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FACULTY OF ELECTRICAL AND ELECTRONICS TECHNOLOGY AND INFORMATION AND COMMUNICATION TECHNOLOGY

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Tuning of Setpoint Weighted PI Controller for the Concentration Control in CSTR with Non-Ideal Mixing

MSc Thesis for the Partial Fulfillment of

Master of Science in Electrical Automation and Control Technology Management

By,

Mohammed Ayele (MTR/254/12)

Supervisor,

Dr. LEBSEWORK NEGASH

August, 2022

Addis Ababa, Ethiopia

TUNING OF SETPOINT WEIGHTED PI CONTROLLER FOR THE CONCENTRATION CONTROL IN CSTR WITH NON-IDEAL MIXING

A Thesis submitted to

TECHNICAL AND VOCATIONAL TRAINING INSTITUTE (TVTI)

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled “Tuning of set point weighted pi controller for the concentration control in CSTR with non-ideal Mixing” is the original work of my own, has not been presented for a degree in this or other universities and all sources of materials used for this thesis work have been fully acknowledged.

Name: - Mohammed Ayele (MTR/254/12)

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Place: Addis Ababa

Date of Submission:

This thesis proposal has been submitted for examination with my approval as a TVTI advisor.

Dr. Lebsework Negash	_________________	_________________
Advisor Name	Signature	Date

TECHNICAL AND VOCATIONAL TRAINING INSTITUTE (TVTI)

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APPROVED BY THESIS ADVISORY COMMITTEE

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ABSTRACT

PID controllers are still the industry standard in control literature, despite considerable advancements in sophisticated process control systems like sliding mode control, internal model control, and model predictive control (MPC).The following are the main advantages of PID controllers over sophisticated control techniques. This means that it: (i) best-in-class and reliable performance for a range of processes; (ii) allows online/offline tweaking and retuning depending on the process under control's performance requirements. Real-time chemical process loops, such as those in continuous stirred tank reactors (CSTR), biochemical reactors, spherical tank systems, and conical tank systems, are typically nonlinear in nature. With a delay time surrounding the operational region, these nonlinear processes can be described as linear processes in stable or unstable process models. A PID controller is then used to effectively control the linear model. However, the unstable system cannot be controlled by the usual PID controller. Due to the big initial leap or undershoot or overshoot that an unstable system with a standard PID controller produces. The set point weighted PI controller is suggested for the control of the unstable system as a solution to this problem. The CSTR with non-ideal mixing is regarded as an unstable process in this study. In this thesis, a set point weighted PI controller is used to regulate the concentration of a chemical in CSTR. The controller's parameters will be adjusted using the optimization process. Based on the outcomes of the simulation, the performance of the set point weighted PI controller and the traditional PID controller will next be compared setpoint weighted PI controller.

KEYWORDS*: set point weighted PI controller, PID controller, CSTR*

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List of acronyms

CFSTR	Continuous Flow Stirred Tank Reactor
CSTR	Continuous Stirred Tank Reactor
1DOF	One Degree Of Freedom
2DOF	Two Degree Of Freedom
FGS	Fuzzy Gain Scheduling
FOPTD	First Order plus Time Delay
IMC	Internal Model Control
IAE	Integral of Absolute Value of Error
IATE	Integral of Time Weighted Absolute Value of Error
ISE	Integral of Square Value of Error
MPC	Model Predictive Control
MFR	Mixed Flow Reactor
NT	No Definite Trend
PFR	Plug Flow Reactor
PI	Proportional Integral
PID	Proportional Integral Derivative
SOPTD	Second Order plus Time Delay
SPW PI	Set Point Weighted PI Controller

CHAPTER 1

INTRODUCTION

1.1 Background

Continuous-time stirred tank reactors (CSTR) are one of the most significant pieces of equipment in chemical operations. CSTRs are exceedingly complex processes because to their nonlinearity, inherent safety hazards, and the potential for many steady states. A mathematical model with well-estimated parameters is required for the construction of a high-performance control system. However, there are unavoidable uncertainties in chemical process modeling due to a lack of process information nonlinearities, variables that change over time, unidentified external or internal disturbances, and so forth. Particularly when the process is nonlinear, the presence of uncertainties might result in a discrepancy between the mathematical model and the actual process, affecting control performance and creating stability problems. As a result, controllers for nonlinear chemical processes is critical for control strategies [1].

Industrial separation procedures, which separates two or more things or contaminants are eliminated from the products, are crucial and essential components of the chemical industries. The separation process is currently facing challenges related to process efficiency and cost. The CSTR is a crucial component of many chemical companies, and CSTR regulation is crucial to the final product's quality. This system's extremely nonlinear dynamic model is provided by the material balance and chemical equilibrium equations, making it one of the most widely used nonlinear systems for control studies. It might be challenging and time-consuming to create an appropriate controller for such CSTR systems because of their nonlinear dynamics and complex behavior. The objective of the current work is to create a simple and efficient control strategy for a continuously stirred tank reactor, which is a non-linear process (CSTR). This strategy will also be useful for choosing the best control approach for non-linear separation processes, which will ultimately lead to effective separation and cost savings. Because of its simple setup and simple implementation, the proportional integral (PI) or proportional integral derivative (PID) controller is still significant and favored among all control loops in process or chemical industries. The integral action, which is proportional to the integral of the error signal, removes steady-state error or offset, while the derivative action provides a signal proportional to the derivative of error, and its function is to reduce maximum overshoot. The proportional action decreases the maximum amount of error in the PID controller by adjusting the controlled variable in accordance with the detected error signal [2].

The back mix, commonly referred to as the continuous stirred tank reactor (CSTR), is a workhorse in many chemical plants, frequently supporting multi-purpose production goals for fine and specialty chemicals. It can handle distillation, solvent extraction, crystallization, and reaction in addition to those. When there is a single product, established market, and a production rate of more than five million kg per hour, it is used for continuous operation. Such a reactor's installation success is heavily dependent on how well its control system is designed. Normal operation assumes that it is perfectly mixed and operating at steady state. Because the temperature and concentration are the same everywhere inside the reaction vessel, they are the same at the exit point as they are elsewhere in the tank, which means that every variable inside the CSTR is the same at every place inside the reactor. In order to estimate the rate of reaction at the exit condition, it is assumed that the temperature and concentration in the exit stream are identical to those inside the reactor. The Arrhenius temperature dependency can be used to get the rate constant. The rate at which the reaction takes place rises with rising temperature. The closed loop system's numerical simulations were carried out by (Pablo et al, 2009). They created a high order sliding mode control, a standard sliding mode control, and an ideal I/O linearizing control. They suggested a solution that employed the same control gain value. Additionally, they suggested a different control whereby existing modeling techniques and prior process knowledge were combined to create greybox models (Madar,et al,2005). Dauda et al. employing a neural network as a design tool, nonlinear control of CSTR for a reversible reaction was done. Luyben (1990) used a proportional level control to regulate the liquid leaving a CSTR as a function of tank capacity, while a different controller regulated the flow rate of cooling water to the jacket in a direct relation to reactor temperature.

The majority of chemical process systems are inherently nonlinear. Although nonlinear processes' behavior may be well understood, effective control strategies are continuously being developed. In process industries, temperature control is a crucial and frequent duty. Take the regulation of temperature in a boiler drum, for instance. Problems can arise from the boiler drum's temperature being too high or too low. The temperature must be kept as close as possible to the necessary set point. The link between the controlled variable and the manipulated variable makes it difficult to control temperature in a CSTR. The wide range of uses for CSTR's temperature control include keeping chemical works' raw materials in stock at a specific temperature and mixing raw materials for work processes and the reactions of output products.

The majority of the chemical industry, as well as the oil and gas production industries, employ CSTRs to combine two or more reactants at a specific temperature while a catalyst is present in order to produce a chemical product at a predetermined temperature.

Stability analysis, constant open loop transfer function, pole placement method, stable inverse of the mode, and synthesis method are all used to construct PI controllers for stable models. Recently, the design of a PI controller for an unstable FOPTD model has gotten a lot of attention. For unstable systems, the performance specifications that are generally acquired for stable FOPTD models cannot be provided. The modified Ziegler – Nichols technique, IMC method, pole placement method, Optimization method, two degrees of freedom method, and synthesis method are all ways for constructing PID controllers for unstable FOPTD systems. The design methodologies in all of the following procedures are quite sophisticated [3].

Designing and utilizing a controller in a real-world environment is a great approach to learn about control systems. An illustration of a system based on control theory is the Continuous Stirred Tank Reactor (CSTR). It is widely used in university process control labs. Engineering for control systems is taught using it. It has connections to actual control issues in the production of antidotes in medicine, chemical manufacturing, and food processing. The control strategies that can be learnt span many significant classical and contemporary design principles, but they are simple to understand. A unique chemical reactor system with several features is the Continuous Stirred Tank Reactor (CSTR) [4].

1.2 Statement of the problem

- Most of the real-time chemical process loops are nonlinear in nature. So, it is difficult to control by PI controller.
- These nonlinear processes can be modeled as linear processes as stable process or unstable process model with a delay time around the operating region.
- The conventional PID controller is not suitable for the unstable system. Because unstable system with conventional PID controller gives large initial jump or undershoot / overshoot.
- To overcome this issue, the set point weighted PI controller is proposed for the control of unstable system.

1.3 Objectives

1.3.1 General objectives

The general objective of this thesis work is to tune and analyze the performance of set point weighted PI controller using optimization algorithm for the concentration control in CSTR with non-ideal mixing.

1.3.2 Specific objectives

- ✓ Develop the nonlinear CSTR model and linearize the model around the operating region.
- ✓ To simulate the mathematical model of CSTR with non-ideal mixing using MATLAB SIMULINK software.
- ✓ To apply the conventional PID controller for the concentration control in CSTR with non-ideal mixing.
- ✓ To apply the set point weighted PI controller for the concentration control in CSTR with Non-ideal mixing.
- ✓ To tune the parameters of the set point weighted PI controller for the concentration control in CSTR with non-ideal mixing using optimization algorithm.
- ✓ To compare and analyzes the performance of the conventional PID and the set point weighted PI controller for various conditions.

1.4 Significance of the thesis work

- ✓ To learn and getting exposure in design and analysis of improved or advanced form of controller for the control of chemical using MATLAB simulation.
- ✓ To learn about application of optimization algorithms for tuning of controller parameters for obtaining better performance of the controller.

1.5 Methodology

The thesis focuses on Tuning set point weighted PI controller for the concentration control in continuous stirred tank reactor (CSTR) with non-ideal mixing system and apply the following steps.

- ➢ Develop and simulate the mathematical model of CSTR with non-ideal Mixing.
- ➢ Conventional PID controller implementation for the concentration control In

CSTR with non-ideal mixing.

- Design set point weighted PI controller for the Concentration control in CSTR with non-ideal mixing.
- Tune the parameters of set point weighted PI controller using Optimization algorithms
- Performance comparison between set point weighted PI controller and the Conventional PID controller.
- Discussion on simulation results and conclusion

1.6 Outline of the thesis

This thesis includes six chapters. The first chapter generally presents the introduction of tuning set point weighted PI controller for the concentration control in CSTR which is the background of the Set point weighted pi controller, statement of the problem, objectives of the study, methodology, scope, and limitation of the study. Chapter two describes different literature related to continuous stirred tank reactors (CSTR) with non-ideal mixing are reviewed. Chapter three describes the mathematical Modeling of a continuous stirred tank reactor (CSTR) and control strategies of the system. Chapter four Design of set point weighted pi controller in CSTR with non-ideal mixing, advantage, and different applications, different control methods are presented and the general characteristic of set point weighted pi controller for the concentration control in STRC. Chapter five discusses the system simulation and results. The performance of the setpoint weighted PI controller is evaluated by simulation study using MATLAB/SIMULINK. Chapter six presents the conclusion and recommendations for future enhancements.

CHAPTER 2

LITERATURE REVIEW

According to Saad, MAlbagul, AObia, O (2011) [5]. Has suggested that for use as a typical nonlinear chemical reactor system, the CSTR requires excellent control of the product concentration. The system's mathematical model was derived. The nonlinear model was then used to create the linear model. Both a traditional PI controller and a PID controller can be used to regulate the concentration in a continuous stirred tank reactor (CSTR). MATLAB SIMULINK was used to conduct the simulation investigation. By contrasting response criteria such settling time, rising time, overshoot percentage, and steady state error, the best controller has been determined.

According to Airikka, PasiLautala, Pentti (2000) [6].Proposes a technique for fine-tuning a weighted set point PI controller. The ability to separate load disturbance and set point response design is made possible using the weight at the given position. Here, the highest absolute value of the closed-loop transfer function between the set point and the solution of a given linear time-invariant model output is calculated using a PI controller tuning and a linear time-invariant model.

PadmaSree, R.Chidambaram, M. (2003) [7]. Has a simple method is proposed to design PI controllers for unstable first order plus time delay systems with a zero. The method is based on (i) closed-loop transfer function matching the corresponding first power of s coefficients in the numerator and denominator and (ii) By specifying the initial jump. Using this method, controller settings can be expressed in terms of model parameters by using simple equations. The controller's robustness to uncertainty in the value of the unstable pole and zero is demonstrated by simulation results. The performance of the controller is evaluated by simulation on a CSTR with non-ideal mixing carrying out an enzymatic re-action.

According to Rajinikanth, V.Latha, K. (2012) has recommended since most real-time chemical process loops are by their very nature unstable, creating an efficient controller for such systems is more difficult than doing so for open loop stable processes. In this research, a two-degree of freedom set point weighted PID controller is used in an attempt to tune a class of unstable systems using modern heuristic techniques like Particle Swarm Optimization and Bacterial Foraging Optimization. By fine-tuning the controller, this research aims to maximize the closed loop performance. The effectiveness of the suggested strategy is demonstrated through a simulated study. In a class of unstable systems, this aids in smooth reference tracking, effective disturbance rejection, and error minimization [8].

According to Shouran, MokhtarMuftah, MohamedNaji (2020) made the Continues The most crucial and essential piece of machinery in many chemical and biochemical businesses is the stirred tank reactor (CSTR). They display second order complex nonlinear dynamics. The effectiveness of the suggested strategy is demonstrated through a simulated study. In a class of unstable systems, this aids in smooth reference tracking, effective disturbance rejection, and error minimization. MATLAB SIMULINK was used to carry out the simulation investigation. The best controller has been identified by comparing response metrics including settling time, rising time, percentage of overshoot, and steady state error [9].

According to Chidambaram,M(2000) [10]. A methodical approach is offered for selecting the set point weighting parameter (b) in the PI/PID controller for stable first order plus time delay systems. The responses of PID controllers created using the Ziegler-Nichols method or the pole placement approach are contrasted without and with set point weighting. This technique drastically lowers the overshoot.

According to Suresh Manic, K.Devakumar, S.Vijayan, V.Rajinikanth, V. (2016) [11].has suggested that this paper's goal be to construct a centralized controller for liquid level in a system comprising two cooperating conical tanks. Methods evaluation For simulation and real-time process implementation, two centralized proportional and integral (PI) controller tuning methods the Tanttu and Liestehto technique and the Davison approach—are used. Results: A centralized PI controller enhances system performance by reducing the interaction between the two interacting conical tanks. Peak Overshoot (PO) and Integral Square Error (ISE) are used to assess the performances. Davison's method has been proven to have a lower response rate than the Tanttu and Liestehto procedures. Applications/Improvements: It is typical to use two interlocking conical tanks as a level control mechanism. In the water treatment and chemical sectors

According to Dhanalakshmi, R.Vinodha, R.(2013) has proposed to the non-linearity and continually changing cross section of the conical tank are the great problem in process control and it cannot be efficiently controlled by the linear PID controllers. Due to the complexity of controlling the conical tank, two approaches are being considered: an adaptive PI controller and one that uses neural networks as the primary control mechanism. The scheduling variable used in both of these methods is level. The output of several linear PI controllers, each of which describes the process dynamics behavior at a different operational level, is combined in the first method. The individual PI controller output insertions that make up the global output are weighted based on the current value of the process variable being measured. The second technique is a neural network is utilized to calculate the PI controller settings based on a scheduling variable that corresponds to a significant shift in the dynamics of the production process in simulink, these two control techniques are implemented in real time. The experimental results show that the proposed control schemes have good set point tracking and disturbance rejection capability [12].

According to Pai, NengShengChang, Shih ChiHuang, Chi TsungA (2010) [13].has suggested a straightforward calculation approach of a realistic PI/PID controller tuning for integrating processes with dead time and inverse response based on a model. PI/PID controller settings are first calculated analytically using the model's direct synthesis disturbance rejection method). The next step is to use the golden-section searching technique to find the DS-d tuning parameter that is best suited to the model and has the lowest IAE score. Finally, these data points are used to create two equations. It's easy to get the model's controller settings by using DS-d formulas to get the value of parameter. These equations allow for the easy determination of DS-d PI/PID parameters without the need for a complicated design. The proposed tuning strategy can perform for load/disturbance variations better than other methods that are currently accessible in the literature, according to simulation results

According to Wu, HangSu, WeihuaLiu, Zhiguo (2014) has come up with an idea PID controller design methods are briefly discussed in the paper. PID controllers have been widely used for several decades, and their design and tuning methods have evolved significantly. Identification of the process model, design of the PID controller structure, tuning methods for the PID Parameters, and the use and expansions of PID are all covered in detail. Tuning methods for PID parameters are discussed [14].

According to Padma Sree, R.Chidambaram, M. (2003) [15].The design of PI controllers for unstable first order plus time delay systems with a zero is suggested using a straightforward manner. The technique is based on I matching the coefficients in the closed loop transfer function's numerator and denominator in a servo issue, and (ii) defining the first (inverse) jump. This approach provides straightforward equations for establishing the controller in terms of the model parameters. Simulations demonstrate that the controller functions well even in the presence of undetermined values for the unstable pole and zero. By simulating a CSTR that performs an enzymatic reaction with less-than-ideal mixing, the performance of the controller is assessed

According to Rajinikanth, V.Latha, K. (2012) [16]. since most real-time chemical process loops are by their very nature unstable, creating an efficient controller for such systems is more difficult than doing so for open loop stable processes. For a class of unstable systems, a two-degree of freedom PID controller tuning technique is suggested on the basis of contemporary heuristic algorithms like Bacterial Foraging Optimization and Particle Swarm Optimization. By fine-tuning the controller, this research aims to maximize the closed loop performance. This work suggests that a novel objective function may be used to track heuristic algorithms in order to obtain the optimal controller parameters, such as KP (Ki), Kid (Kd), and with the least amount of iterations. A class of unstable systems can obtain improved system performance, such as smooth reference tracking and appropriate disturbance rejection, as a result of a simulation study.

According to Bingi, KishoreIbrahim, RosdiazliKarsiti, MohdNohHassan, Sabo Miya (2017) [17].has suggested to The CSTR processes extremely nonlinear and dynamic behavior has made control difficult. The CSTR processes are also unreliable. PID controllers have been tried in the past for these kinds of processes. Due to the limits of PID controllers, however, low performance is achieved. The controllers' performance can only be optimized for a limited number of parameter alterations when heuristic techniques are used to modify them. The set-point weighted PID controller for the CSTR process is to be tuned using the fuzzy gain scheduling (FGS) adaptation mechanism, which is proposed in this study. Simulated results indicated that compared to a FGS-PID controller, the proposed technique had improved set-point tracking and disturbance rejection

According to Pandey, IndrajitPanda, AtanuBhowmick, Parijat (2021) [18].The PI Control algorithm used on a common nonlinear process is addressed in this paper, which is based on EKF and UKF tuning logic. To illustrate the practical applicability and efficacy of the suggested tuning procedures, a typical CSTR process was chosen. Even in the face of observational noise, the servo and regulatory performance was shown to be satisfactory when tuning approaches were used. The performances of the proposed PI techniques have been analyzed and compared with traditional adaptive PI (TA-PI) control law. TA-PI control strategy was shown to be less effective than the offered techniques for temperature control when tested in comprehensive simulations.

According to So, Gun BaekJin, Gang Gyoo (2018) [19]. Design methods for nonlinear variable-gain PID controller that can be represented by fuzzy rules are presented in this paper. A genetic algorithm is used to modify user-defined parameters by decreasing the integral of absolute error and the weighted control input deviation index. Overshoot, settling time, set-point tracking, disturbance peak recovery time, disturbance rejection, and parameter changes were all detected in the experimental findings from the suggested controller on a continuous stirred tank reactor (CSTR). When compared to two previous approaches, the suggested controller had less overshoot and a shorter settling time for tracking set points, as well as a lower peak disturbance and a shorter recovery time for disturbance rejection.

According to Sinha, AbhinavMishra, Rajiv Kumar (2018) [20].The most crucial and essential piece of machinery in many chemical and biochemical industries, Continuous Stirred Tank Reactors (CSTR) exhibit second order complex nonlinear dynamics. Numerous design and control issues are brought on by the CSTR's nonlinear dynamics. Even in the face of perturbations and parametric anomalies, the suggested controller ensures a stable closed loop behavior throughout a number of working points. This work offers an event-driven sliding mode control to regulate temperature and concentration states that are very close to a CSTR's equilibrium points. To guarantee desired performance with little computational cost, a special dynamic event triggering rule is offered. SMC and event triggering work together to reduce the computational load on the controller while maintaining the inherent robustness of classic SMC.

The method for creating reliable PI controllers for systems with interval parametric uncertainty is presented in this study. Plotting the stability boundary locus in the (Kp, Ki) - plane of controller parameters is the foundation of the suggested approach. The intended strategy is validated by simulations of the control of the continuous stirred tank reactor (CSTR) with propylene oxide to propylene glycol hydrolysis. Three variables in the reactor are unknown: the reaction enthalpy, the pre-exponential part of the reaction rate constant, and the overall heat transfer coefficient. The temperature of the reacting mixture is the regulated output, while the volumetric flow rate of the coolant is the control input [21].

Due to the prevalence of Proportional-Integral-Derivative (PID) type controllers in industrial control systems; there has been ongoing interest in determining their tuning parameters.

Given their flexibility in terms of processes, this makes sense. Additionally, they function well under a variety of operating circumstances. Additionally, engineers are familiar with them, and using analog or digital technology, they are simple to execute. As a result, more than 90% of control loops employ PID controllers, with the majority of loops using PI controllers because the derivative action is rarely used. The work of Ziegler and Nichols, Cohen and Coon, and Aström and Hagglund are among the most prominent ways for adjusting PID type controllers. Among the most well-known approaches are design strategies based on integral performance criteria. Other typical design strategies for determining tuning parameters of PID type controllers include internal model control (IMC) and controller synthesis [22].

CSTRs are among the most important plants in the chemical and food industries. Their operations are tainted by numerous uncertainties. Some of them are caused by unknown or varying parameters. In other circumstances, the operating point of the reactor alters or the reactor dynamics are altered by various changes in inlet stream parameters [23].

The method for creating reliable PI controllers for systems with interval uncertainty is presented in the study. The suggested technique combines the pole placement method with the method based on mapping the stability boundary locus in the (kp, ki)-plane. The designed method is validated by simulations. It is utilized for the continuous stirred tank reactor with powerful PI controller design and propylene oxide hydrolysis to produce propylene glycol. The reactor's three unidentified parameters are the reaction enthalpy, the pre-exponential factor, and the total heat transfer coefficient. The controlled output is the temperature of the reacting mixture, and the control input is the volumetric flow rate of the coolant. As a mathematical representation of the reactor, the 4th order transfer function with interval polynomials in the numerator and denominator has been found. The robust PI controller design for the reactor uses a method based on mapping the stability boundary locus in the plane of controller parameters in conjunction with the pole placement approach. For the reactor, sixteen Kharitonov plants were constructed [24].

It was investigated whether it was possible to use reliable static output feedback controllers to stabilize open-loop unstable processes. For the design of robust PID-like controllers, a non-iterative technique based on the resolution of linear matrix inequalities was employed. The design process verified the closed-loop robust quadratic stability and the promised cost of control under sufficient conditions. Simulations were used to confirm that it is possible to stabilize a continuous stirred tank reactor using robust PI and PID controllers. Reaction rate constant and reaction enthalpy were two variables in the hypothetical reactor with a single first order exothermic reaction that were unclear. The reactor also had a number of steady states and was stable in the vicinity of its open-loop unstable steady state. The described method can be utilized to construct reliable stabilizing PID controllers, according to simulation results [25].

The main objective the goal of the PIDTOOL software design is to produce an easy-to-use tool for quick PID controller tuning, effective control quality evaluation, and straightforward step-response-based process model identification. Using its graphical user interface, the MATLAB-Simulink programming environment has been used to construct the PIDTOOL. In situations where the process model is unknown, the PIDTOOL software offers the ability to identify the regulated process from its step response even if its primary concentration is on PID controller tuning. Depending on how it is dumped, the step response in the updated PIDTOOL might be either periodic or aperiodic. Either the data file or set can be used to load the step response data directly. Filtration is possible with PIDTOOL when the noisy step response data are loaded. An n-th order plus time-delay transfer function model of a controlled process is produced as a result of identification. In the case of an a periodic step response, one can choose between identifying the first order plus time delay transfer function or the higher order plus time delay transfer function. The PIDTOOL makes it possible to tune different PID controller types, including P, PI, PID, and PD controllers [27].

One of the processes that are used the most in industries is level control. It may, however, exhibit nonlinearities, which could make undertaking the endeavor challenging. Because just the modeling that accurately captures the behavior of the system is required, the PID controller is still a widely used architecture. This work's goal is to locate, manage, and check out a level tank system from a SMARR training facility. First, system identification techniques were used to fine-tune the controllers (Smith, Broida, Viteckova, and Artificial Neural Network), bringing it closer to a First Order plus Dead Time transfer function (FODT). The PI/PID controllers were tuned using optimization methods as the Bat Algorithm, Bacterial Foraging Optimization, Genetic Algorithm, Bee Swarm, Bat Algorithm, Ant Colony Optimization, and Shuffled Frog-Leaping. This parameterization comprised not just optimization techniques but also the Cohen-Coon, Hallman, Internal Model Control

(IMC), Chien-Hrones-Reswick (CHR), and Integral of Absolute Error (ITAE) analytical/classical PI/PID controller tuning techniques. In order to compare the outcomes of simulations and experiments, nonintrusive performance indices based on integral errors (IAE, ISE, ITAE, and ITSE) were introduced. The outcomes were fascinating, showing that the conventional identification approach produced the best outcomes. Optimization algorithms beat analytical/classical tuning techniques for PID controller tuning, demonstrating that the Shuffled Frog-Leaping technique had a better execution [28].

This work takes into account the stability of the concentration in the isothermal reactor. For this, both the heterogeneous catalytic and the autocatalytic reactions are used. From this perspective, the technical issues with reactor design and operation are also taken into account. Many researchers have recently explored the temperature stability of the chemical reactor both theoretically and empirically. This work aims to describe the chemical reactor's concentration stability. Instead of using the heat balance equation, which results in temperature stability, in this situation, the mass balance equation must be used [29].

The practical implementation of nonlinear process control techniques is now possible thanks to recent improvements in nonlinear systems theory as well as in control system hardware and software. This review article examines several nonlinear control system methodologies, from ad hoc or process-specific tactics to nonlinear programming-based predictive control methods. The ability of these methods to deal with issues like time delays, restrictions, and model uncertainty that are frequently present in chemical processes is highlighted. A substantial number of objectives for future study in nonlinear control of chemical processes are specified, despite the recent nonlinear control success being positive [30].

Given the exponential daily rise in computer processing speed, simulation is an essential tool. Through simulation, one will be introduced to an understanding of many different pieces of equipment. Over an actual experiment, simulation using a mathematical model has a number of benefits, including price, reduced time commitment, and knowledge about non-available equipment. This research focuses on controlling a continuous stirred tank reactor (CSTR) for virtual experiment using proportional integral derivative (PID). In this work, non-isothermal CSTR and several control modes were employed. At both the steady state and dynamic point, values were chosen. The work's findings demonstrated the non-isothermal continuous stirred tank reactor's stability under various tuning conditions and disturbances [31].

The process variables, including as flow, pressure, level, concentration, and temperature, are the main factors that must be handled in both set point and load variations in all process industries. This work introduced the CSTR (control system for propylene glycol synthesis in a non-isothermal setting). A fundamental mass and energy balance served as the foundation for the dynamic and control system. In contrast to the two manipulations, which are inlet volumetric flow rate and coolant temperature, the two perturbations are inlet concentration and temperature [32].

A control method that has been utilized successfully for many years is PID control. PID control is so well-liked in the academic and industrial sectors because of its simplicity, durability, wide range of applicability, and nearly perfect performance. PID controllers are frequently found to be improperly tuned, and some efforts have been made to systematically fix this issue. An overview of PID theory is provided in the paper, followed by discussions of some of the most popular PID tuning strategies and an examination of several more recently developed, promising methods [33].

The project's goal is to create various temperature controllers for Continuous Stirred Tank Reactor (CSTR) systems. First, a tuned proportional integral (PI) controller based on Zeigler-Nichols, modified Zeigler-Nichols, Tyreus-Luyben, Shen-Yu, and IMC is constructed, and comparisons with fuzzy logic controllers are performed. Responses for the aforementioned controllers are received once simulations are run. Performance indices include Maximum Peak Overshoot, Settling Time, Rise Time, ISE, and IAE [34].

One method that has been popular in controller design for nonlinear systems is finding certain global transformations that turn the nonlinear model in the original variable into an exact linear model in a different set of variables. Then, for practical purposes, the similar linear system with a back translation to the original variables can be readily designed using linear controller design methodologies [35].

2.1 Summary

Most of the real time chemical process loops are unstable in nature and designing a suitable controller for such systems are difficult than open loop stable processes. Continuous Stirred Tank Reactors (CSTR) is the most important and central equipment in many chemical and biochemical industries which exhibit complex nonlinear dynamics of the second order. Continuous stirred tank reactor system (CSTR) is a typical chemical reactor system with complex nonlinear characteristics where an efficient control of the product concentration in CSTR can be achieved only through accurate model. From the literature review, it has been observed that various techniques have been employed in order to improve the transient and steady state responses.

The tuning of set point weighted pi controller device is difficult to fulfill the control requirement due to the inherent limitation of control techniques. Still, it needs better controller techniques for tuning of set point weighted PI Controller for the concentration control in CSTR system. With a delay time surrounding the operational zone, these nonlinear processes can be described as linear processes in stable or unstable process models. A PID controller is then used to effectively control the linear model. However, the unstable system cannot be controlled by the usual PID controller due to the big initial jump or undershoot or overshoot that an unstable system with a standard PID controller produces. To overcome this issue, the set point weighted PI controller is proposed for the control of the unstable system. In this study, the CSTR with non-ideal mixing is considered an unstable process. In this thesis work, the concentration of a chemical in CSTR is controlled by a set point weighted PI controller. Still, it needs better controller techniques for tuning of set point weighted PI Controller for the concentration control in CSTR system.

CHAPTER 3

MODELING OF THE PLANT

3.1 Modeling Of Continuous Stirred Tank Reactor System (CSTR)

This section will force a specific reaction by concentrating the output flow from two chemical reactors. The simple concentration process control is shown in Figure 1. The overflow tanks are envisioned as two identically dense, well-mixed isothermal reactors. We can assume that the volumes in the two tanks are constant and that all flows are equal and constant based on the assumptions for the overflow tanks. The chemical reaction is also first order $-KC_A$.

The transfer function of the whole system can be obtained according to the following assumptions of parameters.

Table 3.1 The transfer function assumptions of parameters.

Flow rate (F)	Volume (V)	Reaction rate (K)
F=0.085$\mathrm{m}^2/\mathrm{min}$	$V_1 = V_2 = V = 1.05\mathrm{m}^3$	K =0.040min^{-1}

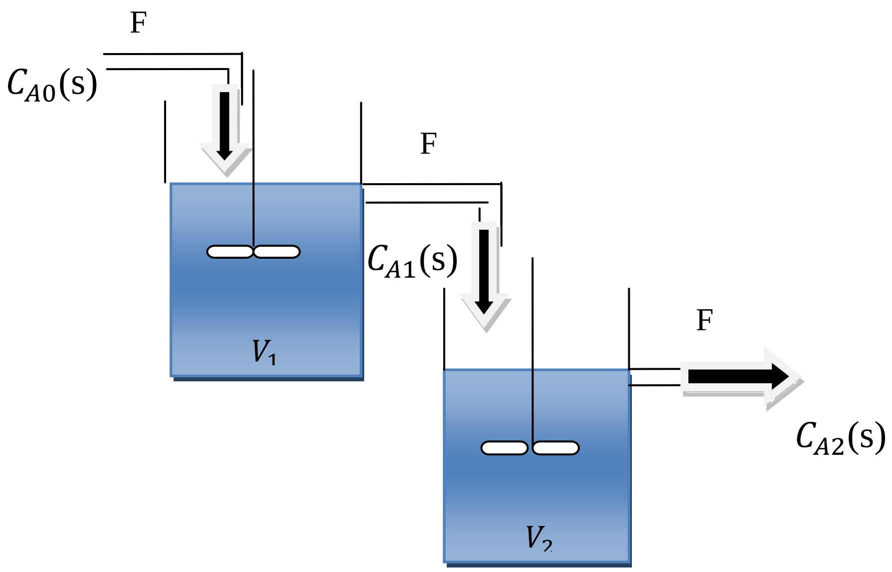

Figure 3.1The simple concentration process control

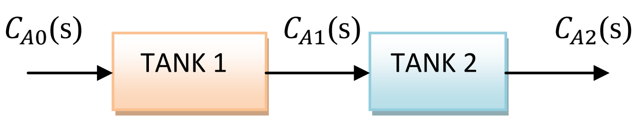

Figure 3.2 The two-tank systems block diagram

The concentration in the second tank needs to be high, albeit according to the first tank's concentration. As a result, the component balances of both tanks are determined. The following formula can be used to compute the first tank's transfer function:

First tank: $V_1 \frac{dC_{A1}}{dt} = F(C_{A0} - C_{A1}) - V_1 K C_{A1}$ (3.1)

Where V_1 is the first tank's volume, F is the flow, C_{A0} is the first tank's intake concentration, C_{A1} is the first tank's outlet concentration, C_{A0} is the first tank's inlet concentration, and K is the reaction rate.

Second tank**:** $\mathrm{V_2} \frac{\mathrm{dC_{A2}}}{\mathrm{dt}} = \mathrm{F}(\mathrm{C_{A1}} - \mathrm{C_{A2}}) - \mathrm{V_2 K C_{A2}}$ (3.2)

Where V_2 is the second tank's volume, F is the flow, C_{A1} is the second tank's input concentration, C_{A2} is the second tank's exit concentration, and K is the reaction rate. Therefore, in most circumstances, two linear ordinary differential equations have to be solved concurrently. The system would be second order if the two equations were unified into a single second-order differential equation. With the initial conditions set to zero, the Laplace transforms for Equations (3.1) and (3.2) are generated to determine the model of the two chemical reactors.

$\mathrm{SVC_{A1}(s) = F\,[C_{A0}(s) - C_{A1}(s)] - VKC_{A1}(s)}$ (3.3)

$\mathrm{S}VC_{A2}(\mathrm{s}) = \mathrm{F}\,[C_{A1}(\mathrm{s}) - C_{A2}(\mathrm{s})] - VKC_{A2}(\mathrm{s})$ (3.4)

By removing $\mathrm{C_{A1}}$(s) from the second equation, the equations can be merged into a single one. First, solve equation for $\mathrm{C_{A1}}$(s) (3). Thus,

$\mathrm{C_{A1}(s)} = \frac{K_P 1}{\tau S+1} \mathrm{C_{A0}(s)}$ (3.5)

Where

$K_{P1} = \frac{F}{F+KV1}$ is the gain of the first tank's transfer function. It is possible to derive the second tank's transfer function.

Where τ_1 is the first tank's time constant.

Where $\tau_1 = \frac{V_1}{F+KV_1} = \frac{1.05m^3}{(0.085m^2/min)+(0.040min^{-1}*1.05m^3)} = 8.25\text{min}$

$$C_{A2}(s) = \frac{K_{P2}}{\tau S-1} C_{A1}(s) \tag{3.6}$$

Where $K_{P2} = \frac{F}{F+KV_2}$ is the gain of the transfer function of the second tank

Where τ_2 is the time constant of the Second tank.

Where $\tau_2 = \frac{V_2}{F+KV_2} = \frac{1.05\text{m}^3}{(0.085\text{m}^2/min)+(0.040\text{min}^{-1}*1.05\text{m}^3)} = 8.25\text{min}$

The gains and time constants can be calculated as follows because they are the same for both tank $\tau = \frac{V}{F+KV} = 8.25\text{min}$

$$K_P = \frac{F}{F+KV} = \frac{(0.085\text{m}^2/min)}{(0.085\text{m}^2/min)+(0.040\text{min}^{-1}*1.05\text{m}^3)} = 0.669$$

Therefore, $G(s) = \frac{CA_2(S)}{CA_0(S)} = \frac{(K_P)^2}{(\tau S+1)^2} = \frac{0.0066}{S^2+0.2424S+0.0147}$ (3.7)

$$CA_0(s) \longrightarrow \boxed{G(s) = \frac{0.0066}{S^2+0.2424S+0.0147}} \longrightarrow CA_2(s)$$

CHAPTER 4

CONTROLLER DESIGN

The system's step response, which was ascertained using the suggested controllers were developed using the MATLAB software's Simulink environment; the entire system.

$$G(s) = \frac{CA_2(S)}{CA_0(S)} = \frac{(K_P)^2}{(\tau S+1)^2} = \frac{0.0066}{S^2+0.2424S+0.0147}$$

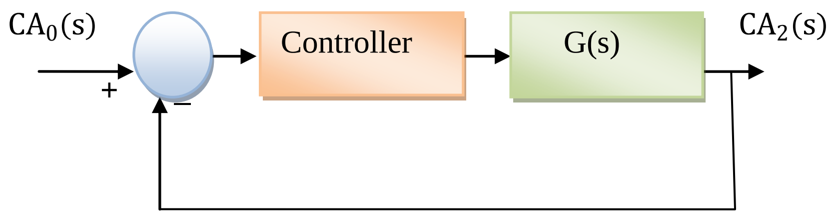

Figure 4.1 The basic configuration of the closed loop system

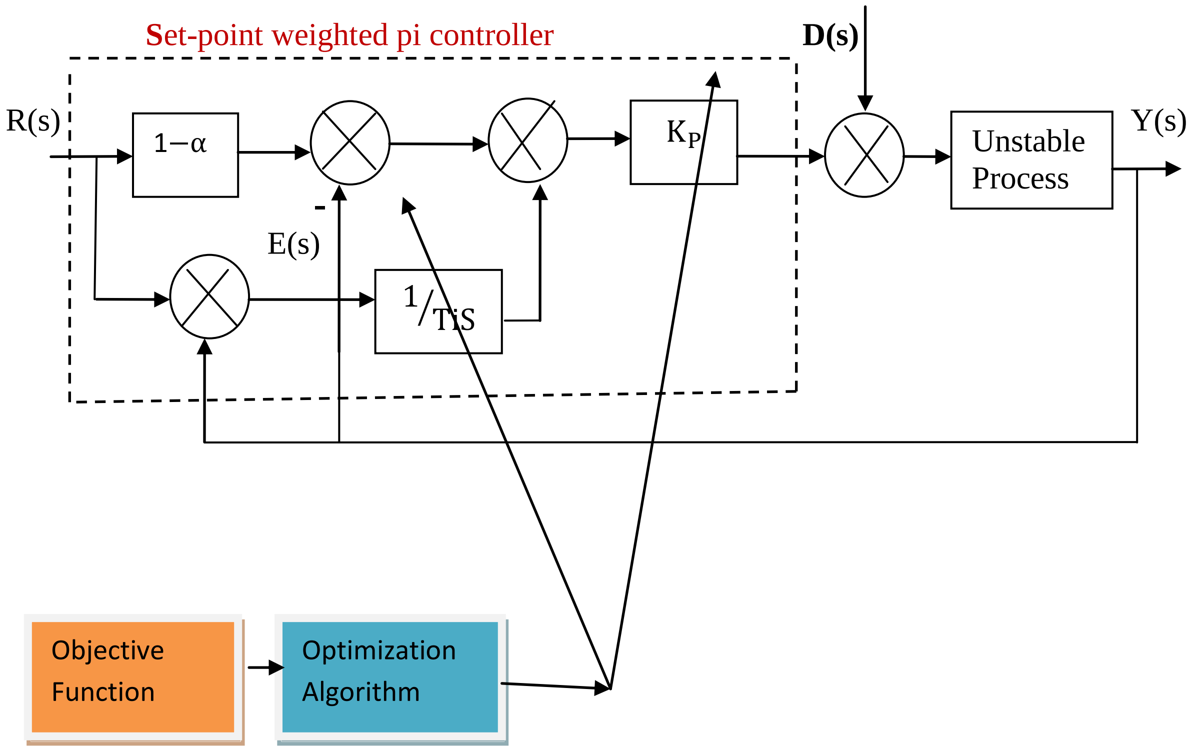

Figure 4.2 Block diagram representation of proposed control scheme

Where:K_P is proportional gain, Ti is integral time constant and α is set point weighting parameter for proportional controller.

The above PI structure can be mathematically represented as follows

$$U(s) = U_1(s) - U_2(s) \tag{4.1}$$

$$U_1(s) = K_P \left[(1-\alpha) + \frac{1}{TiS}\right] \tag{4.2}$$

$$U_2(s) = K_P \ (\alpha) \tag{4.3}$$

When $\alpha = 0$ and the controller will be a PI structure. In this, PI part responds for e (t). In this structure proportional kick by the P is maximum (since, when t = 0, e (t) = max, and y (t) = 0). Where the PI part works based on (2). From (2), it is observed that, the value of proportional gain in U_1 (t) is K_P $(1-\alpha)$.

The Objective Function (OF) is improve the correctness of the optimized controller parameters. The optimization algorithm will be employed for tuning the parameters of controller. The purpose of this paper is to present tuning the parameters based on the PIDTOOL Tuner algorithm to tune a classical and modified structured PI controller for unstable processes to meet set point tracking and disturbance rejection specifications.

In a closed loop control system, the controller *C*(s) continuously corrects the value of *U*(s) Until the difference among reference input *R*(s) and the process output *Y*(s) is zero Irrespective of the external disturbance signal *D*(s).

4.1 PID Tuning Algorithm

Typical PID tuning objectives include:

Algorithm for tuning PID controllers meets these objectives by tuning the PID gains to achieve a good balance between performance and robustness. By default, the algorithm chooses a crossover frequency (loop bandwidth) based on the plant dynamics, and designs for a target phase margin of 60°. When you interactively change the response time, bandwidth, transient response, or phase margin using the PID Tuner interface, the algorithm computes new PID gains. For a given robustness (minimum phase margin), the tuning algorithm chooses a controller design that balances the two measures of performance, reference tracking and disturbance rejection. You can change the design focus to favor one of these performance measures. To do so, use the Design Focus option of PID tune at the command line or the Options dialog box in PID Tuner.

When you change the design focus, the algorithm attempts to adjust the gains to favor either reference tracking or disturbance rejection, while achieving the same minimum phase margin. The more tunable parameters there are in the system, the more likely it is that the PID algorithm can achieve the desired design focus without sacrificing robustness. For example, setting the design focus is more likely to be effective for PID controllers than for P or PI controllers. In all cases, fine-tuning the performance of the system depends strongly on the properties of your plant. For some plants, changing the design focus has little or no effect.

4.2 Proportional Integral (PI) Controller

Another name for proportional integral controller is proportional plus integral (PI) controller. It is a type of controller that employs proportional and integral control actions. It is referred to be a PI controller as a result. The proportional-integral controller uses both proportional and integral controller control actions. In order to operate the plant, a proportional-integral controller (PI Controller) weights the error (the difference between the output and the intended set-point) and the integral of that value.[36]

4.3 Proportional and integral controller

As the name of the controller implies, the output, sometimes referred to as the actuating signal, is equal to the sum of the proportional and integral components of the error signal.

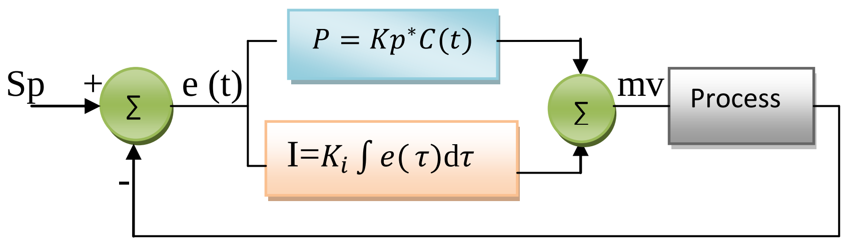

Figure 4.3 Control system with PI controller

The output of a proportional and integral controller, as is common knowledge, is directly proportional to the sum of the proportional error and integration of the error signal.

Taking away the existing proportionality sign,

$$A(t) = K_i \int_0^t e(t)dt + K_p e(t) \tag{4.4}$$

Where, K_i and k_p proportional constant and integral constant respectively. The proportional controller with integral control action restores high order to the original system. As a result, if Kp is big, the control system may become unstable because the roots of the characteristic equation may have a positive real part. Integral control tends to remove or reduce steady-state error in response to varying inputs, whereas proportional control tends to stabilize the system.

4.4 Proportional and Derivative controller

The output, also known as the actuating signal, is equal to the sum of the proportional and derivative components of the error signal, as the name of the controller implies. Let's now perform a mathematical analysis of the proportional and derivative controllers. Combinations of the benefits and drawbacks of proportional and derivative controllers are advantages and downsides.

4.5 Set point Weighted PI Controller

Let's parameterize a PI controller as

$$U\,(\mathrm{t}) = K_p\left(ep(t) + \frac{1}{ti}\int_0^t e(\tau)d\tau\right) \qquad (4.5)$$

Where proportional gain K_p, integral time *t*, and control signal u are tuning parameters (ISA PI controller) and

$$\frac{td}{N}\dot{e}f(t) = ed(t) \qquad (4.6)$$

e_f(t) is a low pass filtered, and N is a filtering value. Integral control errors and proportional components are

$$e_p(\mathrm{t}) = b_r\,(\mathrm{t}) - y\,(\mathrm{t}) \qquad (4.7a)$$

$$\mathrm{e}\,(\mathrm{t}) = r\,(\mathrm{t}) - y\,(\mathrm{t}) \qquad (4.7b)$$

Where *y* is the process output and *r* is the set point. The band *c* parameters are set point weights for tuning.

$$\mathrm{U(s)} = K_r\,(\mathrm{s})\,\mathrm{r(s)} - K_Y\,(\mathrm{s})\,\mathrm{y(s)} \qquad (4.8)$$

Where the controller transfer functions are

$$K_r\,(\mathrm{s}) = K_p\left(\mathrm{b} + \frac{1}{\mathrm{tiS}}\right) \qquad (4.9a)$$

$$K_y\,(\mathrm{s}) = K_p\left(1 + \frac{1}{\mathrm{tiS}} +\right) \qquad (4.9b)$$

Exactly where controller K_y (s) is comparable to the typical parameterization for a PI controller with a 1DOF (one degree of freedom).

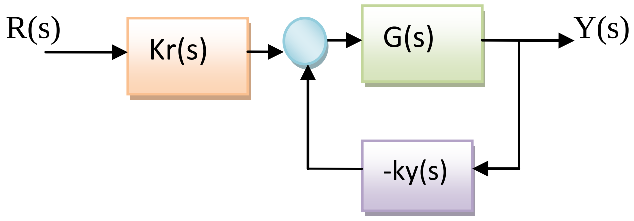

Figure 4.4 Setup with two degrees of freedom for closed-loop control

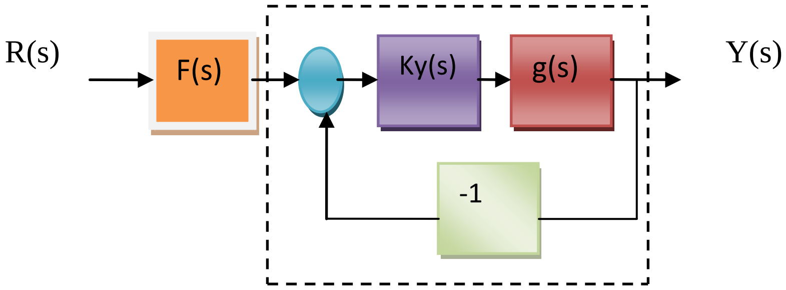

Figure 4.5 A closed loop system with a pre filter and two degrees of freedom combined with one degree of freedom (dotted)

The 1DOF closed loop transfer function with the pre-filter F(s) for a 2DOF situation; T can be used to generate the closed loop transfer function from set point to output (s).

$$T_r\ (\mathrm{s}) = \frac{\mathrm{g(s)kr(s)}}{1+\mathrm{g(s)ky(s)}} = \frac{\mathrm{kr(s)}}{\mathrm{ky(s)}}\frac{\mathrm{g(s)ky(s)}}{1+\mathrm{g(s)ky9s)}} = \mathrm{F(s)T(s)} \tag{4.10}$$

Where *g*(s) is a function used to transfer processes. The ratio of the controller transfer functions (5a) and the pre filter F(s) is all that the pre filter *F*(s) is (5b)

$$\mathrm{F(s)} = \frac{kr(s)}{ky(s)} = \frac{tdti\left(\frac{b}{N}+c\right)s^2+\left(\frac{td}{N}+bti\right)s+1}{tdti\left(\frac{1}{N}+1\right)s^2+\left(\frac{td}{N}+ti\right)s+1} \tag{4.11}$$

For a PI controller, the pre-filter is simplified to be

$$\mathrm{F(s)} = \frac{bti(S)+1}{tiS+1} \tag{4.12}$$

It is essentially b E [0, 1] lag compensator. It has a quicker zero at s =-l/ and a pole at s =1/*ti*(*bti*). As b approaches zero, the zero approaches. *F*(s) is a low-pass filter with a time constant *ti* for *b* = 1 and 0 respectively. For any b E [0, 1], the pre-static filter's gain is *F* (0) = 1 [37].

4.6 Proportional, Integral and Derivative Controller (PID)

In industrial control applications, a PID controller is typically used to control temperature, flow, pressure, speed, and other process variables.

✓ Proportional, Integral, and Derived (PID).

- ✓ Popular within the sector.
- ✓ Simple to implement

When used in this way, the three PID components provide the following outcomes:

- ✓ **P element:** The error at time t in the "present" is proportional to this inaccuracy.
- ✓ **I element:** proportionate to the accumulation of "previous" errors as represented by the error's integral up to t.
- ✓ **D element:** The derivative of the error at time t can be thought of as being proportional to this error prediction.

The PID controller was first introduced in 1939 and is now the most widely used process control controller. According to a survey conducted in Japan in 1989, PID controllers and enhanced variants of the PID controller account for more than 90% of the controllers used in process industries. PI controllers are extensively utilized because derivative action is subject to measurement noise. The term "PID control" refers to a feedback control system that employs a PID controller as the principal tool.

Figure following depicts a block diagram of the fundamental composition of traditional feedback control systems. The process is what has to be controlled in this diagram. Control is used to guarantee that the process variable y tracks the set-point value r. The controller gives instructions to adjust the controlled variable u in order to accomplish this goal. As an example of a procedure where a liquid is heated to the desired temperature by burning fuel gas, consider a heating tank. The temperature of the liquid is a process variable y, while the fuel gas flow is a process variable u. Any element that influences the process variable but is not the controlled variable is referred to as a "disturbance." The graph that follows makes the assumption that the controlled variable has just one disturbance. There are instances, though, where a significant disturbance must be dealt with or one enters the process in an unconventional way. The mistake e has the formula e = r - y. The computational rule that determines the manipulated variable u based on its input data, which is the error e, is known as the compensator $C(s)$ in the figure. Finally, although it is not stated clearly here, it is expected that the process variable y is precisely measured in real time by the detector such that the input to the controller can be viewed as being equal to y.

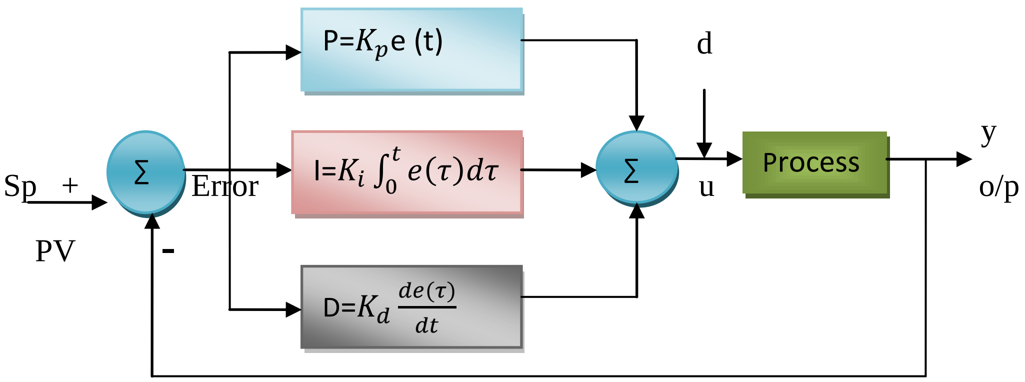

Figure 4.6 System with PID controller

Therefore, the PID controller can be thought of as a controller that considers the mistake in the present, past, and future. The PID controller's transfer function $G_c(s)$ is:

$$G_c(s) = K_p(1 + \frac{1}{sT_i} + T_d s) \tag{4.13}$$

4.7 PID Controller structure

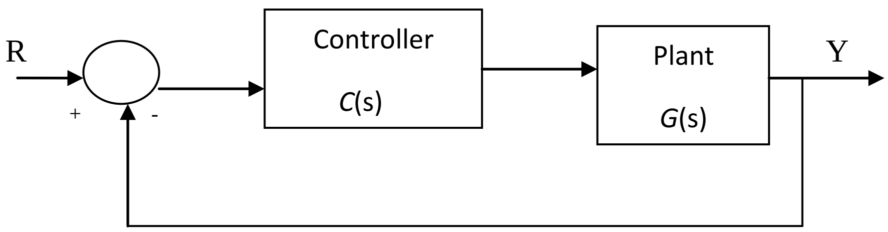

Figure 4.7 PID controller structure

We assume that during this course, the controller will be employed in a unity feedback system that is closed-loop. The variable e is used to communicate the tracking error to the PID controller. The proportional gain (K_P) times the magnitude of the error, the integral gain (K_I) times the integral of the error, and the derivative gain (K_D) times the derivative of the error make up the control signal u that is sent from the controller to the plant.

$$u = K_p e + K_I \int edt + K_D \frac{de}{dt} \tag{4.14}$$

Due to the PID Controllers' broad usage, due to their simplicity and remarkable, if not faultless performance in many applications, PID controllers are employed in more than 95% of closed-loop industrial processes. It may be tuned by operators without sophisticated control knowledge, unlike many other contemporary controllers that are significantly more difficult but frequently give only small benefits. In reality, most PID controllers are locally tuned. The results of increasing K_P, K_I and K_D controller parameters are as follows:

Table 4.1 PID settings impact system dynamics

Response	Rise Time	Overshoot	Settling Time	S-S Error
K_P	Decrease	Increase	NT	Decrease
K_I	Decrease	Increase	Increase	Eliminate
K_D	NT	Decrease	Decrease	NT

NT: no definite pattern. Minor modification

Consider making notes about this table. Later on in the session, it will be helpful.

The first stage in building a PID controller is

- To identify the aspects of the system that needs to be addressed.
- To shorten the rising time, use K_P.
- To shorten overshoot and settling times, use K_D.
- To get rid of the steady-state error, use K_I. [39].

4.8 Continuous stirred tank reactor (CSTR) Model

A Continuous Stirred Tank Reactor (CSTR) is a kind of reaction vessel where the reagents, reactants, and occasionally solvents flow into the reactor at the same time as the reaction product(s) exit the vessel. The tank reactor is therefore regarded as an essential tool for continuous chemical processing. Under steady-state circumstances, CSTR reactors perform consistently with good mixing. The material composition inside the reactor, which depends on residence duration and reaction rate, is identical to the ideal output composition. Under steady-state circumstances, CSTR reactors perform consistently with good mixing. The material composition inside the reactor, which depends on residence duration and reaction rate, is identical to the ideal output composition. In industrial processing, CSTRs are frequently used, particularly in homogenous liquid-phase flow applications that demand continuous agitation.

4.8.1 Chemical reactors

Chemical processes are contained in chemical reactors, which are vessels used in chemical engineering. Chemical engineering has many different components that go into chemical reactor design. Chemical processes are either exothermic (release energy) or endothermic (store energy), hence a steady temperature must be maintained in a reactor by either withdrawing or adding energy (require energy input). Exothermic reactions are the most fascinating systems to research owing to possible safety concerns (sudden temperature increases, commonly known as "ignition" behavior), novel behavior, such as many steady-states, and fascinating behavior (for the same value of the input variable there may be several possible values of the output variable) [40].

4.8.2 **Classification of chemical reactor models**

Various chemical reactors' most important process variables should be estimated by there are two principal fundamental models that are used:

4.8.2.1 **Batch** reactor model (batch)

A vessel class called as a "batch reactor" is extensively employed in the process industries. The name of these containers is deceptive because they are employed in numerous processes, including liquid/liquid extraction, batch distillation, product mixing, and solids dissolution. They have a nomenclature that describes the role they serve, thus they are not usually referred to as reactors (such as crystallizer, or bio reactor). One or more fluid reagents are introduced to a tank reactor with an impeller, which stirs the reagents to ensure proper mixing while the reactor effluent is being drained. An impeller is a rotating component or a pump. The residence time is calculated by dividing the tank volume by the normal volumetric flow rate through the tank. The continuous stirred-tank reactor (CSTR), often referred to as a vat- or back-mix reactor, a mixed flow reactor (MFR), or a continuous-flow stirred-tank reactor, is a typical chemical reactor model in chemical engineering and environmental engineering (CFSTR). A continuous agitated-tank reactor (CART) is a device that continuously stirs a tank of fluid to produce an output. A CSTR is a model used to predict the key unit operation variables. All fluids, including gases and liquids, can be modeled mathematically. It is common practice to model a CSTR's behavior after an ideal CSTR, which implies total mixing. Reagent is promptly and uniformly mixed throughout the entire reactor when it is added to a properly mixed reactor. As a result, the material composition in the reactor, which is influenced by residence time and reaction rate, is the same as the composition of the output. The CSTR is the ideal limit of 100% mixing in reactor design since it is the antithesis of a plug flow reactor (PFR). Real-world reactors never operate precisely; instead, they fluctuate between the CSTR and PFR mixing limits [17].

4.8.2.2 **Features of a batch reactor**

- ✓ The reactor is charged (or filled) through the openings at the top while the reaction is taking place.
- ✓ The reaction is carried out before anything else is added or removed, and the tank is easily heated or cooled by a jacket.

Table 4.2 Kinds of phase present in batch reactor

Kinds of Phases Present	Usage	Advantages	Disadvantages
1. Gas phase 2.Liquid phase 3.Liquid Solid	1. Low-volume production 2.One-off or intermediate production 3. testing newly created but unfinished processes 4. The production of pricey goods. 5.Pharmaceutical, Fermentation	1. High conversion per unit volume for one pass 2.Flexibility of operation-same reactor can produce one product one time and a different product the next 3. Easy to clean	1.High operating cost 2.Product quality more variable than with continuous operation 3. Difficulty of large-scale production.

4.8.2.3 **Continuous stirred tank reactor (CSTR)**

A Continuous Stirred Tank Reactor (CSTR) is a kind of reaction vessel where the reagents, reactants, and occasionally solvents flow into the reactor at the same time as the reaction product(s) exit the vessel. The tank reactor is therefore regarded as an essential tool for continuous chemical processing.

4.8.2.4 **Characteristics of Continuous stirred tank reactor (CSTR)**

- ➢ Run at steady state, the tank must have an equal mass flow rate in and out else it will overflow or empty (transient state).
- ➢ The reaction rate related to the output concentration at the end.
- ➢ An impeller is included in the reactor to guarantee appropriate mixing.
- ➢ By dividing the tank's capacity by the average volumetric flow rate through the tank, the

residence time, or the average amount of time a discrete quantity of reagent spends inside the tank, can be calculated [41].

CHAPTER 5

SIMULATON AND RESULT ANALYSIS

5.1 Open loop analysis

This chapter uses MATLAB/SIMULINK software to simulate the CSTR with non-ideal mixing and explain the simulation findings. The comparative study of classical PID controller with set point weighted PI controller designed for the proposed system performance is also presented. Then the MATLAB code of the model of CSTR with non-ideal mixing in transfer function and the designed controller is developed in MATLAB. This model is used to simulate and track the system's anticipated performance in response to the proposed control system, and simulation results are displayed as graphs. Finally, the comparative analyses of the results have been discussed in terms of the selected parameters to illustrate performance of the designed and tuned controllers.

5.2 Designing controller for CSTR with non-ideal mixing system

As it is mentioned in objectives, there are two cases of proposed controller design and tuning for the system model that characterizing system performance of the system dynamics. The first one is the classical PID controller, and the second one is set point weighted PI controller. Then the Simulink model, designing and tuning as well as simulation results of the corresponding these two cases of the set point tracking and disturbance rejection properties of the two controller types are discussed below. The PID Tuner tool algorithm, which is automatic tuning method, is used to design and tune the optimized controller in terms of basic performance parameters such as low overshoot, faster set point response, input disturbance rejection, little rise time as well as a little settling time and the tuning results are discussed as follows.

The design flow with PID tuner algorithm involves the following tasks:

1. Launching the PID tuner, which automatically generates the linearized model of plant from Simulink model and design the initial controller parameters?
2. Tune the controller design parameters by manually adjusting design criteria in the two design modes.
3. Export the parameters of designed controller back to the PID controller block and verify the performance of the designed controller performance in the Simulink.

For SPW-PI controller design, the same algorithm is followed by manually adjusting of weights ‘b’ in the block dialog to achieve the good step reference tacking.

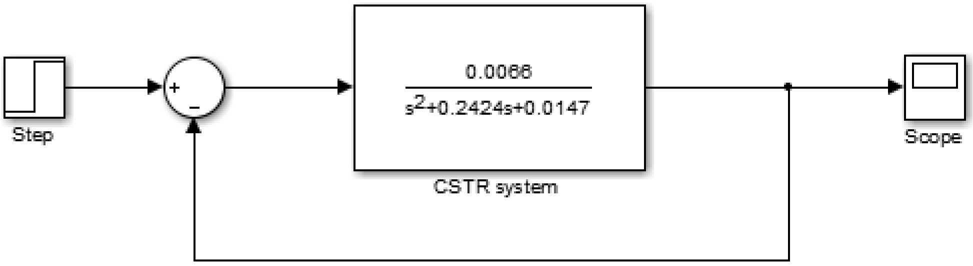

Figure 5.1 Simulink model of CSTR system without controller

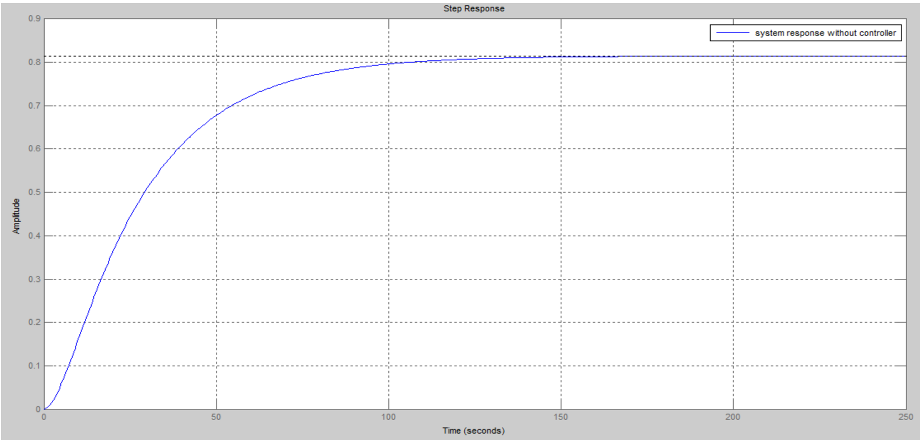

Figure5.2 Simulated open loop CSTR with non-ideal mixing system model

The set point step tracking without controller is too slow and the Steady State error is very high. To improve the performance of the system the proposed controller is tuned and the simulation result is as discussed below.

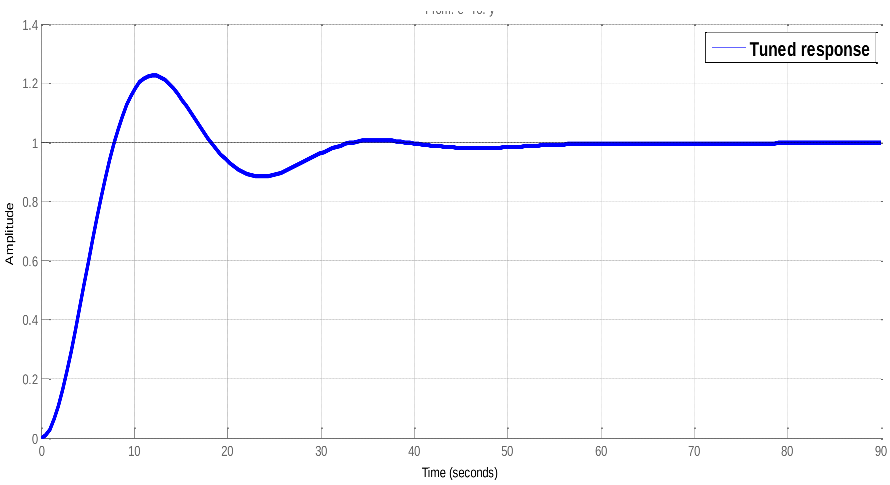

Figure 5.3 Simulated closed loop system model with tuned PID controller

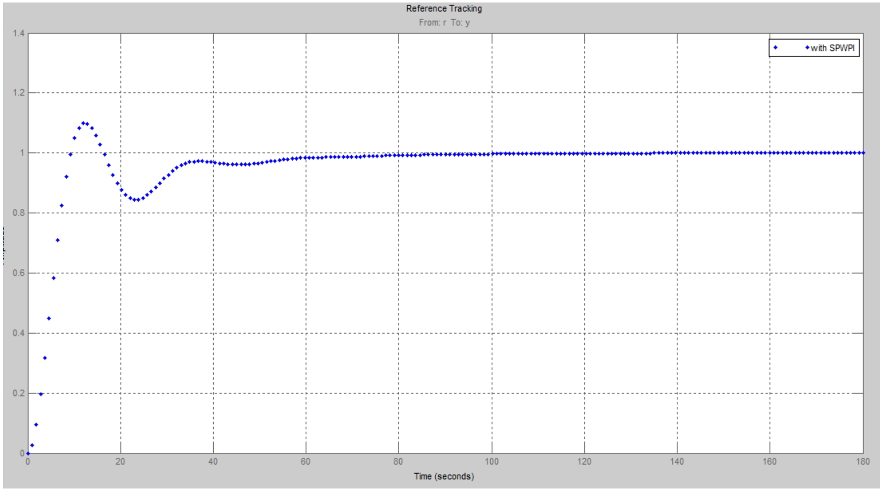

Figure 5.4 Simulated closed loop system model with tuned SPWPI controller

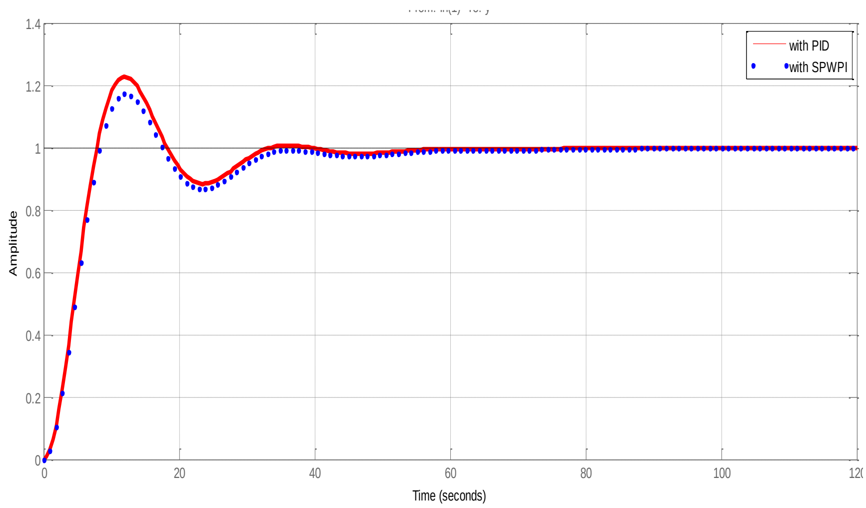

Figure 5.5 comparison of system response with classical PID and SPWPI controller

As seen in Figure 15-16, the reference weighting factor b has a significant impact on the closed-loop responses. It has a value between ‘0’ and ‘1’, with default value of one.

As shown by simulation results, reducing the value of ‘b’ results with smoother tracking of set point without affecting the disturbance rejection curve. The disturbance occurs at the reactor feed temperature, the following figure shows the input disturbance rejection plot that assumes the step disturbance occurs at the plant model input

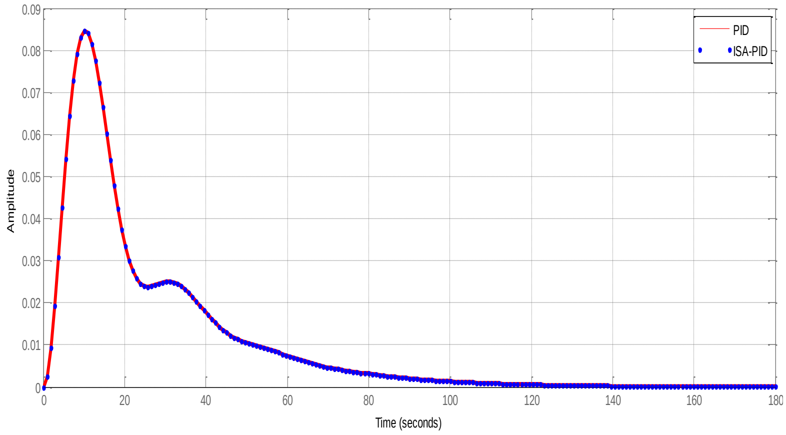

Figure 5.6 comparison of input disturbance rejection response

As presented, the results by graphs above for the system with tuned controller, the steady state error is reduced and response is faster, however maximum overshoot at start-up of the set point tracking response is too high in case of classical PID controller.

The responses to a step disturbance are identical, but the set point weighted PI controller eliminates the overshoot in the response to a set point change. Comparing the tuned classical PID controller and set point weighted PI controllers it can be observed how the proportional and integral gains are nearly the same, but the main difference coming from the set point weight b, which decreases the overshoot significantly.

Generally, when the two-controller cases simulation results are observed, the system with set point weighted PI controller has better performance as shown by set point tracking with less overshoot with same input disturbance(a sudden change in temperature) reduction.

5.3 **Matlab Simulink block diagram**

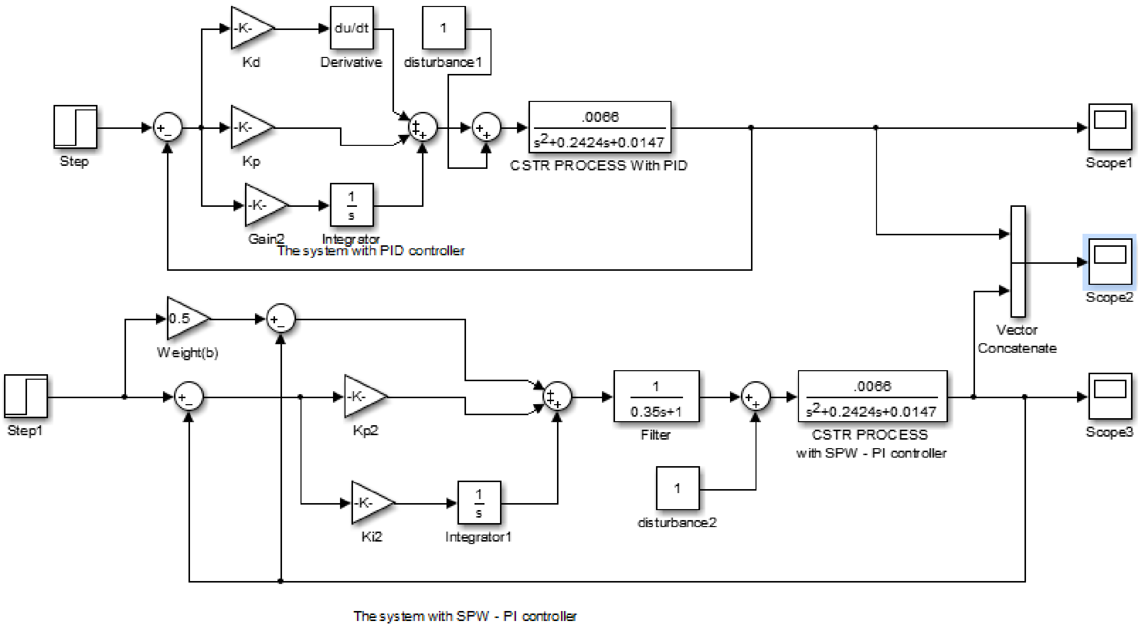

Figure 5.7 simulink model of the system with disturbance

Table 5.1 Conventional PID controller performance measure

Controller parameter and performance measure	Conventional PID controller	
	Reference tracking	Disturbance rejection
K_P	2.0123	2.0123
K_I	0.17193	0.17193
K_D	2.4819	2.4819
Rise time	16.8	19.3
Settling time	41.9	79.3
Overshoot (%)	3.79	4.5

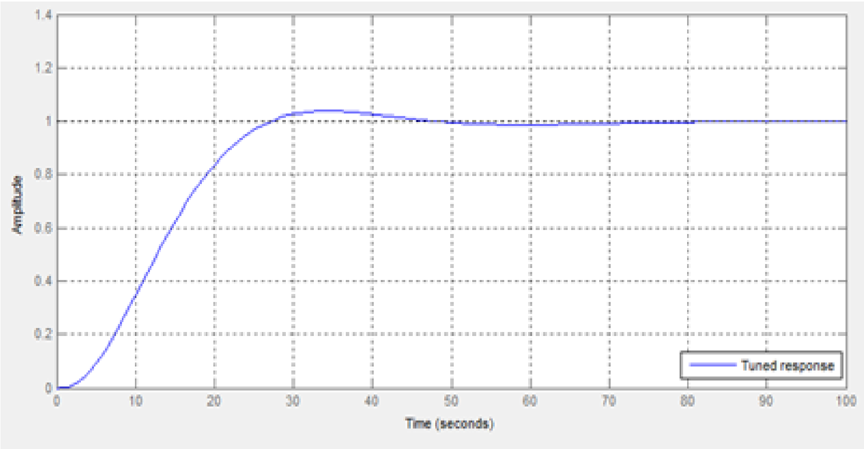

Figure 5.8 Tuned set point tracking with PID controller

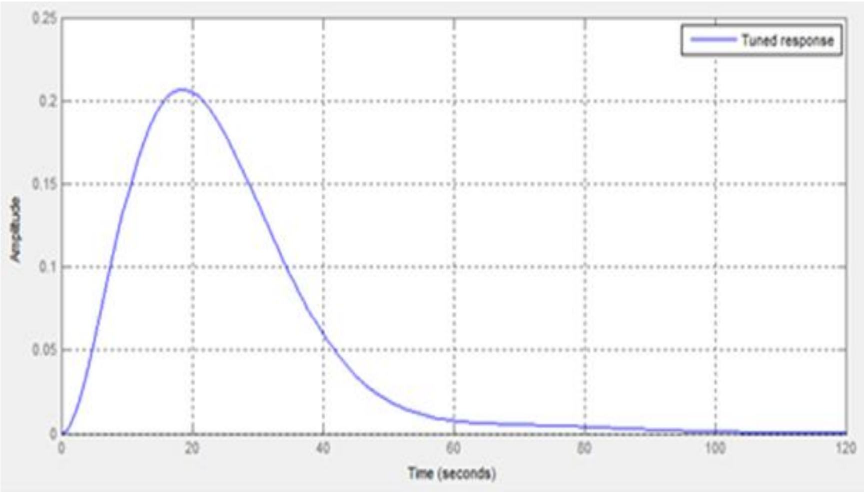

Figure 5.9 Disturbance rejections with PID controller

Table 5.2 SPW-PI controller performance measure

Controller parameter and performance measure	SPW-PI controller	
	Reference tracking	Disturbance rejection
K_P	2.6564	2.6564
K_I	0.20028	0.20028
Rise time	16	18
Settling time	24.2	79.1
Overshoot (%)	1.99	2.3

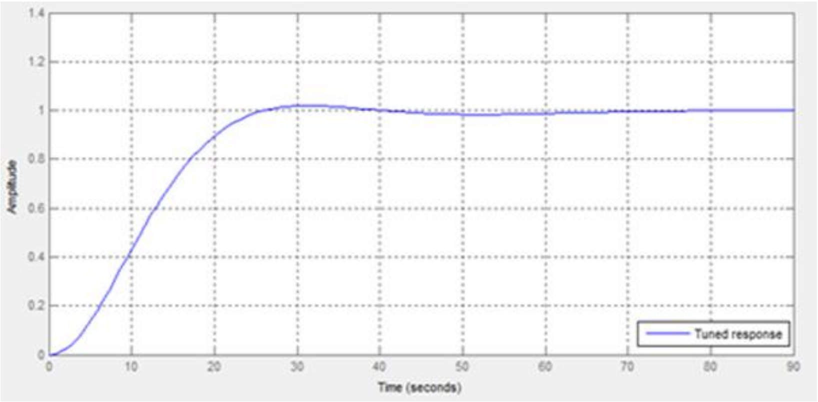

Figure 5.10 Tuned Set point tracking with SPW-PI controller

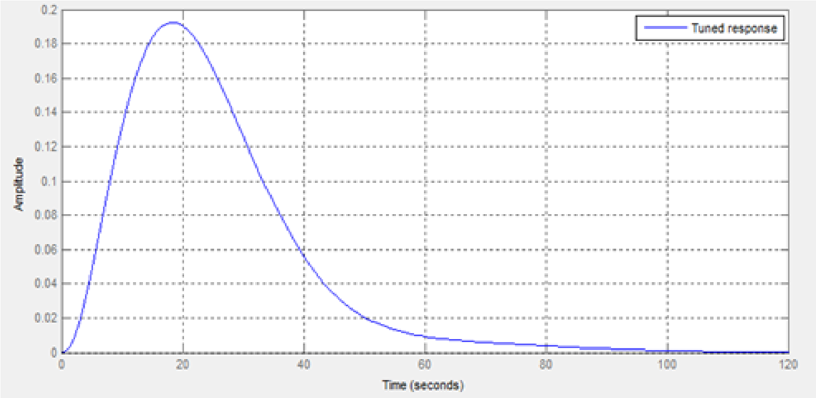

Figure 5.11 Disturbance rejection with SPW-PI controller

5.4 **Performance measures of the controllers**

Table 5.3 Performance Measures of the two types of controller

Performance Measures						
Controller Type	Control Objective	Time Response			Disturbance Rejection Response	
	Control Objective	Rise Time [sec]	Settling Time[c]	Overshoot (%)	Peak value	Settling Time[sec]
Classical PID controller	Balanced performance	16.8	41.9	3.79	0.207	79.3
SPW-PI Controller	Balanced performance	16	24.2	1.99	0.192	79.1

As shown by the simulation results, the response indicates that, during set-point change, the classical PID controller produced higher overshoots while the SPW-PI controller produced smaller overshoots with appropriate selection of weighted value b SPW-PI controller is capable of fast disturbance rejection without significant increase of overshoot in set point tracking which gives an accepted performance within linear and nonlinear systems. It is worth stressing that the reduction of the overshoot obviously implies that the control effort is reduced.

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 **Conclusion**

In conclusion, this project was completed effectively in that two controllers were designed and the other project goals were met. It is effectively created and constructed a model for a CSTR system. The best controller needs to be chosen amongst these two types. It is selected based on criteria including having a short rise and settling time, having reduced steady-state error, and having less overshoot. It is vital to choose which criterion we want to attain the most because all of these criteria cannot be met simultaneously. Less overshoot and less steady-state error are the two criteria that are most important for CSTR systems. A comparison of these controllers has been conducted to determine which controller can meet the requirement. The two controllers that were successfully designed were contrasted in the result and discussion section. Each controller's reaction was charted in a single window, as shown. Because it has a lower steady-state error at a faster rate, the SPW-PI controller offers the best performance, as shown by the simulation results. Reaching the steady state takes only a short while. Additionally, it overshoots less. Consequently, the SPW-PI controller is the best controller for the continuous stirred tank reactor system when compared to the classical PID controller (CSTR).

6.2 recommendations for the future work

The design of two controllers and the accomplishment of the other project goals make this thesis paper a success. It is effectively created and constructed a model for a CSTR system. In light of this, the thesis might additionally cover the design of PDFLC to control the concentration of the CSTR linear model for continuous stirred tank reactors. The system exhibits substantial nonlinearity properties and is a typical chemical reactor. To create a functional controller for the product of concentration in CSTR, an accurate mathematical model of the system must first be derived. Then a number of controllers are used. If the studied controller's parameters are adjusted using the trial-and-error method. However implementing with PDFLC is more preferable.

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Appendix

```
%% Step 1
G = tf([0.0066],[ 0.2424 0.0147]);
G.InputName = 'u';
G.OutputName = 'y';
pidtool(G,'pi')

%% step 2
C = pid(11.2062,0.51);
C.InputName = 'e';
C.OutputName = 'u';
C

%% step 3
C.InputName = 'e';  C.OutputName = 'u';
G.InputName = 'u';  G.OutputName = 'y';
Sum = sumblk('e = r-y');
 T = connect(G,C,Sum,'r','y')

%% step4:The following code constructs an ISA-PID from F and C
b = 0.94;
F = tf([b*C.Kp C.Ki],[C.Kp C.Ki]);
F.InputName = 'r';
F.OutputName = 'uf';
Sum = sumblk('e','uf','y','+-');
SPWPI = connect(C,F,Sum,{'r','y'},'u');

tf(SPWPI)
%% Step 5:  Closed-loop system with PI controller for reference tracking
sys1 = feedback(G*C,1);
% Closed-loop system with ISA-PID controller
sys2 = connect(SPWPI,G,{'r','u'},'y');

step(sys1)
legend('with PID')
title('Reference Tracking')
grid

step(sys2(1),'b.');
legend('with SPWPI')
title('Reference Tracking')
grid

% Compare responses
step(sys1,'r-',sys2(1),'b.');
legend('with PID','with SPWPI')
title('Reference Tracking')
```

```
% step 7:Closed-loop system with PI controller for disturbance rejection
sys1 = feedback(G,C);
% Compare responses
step(sys1,'r-',sys2(2),'b.');
legend('PID','ISA-PID');
title('Disturbance Rejection')
```