CONCENTRATION CONTROL OF AN ISOTHERMAL CSTR BY SOFT COMPUTING TECHNIQUES

A THESIS

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CERTIFICATE

I, **Snigdha Chaturvedi**, Roll No. **2K12/C&I/020** student of M. Tech. (**Control and Instrumentation**), hereby declare that the dissertation titled "**Concentration Control of Isothermal CSTR by Soft Computing Techniques** " under the supervision of **Dr. Narendra Kumar**, Professor, Electrical Engineering Department, Delhi Technological University in partial fulfillment of the requirement for the award of the degree of **Master of Technology** has not been submitted elsewhere for the award of any Degree**.**

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ABSTRACT

Continuous Stirred Tank Reactor plays a very important role in all chemical reactions and it is difficult to control because of its highly non linear system. Since it is difficult to find the optimal or PID parameters near optimal values by conventional tuning methods like Ziegler Nichols method, stochastic optimization methods like Particle Swarm Optimization method and Bacterial Forging Optimization algorithms methods are used for PID tuning.

The primary objective of this work is to analyze the implementation of PSO method and BFO method for PID controller optimal tuning for concentration control of CSTR. The comparative study is done on the basis of step response analysis. Next the stochastic methods are applied for finding optimal tuning PID parameters using error indices as objective functions like integral time absolute error, integral square error, etc for concentration control of CSTR. First, PSO is utilized to optimize PID parameters for concentration control of CSTR. Secondly, the Bacterial Forging algorithm is implemented to obtain the optimized PID parameters for concentration control of CSTR . The results obtained by implementation of PSO and BFO algorithm on CSTR process are compared on the basis of step responses. MATLAB software is used for all calculations and analysis.

The conventional tuning methods are not very efficient in this case because there are non linear ties in the system. The output of CSTR concentration control system tuned by conventional method i.e. Ziegler Nichols has a high overshoot and settling time. The main objective of this work is to apply PSO and BFO to design PID controller for an isothermal CSTR to get an output with better step response.

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INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 OBJECTIVES OF THESIS

Continuous stirred tank reactor CSTR plays a very important role in process industry. Because CSTR is immensely used in process industry, control engineers are taking much interest in developing intelligent techniques for control mechanism to get desired results. The continuous progress of process industry has increased the need of chemical and control integration with artificial intelligence.

Due to strong non linear ties, the problem of CSTR control is always an attracting task for control system engineers.

Generally these chemical reactors are controlled by PID controllers and the tuning of controller gains is done on the basis of the linearization of reactor models around operating point. If the process has larger disturbances or it has a higher state sensitivity, then its state trajectory can deviates from original and hence it degrades the performance of the controller. Artificial intelligent (AI) based techniques are proved to be better in variety of areas and hence, these are considered as better method for PID tuning.

MATLAB software is used for analysis of the performance of PSO and BFO on the concentration control model of CSTR. The comparative analysis is done on the basis of PID controller parameters obtained by PSO and BFO and time domain performance parameters like rise time, settling time, max. overshoot, peak time etc of CSTR with these optimized PID controller parameters.

The mathematical model of an isothermal CSTR has been developed. The system is modeled to obtain the steady state values and hence, the state space model. From the state space model the transfer function model of the system is calculated. The main aim of the controller developed for the CSTR process is to maintain the concentration of the product.

The idea PID controllers is discussed briefly along with its the block diagram for different form. There are different conventional methods for PID tuning which have been widely used before the immergence of these AI techniques. These conventional methods are Zeigler Nichols, Open loop, Cohen Coon method etc. ZN method is implemented to our CSTR concentration control model for PID tuning.

Artificial intelligence methods for PID tuning are becoming popular nowadays over conventional methods due to their better performance.. Their performance is analyzed on CSTR concentration control.

1.2 CHAPTER LAYOUT

The layout of this work is represented below:

Chapter No. 1 : In this chapter a brief introduction of the thesis is described

Chapter No. 2 : This chapter includes the Literature review in reference to this thesis work

Chapter No. 3 : Continuous stirred tank reactor (CSTR) modeling and transfer function related to concentration control

Chapter No. 4 : This chapter describes PID controller structure and its conventional tuning methods.

Chapter No. 5 : Particle Swarm Optimization method and optimal PID tuning with PSO is discussed in this chapter

Chapter No. 6 : Bacterial Forging Optimization and optimal PID tuning with BFO is discussed in this chapter.

CHAPTER NO. II
LITERATURE REVIEW

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter few literature reviews are given which are relevant with the thesis work. These are related to the work done on BFO and PSO.

2.2 LITERATURE REVIEW

Geetha. M and, A.K. Balajee.[23] Created a research paper '*Optimal Tuning of Virtual Feedback PID Controller for a Continuous Stirred Tank Reactor (CSTR) using Particle Swarm Optimization (PSO) Algorithm'.* In this paper virtual feedback control is implemented to control the state variables using Extended Kalman Filter (EKF) in the feedback path. They have implemented a virtual feedback PID controller and tuning is done by PSO algorithm for minimum square error condition.

Abhishek Singh and Dr. Veena Sharma[32] worked on a research paper titled '*Concentration Control of CSTR Through Fractional Order PID Controller by Using Soft Techniques'*. In this paper they implemented different controllers using soft computing techniques on CSTR and have found that fractional order controllers are proved to be better.

Mohammad Ali Nekoui and Mohammad Ali Khameneh [13] wrote a research paper named '*Optimal Design of PID Controller for a CSTR System Using Particle Swarm Optimization'*. In this paper the optimal PID controller parameters are calculated on the basis of particle swarm optimization (PSO) method for continuous stirred tank reactor (CSTR). The mathematical model of experimental step up is developed near the operating point

Yogendra Kumar Soni and Rajesh Bhatt[33] worked on a research paper titled *'BF-PSO optimized PID Controller design using ISE, IAE, IATE and MSE error criteria'* A BF-PSO PID controller is designed for the system to meet the desired performance characteristics by using BF -PSO optimization algorithm. PID controller

gain values Kp, Ki, Kd are found and applied to the PID controller system .The PID controller closed loop response for the system is observed for ISE, IAE, IATE and MSE error performance indices. A comparison of system performance of the system is observed for all four error performance indices.

Fernando G Martins[7] wrote a research paper named '*Tuning PID Controllers using the ITAE Criterion'* this paper describes how MATLAB/SIMULINK can be helpful in application of ITAE based calculation of PID parameters.

Vishal Vishnoi[36] wrote a research paper titled '*Swarm Intelligence Based Tuning of the Controller Parameters for Concentration Control of Isothermal Continuous Stirred Tank Reactor'.* This paper gives particle swarm optimization based PID controller tuning for concentration control of isothermal chemical reactor. The performance analysis of the PID controller is performed to study different controllers in this paper. PD-fuzzy controller gives better performance than the conventional controllers to control the concentration of isothermal CSTR. Then the performance of PSO-PID is studied and it is observed that it gives best output results for the concentration control of isothermal continuous stirred tank reactor.

Mahbubeh Moghaddas and Mohamad Reza Dastranj[28] wrote a research paper titled '*Design of Optimal PID Controller for Inverted Pendulum Using Genetic Algorithm'.* In this paper an optimal PID controller is designed for inverted pendulum by using genetic algorithms. It is seen that results are better than conventional ones.

A.Agalya and B.Nagaraj[37] worked on the research paper '*Concentration Control of Continuous Stirred Tank Reactor Using Particle Swarm Optimization'.* In this paper the ISE criterion is used to find the PID parameters Kp, Ki, Kd for PSO algorithm. Simulations are performed with different PID control structures. The results show that PSO PID gives better results as compared to conventional methods.

M.K. Tan and Y.K. Chin wrote a research paper titled '*Genetic Algorithm Based PID Optimization in Batch Process Control'.* In this paper a new modified genetic algorithm (GA) approach is given which is based on the online model parameters and PID gain. The simulations are performed and the results show that the proposed modified GA auto-tuning method is a better than the original GA method.

N. Yadaiah and Srikanth Malladi [39]worked on a research paper titled '*An Optimized relation between Ti and Td in Modified Ziegler Nichols PID controller Tuning'*. This paper presents an optimized tuning strategy in which a factor α relates integral time with derivative time. Here, in this paper a modified ZN method is used and the selection of this factor is carried out by minimizing ITAE with PSO and GA.

Mehmet Korkmaz, Ömer Aydoğdu, and Hüseyin Doğan created a research paper titled '*Design and Performance Comparison of Variable Parameter Nonlinear PID Controller and Genetic Algorithm Based PID Controller'*. In this paper PID controller based on non linear variable parameter method and PID controller based on genetic algorithm optimization are achieved. In this method first of all a variable type of function is defined variable coefficients of PID controller are determined. In this way the Non Linear PID controller changes its values according to the change in output. Then the GA based PID controller is compared with this NL PID controller and found to be better.

Zhangjun and Zhang Kanyu[18] worked on a paper '*A Particle Swarm Optimization Approach for Optimal Design of PID Controller for Temperature Control in HVAC'*. In this paper author gave a novel approach for finding optimal PID parameters by finding the solution in the search space of Kp, Ki and Kd. The mathematical model of a HVAC system is developed near operating point and PSO algorithm is applied to adjust the PID parameters.

Akhilesh Kumar Mishra and Anirudha Narain [40]wrote a research paper named '*Speed Control Of Dc Motor Using Particle Swarm Optimization Technique'*. In the proposed work speed of a DC motor is controlled by selecting of PID parameters using bio inspired optimization technique i.e. PSO. The mathematical model of DC motor is developed. Then PSO is applied to this model and has advantages over conventional methods.

Hugo Ojeda-Elizarras and Rafael Maya-Yescas[34] worked on a research paper titled '*Fuzzy Control of a Non Linear system with inverse response: Van De Vusse Reaction'*. In this paper they designed a fuzzy logic controller for a non linear process with inverse response such as Van De Vusse reaction. This process has difficulties in the application of conventional feedback control loop. The Van De Vusse reactor has zeros on right half of the s plane which gives inverse response for certain operating

conditions. Fuzzy control is applied and compared with conventional tuning approaches like Ziegler Nichols for P, PI, and PID control.

V. Rajinikanth and K. Latha[25] worked on a paper titled '*I-PD Controller Tuning for Unstable System Using Bacterial Foraging Algorithm: A Study Based on Various Error Criterion'*. In this paper author proposed a tuning process for the I-PD controller for a unstable process with delay by Bacterial Forging Algorithm. From this tuning process the PID parameters are calculated by minimizing multiple objective performance criterion. A comparison is done for different objective functions like ISE, IAE, ITSE and ITAE.

T.O' Mahony and C.J. Downing[12] wrote a paper titled '*Genetic Algorithm for PID parameter Optimization: Minimizing Error Criteria'*. In this paper the application of Genetic Algorithm is done to a variety of processes and compared with the conventional tuning methods. Simulation results show that Genetic Algorithm overcomes many of the difficulties associated with existing rules, and gives satisfactory performance.

. Susmita Das and Ayan Chakraborty[27] wrote a paper titled '*Study on Different Tuning Approach with Incorporation of Simulation Aspect for Z-N (Ziegler-Nichols) Rules'*. In this paper the PID tuning method of Ziegler Nichols is studied with simulation aspect. The coding is done in MATLAB. The MATLAB coding is developed in two different parts i.e. in first part Routh Hurwitz criteria coding is done to check for the system stability or instability condition..

Sapna Gupta and Rajeev Gupta [45]created a research paper titled '*PSO and PSO-BFO Based Tuning of PID Controller: A Comparative Evaluation'*. The aim of this paper is to analyses the PID controller tuning by swarm optimization technique. A combination of PSO and BF-PSO based PID controller is analyzed. PSO process slows down around global optimum. To overcome this problem author has implemented hybrid algorithm BF-PSO for PID tuning.

2.2 CONCLUSION

From the review of above mentioned research papers, the implementation of various soft computing techniques on PID controller have been studied. In these papers authors have used different efficient objective functions.

CHAPTER III
CONTINUOUS STIRRED TANK REACTOR

CHAPTER III

CONTINUOUS STIRRED TANK REACTOR

3.1 INTRODUCTION

The chemical reactors are important parts of a chemical process industry used for performing chemical reactions. Chemical reactors is a place where chemical reactions takes place. The selection of chemical reactor in done on the basis of many points of chemical engineering. Chemical reactors are designed so that the reaction performed is efficient and will gives desired product as the output. It ensures two conditions maximum profit and less cost. Generally in a chemical reactions we need some expenses at the time of operation for example, heat energy as input, energy change removal, raw materials , labor charge etc. Changes in energy can be in different forms like heating or cooling, pumping to increase the pressure, agitation, etc. There are different types of chemical reactors like batch reactors, semi batch reactors and continuous reactors.

3.2 CSTR

The CSTR consists of a tank, which is well mixed stirred into which there is continuous flow of reacting materials, and the partially reacted materials are passed continuously. These vessels are squad in shape (i.e. cylindrical as well as deep) therefore, good stirring of contents is essential otherwise there could occur a bulk and streaming of the fluid between inlet and outlet and much of the volume will be occupied as dead space.

The important characteristic of the CSTR is stirring. The estimation of its performance is based on the fact that its contents are perfectly mixed. In a CSTR the effluent stream has same composition as its contents.

A fair approximation of perfect mixing is attained in CSTR if the fluid phase is not too viscous. In general terms, we say that if an entering element of material is distributed uniformly throughout the tank in a time much shorter than the average time of residence in the tank then it is probably called to be perfectly mixed.

One greatest advantage of CSTR apart from its simplicity of concentration is that temperature control is very easy. The reagents entering the first vessel plunge immediately into a large volume of partially reacted fluid and, because of stirring local hot spots do not occur. CSTR offers a large area of cooling surface.

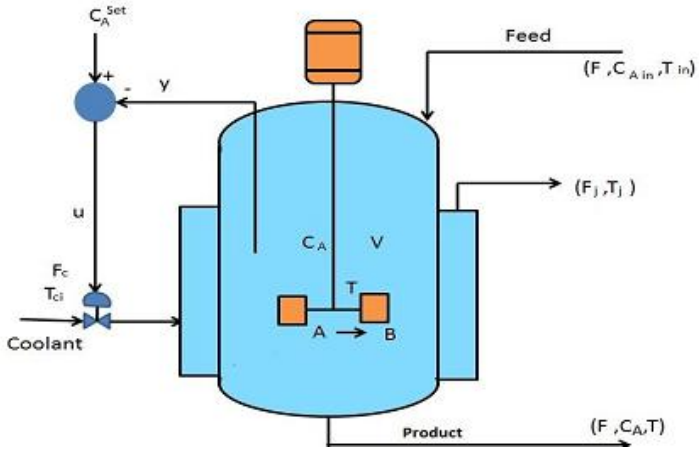


Figure3.1 Basic Diagram of CSTR[37]

For these very reasons the typical fields of application of CSTR are continuous processes of sulphonation, polymerization etc. It is used very extensively in organic industry and particularly in production of plastics, explosives, synthetic rubber etc.

Chemical reactions occurring in reactors can be exothermic means releasing heat or endothermic means absorbing heat..

Some points of consideration in CSTR:

1. At steady-state condition, the input flow rate should be equal to the flow rate of the output otherwise situations of empty tank or overflow can occur.

2. The reaction is performed on the basis of reaction rate of the final output product

3. It is economically advantageous to connect several CSTRs in series. The CSTR connected first operates at a higher product concentration and hence it operates at a reaction rate which is higher. Therefore, the reactor sizes are varied in order to reduce the total cost of investment required to perform the given process.

3.3 MATHEMATICAL MODELLING OF ISOTHERMAL CSTR

An isothermal CSTR is a reactor which operates at constant temperature and volume. The reactions considered is a set of irreversible reactions. The stream feed at the input consists of a single component A. The conversion of reactant in a CSTR is a found to be function of residence time. space velocity its inverse. In case of a isothermal type of CSTR, the concentration of the product can be controlled by changing the flow rate of the feed, which changes the space velocity or its inverse residence time.

In this work, we consider a series – parallel reaction scheme which is in the following form which is also given as Van De Vusse reaction scheme:

$$A \xrightarrow{K1} B \xrightarrow{K2} C \qquad (3.1)$$

$$2C \xrightarrow{K3} D \qquad (3.2)$$

Component B is the product which is desired, and it is the intermediate product in the series parallel reaction. In this reaction we have to study about the steady state condition and behavior that occurs with this reaction scheme. Klatt and Engell(1998) studied that production of cyclopentenol from cyclopentadiene is based on Van de vusse reaction series where, A= cyclopentadiene, B= cyclopentenol, C= cyclopentaediol, D= dicyclopentadiene

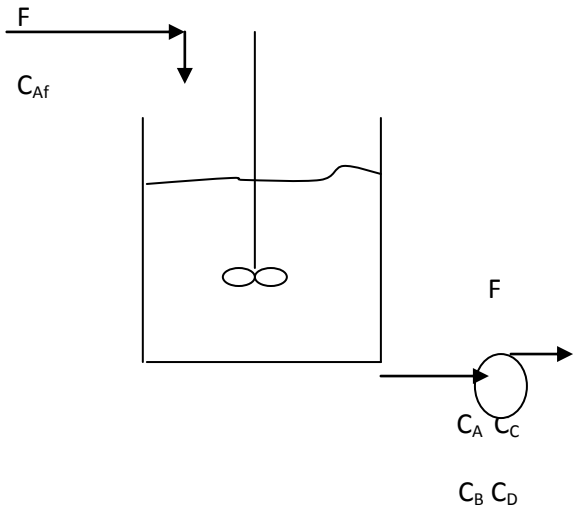


Figure 3.2 Isothermal CSTR representation

Rate of formation / unit volume of components A,B,C and D is:

$$r_A = -K_1 C_A - K_3 C_A^2 \quad (3.3)$$

$$r_B = K_1 C_A - K_2 C_B \quad (3.4)$$

$$r_C = K_2 C_B \quad (3.5)$$

$$r_D = \frac{1}{2} K_3 C_A^2 \quad (3.6)$$

The overall material balance (for a perfectly mixed tank) is given as:

$$\frac{d(V\rho)}{dt} = F_i \rho_i - F\rho \quad (3.7)$$

The liquid phase density is observed not to be function of concentration. Therefore , the inlet stream density is equal to the outlet stream density.

$$\rho_i = \rho \quad (3.8)$$

Therefore, $\frac{dV}{dt} = F_i - F$ (3.9)

So, $F_i = F$ (3.10)

For a constant volume condition, the following equations are derived:

$$\frac{d(VC_A)}{dt} = F\left(C_{Af} - C_A\right) - VK_1 C_A - VK_3^2 C_A \quad (3.11)$$

Simplifying eqn (11) we get

$$\frac{d(C_A)}{dt} = F/V\left(C_{Af} - C_A\right) - K_1 C_A - K_3^2 C_A \quad (3.12)$$

$$\frac{d(C_B)}{dt} = -\frac{F}{V} C_B + K_1 C_A - K_2 C_B \quad (3.13)$$

$$\frac{d(C_C)}{dt} = -\frac{F}{V} C_C + K_2 C_B \quad (3.14)$$

$$\frac{d(C_D)}{dt} = -\frac{F}{V} C_D + 1/2 K_3 C_A^2 \quad (3.15)$$

In the above equation number 3.12 and 3.13 the products does not depends on the concentration of reactant C or D. Since we are concerned only about of product concentration B, for which only two of the equations are taken into account:

$$\frac{d(C_A)}{dt} = F/V\left(C_{Af} - C_A\right) - K_1 C_A - K_3^2 C_A \quad (3.12)$$

$$\frac{d(C_B)}{dt} = -\frac{F}{V} C_B + K_1 C_A - K_2 C_B \quad (3.13)$$

3.4 STEADY STATE ANALYSIS

For the steady state condition, for component A, $\frac{dC_A}{dt} = 0$

$$-k_3 C_{AS}^2 - K_1 C_{AS} - \frac{F_S}{V} C_{AS} + \frac{F_S}{V} C_{AfS} = 0 \quad (3.16)$$

$$C_{AS} = \frac{-\left(K_1 + \frac{F_S}{V}\right) + \sqrt{(K_1 + F_S/V)^2 + 4K_3\left(\frac{F_S}{V}\right)C_{Afs}}}{2K_3} \quad (3.17)$$

For the steady state condition, for component B, $\frac{dC_B}{dt} = 0$

$$C_{BS} = \frac{K_1 C_{AS}}{\frac{F_S}{V} + K_2} \quad (3.18)$$

For this particular reaction under consideration, the values of rate constants is,

$$K_1 = 50\ hr^{-1} = \frac{5}{6} min^{-1}$$

$$K_2 = 100\ hr^{-1} = \frac{5}{3} min^{-1}$$

$$K_3 = 10 \frac{mol}{liter.hr} = \frac{1}{6} \frac{mol}{liter.hr}$$

Steady state feed concentration is:

$$C_{Afs} = 10 gmol/liter$$

The concentration are a function of the space velocity (F_S/V) , it has units in inverse time. The space velocity can be thought of as number of reactor volumes that change over per unit time. It is inversely related to the fluid residence time (V/F_s), which has units of time and can thought of as average time that an element of fluid spends in the reactor.

The concept of conversion is important in chemical reaction engineering. The conversion of reactant A is defined as the fraction of the feed stream component that is reacted.

$$X = \frac{C_{Ai} - C_A}{C_{Ai}} = \frac{(\frac{kV}{F_S})}{(\frac{kV}{F_S}+1)}$$

This conversion is the function of a term K_v/F_s which is dimensionless, which is known as Damkohler number. The Damkholer number is the fraction of the characteristic residence time and the characteristic reaction time and is widely used by chemical reaction engineers. Different chemical recation systems can have the same conversion if their Damkholer number is same. A system with a low residence time and large rate constant can have same conversion as a system with high residence time and low rate constant.

Here, we can notice that this process has a non linear relationship between the steady state rate of dilution i.e. (F/V) and the steady state product concentration B. A maximum value of concentration exists that has to be achieved. The reactor is only controllable until the maximum point is reached because at the maximum point the gain of the process becomes zero. For the required dilution rates there are always two dilution rates that can be achieved which is known as input multiplicity.

For the parameter values taken in the above case, a steady state concentration of B 1.117 gmol/liter can be achieved with either $F_S/V=0.57$ min^{-1} or $F_S/V=2.87$ min^{-1}. The process gain is positive for case 1 and negative for case 2. Therefore, for the controller design, it is important to note whether you are operating on left hand side or right hand side of the peak value.

3.5 LINEAR ANALYSIS

The linear state space model using these equations can be represented as:

$$\dot{X} = AX + BU \qquad (3.19)$$

$$Y = CX + DU \qquad (3.20)$$

Here, the state variables, input variables and output variables are represented in derivative form. The first input parameter which is dilution rate is manipulated considered as manipulated input and the second input which is the feed concentration of A is considered as the disturbance .

Where, the state variable is X represented as:

$$X = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} C_A & -C_{AS} \\ C_B & -C_{BS} \end{bmatrix} \quad (3.21)$$

The variable Y which is the output is given as:

$$Y = [C_B \quad -C_{BS}] \quad (3.22)$$

The variable U which is the input is given as:

$$U = \begin{bmatrix} F/V & -F_S/V \\ C_{Af} & -C_{AfS} \end{bmatrix} \quad (3.23)$$

Line arising the two modeling equations at steady state condition we find the following state space models:

Two dynamic functional equation are

$$\frac{d(C_A)}{dt} = f_1\left(C_A, C_B, \frac{F}{V}\right) = \frac{F}{V(C_{Af} - C_A)} - K_1 C_A - K_3^2 C_A \quad (3.24)$$

$$\frac{d(C_B)}{dt} = f_1(C_A, C_B, \frac{F}{V}) = -\frac{F}{V} C_B + K_1 C_A - K_2 C_B \quad (3.25)$$

The elements of state matrix A and B are given as:

$$A = \left.\frac{\partial f_i}{\partial x_i}\right|_{x_s, u_s} \quad (3.26)$$

$$B = \left.\frac{\partial f_i}{\partial u_i}\right|_{x_s, u_s} \quad (3.27)$$

Therefore, the state model of the system is given as:

$$A = \begin{bmatrix} -\frac{F_S}{V} - K_1 - 2K_3 C_{AS} & 0 \\ K_1 & \frac{-F_S}{V} - K_2 \end{bmatrix} \quad (3.28)$$

$$B = \begin{bmatrix} C_{AfS} - C_{AS} & F_S/V \\ -C_{BS} & 0 \end{bmatrix} \quad (3.29)$$

$$C = [0 \quad 1] \quad (3.30)$$

$$D = [0 \quad 0] \quad (3.31)$$

For the steady state operating point C_{AS} =3gmoll^{-1}, C_{BS}=1.117 gmoll^{-1} and F_S/V=0.5714min^{-1} the state space model is :

$$A = \begin{bmatrix} -2.4048 & 0 \\ 0.8333 & -2.2381 \end{bmatrix} \quad (3.32)$$

$$B = \begin{bmatrix} 7 & 0.5714 \\ -1.117 & 0 \end{bmatrix} \quad (3.33)$$

$$C = [0 \quad 1] \quad (3.34)$$

$$D = [0 \quad 0] \quad (3.35)$$

Here, the first input (u_1, manipulated) is the dilution rate (F/V), second input (u_2, disturbance) is the feed concentration (C_{Af}), output is defined as the concentration of intermediate component B. The eigen values of A are -2.4048 and -2.2381 min^{-1}.

The transfer function between manipulated input and output for the reactor is derived by formula $G(s) = C[sI - A]^{-1}$

The state space form can be converted into transfer function by Matlab commands and given as:

$$G(s) = \frac{-1.117s+3.1472}{s^2+4.6429s+5.3821} = \frac{0.5848(-0.3549s+1}{0.1828s^2+0.8627s+1} \quad (3.36)$$

The transfer function poles which are (-2.2381 and -2.4048) are equal to the eigen values of A matrix. Also one positive zero (1/0.3549) in G(s) gives an inverse response

Let us study the output response of the Van De Vusse reactor for concentration C_B in gmol/liter. The open loop response for the concentration control of CSTR is given below.

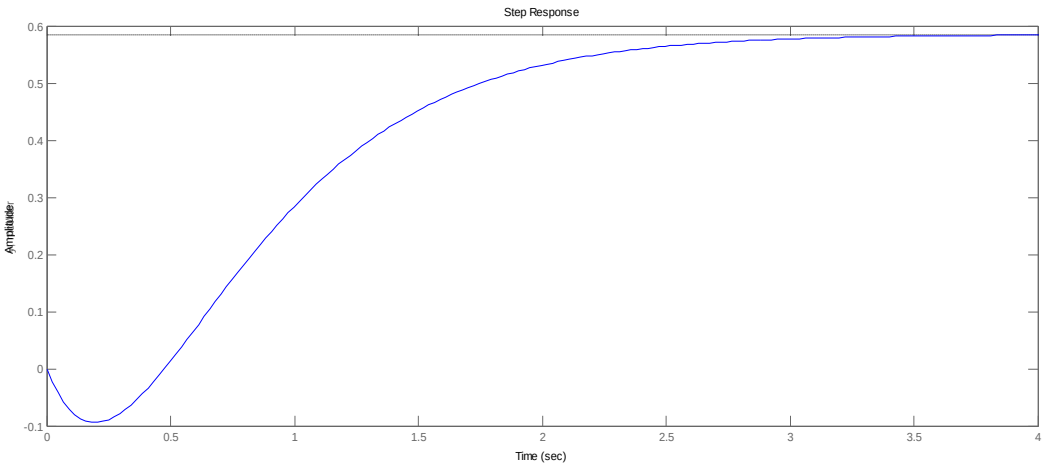


Figure 3.3 Response of the concentration as a function of time

In the above plot we observe that the response i.e. concentration initially decreases, before increasing to a new steady value.

3.6 CONCLUSION

In this chapter we have studies about the introduction of CSTR. We have studied the mathematical modeling of CSTR for concentration control of a Van De Vusse reaction. The response of this system is found to have inverse characteristics.

CHAPTER IV
PID CONTROL OF CSTR

CHAPTER IV

PID CONTROL OF CSTR

4.1 INTRODUCTION

This chapter describes the Proportional-Integration-Derivative PID controller and its main tuning approaches.

4.2 PID CONTROLLER

PID controllers are widely used as the controller strategy due to their simplicity in design and its reliable operation. It contains three types of controller actions, the proportional action, integral action and derivative controller action. The figure given below shows the parallel form of the PID controller:

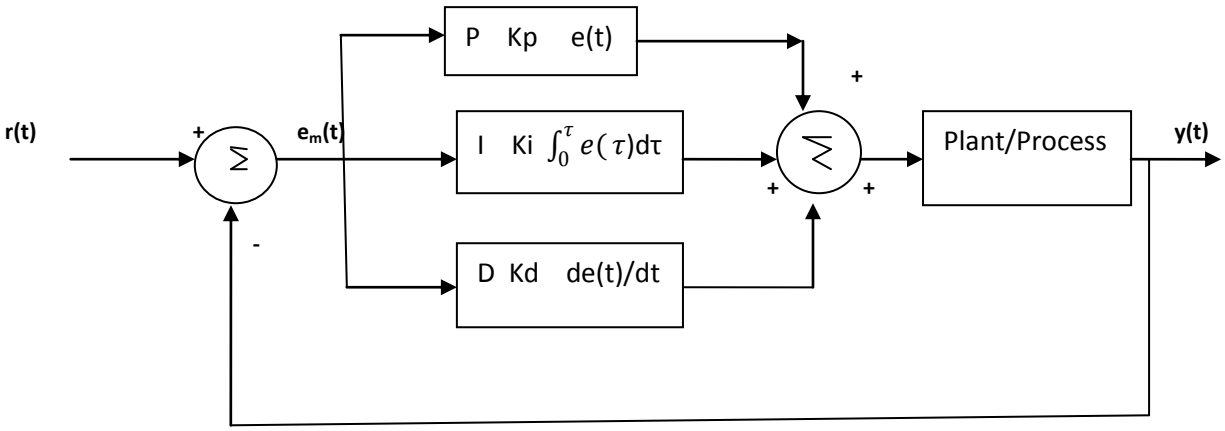


Figure 4.1 PID controller Block Diagram

Where, r(t) is the reference value, y(t) is the output of the system, $e_m(t)$ is the measured error , which is defined as the difference between the reference value and actual output , and c(t) is the control output:

$$e(t) = u(t) - y(t) \qquad (4.1)$$

$$c(t) = K_P[e(t) + \frac{1}{T_i}\int_0^t e(t) + T_d \frac{de(t)}{dt}] \qquad (4.2)$$

Here, K_p is the proportional gain,

T_i is the integral time, $K_p * (1/T_i)$ is the integral factor

T_d is the derivative time, $K_P * T_d$ is the derivative factor

The parallel form of PID controller like shown in figure 4.1 is commonly found although there are a few difference structures which exist like series architecture (McMillan, in 1983) and the modification of the series and parallel architecture (given by Johnson et al. in 2005).

4.2.1 PROPORTIONAL TERM

Form the above equation we know that the proportional term is $K_P * e(t)$ .The proportional term is directly proportional to the error change .Proportional control will act to reduce the error. The value of proportional control is directly proportional to the proportional gain K_P, if we increase the proportional gain, the control action increases, but if the proportional gain value becomes too higher, the system can enter into continuous oscillations and become unstable.

4.2.2 INTEGRAL TERM

The expression of integral term is $K_p * \frac{1}{T_i} \int_0^t e(t)$. The integral term keeps on increasing its value unless the error of the system becomes zero therefore, we can say that it reduces the steady state error. The integral term can eliminates the value of steady state error, but on the other hand it also slows down the response. There are several advantages of increasing the integral gain. Increasing the integral gain can decrease the maximum overshoot and enhances system stability.

4.2.3 DERIVATIVE TERM

The expression of derivative term is $K_P * T_d \frac{de(t)}{dt}$. In control systems generally it is always required to speed up the process. In the case when error occurs in a system immediate control action is required, but it is also necessary to study the rate of change of error. To achieve the desired target, derivative control action is performed. The derivative control action depends on T_d which is known as derivative time constant. If we increase the value of T_d control action related to rate of change of error increases. Derivative term effects system stability.

The derivative action depends on the rate of error change. If the error starts changing at a faster rate the derivative control comes into play and it reduces the error before it becomes larger. This term reduces the overshoot of the system and increases the stability of the system.

But derivative controller alone cannot be applied to the systems with noise because it is extremely sensitive to these noise signals. So, there is a requirement of adding a filter if we want to use a derivative controller.

4.3PID CONTROL ALGORITHMS

4.3.1 ON OFF CONTROL

An on off controller is similar to a controller generally used in home heating unit. On off controller is one of the simplest form of controller. Let us take a example of controlling water supply to a water tank it can be done with a on-off valve, which on when the supply is needed and made off when we want to cut off the supply. But this type of controller cannot be applied if we have to regulate a specific variable which is the biggest disadvantage and makes its use limited in the industry.

4.3.2 PROPORTIONAL CONTROL

A proportional controller as its name suggests, takes action in proportion to the error. Here, error is defined as the difference between desired set point and actual output value. Proportional controller is a continuous type of controller. Since, the control action is directly proportional to the error therefore, higher the value of error higher is the corrective action taken. If we increase the proportional gain system becomes more sensitive to the changes in the set point but at the same time the system becomes prone to oscillations which can cause instability.

The proportional action decreases the rise time of the system means makes it faster, but increases the percentage overshoot and steady state error which means decreases the stability.

The advantages are as follows:

1. It is simple in structure and can be tuned easily.

2. It responds very rapidly with respect to time.

3. It is relatively stable dynamically.

The disadvantages of this type of controller are:

1. Offset error: When there are frequent changes in the load, set point changes continuously. Sometimes, due to these continuous changes the control variable attains a different new equilibrium point which is called new operating point. Offset error is defined as the difference between new operating point and the set point of the system. To understand the offset error let us take example of level control system, for a step increase in the input flow to maintain the level we have to open the valve wider. In proportional control since the control signal is directly proportional to the error, it should be continuously present. To maintain a constant error signal the liquid level should be raised above a desired level which is the new operating point.

2. Overshoot: If there is a significant time of oscillation period, or overshoot occurs. Although in some of the cases, the period of this oscillation is moderate, this, in some cases, can be highly undesirable.

4.3.3 PROPORTIONAL PLUS DERIVATIVE CONTROL

When we add derivative control action to the proportional control it is called P+D controller. The derivative controller adds a lead effect to the system, thereby reduces the oscillations of the system. Proportional plus derivative controller decreases the offset value but cannot eliminate it completely. Increasing the proportional term can lead to increase the system overshoot and decrease the stability. To overcome this problem we add a derivative control action to the proportional term. The derivative action is directly proportional to the rate of change of error. In a proportional plus derivative controller the increase in derivative gain decreases the overshoot and settling time.

4.3.4 PROPORTIONAL INTEGRAL CONTROL

The integral controller takes action proportional to the past accumulated error values. If we increase the integral gain it reduces the rise time and steady state error. A controller without Derivative controller is required when:

a) System response speed is not taken into consideration

b) system works at higher noise and disturbances

c) system has delay in the response

when the system response is delayed it is necessary to predict the error. In such type of systems derivative controller cannot be used because error is delayed.

4.3.5 PROPORTIONAL INTEGRAL DERIVATIVE CONTROL

The stability of the system is increased by the derivative control action and the integral control action speeds up the response. We use the PID controller in the processes which employ more than one storage elements. PID controller has its application in variety of areas, not only in the industries but in the control of mobile objects and the areas where set point is précised. The general forms in which PID controller is given are:

a) $u(t) = K_C[e(t) + \frac{1}{\tau_i}\int_0^t e(t) + \tau_d de(t)/dt]$ (4.3)

b) $u(s) = K_C\left[1 + \frac{1}{\tau_i s} + \tau_d s\right]e(s)$ (4.4)

c) $u(s) = K_C\left[{(1 + \tau_i s + \tau_i \tau_d s^2)}/{\tau_i s}\right]e(s)$ (4.5)

4.4 PID TUNING METHODS

PID controller tuning involves the best selection of parameters K_P, T_i, and T_d. Controller tuning is generally based on the process. The conventional tuning methods are Ziegler- Nichols method, Cohen coon method and Chien-Hrones-Reswick procedure. These tuning methods are used to determine the controller parameters for proportional, derivative and integral control according to the process characteristics. These methods can be applied in both cases when the process mathematical model is known and when it is unknown. The fine tuning is done after the application of these methods using the process knowledge.

4.4.1 ZIEGLER – NICHOLS PID TUNING METHOD

In a paper published by Ziegler Nichols in 1942 they described two methods for tuning of P, PI and PID controller.

In the closed loop method consider the case with Proportional control only, in this case increase the magnitude of the proportional gain until the system enters the condition of oscillations. This condition is the verge of stability for slightly larger values of gain, the closed loop system is unstable, while for slightly low value it is stable.

This value of proportional gain which causes oscillation is called the critical value or ultimate gain value K_{CU}. The critical or ultimate time period P_U is defined as the peak to peak period or time between successive peaks in continuous oscillating process outputs. Depending on the controller chosen P, PI, PID the tuning parameter values are given in the table below:

Table 4.1 Ziegler Nichols Closed Loop Oscillation Tuning Method

Controller type	K_C	T_I	T_D
P type	O.5 K_{cr}	-	-
PI	0.45 K_{cr}	$P_{ut}/1.2$	-
PID	0.6 K_{cr}	$P_{ut}/2$	$P_{ut}/8$

2. Ziegler Nichols Open loop tuning method

The open loop Ziegler Nichols method proposed tuning parameters for a process that has been identified as integrator + time delay based on an open loop process step response,

$$g_p(s) = \frac{ke^{-\theta s}}{s} \qquad (4.6)$$

The same rules can be applied to a system with first order and time delay processes because first order + time delay process have a maximum slope of $k = k_p/\tau_p$ at t=Θ for a unit step input change.

$$g_p(s) = \frac{k_p e^{-\theta s}}{\tau_p s+1} \qquad (4.7)$$

Table 4.2 Ziegler Nichols open loop tuning parameters

Controller type	K_C	T_i	T_D
P only	$\frac{1}{k\theta} or \frac{\tau_p}{k_p\theta}$	-	-
PI	$\frac{0.9}{k\theta} or \frac{0.9\tau_p}{k_p\theta}$	3.3θ	-
PID	$\frac{1.2}{k\theta} or \frac{1.2\tau_p}{k_p\theta}$	2θ	0.5θ

4.4.2 COHEN-COON METHOD

The method developed by Cohen Coon in 1953 is based on the process model with first order + time delay. The tuning parameters are developed to find a response with a decay ratio of 1/4. The tuning parameters are function of model parameters. Cohen coon is method complex than Ziegler Nichols method. The sensitivity of this method is more than Ziegler Nichols method.

A major problem with Cohen Coon is that it is not very robust that is, a small variation in the parameters of the process can cause the closed loop system to become unstable. The table given below explains the Cohen Coon tuning parameter values:

Table 4.3 Cohen Coon tuning parameters

Controller type	K_c	T_I	T_D
P only	$\frac{\tau_P}{k_p\theta}\left[1+(\frac{\theta}{3\tau_p})\right]$	-	-
PI	$\frac{\tau_P}{k_p\theta}\left[0.9+(\frac{\theta}{12\tau_p})\right]$	$\theta\frac{[30+3\theta/\tau_p]}{9+20\theta/\tau_p}$	-
PID	$\frac{\tau_P}{k_p\theta}\left[\frac{4}{3}+(\frac{\theta}{4\tau_p})\right]$	$\theta\frac{[32+6\theta/\tau_p]}{13+8\theta/\tau_p}$	$\frac{4\theta}{11+2\theta/\tau_p}$

4.4.3 PID TUNING USING STOCHASTIC APPROACHES

PID controllers tuning becomes difficult for higher order and complex plants when using conventional methods. Therefore, the control system engineers shifted their

attention to the stochastic approaches which provides a heuristic searching process to the tuning mechanism. In general, the structure for optimization tuning of a PID controller is illustrated as in Figure 4.5

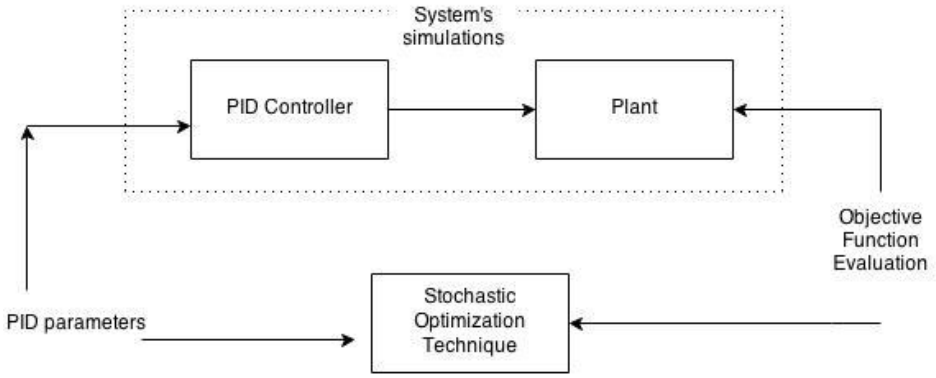


Figure 4.2 Structure for Optimization of PID controller tuning

The PID parameters are stochastically provided by the optimizing methods to the PID controller and the closed loop system is then simulated to get the system's output responses. From the responses, the objective function of the optimization technique is evaluated and the objective value is processed by the optimizing system. There are many stochastic techniques that employed as an optimization technique for PID controller parameters tuning such genetic algorithms (GA), particle swarm optimization (PSO), ant colony optimization, bacteria foraging based optimization and simulated annealing optimization.

Regardless of the stochastic optimization techniques, the calculation of objective function is a critical part in the optimization. The most commonly used objective function employed is the summation of errors between the reference set point and the actual response output. The three commonly used errors performance indices are integrated absolute error (IAE), mean square error (MSE) and integrated time weighted absolute error (ITAE). These commonly defined performance indices are generally taken as the objective functions for optimization.

4.4.4 PERFORMANCE INDICES

A performance index factor is defined as a quantitative measure of the performance of the system response. The performance calculation is usually used in

research environment to minimize the value of error between the reference input & desired output.

A. Integral Absolute Error (IAE): It is generally used for the systems where we have to suppress all errors equally.

$$IAE = \int_0^T |e(t)|\, dt \qquad (4.8)$$

B. Integral Square Error (ISE): It is generally used for suppressing large amount of initial errors.

$$ISE = \int_0^T e^2(t)\, dt \qquad (4.9)$$

C. Integral Time Absolute Error (ITAE): It is generally used to reduce the initial large amount of error.

$$ITAE = \int_0^T t|e(t)|\, dt \qquad (4.10)$$

D. Integral time Square Error (ITSE): It is used for the systems where large errors persists and they are problematic.

$$ITSE = \int_0^T te^2(t)dt \qquad (4.11)$$

4.5 APPLICATION OF PID CONTROLLER IN CHEMICAL REACTORS

Chemical reactors produce bulk chemicals, intermediate products, petro chemicals, pharmaceuticals chemicals, polymers etc. In pharmaceuticals and other specialty chemical production we generally use batch type of reactors while in other products we mainly use continuous type of reactors.

The controller used for temperature is most important because the rate of reaction is an exponential function of temperature by Arrhenius Equation. The dead time to time constant ratio for batch and continuous reactors are very small (usually < 0.001). As a result the PID gains are much larger. The factors which effect the accuracy of temperature sensor, threshold sensitivity and resolution of control elements.

In cascade control of reactor the reactor temperature acts as primary PID and the output of this PID is the set point. In such case PID controller linearises the reactor

temperature loop and results in faster compensation to disturbances. If there is a sudden change in set point or large disturbances, control system can jump into oscillations.

The PID controllers are also used to control the reactant feed flow because it is important to keep the reactants in optimal ratio because the rate of reaction and complete reaction to be done depends reactants. The instruments used for concentration control are coriolis meters with mass flow and density measurement which is used to provide a component mass as its control variable can slowly cut the ratio of reactants. On the other hand, for exothermic reactions the controlled variables is cooling rate which controls the rate of reaction and indirectly used to trim the feed ratio.

The concentration and temperature profile of a batch reactor can be controlled by a PID controller whose control variable is the rate of change in temperature or concentration. However, in case of highly exothermic reactions there is large sudden increase in rate of reaction in such a case the exponential reaction rate can create a runaway response. In such type of reactors, there is a window of PID gains with very low gain values to prevent the runaway conditions and growing oscillations. We can also prevent the runaway condition by maximizing the derivative action. If the control variable is the rate of change in temperature, then integral mode is proportional mode proportional mode is the derivative mode for temperature response. The important point of consideration is the settling of integral time for the runaway reactions. To overcome this the control variable is changed from rate of temperature to temperature the time of reset should be increased by factor of 10.

4.6 CONCLUSION

The PID controller operation is studied in its different forms. Its different tuning approaches and application in chemical reactors was also studied. Thus, it is observed that tuning PID controllers with best parameters is an issue with conventional methods.

CHAPTER V
PARTICLE SWARM OPTIMIZATION

CHAPTER V

PARTICLE SWARM OPTIMIZATION

5.1 INTRODUCTION

Particle Swarm Optimization is a stochastic optimization approach which is population based. It was first introduced by Kennedy and Eberhart in 1995 in a research paper. The basic control parameters are coefficients of acceleration, inertia weight, velocity clamping and swarm size. But wrong selection of these parameters may lead to cyclic or divergent behavior.

The research originally done by Kennedy and Eberhart started out to find the local agents rules for simulating the social behavior foe a flock of birds or a school of fishes. This work was inspired by work of Reynolds who programmed a flock of agents by interacting rules. After which they found that some type of interaction in the flock can effect the efficiency of finding the important beneficiary location such as food. They saw this nature is effective in developing a novel algorithm for general non linear programming. So they improved and updated the agents position. Thus Particle Swarm Optimization was born.

Particle Swarm Optimization is a technique used to explain the search space of a given function to find the parameters required to maximum or minimum a particular objective function. PSO describes two different concepts: the idea based on swarm intelligence which is basically the observation of swarming habits by certain kind of animals like birds, fishes and the other one is evolutionary computation.

PSO is inspired by the simulation of social behavior and not by survival of the fittest. Swarm intelligence is easy to implement it has no gradient information required to make a fit candidate for a variety of optimization solving problems. PSO is applied successfully in wide range of areas of optimization from artificial neural network (ANN) training to reactive power, voltage control and speed control etc.

5.2 PSO ALGORITHM

PSO algorithm is used as an optimization technique. The process of PSO starts with the flow of swarms and particles in the space defined which is called as search space. Then the change in the position of the particles is done on the basis of experience and knowledge of other particles. In PSO the particles move towards the successful spaces. The particles exchange knowledge from each other and moves towards the best neighbor. The objective of PSO is that each particle should change its position every second to reach the best position in the search space.

In the first step, the initial components are randomly generated as possible solutions, then they move towards optimum positions by moving in group movements, which are a based on pattern. The change in position depends on two points:

1) The Best position of any component found in previous movements

2) Position of the best particle in entire population

In the end of the process, all the particles converge around the optimal point. By increasing the number of parameters the dimension of the search space increases. Let us assume for n- dimensional search space of the problem the position of ith particle in the population is shown by a n – dimensional vector:

$$X_i = (x_{i1}, x_{i2}, x_{i3} \dots \dots \dots . x_{in}) \quad (5.1)$$

The shift produced by each particle is given by:

$$V_i = (v_{i1}, v_{i2}, v_{i3} \dots \dots \dots . . v_{in}) \quad (5.2)$$

Best position of the particle is given as:

$$P_{besti} = (P_{i1}, P_{i2}, P_{i3} \dots \dots \dots . . P_{in}) \quad (5.3)$$

Therefore, the particles movement in (n+1)th iteration is equal to:

$$V_{ij}^{(n+1)} = wV_{ij}^{(n)} + c_1 u_1 \left(P_{bestij} - x_{ij}^{(n)}\right) + c_2 u_2 \left(gbest_j - x_{ij}^{(n)}\right) \quad (5.4)$$

Where, gbest is the best particle in the whole population and its value is present in each phase, i=1,2,3….m where, m denotes the total number of particles, and j = 1, 2,3…..n and n is the dimension of search space, W is defined as the inertia's factor, C_1 and C_2 are known as acceleration constants, $x_{ij}^{(n)}$ is particle's current position, u_1 and u_2 are random numbers between 0 and 1.

The new position of a particle at this phase is:

$$X_{ij}^{(n+1)} = X_{ij}^{(n)} + v_{ij}^{(n+1)} \qquad (5.5)$$

the coefficients c_1 and c_2 are cognitive and social factors.

By the proper selection of these values helps in rapid and suitable convergences, however wrong selection can cause divergence effect. For example, let us consider the coefficient c_1 larger than c_2 and now if we increase c_2 early convergence can occur. Generally, c_1 is kept larger, because of which particles search autonomously and are scattered. On the other hand, if c_2 is kept larger, the particles collect at a place. So, the choice of these constants is an important issue. The velocity diagram is given as:

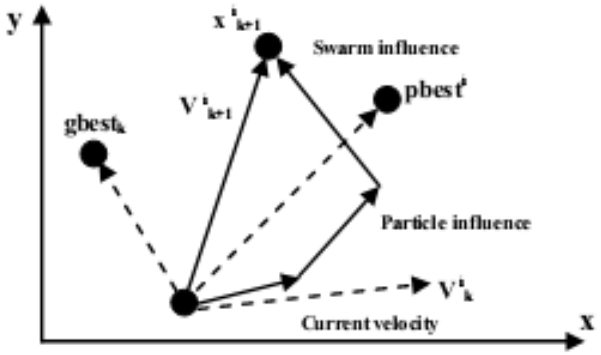


Figure 5.1 Velocity Vector Diagram[5]

We can observe from the above figure that if the parameters are increased the area of the search space increases. So, the movements of the particles should also be increased for early convergence.

Steps in the Particle Swarm Optimization algorithm are:

Step no. 1: Initialization of position and velocity: In this step we initialize the position and velocity of the particle in the range defined.

Step no. 2: Velocity Update: The particles velocities are updated after each iteration according to the formula:

$$v_i = wv_i + c_1R_1(P_{ibest} - P_i) + c_2R_2(g_{ibest} - P_i) \quad (5.6)$$

Where, P_i and v_i are given as position and the velocity of the ith particle.

P_{ibest} and g_{ibest} are 'best' position of objective value obtained by ith particle individually and whole population respectively.

W is the inertia factor

R_1 and R_2 are random values between 0 and 1

c_1 and c_2 are weighing factors controlling both the terms

Step no. 3: Position Update: The position of the particles is updated by the formula:

$$P_i = P_i + v_i \quad (5.7)$$

Step no. 4: Update the memory: update P_{ibest} and g_{ibest} when the condition given below is satisfied:

$$P_{ibest} = P_i \; if \; f(P_i) > f(P_{ibest})$$

$$g_{ibest} = g_i \; if \; f(g_i) > f(g_{ibest})$$

Step no. 5: Checking Termination: This algorithm is terminated after the defined number of iterations are performed or it can also terminate because of the failure of the process in between.

5.3 TUNABLE PARAMETERS IN PSO

PSO requires a comparatively less number of parameters to be defined. The process of initialization is very simple. We define a number of parameters in process of PSO:

1) **Number of particles**: It is important factor in PSO initialization. In practical applications the best choice for this parameter is usually selected in between the range of 20 and 40. But if the problem taken is difficult and complex then we increase the factor to 100 or 200.

2) **Inertia Weight**: The convergence of PSO depends on this factor. Weight of inertia affects the previous velocity control on the current velocity.

3) **Learning factors**: Learning factors are c_1 and c_2 where, c_1 is coefficient of self recognition and c_2 is the social component are not much important for convergence of PSO. If these parameters are finely tuned it aids in fast convergence of local minima. Usually, they are chosen as $c_1 = c_2 = 2$ but some experiments indicates other values also provide better results. In some papers it is also reported that greater self recognition component c_1 such that $c_1 + c_2 = 4$ gives better results.

4) **Dimension and Range of particles**: The range and dimension of the particles depend on the problem taken.

$Velocity_{max}$: It is defined as the maximum change one particle can take during one iteration.

5) **Stopping Condition**: Two criteria are given for stopping condition we can chose any of them:

- The process is stopped after the maximum number of iterations specified by the user are reached.
- The process is stopped when the difference between the objective function value and best value of fitness is less than set value of threshold.

5.4 NEIGHBOURHOOD TOPOLOGIES

The different types of topologies are observed based on the swarm behavior. The most common of them are:

5.4.1 Ring topology

In this topology particles are connected in circle to their immediate neighbors. In this type of topology there are no ends. If we compare the star topology to the ring topology the flow of information is slow. This causes more exploration of search space and decreases the change of convergence prematurely.

5.4.2 Star Topology

It is known as one of the common computer network setups in which all the particles are connected to a central particle called hub. It results in premature convergence because it is very fast.

5.4.3 Von Neumann Topology

Kennedy and Mendes proposed this type of topology. This topology also slows down the convergence rate. It hence increases exploration of the search space and decreases the chance of premature convergence.

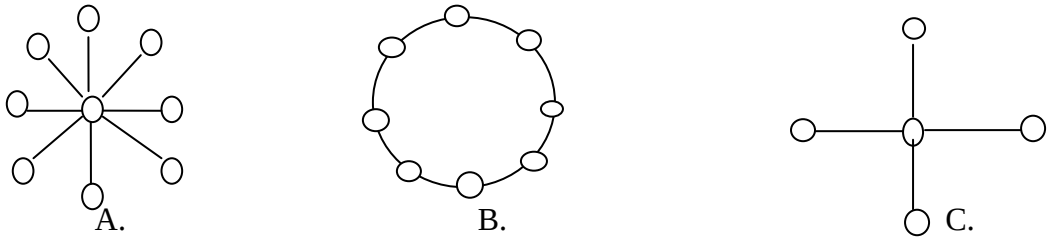


Figure 5.2 A. Star Topology, B. Ring Topology C. Von Neumann Topology

5.5 PSO FLOW CHART

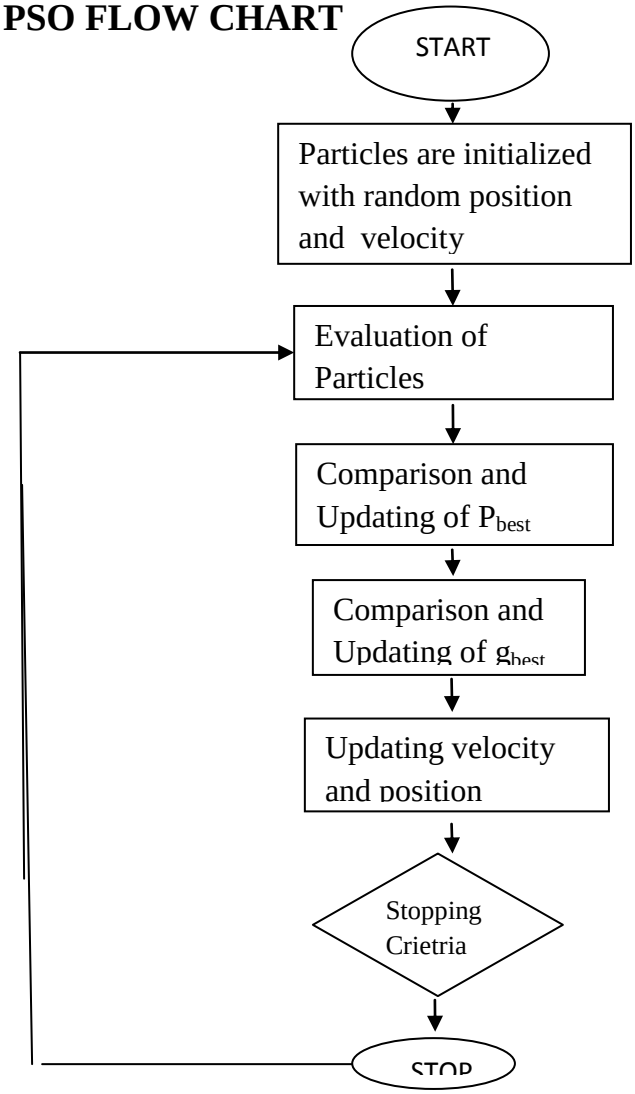


Figure 5.2 Flowchart of PSO

5.6 CONCLUSION

Particle swarm optimization is a technique which has a simple structure and can be used for optimization of PID controller parameters. It is a bio inspired algorithm which is very easy to implement for various optimization purposes.

CHAPTER VI
BACTERIAL FORGING OPTIMIZATION ALGORITHM

CHAPTER VI

BACTERIAL FORGING OPTIMIZATION ALGORITHM

6.1 INTRODUCTION

Bacterial Forging Optimization Algorithm was proposed by Passino, in the family of nature inspired optimization algorithms. Recently, many natural swarm inspired algorithms like PSO, ACO has proved their effectiveness in many domains. Bacterial Forging Optimization Algorithms is based on the same trend of swarm based algorithm. It is based on the application of forging method of bacteria called E.Coli. The communication between the individual bacterium are carried out by exchanging information in the form of signals. The process by which bacterium moves in small steps for the search of nutrients is called Chemotaxis.

Since, its research in Bacterial Forging Optimization Algorithm has attracted many scholars for research because of its biological inspiration and its simple structure. The major research areas of BFOA are developing the mathematical models, adaptation techniques and modification of the algorithm.

6.2 BACTERIAL FORGING OPTIMIZATION ALGORITHM

In the forging process of the bacteria, locomotive action is performed by flagella. The bacteria performs two operations basically summing and tumbling at the time of forging. Rotation of E.Coli bacteria causes the flagella to move in anticlockwise direction

. When the flagella moves in the counterclockwise direction it the bacterium starts to swim at a faster rate. During the forging process the bacteria undergoes chemotaxis in which the bacteria tend to move in the search of nutrient gradient. The E.Coli bacteria cover a longer distance in the areas having higher chances of nutrients.

When these bacteria get sufficient food, they get increase in length and when suitable temperature is present they break from middle to replicate itself. This process of replication is termed as reproduction. Sometimes, due to adverse environmental

conditions the chemotaxis phenomenon is disturbed. This leads to event of elimination-dispersal in the real population of bacteria, where all the bacterial are killed in a particular region or get dispersed into a new part of the environment.

Bacterial Forging Optimization Algorithm is based on four basic processes like Chemotaxis, Swarming, Reproduction and Elimination Dispersal for solving any optimization problem.

Chemotactic step is defined as a tumble or a run. Chemotactic step index is denoted by j. The reproduction step index is denoted by k. The index of elimination dispersal is denoted by l.

. Let:

D: Denotes the dimension

S: Total No. of bacteria in the population

N_{ce}: No. of chemotactic steps

N_{sl}: length of swimming

N_{re}: Reproduction steps number

N_{ed}: No. of elimination dispersal events

P_{ed}: The Probability of elimination dispersal

Let $P(j,k,l)$= $\{\theta^i(j,k,l)\ , i = 1,2 \ldots\ldots S\}$ denotes the position of every bacteria in the population. $J(i,j,k,l)$ denotes the cost value at the position of ith bacterium $\theta^i(j,k,l)\ \epsilon\ R^P$.foe simulation purposes the population is taken small. The four main steps in Bacterial Forging Optimization Algorithm:

1) Chemotaxis: In this process the E.Coli bacteria moves by two methods swimming and tumbling. The E.Coli bacteria can swim for a time specified or tumble. This movement can be represented mathematically as:

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i).(\Delta(i)/\sqrt{\Delta^T(i)\Delta(i)}) \qquad (6.1)$$

Where, $\theta^i(j,k,l)$ represents ith bacteria step at jth chemotactic step, kth reproduction and lth elimination dispersal step. C(i) is the size of step in the random direction. Δ indicates random vector in between [-1,1].

2) Swarming: E.Coli bacteria come in a group and move themselves in ring by moving nutrient gradient.. The information exchange represented by the following function:

$$J_{CC}\left(\theta, P(j,k,l)\right) = \sum_{i=1}^{S} J_{CC}(\theta, \theta^i(j,k,l)) =$$
$$\sum_{i=1}^{S}\left[-d_{attractant}\ \exp\left(-w_{attractant}\ \sum_{i=1}^{P}\left(\theta_m - \theta_m^i\right)^2\right]\right. +$$
$$\sum_{i=1}^{S}\left[-h_{repellant}\ \exp\left(-w_{repellant}\ \sum_{i=1}^{P}\left(\theta_m - \theta_m^i\right)^2\right]\right. \qquad (6.2)$$

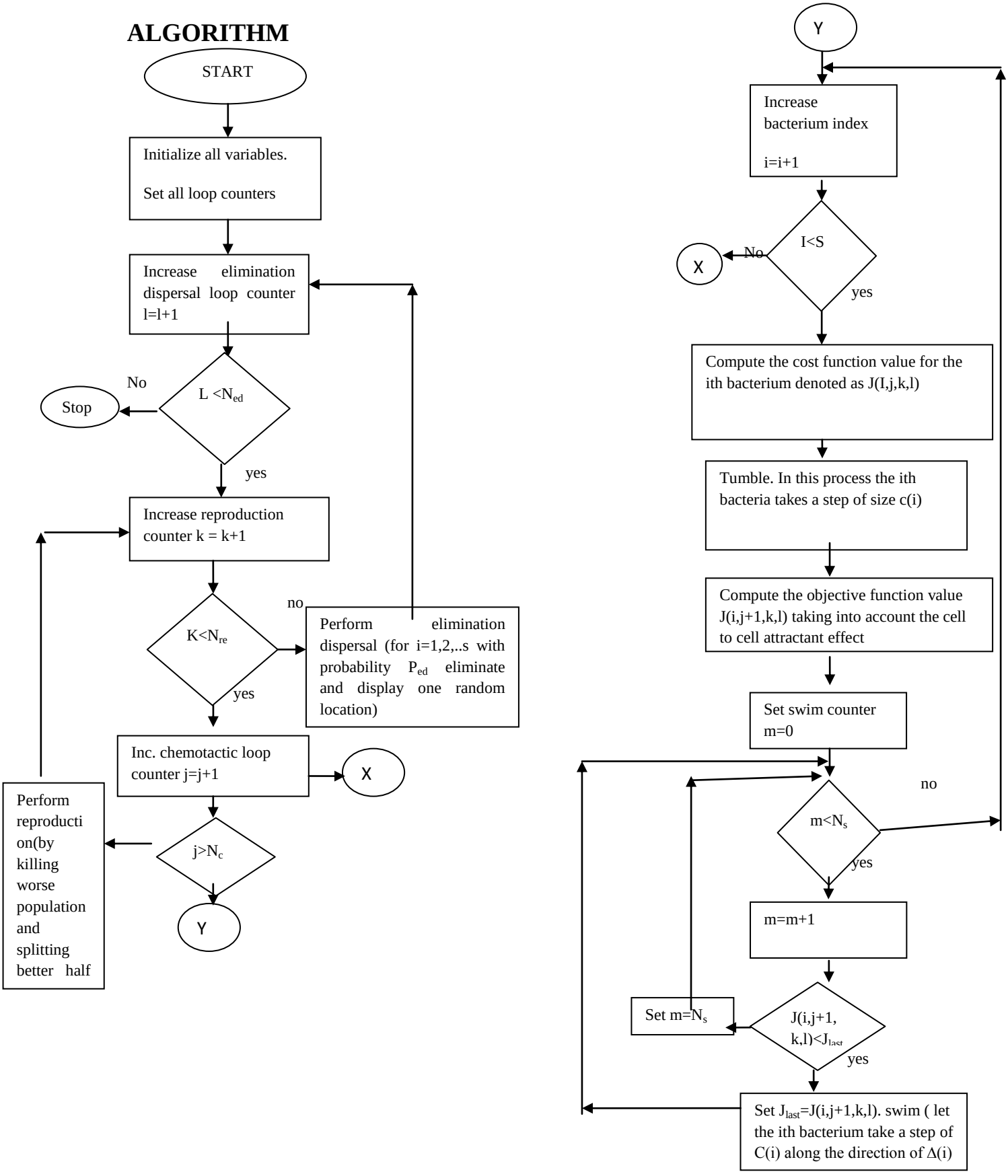
Where, $J_{CC}\left(\theta, P(j,k,l)\right)$ is a objective function value added to the original objective function to make it time varying.

P- represents the no. of variables to be optimized, and and $\theta = \left[\theta_1, \theta_2, \theta_3 \ldots\ldots\ldots \theta_p\right]$ is the point of the p- dimensional search domain.

3) Reproduction: The bacteria with least health dies while some split up themselves into two. Hence, the swarm population remains constant.

4) Elimination- Dispersal: Because of sudden environmental changes a group of weak health bacteria kill themselves or get dispersed into a new area. This event is called elimination- dispersal events.

6.3 FLOWCHART OF BACTERIAL FORGING OPTIMIZATION ALGORITHM



6.4 CONCLUSION

Bacterial forging optimization algorithm is also a bio inspired method used for optimization. It is proved that it is better than particle swarm optimization because it takes less time for optimization.

CHAPTER VII
RESULTS AND PERFORMANCE ANALYSIS

7.1 INTRODUCTION

In this chapter two optimization techniques particle swarm optimization and Bacterial Forging Algorithm are applied on the concentration control of CSTR process and the response is analyzed with the conventional PID control methods.

7.2 OPEN LOOP STEP RESPONSE OF CSTR PROCESS

Let us study the output response of the Van De Vusse reactor for concentration C_B in gmol/liter. The open loop response of the CSTR concentration control of B C_B is given below.

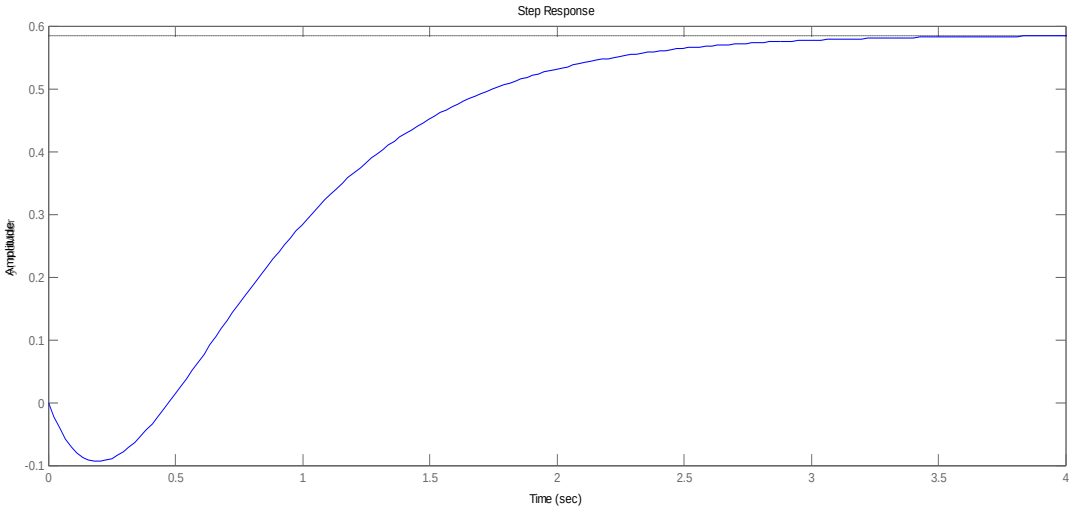


Figure 7.1 Open loop Response of CSTR process for Van De Vusse reaction

The Van De Vusse reaction has an input multiple and right half plane zeros which results in inverse response characteristics. The dynamics of the reactor the reactor are given by differential equations.

The objective of the process is to maximize the production of B, the response of concentration of B more important than the changes in input. In this case we observe how the system response changes under certain operating conditions. For the same operation conditions there are two cases of which case1 exhibits inverse response. It is a typical system with a positive gain and inverse response.

This process has a non linear relationship between the dilution rate (F/V) at steady state and the concentration of product B at steady state. There exists a maximum concentration of B that can be achieved.

If we study the poles and zeros the system is stable because it has all the poles on right hand side of the s plane. It contains a right hand pole zero, indicating a inverse response.

7.3 CONCENTRATION CONTROL OF CSTR BY PID CONTROLLER

In the case study of CSTR the linear state space model is given by:

$$\dot{X} = AX + BU$$

$$Y = CX + DU$$

is found in chapter 2 Mathematical modeling of CSTR. Then the linearization of the above modeling equations is done at steady state condition and the state space model is found. Then finally the manipulated input output process transfer function is calculated with the help of Matlab from the formula:

$$G_p(s) = C[sI - A]^{-1}B \tag{7.1}$$

$$G_p(s) = \frac{-1.117s+3.1472}{s^2+4.6429s+5.3821} \tag{7.2}$$

In this process it is observed that this process exhibits inverse characteristics. To overcome these problems we apply PID controller to the CSTR process. To find the PID tuning parameters let us apply Ziegler Nichols tuning method.

To find the desired Kp, Ki and Kd by Ziegler Nichols rule the following steps are followed:

1) Characteristic equation of the CSTR process is given by:

$$s^2 + (4.6429 - 1.117K_c)s + (5.3821 + 3.1472K_c) \tag{7.3}$$

By solving this equation the value of Kc i.e. the critical gain is given by:

$$K_c = 1.89 \tag{7.4}$$

2) Calculate the peak to peak period called the critical time period P_{ut}.

3) The values of Kp, Ki and Kd are found by ZN rules:

$$K_p = 1.89 \tag{7.5}$$

$$K_i = 1.53 \tag{7.6}$$

$$K_d = 0 \tag{7.7}$$

By giving these PID parameters to the simulink model of Concentration control of CSTR the results are given by:

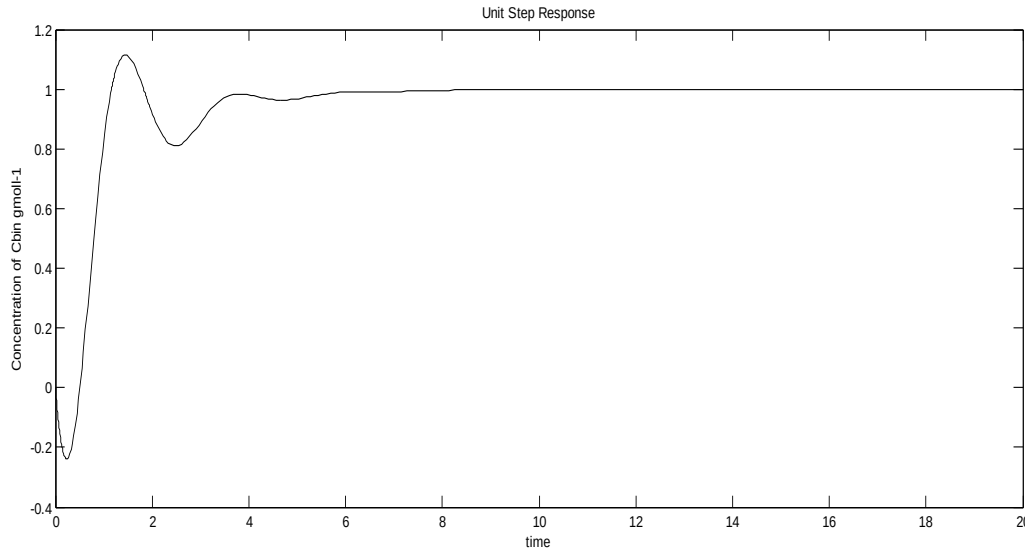


Figure 7.2 Ziegler Nichols Tuned Unit Step Response of concentration control of CSTR

The performance specifications of the Ziegler Nichols tuned concentration control of CSTR are rise time is 1.3016 sec, settling time is 10.9300 sec, overshoot is 10.9091% and peak time is 10 sec. This response is not very satisfactory as it has delay also some overshoot is present.

7.4 OBJECTIVE FUNCTION

Selection of appropriate objective function is the most crucial part of optimization of any system. In this problem we have to select the objective function whose minimization can give us optimal PID parameters. The PID controller designed should give better performance. In this case the error indices are being minimized.

The newly designed PID controller is applied in the feedback loop with CSTR transfer function. The CSTR process is given a step type of input and then different error indices are calulated i.e. ISE, IAE, ITSE and ITAE.

Integral square error (ISE) strongly overcomes the large errors and Integral absolute error (IAE) suppresses the smaller errors more effectively. Integral time absolute error (ITAE) works on errors that persists for a longer time.

$$IAE = \int_0^T |e(t)|\, dt \tag{7.1}$$

$$ITAE = \int_0^T t|e(t)|\, dt \tag{7.2}$$

$$ITSE = \int_0^T te^2(t)dt \tag{7.3}$$

$$ISE = \int_0^T e^2(t)\, dt \tag{7.4}$$

7.5 CONCENTRATION CONTROL OF CSTR BY PSO PID

Particle swarm optimization is used to find the best PID parameters. Then these PID parameters are implemented on the CSTR process. In this method, the objective functions are different performance indices. The different performance indices are ITAE, ISE, IAE, ITSE. The block diagram shown below describes how PSO is applied to tune the PID parameters for better performance of CSTR concentration control.

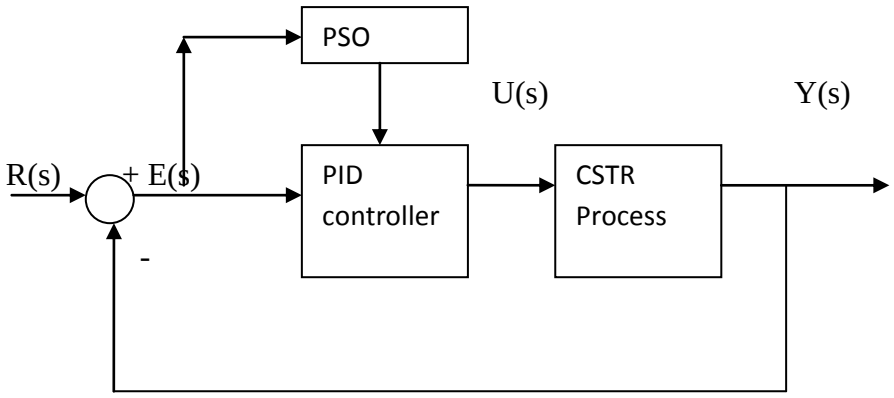


Figure 7.3 Block diagram of PSO tuning of PID controller

7.5.1 OPTIMIZATION PROCESS OF PSO-PID CONTROLLER

Step1: Initialize the random initial values for the particles of swarm.

Step 2: Calculate objective function value for each of the particle.

Step 3: In this step comparison of new fitness value and local fitness value is done. According to this local best position is updated.

Step 4: Global best position is found by searching the best local best position and is denote as g_{best}.

Step 5:Next the velocity and position is updated.

Step 6: Update the controller parameters.

Step 7: Check for the termination condition whether, the maximum number of iterations are reached.

The variables used in PSO PID are assigned the values given below. It is then simulated by MATLAB software:

1) Number of particles or swarm size = 25

2) Acceleration constants, $C_1 = 2$ and $C_2 = 1.5$

3) Inertia factor w = 0.7

4) Dimension of the problem = 3

With the following PSO variables the program is run to find the different PID optimizing parameters. The PSO optimization is done for different performance indices ITAE, ISE, IAE and ITSE respectively. The various performance indices are evaluated in the simulink diagram only and are given to the workspace. .

The simulink diagrams of CSTR concentration control by PSO-PID control are given as:

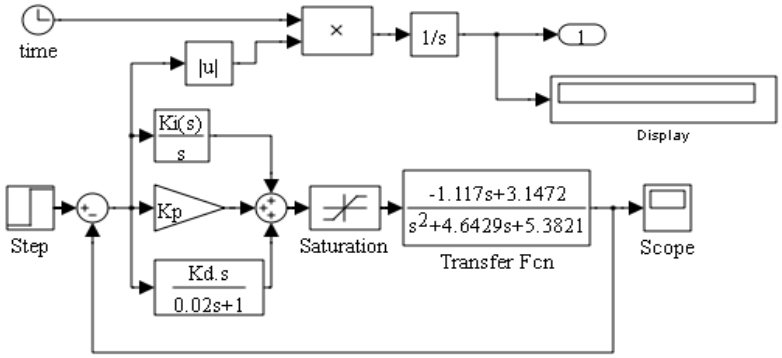


Figure 7.4 Simulink Model of PSO PID control of CSTR with ITAE as objective function

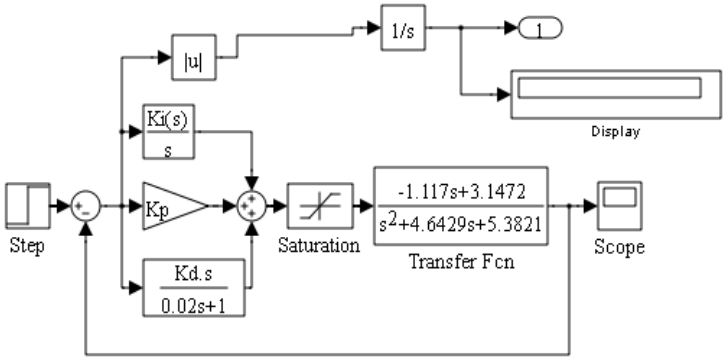


Figure 7.5 Simulink Model of PSO PID control of CSTR with IAE as an objective function

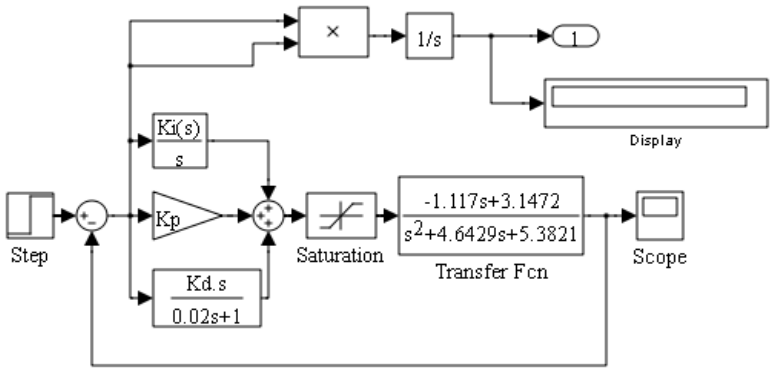


Figure 7.6 Simulink Model of PSO PID control of CSTR with ISE as an objective function

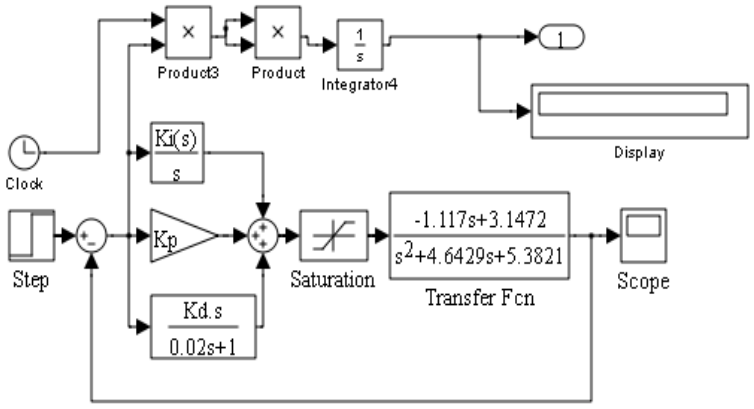


Figure 7.7 Simulink Model of PSO PID control of CSTR with ITSE as an objective function

By applying PSO-PID the values of optimized PID control parameters Kp, Ki and Kd by different objective function values are given in a table below:

Table 7.1 Optimized PID parameters by PSO

Error indices/PID parameters	Kp	Ki	Kd
ITAE	2.89	2.40	0.71
ISE	2.49	2.1097	0.6183
IAE	3.35	4.2745	0.6458
ITSE	3.2380	2.5115	0.6197

Simulations are carried out with the objective function and the given PSO algorithm for PID optimization for which the variables are defined above. For the optimized PID parameters the simulation results are shown below:

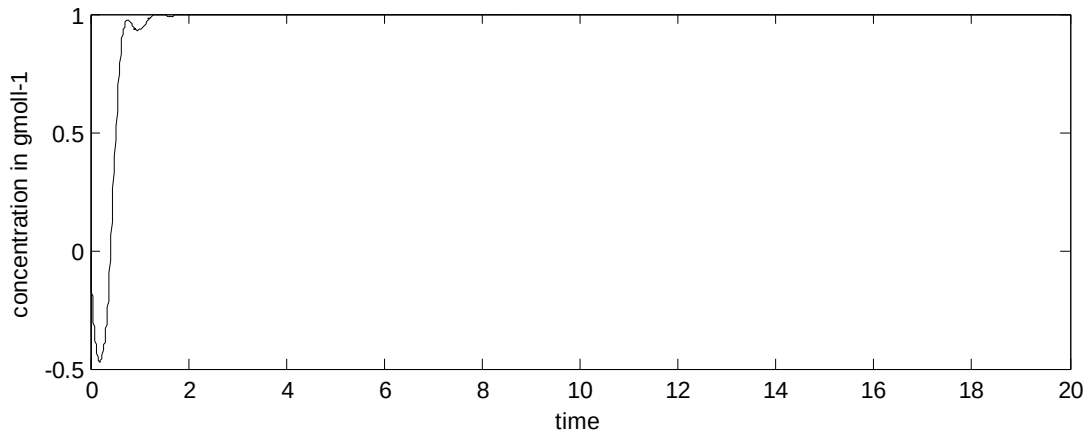


Figure 7.8 Unit Step Response of Concentration control in CSTR by PSO-PID with ITAE as fitness function

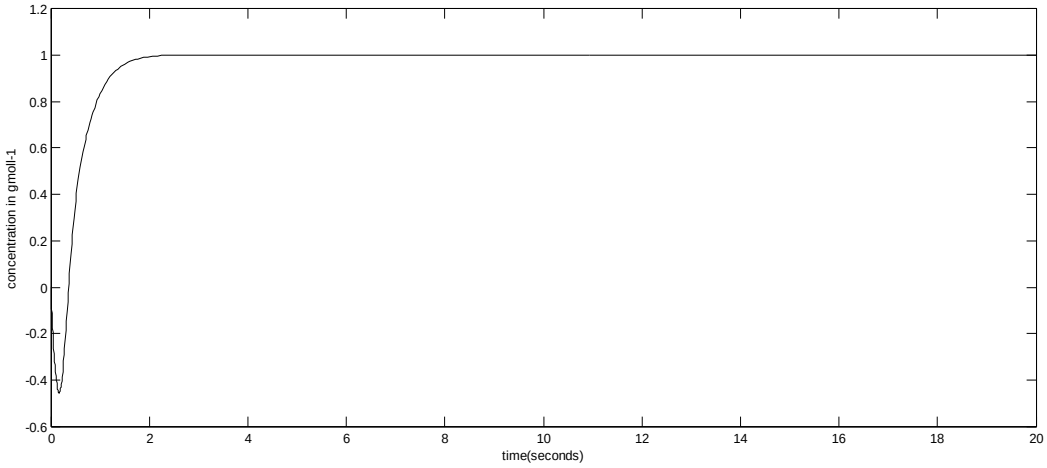


Figure 7.9 Unit step response of concentration control in CSTR by PSO-PID with ISE as fitness function

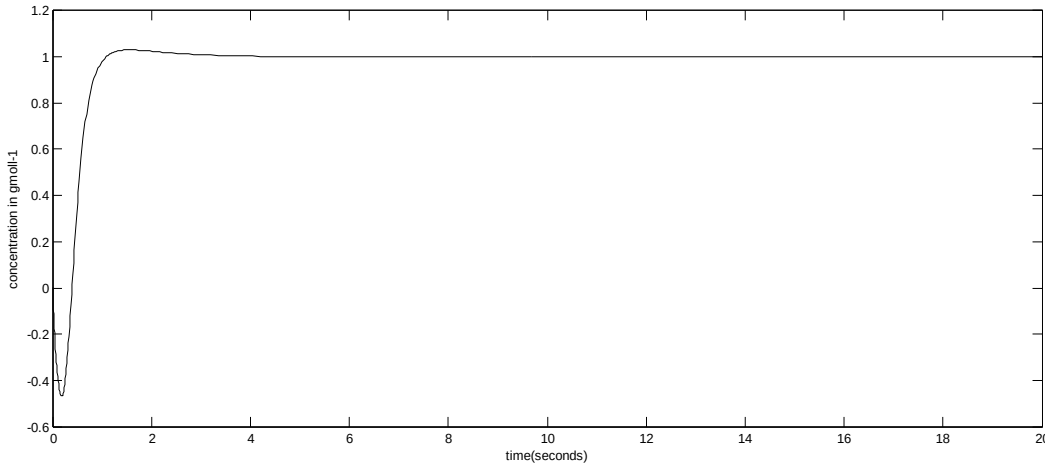


Figure 7.10 Unit step response of concentration control in CSTR by PSO-PID with IAE as fitness function

7.6 CONCENTRATION CONTROL OF CSTR BY BFOA PID

The bacterial forging optimization technique is adopted to find the optimal results. Then these PID parameters are implemented on the CSTR transfer function.

In this method, the objective functions are different performance indices. The different performance indices are ITAE, ISE, IAE, ITSE. The block diagram shown below describes how BFOA is applied to tune the PID parameters for better performance of CSTR concentration control.

7.6.1 THE BFOA-PID OPTIMIZATION ALGORITHM

The various steps followed in finding PID controller parameters are:

i) Variables are initialized.

ii) Calculate the velocity and position of every bacterium by summing and tumbling processes.

iii) Place the best position in the PID parameters.

iv) Error is calculated by simulation.

v) Next the local and global best positions are calculated.

vi) Tumble is given by calculating its velocity.

vii) Next is the reproduction process is carried out.

viii) Condition is checked for minimum cost value.

Minimization of the error indices is done by application of optimal algorithms. Objective function values are minimized in each iteration. Also the corresponding Kp, Ki and Kd values are calculated. Condition is checked to find whether the objective function is minimum. If condition is checked for minimum objective function value then, Kp, Ki and Kd values found out during this iteration is considered to be optimum. Otherwise the process repeats and next iteration starts. This algorithm is developed such that if the error remains at a fixed value for 100 iterations that values of PID parameters are considered at final parameters.

7.6.2 BACTERIAL FORGING OPTIMIZATION TUNED PID CONTROL

The Bacterial Forging Optimization Algorithm is used for optimizing PID parameters. For the variables given below a simulation is done in MATLAB and the PID parameters are calculated:

1) Dimension, Dim = 3

2) Total Number of the bacteria population, $N_b = 10$

3) Total Number of the Chemotactic steps $N_{ce} = 10$

4) Length of swim, $N_l = 4$

5) Number of reproduction steps $N_{re} = 4$

6) Number of elimination-dispersal events $N_{ed} = 1$

7) Number of bacteria reproductions per generation $S_r = s/2$

8) Probability that each bacteria will be eliminated/dispersed $P_{ed} = 0.25$

The unit step responses of CSTR concentration control by BFO are given below:

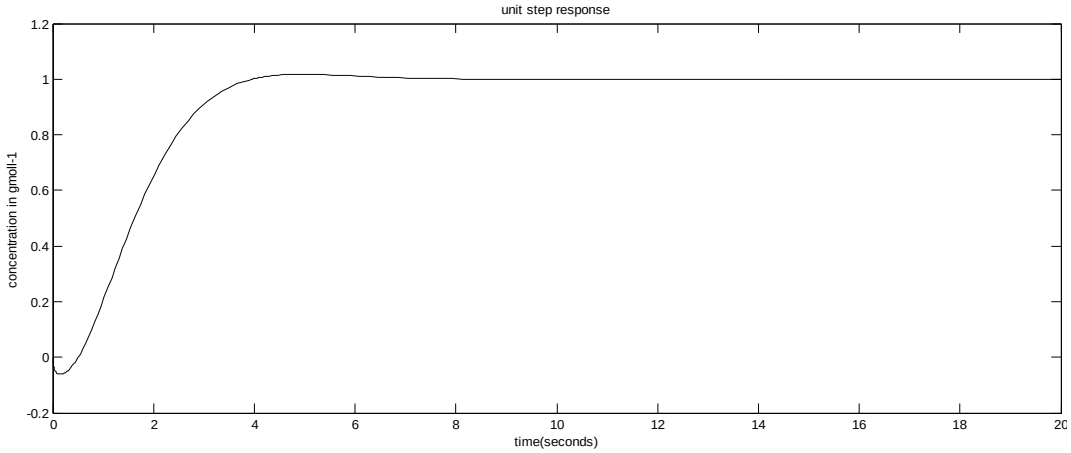


Figure 7.11 Unit step response of concentration control of CSTR by BFO-PID with ITAE as fitness function

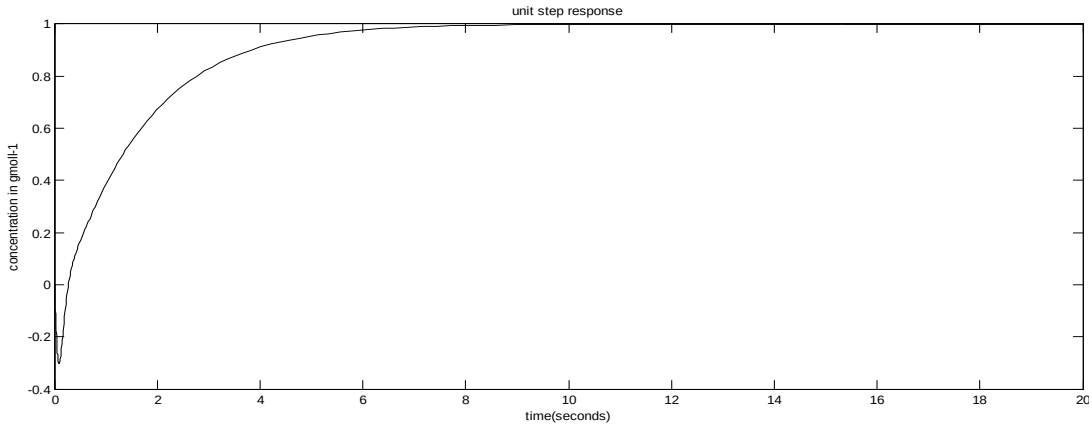


Figure 7.12 Unit step response of concentration control of CSTR by BFO-PID with ISE as fitness function

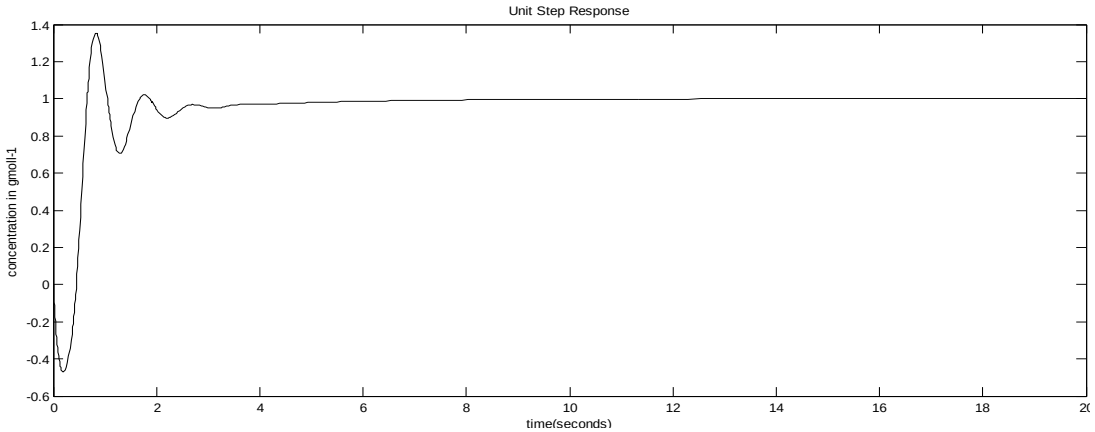


Figure 7.13 Unit Step Response of concentration control of CSTR by BFO-PID with IAE as fitness function

Table 7.2 Optimized PID parameters by BFOA

Error indices/PID parameters	Kp	Ki	Kd
ITAE	3.2978	2.2339	0.7464
ISE	1.0171	0.9289	0.5009
IAE	3.8227	1.8482	0.6347

7.7 PERFORMANCE ANALYSIS

In this section we compare the performance of different tuning methods on the concentration control of CSTR. The different optimal tuning methods are compared with the conventional PID controller tuning methods. The performance specifications of different tuning methods is given as:

Table 7.3 Comparison of different tuning methods for CSTR model with ITAE as fitness function

Tuning Algorithms/performance specification	Rise Time(seconds)	Settling time (seconds)	Max. overshoot %	Peak time (seconds)
ZN	0.226	4.68	10%	11
PSO	1.18	8.85	2.778	6

BFO	0.753	8.88	2.777	6

Table 7.4 Comparison of different tuning methods for CSTR model with ISE as fitness function

Tuning Algorithms/Performance specification	Rise Time (seconds)	Settling time (seconds)	Max. overshoot %	Peak time (seconds)
ZN	0.226	4.68	10%	11
PSO	0.7563	11.95	13.86%	11
BFO	0.753	9.98	9.90%”	6

Table 7.5 Comparison of different tuning methods for CSTR model with IAE as fitness function

Tuning Algorithms/Performance specification	Rise Time (seconds)	Settling time (seconds)	Max. overshoot %	Peak time (seconds)
ZN	0.226	4.68	10%	11
PSO	0.7563	11.83	9.90%	6
BFO	0.753	10.84	8.90%”	6

7.8 CONCLUSION

From the above results we conclude that BFO performs better than PSO in terms of maximum overshoot and settling time. The bio inspired techniques perform better than the conventional methods in terms of maximum overshoot etc for different objective functions.

CHAPTER VIII
CONCLUSION

CHAPTER VIII

CONCLUSION

8.1 INTRODUCTION

In this chapter the conclusions of the work are presented .

8.2 CONCLUSION

In this project, the PID controller tuning was done using a conventional tuning algorithm i.e. Ziegler Nichols method, and then two bio inspired techniques PSO and BFO were used for PID optimization. By comparing all the three methods, it is found that the optimal tuning methods are better implemented than conventional ones. Also, the PID controller parameters obtained from these algorithms gives better tuning result than other methods.

The results of open loop and closed loop PID controller implementation on concentration control of CSTR are not satisfactory.

Optimizing the PID parameters on the basis of error indices provide better performance in terms of overshoot, rise time and settling time for CSTR process and proves better to the conventional methods. When PSO algorithm is applied for obtaining the PID parameters for performance of the system. Using PSO algorithm we are able to get a fast response i.e. rise time decreases, overshoot also decreases. Next we apply bacterial forging algorithm for PID tuning. The optimized PID parameters are applied to the concentration control of CSTR. The results obtained are better than PSO and conventional method in terms of rise time, overshoot, settling time etc.

The speed of PSO algorithm is faster than BFO. PSO calculates the optimal parameters faster than BFO. The structure of PSO is simpler than BFO.

8.3 FURTHER SCOPE OF WORK

In future we can modify Particle Swarm Optimization and Bacterial Forging Optimization algorithms further for better performances. We can also use hybridization in algorithms and apply on this system. Some of the advanced algorithms are micro-

biological algorithms and smart BFO which have proved better than the original algorithms. We can apply these algorithms on the concentration control of CSTR.

We can also use different forms of PID controller like in this work we have used parallel form of PID controller we can also use series PID and ideal PID controller with lag etc.

In future we can also study the performance on the basis of frequency domain analysis. These swarm intelligence approaches have proved better in time domain analysis, we can also analyze the performance in frequency domain analysis.

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