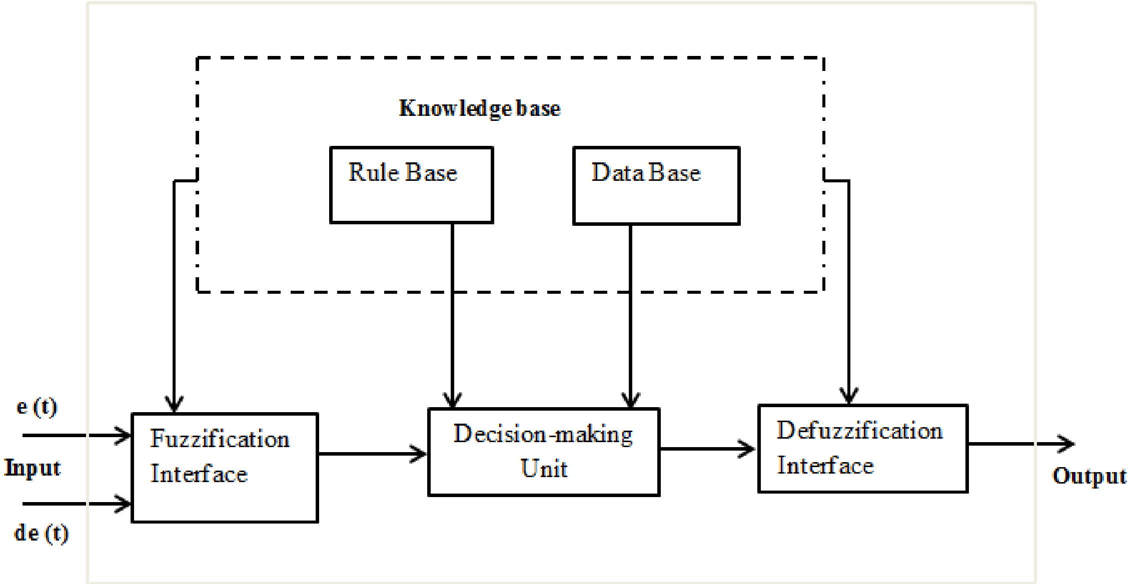

Figure 4.12: Block diagram of FLC [38]

The FLC has the three main parts as that shown in Figure 4.12 above:

1. Fuzzification
2. Defuzzification
3. Fuzzy Database and Rule Base

4.16.1 Fuzzification

Fuzzification is the first step in a FLC that changes the each item of the input data to degrees of membership by finding the one or more membership function. It compares the input data with these rules to determine how well the condition of each rule matches that this accurate information is an opportunity. The degree of membership for each linguistic term connected with this input variable [34-35].

4.16.2 Defuzzification

The control actions should take the form of a crisp value. The process of transforming the fuzzy set assigned to a control output variable to a crisp value. The inverse of fuzzification is called defuzzification. The utilization of Center of gravity (COG) and Fuzzy Logic Controller (FLC) produces a linguistic output variable required for fuzzy number which is implemented between 0 to 1. According to the needs of the real world, linguistic variables must be converted into a crisp output. There are a few strategies for the defuzzification yet the most widely recognized methods are as the following [35].

- Centre of Area Method
- Mean of Maxima Method

4.16.3 Fuzzy Rule Base

The basis of the fuzzy rule is in term with "If-Then" format. If the formally known side as the condition and the Then side is called the conclusion. The PC is capable of executing the rules and calculating the signal control depends on the measured input error (e) and change in error (de) [18]. Fuzzy rules base controller, control system is close to the natural language. The rule based is easy to understand and simple to keep up for an end user, and an equivalent controller can be executed using the conventional techniques.

The technique of fuzzy logic provieds good control strategies for designing intelligent controller for dofferent techniques.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

After the execution of the proposed PID controller, the fuzzy controller, and genetic algorithm, the results of CSTR are achieved the performance and GA is compared to various other techniques considered in this work for different performance indices. The calculation have been done in MATLAB/Simulink 2014A version.

The transfer function and disturbance show the model of feedback control scheme for the concentration control of isothermal CSTR. This process has been discussed in chapter. 3.

The transfer function of the input-output process for the reactor is

$$g_p(s) = \frac{-1.117\,s+3.1472}{s^2+4.6429\,s+5.3821} \tag{5.1}$$

And the input-output is disturbance transfer function

$$g_d(s) = \frac{0.4762}{s^2+4.6429\,s+5.3821} \tag{5.2}$$

The controller outputs in the time domain are given by:

$$\boldsymbol{u(t) = K_p e(t) + K_d \frac{de(t)}{dt} + K_i \int_0^t e(t)dt} \tag{5.3}$$

The PID controller is tuned by Zeigler-Nichols technique. Simulink models as shown in figure 5.1. In this Simulink model, the PID controller, the values of the K_p, K_i and K_d are 0.355, 1.079 and 0.029, respectively, displayed in the Table 5.3.

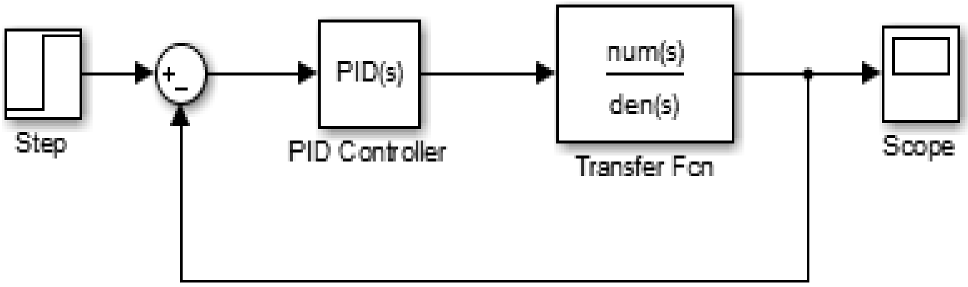

Figure 5.1 PID controller's Simulink model for CSTR concentration control

The system in figure 5.1 is given step input and the PID controller's unit step response is observed in figure 5.2.

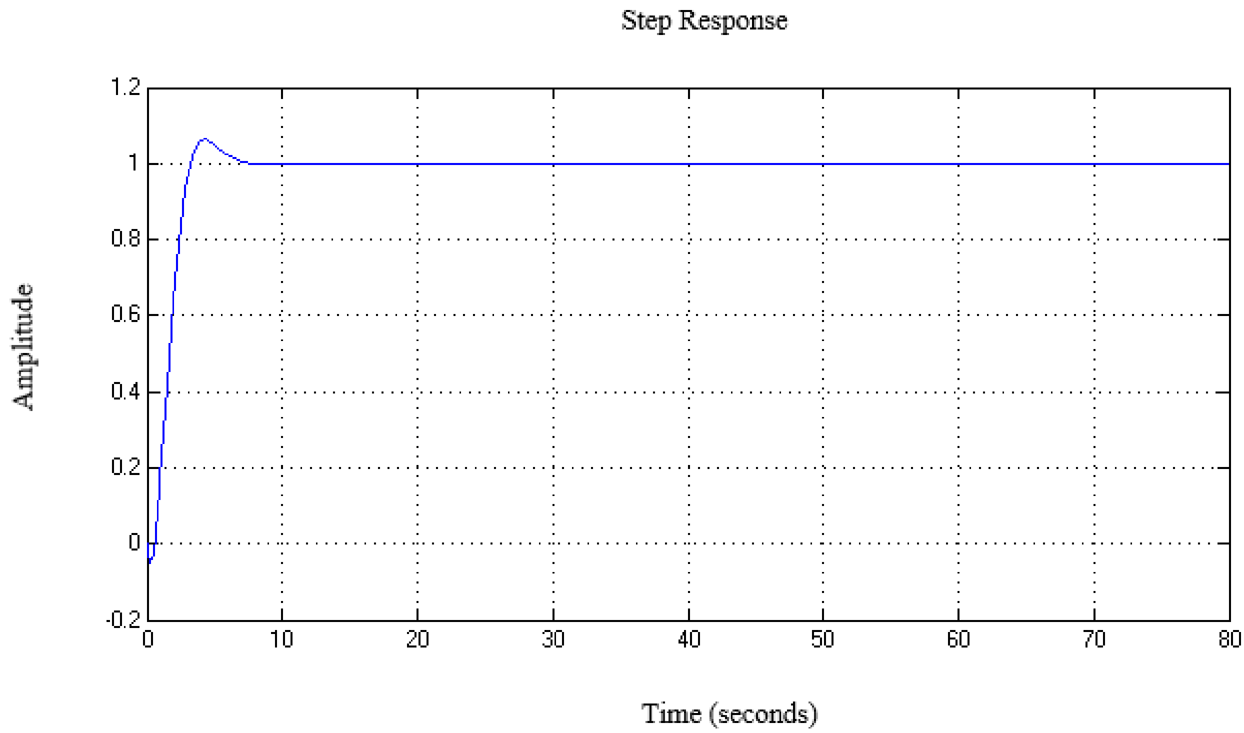

Figure 5.2: PID controller's unit step response for CSTR concentration control

Figure 5.2, shows PID controller's unit step response. In this PID controller's unit step response, here overshoot is 6.23 %, the settling time is 5.92 sec along with rise time is 1.92 sec. There is a time delay and inverted response. So Fuzzy controller is used to reduce the rise time, settling time and overshoot and also try to remove the time delay and inverted response. For optimum results, the responses for example overshoot, settling time, rise time, etc. of controllers could be compared.

5.2 Design of the Fuzzy Logic Controller

The controller in this fuzzy work is a Mamdani type FIS system based one and the basic structure of the FLC has been displayed in Figure 5.4. It uses a rule base in linguistic terms, the fuzzy controller has two inputs, first the error (E) and second is the rate of variation on error (EC). Error is the difference between the reference value and the output of the regulator controller. The fuzzy controller output has effect of input membership function in the fuzzy controller inputs that used. Triangular membership functions are selected to fuzzify the inputs and output variables. Fuzzy sets have been moved for the two inputs and one output i.e.

twenty-five fuzzy sets for output variables (NL, NM, ZE, PL, and PS). The fuzzy rules made for control action are displayed in Table 5.1.

Table 5.1: IF-THEN Fuzzy Logic Controller of Rule Base

U(t)	**Δe(t)**					
e(t)		**NL**	**NM**	**ZE**	**PM**	**PS**
	NL	NL	NL	NM	NM	ZE
	NM	NL	NM	NM	ZE	PM
	ZE	NM	NM	ZE	PM	PM
	PM	NM	ZE	PM	PM	PS
	PS	ZE	PM	PM	PS	PS

Table 5.1 shows the IF-THEN fuzzy controller rule base. In the fuzzy logic, Mamdani Inference System is used to develop the basis of control rules. There is a total of twenty-five rules in this fuzzy rule. NL means Negatively Large, NM means Negatively Medium , ZE means Zero, PM means Positively Medium, and PS means Positively Small. The rules are shown in the above Table as IF e(t) is PL and Δe(t) is NM THEN u(t) is NL.

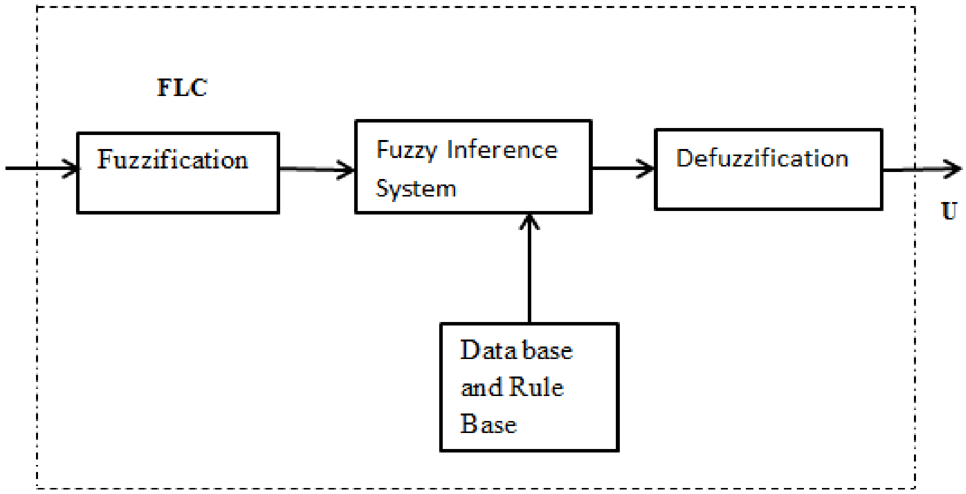

Figure 5.3: Designing of the Fuzzy Controller

In the above Figure 5.3, Where E is input and U is the output. Starting from E is first from fuzzified using fuzzification techniques then using the fuzzy knowledge rule base and output is derived and using the defuzzification is done.

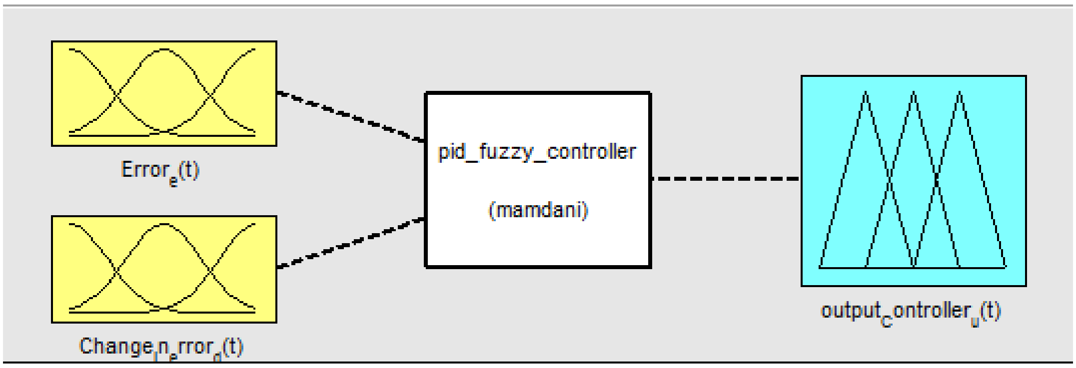

Figure 5.4: Development of Mamdani FIS for Fuzzy Logic Controller

Figure 5.4 indicates that fuzzy inference system, in which there are two inputs of error (E) and the rate of error, EC and the one output, U.

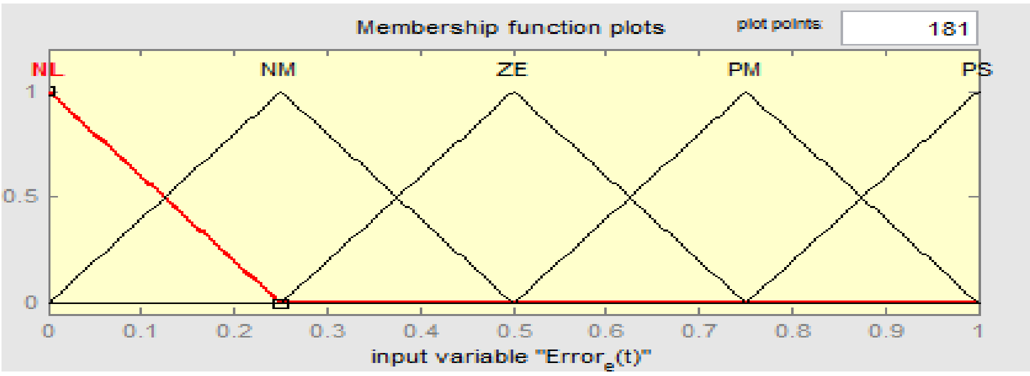

Figure 5.5: The Membership function (MF) for first input error (E)

Figure 5.5 indicates that graphs of the membership function (MF) for the first input error. Triangular membership function for first input.

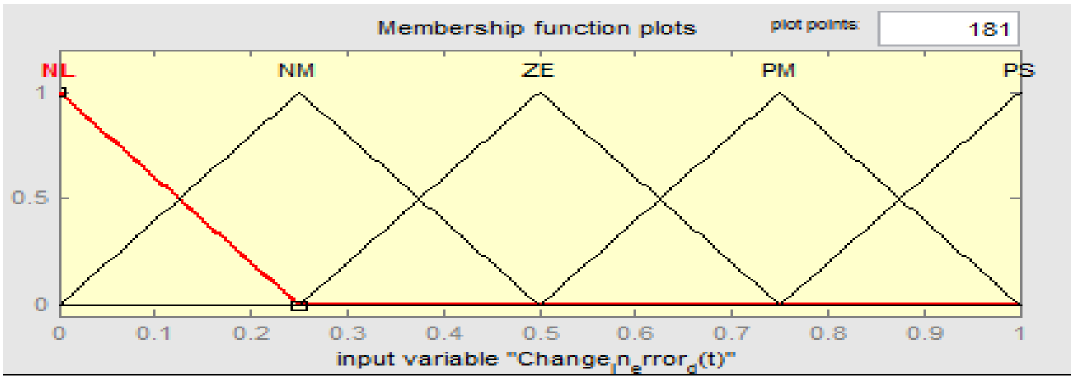

Figure 5.6: The Membership function(MF) for second input error (EC)

Figure 5.6 indicates that graphs of the membership function (MF) for the second input error. Triangular membership function for the second input.

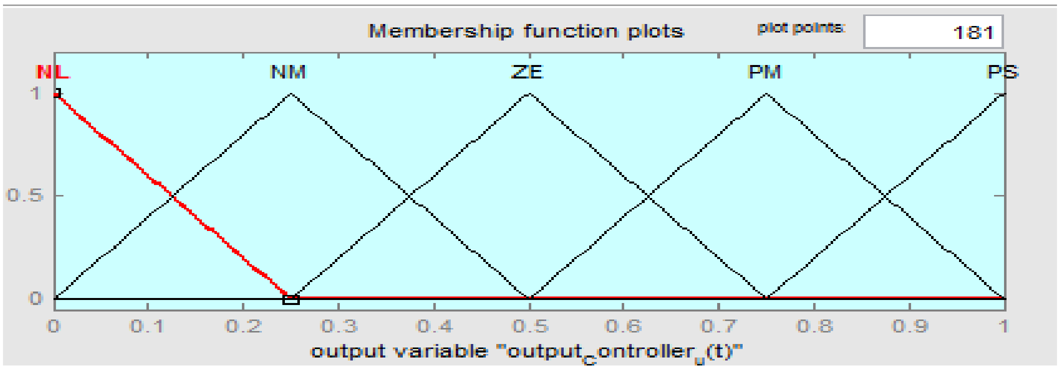

Figure 5.7: Membership function (MF) of output

Figure 5.7 indicates that the graphs of the membership function (MF) for output. Triangular membership function for output.

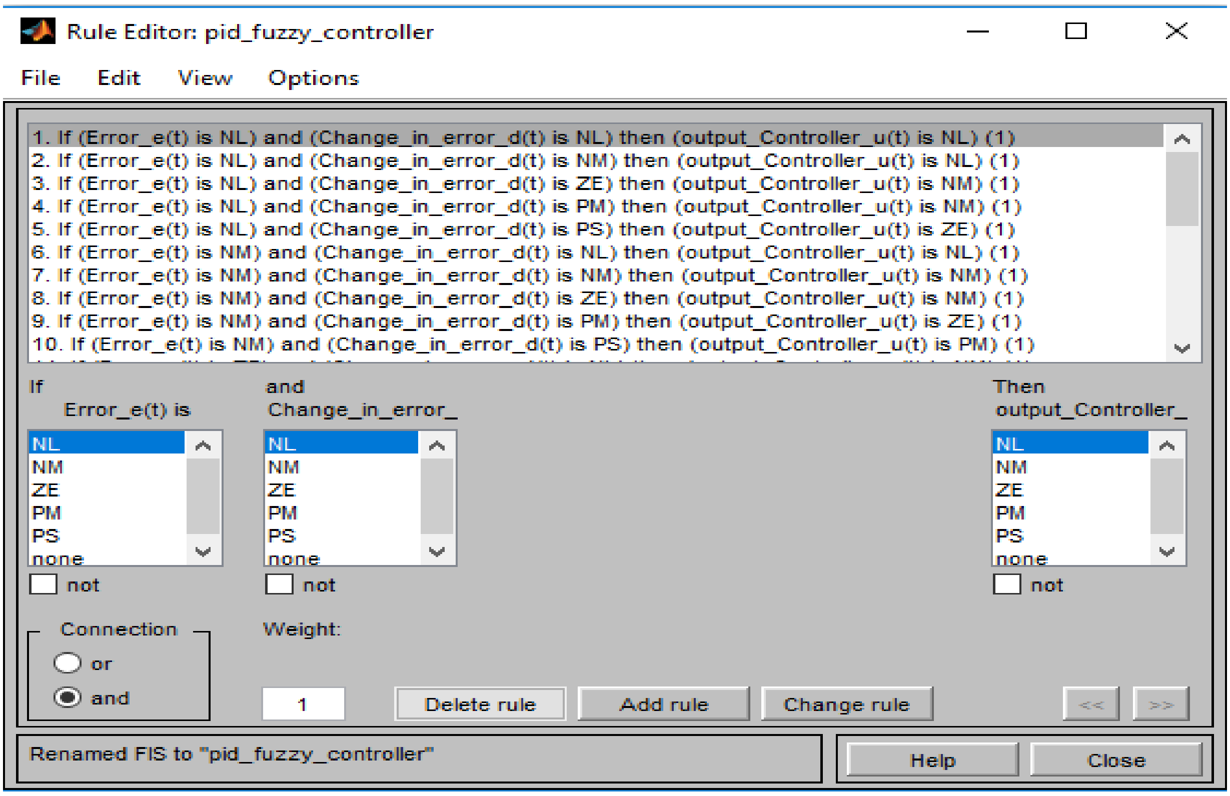

Figure 5.8: Fuzzy Rules Base Editor

Figure 5.8 indicates that the fuzzy logic controller of the fuzzy rule base editor. It has the 25 fuzzy rule base with the condition of the IF-THEN rule base.

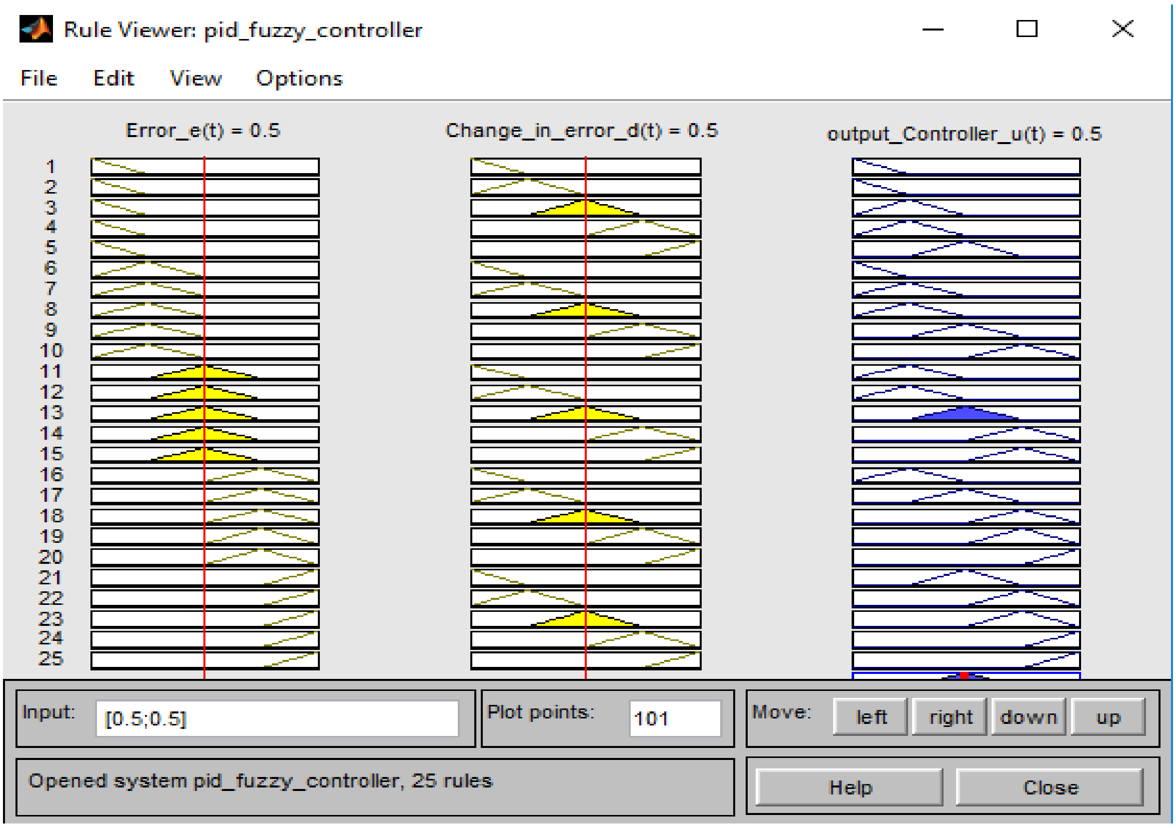

Figure 5.9: Fuzzy Rule Viewer

This Figure 5.9 indicates that the fuzzy rule viewer of the FIS. Rule viewer shows that calculation rule at a time.

And, now the Simulink model can be used to simulate fuzzy logic controller. Step unit response Simulink model of the FLC are displayed in Figure 5.10.

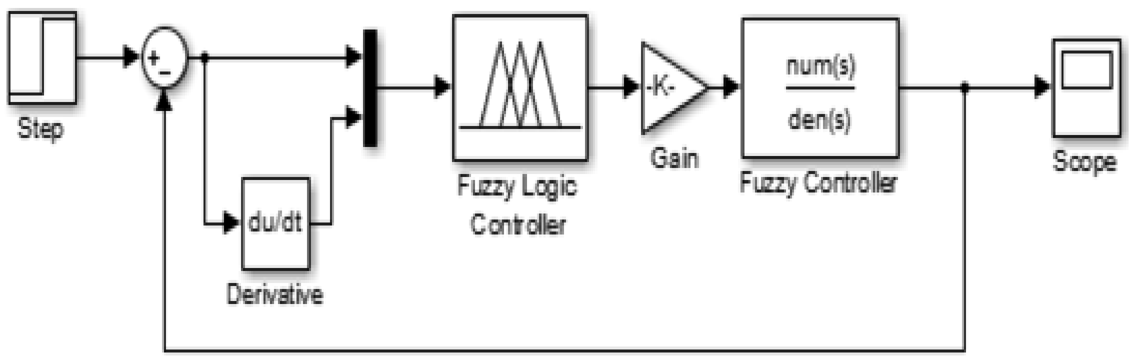

Figure 5.10: Fuzzy Logic controller's Simulink model

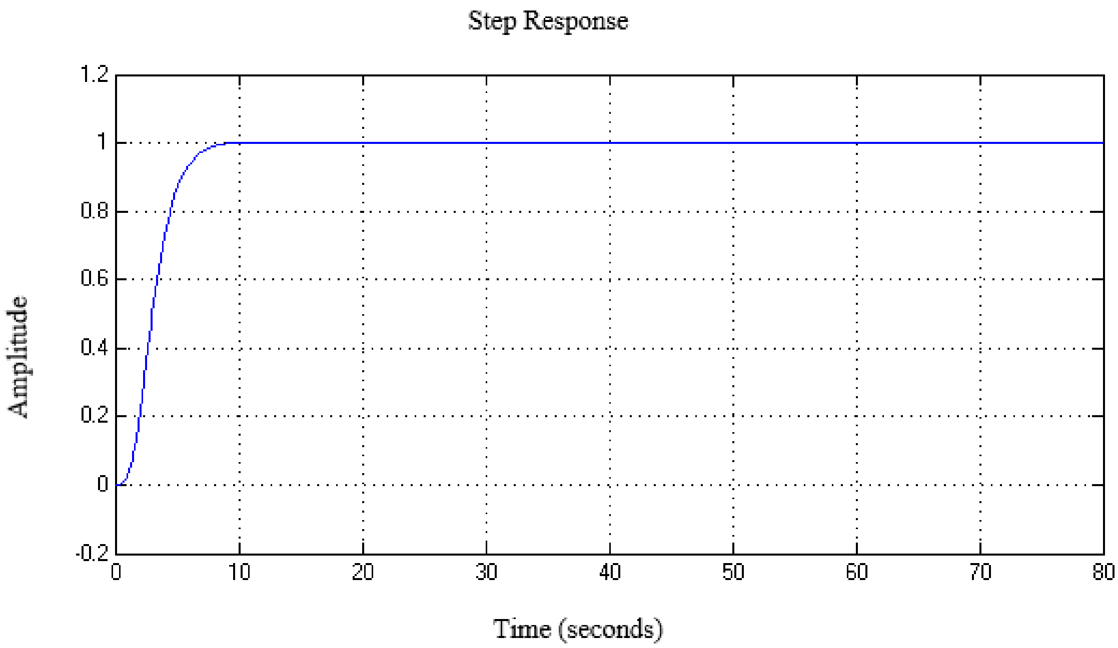

Figure 5.11: Fuzzy logic controller's unit step response for isothermal CSTR concentration process

In the above Figure 5.11, Fuzzy logic controller's unit step response for isothermal CSTR concentration process. This response that the overshoot is lower than the conventional PID controller i.e. it indicates the capability of the fuzzy controller.

For the optimal solution Genetic Algorithm is used. Currently, modify the PID controller along with developing the parameters of the PID controller based on the GA. The Simulink is set up to the PID controller for various population sizes M = 10, 15, 20, 25, 30, 35, 40, 45, 50 and then start afterward begin to simulate step response unit for various sizes it is acquired that the population sizes (M), peak overshoot, time rise and settling time. At that time, these responses are analyzed. After the comparison, the best output possible outcomes are selected.

5.3 Fitness Function Concept for the Design

It is the toughest part of GA in which the best PID controller for the system needs to be assessed. It can create an objective function to find a PID controller that gives the overshoot, faster rise time or settling time. Every chromosome in the population has once again been the objective function. Chromosomes are then assessed along with the number is assigned to represent the fitness level, the higher the number the better its physical fitness. GA uses the estimation of the chromosome to make another population composed of several fitness individuals [40]. To obtain satisfactory PID controller performance, three values are corresponding to the three properties of chromosomes i.e. K_p, K_i and K_d are considered as real numbers to mark the individual to evaluate the system. The PID controller has placed a unity feedback loop into the CSTR system. The control structure receives one step input, and the error is evaluated in the proper error performance index as the objective functions, i.e. ISE, IAE, ITSE, and ITAE. Fitness function, it is a function of steady-state error, peak overshoot, rising time and settling time. Chromosomes have been assigned a full fitness value, according to the magnitude of error, the higher the fitness value, the smaller the error. The performance index is a qualitative measure of the index system [41]

$$\text{Fitness value} = \frac{1}{\text{performance index}} \tag{5.4}$$

5.4 Design PID Tuning Controller with Genetic Algorithm

Optimal tuning of PID controller based the genetic algorithm (GA) is shown below in figure 5.13. For the improvement of each process, the design of the objective function is also important. Apart from this, it is important to keep in mind that the methods of coding in the case of GA are necessary, i.e. functional parameter representation which is completed with MATLAB/Simulink implementation of the Genetic Algorithm module.

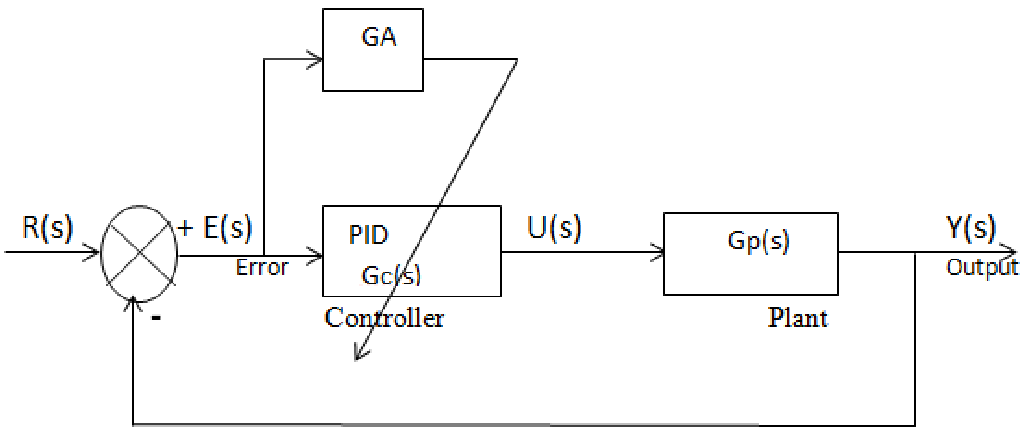

Figure 5.12: Structure of optimal PID tuning controller with Genetic Algorithm

5.5 Genetic Algorithm Based Simulation and Result Analysis

In this section, the optimal tuning results of the PID controller by utilizing the techniques of GA has been discussed. To use the genetic algorithm, the parameter has been used for optimal adjustment criteria for CSTR system as shown in Table 5.2.

Table 5.2: Genetic Algorithm parameters

GA Property	Value/Method
Population Size	10,15,20,25,30,35,40,45,50
No. of Generation	60
Mutation probability	0.01
Crossover probability	0.95
Crossover Method	Two point method
Selection Method	Stochastic method
Mutation Method	Uniform method
Range(K_p, K_i , K_d)	[0,50], [0,50], [0,50]

5.5.1 Simulation results for different population sizes

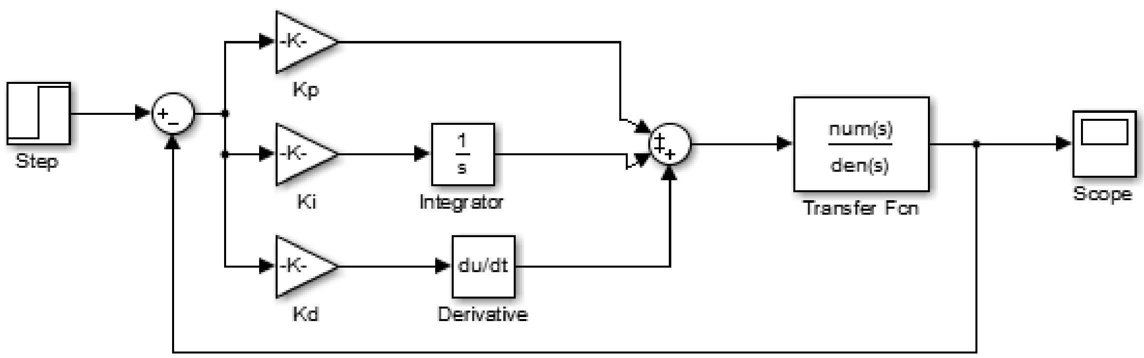

Figure 5.13: Simulink Model PID tuning based Genetic Algorithm

The PID controller's Simulink model is shown in figure 5.13 for various population sizes. This model is working effeicently and gives desired response as well.

The results are taken at M = 10, 15, 20, 25, 30, 35, 40, 45, 50 and the values of the tuning K_p, K_i and K_d are also varying as per requirements.

Transient response for PID Controller such as, peak overshoot, rise time, and settling time, of the controllers is given below in Table 5.3.

Table 5.3: Different Controllers for their transient response

Parameters/Type	Overshoot (%)	Rise time (sec)	Settling time (sec)
PID Controller	6.23	1.92	5.92
Fuzzy Controller	0	3.3	8.1

In these different controller responses, the best output results for the fuzzy controller are recorded. In fuzzy controllers, there is no peak overshoot compared to other controllers.

5.6 Tuning of the PID Controller using the Genetic Algorithm (GA)

The comparison of transient response of the PID controller for the various population sizes (M) of GA for ITAE objective function is shown in the Figure 5.14.

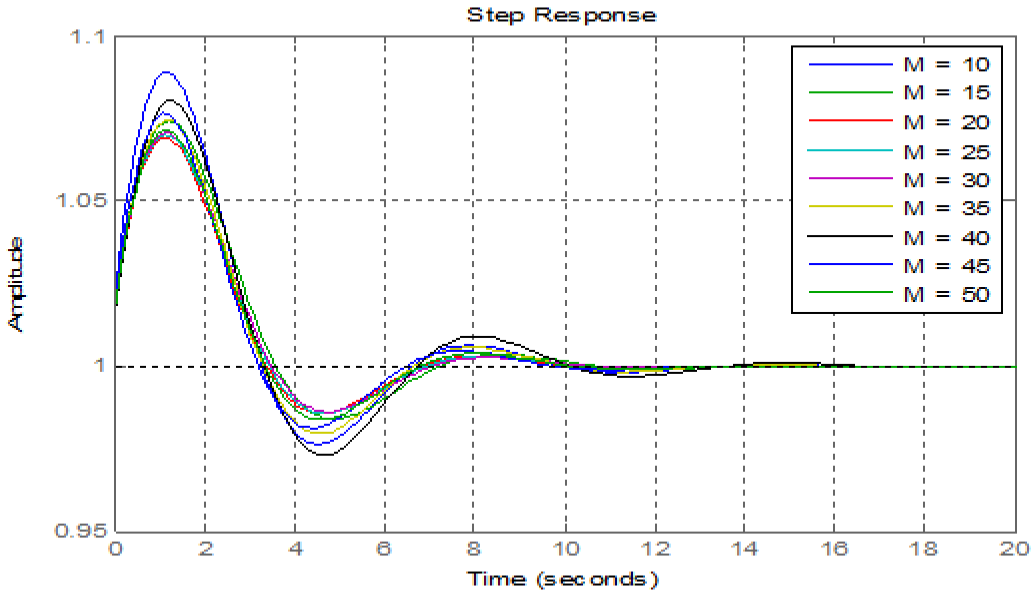

Figure 5.14: Comparison of PID controller unit step response of the various population sizes (M) of GA for the ITAE objective function

Gain of the values and best fittest solution of various population sizes of GA for the ITAE objective function shown below in Table 5.4.

Table 5.4 ITAE objective function, the gain of values and best fittest solution of various population sizes for GA

Population Size(M)	K_p	K_i	K_d	Optimal best fittest solution F_{best}
M = 10	37.184	41.179	40.460	0.0377
M = 15	46.290	44.221	48.863	0.0310
M = 20	49.703	49.908	48.897	0.0298
M = 25	49.427	48.580	48.880	0.0299
M = 30	49.478	47.019	48.461	0.0302

M = 35	42.826	49.245	49.101	0.0313
M = 40	37.166	46.913	49.549	0.0327
M = 45	43.359	48.607	44.592	0.0330
M = 50	47.099	49.263	48.825	0.0304

Table 5.5 shows the comparative results of transient response i.e. overshoot, the rise time and the settling time.

Table 5.5 The transient response of various population sizes for GA for ITAE objective function

Population Size(M)	**Overshoot (%)**	**Rise time(Sec)**	**Settling time(sec)**
M = 10	8.03	0.392	9.46
M = 15	7.42	0.46	9.99
M = 20	6.91	0.473	9.35
M = 25	6.98	0.477	9.49
M = 30	7.02	0.493	9.95
M = 35	7.44	0.381	11.7
M = 40	8.9	0.326	12.6
M = 45	7.64	0.413	9.13
M = 50	7.12	0.438	9.48

It is clear form Table 5.5, that the response to the population size **M = 20**, for the ITAE objective function, shows the less overshoot and quick rise time response in comparison to the other population sizes of genetic algorithm while settling time is less for M = 45.

The comparison of transient response of the PID controller for the various population sizes (M) of GA for ITSE objective function is shown in the Figure 5.15.

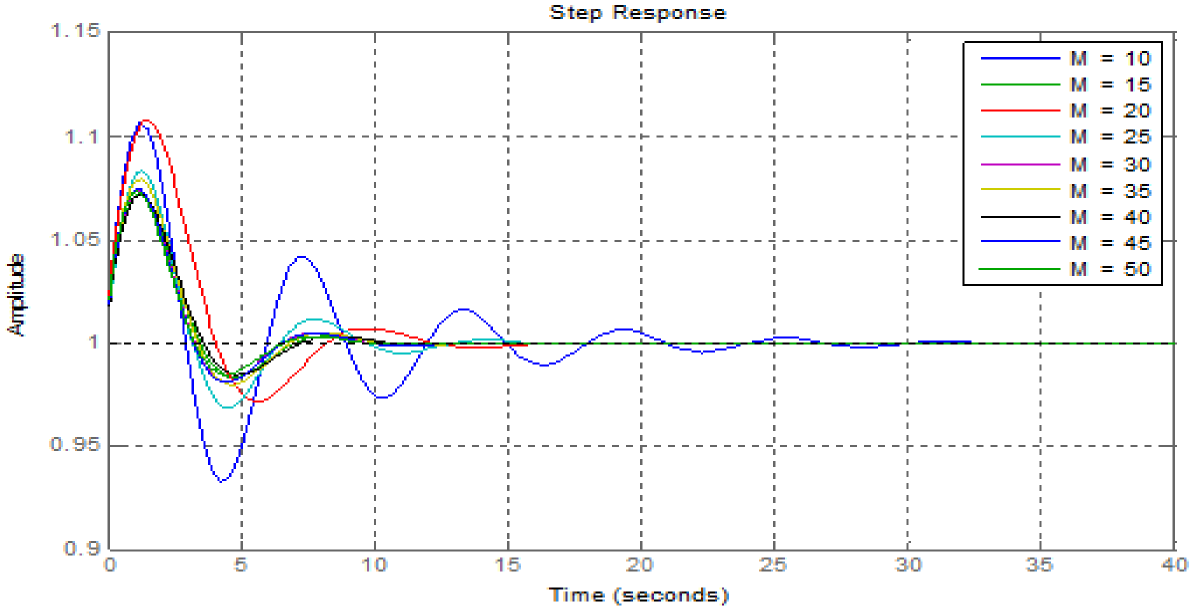

Figure 5.15: Comparison the PID controller unit step response of the various population sizes (M) of GA for the ITSE objective function

Gain of the values and best fittest solution of various population sizes of GA for the ITSE objective function shown below in Table. 5.6

Table 5.6 ITSE objective function, Gain of values and best fittest solution of various population sizes for GA

Population Size(M)	K_p	K_i	K_d	**Optimal best fittest solution** $\mathbf{F_{best}}$
M = 10	18.966	47.433	43.029	0.00366
M = 15	46.734	47.106	48.949	0.00192
M = 20	32.110	27.687	40.778	0.00348
M = 25	34.182	48.476	47.785	0.00230
M = 30	44.030	49.846	46.813	0.00207
M = 35	41.783	44.835	45.632	0.00228
M = 40	47.918	45.741	49.959	0.00185
M = 45	43.743	49.917	46.677	0.00208
M = 50	46.921	48.784	44.016	0.00210

Table 5.7 shows the comparative results of transient response i.e. overshoot, the rise time and the settling time.

Table 5.7 The transient response of various population sizes for GA for ITSE objective function

Population Size(M)	Overshoot (%)	Rise time(Sec)	Settling time(sec)
M = 10	10.7	0.191	25.9
M = 15	7.24	0.446	9.70
M = 20	10.8	0.484	11.6
M = 25	8.33	0.297	14.4
M = 30	7.42	0.404	9.25
M = 35	7.92	0.409	9.63
M = 40	7.18	0.468	9.92
M = 45	7.45	0.40	9.23
M = 50	7.36	0.469	8.99

It is clear form Table 5.5, that the response to the population size **M = 40**, for the ITAE objective function, shows the less overshoot and quick rise time response in comparison to the other population sizes of genetic algorithm while settling time is less for M = 50.

The comparison of transient response of the PID controller for the various population sizes (M) of GA for IAE objective function is shown in the Figure 5.16.

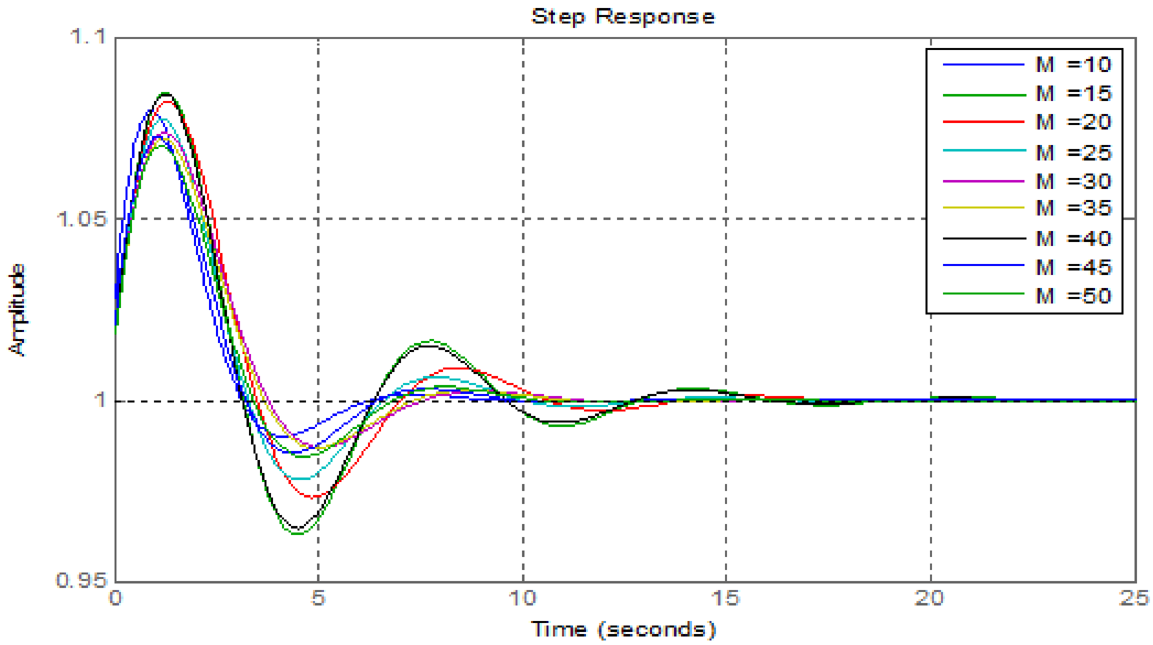

Figure 5.16 Comparison the PID controller unit step response of the various population's size (M) of GA for the IAE objective function

Gain of the values and best fittest solution of various population sizes of GA for the IAE objective function shown below in Table 5.8

Table 5.8 IAE objective function, Gain of values and best fittest solution of various population sizes for GA

Population Size(M)	K_p	K_i	K_d	**Optimal best fittest solution** $\mathbf{F_{best}}$
M = 10	47.872	45.476	33.179	0.0652
M = 15	30.922	49.619	49.659	0.0570
M = 20	36.967	43.384	49.90	0.0553
M = 25	41.011	47.950	47.511	0.0551
M = 30	48.866	41.646	48.088	0.0526
M = 35	49.476	44.062	48.555	0.0518
M = 40	31.894	49.596	49.025	0.0572
M = 45	47.721	49.955	44.047	0.0551
M = 50	48.361	49.540	49.751	0.0508

Table 5.9 shows the comparative results of transient response i.e. overshoot, the rise time and the settling time.

Table 5.9 The transient response of various population sizes for GA for IAE objective function

Population Size(M)	**Overshoot (%)**	**Rise time(Sec)**	**Settling time(sec)**
M = 10	7.96	0.633	5.88
M = 15	8.42	0.262	15.1
M = 20	8.25	0.337	13.1
M = 25	7.72	0.372	11.8
M = 30	7.17	0.535	10.0
M = 35	7.37	0.523	9.81
M = 40	8.49	0.270	15.3
M = 45	7.25	0.473	8.87
M = 50	7.28	0.449	9.53

It is clear form Table 5.5, that the response to the population size **M = 30**, for the ITAE objective function, shows the less overshoot and quick rise time response in comparison to the other population sizes of genetic algorithm while settling time is less for M = 10.

The comparison of transient response of the PID controller for the various population sizes (M) of GA for ISE objective function is shown in the Figure 5.17.

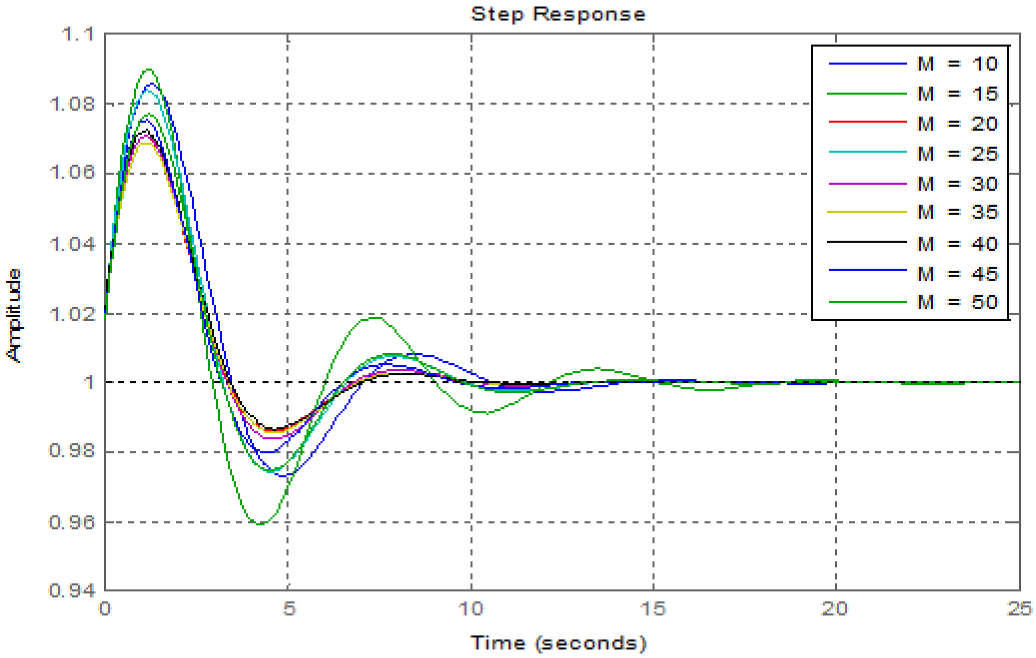

Figure 5.17 Comparison the PID controller unit step response of the various population's size (M) of GA for the ISE objective function

Gain of the values and best fittest solution of various population sizes of GA for the ISE objective function shown below in Table 5.10.

Table 5.10 ISE objective function, Gain of values and best fittest solution of various population sizes for GA

Population Size(M)	K_p	K_i	K_d	Optimal best fittest solution F_{best}
M = 10	36.415	41.185	47.194	0.00369
M = 15	28.618	49.994	44.886	0.00427
M = 20	49.290	48.263	46.858	0.00298
M = 25	37.235	44.659	45.498	0.00376
M = 30	47.343	49.486	48.895	0.00289
M = 35	49.668	49.571	48.993	0.00279

M = 40	49.115	46.004	45.474	0.00312
M = 45	42.905	49.958	46.509	0.00327
M = 50	38.831	49.919	49.395	0.00321

Table 5.11 shows the comparative results of transient response i.e. overshoot, the rise time and the settling time.

Table 5.11 The transient response of various population sizes for GA ISE objective function

Population Size(M)	Overshoot (%)	Rise time(Sec)	Settling time(sec)
M = 10	8.59	0.350	13.0
M = 15	8.99	0.253	14.5
M = 20	7.08	0.491	9.29
M = 25	8.38	0.351	12.2
M = 30	7.09	0.440	9.46
M = 35	6.92	0.473	9.41
M = 40	7.24	0.518	9.29
M = 45	7.52	0.392	9.21
M = 50	7.73	0.333	12.2

It is clear form Table 5.5, that the response to the population size **M = 35**, for the ITAE objective function, shows the less overshoot and quick rise time response in comparison to the other population sizes of genetic algorithm while settling time is less for M = 45.

After using all the objective function i.e. ITAE, ITSE, IAE, ISE in the GA based PID controller. It can be understood that the ITAE objective function have better output result i.e. less overshoot and fast rise time as compared to the other objective function.

CHAPTER 6
CONCLUSION & FUTURE SCOPE

6.1 Conclusion

Designing a controller for any process is a very complicated and time taking challenge for control engineers. Many processes and chemical industries are using Continuous Stirred Tank Reactor (CSTR) for their operation. A chemical reactor is one of the fundamental parts of the system used to incorporate exothermic and endothermic chemical reactions. There are isothermal chemical reactors, and non-isothermal chemical reactors. In this dissertation, soft computing methods have been compared with modifying the PID controller. These controllers are tuned with different control stratergies to control the concentration of an isothermal CSTR, which is a second-order system with zero right half plane and it additionally understands the concentration of an isothermal CSTR that is prepared with state space condition.

In this dissertation, performance evaluation of different intelligent controllers such as conventional PID controller and Fuzzy Logic Controller has been compared and similarly Genetic Algorithm based PID controller also has been evaluated with the different types of objective function. The performance analysis regarding the rise time, settling time, and maximum overshoot percentage by applying to the step response of a dynamic system has been done. In comparsion, that FLC gives better response than conventional PID controller. After that the genetic algorithm based on PID controller that has been used for various population sizes i.e. M = 10, 15, 20, 25, 30, 35, 40, 45, 50, using different types of objective function such as ITAE, ITSE, IAE, ISE. It has been found that the ITAE, ITSE, IAE and ISE objective function, gives best output results the transient response to the population size M = 20, M = 40, M = 30, and M = 35 respectively as compared to the other population sizes for genetic algorithm based PID controller.

6.2 Future Scope

In the future, the prospects can optimize the project based on the PSO optimized PID controller, which can produce good robustness, against uncertainty, and fusion with the same system and also this work may be extended with the help of differential evolutions and hybrid differential evolution algorithms.

LIST OF PUBLICATIONS

Related Publications :

[1] Sanjeev Tripathi and Sunil K. Singla, **"A Comparative analysis of the Conventional and Intelligent Fuzzy Based Controller for Higher-order system",** in *International Journal Research Electronic (IJRE),* volume - 4, Issue - 2, 2017.

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