CHAPTER 1

INTRODUCTION

This chapter emphasizes the significance and characterization of Continuous Stirred Tank Reactor (CSTR) plant and highlights the linear and non-linear control methods for the plant.

1.1 CONTINUOUS STIRRED TANK REACTOR (CSTR)

Chemicals are the elementary resources with significant applications in almost every domain of human life. These artificial or synthetic resources are products of various other chemicals manufactured under careful conditions. It is necessary that the elementary and environmental conditions of chemicals should be closely monitored as their properties are sensitive to concentration, temperature and quality of input contents. Mixing of various reactants has a large influence on the yield and selectivity of a broad range of chemical processes. Therefore, the design and operation of mixing devices often determines the profitability and environmental acceptability of the whole plant.

A CSTR is a plant that softly mixes the chemical constituents to keep the proportion of inputs uniform in the tank. To ensure its successful operation, it is necessary to understand its dynamic characteristics. A good understanding would ultimately enable effective design of a control system. CSTR consists of a vessel with a stirrer for mixing, a jacket that surrounds the vessel for heating or cooling, feed lines entering the vessel and a liquid product stream exiting from the bottom. The liquid in the reactor is assumed to be perfectly mixed, with non-radial, axial or angular gradients in properties.
like temperature and compositions. The product stream has the same temperature and compositions as the contents of the liquid in the vessel. CSTR with stirrer and pump around the heat transfer surface is shown in Figure 1.1.

![CSTR Diagram](Source: Image courtesy from http://www.metal.ntua.gr/~pkousi/e-learning/bioreactors/page_06.htm)

**Figure 1.1 CSTRs, (a) With stirrer and internal heat transfer surface, (b) With pump around mixing and external heat transfer surface**

As the mixture compositions in a CSTR system are within the reactor, the driving forces of a reactor like the concentration of input materials are required to be quite minimal. Hence, in the case of zero and negative order reactions, the CSTR system occupies the maximum vacant volume of a reactor in order to carry out the desired operations. However, if the forces are minimal in any reactor, the subsidiary exothermic and endothermic reactions could be controlled with minimal efforts. For a system where in conversion rates are expected to be high, a number of CSTRs could be installed in series. A balanced performance in output can be formulated by segmenting a vessel into compartments in serious concentrations of back-mixing and short-
circuiting. The number of CSTR stages and the performance of tubular plug-flow reactor are proportional to each other.

CSTRs are convenient in design processes and they handle isothermal reactions properly against tubular reactors. If the constitution of CSTR demands close range of temperature for operations, the strict control (perfect or optimal control) on the concentration of ingredients for optimum benefit in series arrangement is necessary. The heat requirements could be adjusted inside or outside CSTR. For example, impellers transfer liquid in upward direction and then downward via heat exchange tubes. Thus, the heat exchange can be carried out through these ventilation systems. CSTR is globally implemented in industries with wastewater treatment plants, i.e. activated sludge reactors.

1.2 CONTROL OF CSTR

Control processes of CSTR are broadly classified into two segments: linear and non-linear. Linear controlling is an early method of control and it provides great benefits to small applications. However, as the time passed, the systems have become more complex and linear methods have failed to provide the acceptable standards of output. The non-linear methods are evolved as the solution for the limitations of linear methods. These non-linear methods have two commonly deployed methods: Proportional Integral Derivative (PID) control and adaptive PID control. The domain of CSTR control problem has always been attracting the control engineers for its controversies in non-linear dynamics. Conventional controllers are limited to linear time invariant system applications. However, in real time applications of CSTR model, the functional parameters are defined in the environment of non-linear characteristics like wear and tear. Furthermore, to deal with this non-linear behavior in these conditions, the employment of intelligent and
adaptive controllers is indispensible due to their capability to tackle the non-linear problems. PID is the most popular feedback controller used in the process industries. It is initially popular in its deployment both in academics and industries for their transit benefits in easy feedback loop mechanism. It relies on the parameters such as proportional gain ($K_p$), integral gain ($K_i$) and derivative gain ($K_d$). Transfer function of the model is required to find out the tuning parameters of a non-linear process. Therefore, searching for novel methods to determine PID controller parameters is of utmost interest of research. When the conventional PID controller (Ogata 2006) is implemented in the chemical process, the problems of inverse response and delay time are controlled in the ongoing processes and are removed considerably, but the response of the plant shows instability in terms of rise time ($t_r$), overshoot ($M_p$), peak time ($t_p$) and settling time ($t_s$). Though the PID controllers satisfy most of the system needs in more nature specific cases, functional cases require adaptive methods for much accurate response. Several researchers have attempted to fuse PID and adaptive control strategies (Rezeka et al. 2010) (Kamalasadan 2007) to meet system requirements.

1.2.1 Linear Control

Linear methods provide linear feedback to CSTR control. Many methods such as Single Input and Single Output (SISO) PID, Multi Input and Multi output (MIMO) PID and Model Predictive Control (MPC) operate in linear steps and closely control the reaction process to consider linear behaviour in the system’s dynamic process.

1.2.2 Non-Linear Control

With the parameter up gradation in CSTR systems, the process has become highly non-linear and frequently troubled by disturbances from
steady state. Moreover, with the problems like frequent floating operating points and the diverse range of non-linear dynamic processes, it is not possible to optimize the controller parameters using linear methods.

1.2.2.1 Proportional Integral Derivative (PID)

PID controller consists of proportional action, integral action and derivative action. It is commonly referred to as ZN PID tuning parameters. It is by far the most common control algorithm. It is mostly used in feedback loops. It can be implemented in many forms as a stand-alone controller or as part of Direct Digital Control (DDC) package or even Distributed Control System (DCS).

It is interesting to note that more than half of the industrial controllers today utilize PID or modified PID control schemes. Figure 1.2 illustrates the closed loop system with PID controller. Such set-up is known as non-interacting form or parallel form.

![Figure 1.2 Block diagram of closed loop system with PID control](image)

1.2.2.2 Adaptive control

The law of adaptation looks for error minimizing parameters between the input and output of the CSTR plant. To achieve this state, the control parameters are iteratively progressed to minimize the error with target
to make it error free. There are numerous adaptation laws that have been developed till now. The maximum number of applications in transition state of system exhibits a rational behaviour in case where in the structure of the system is unknown. Hence the controller manages a stable performance level despite the process being noisy and fluctuating.

1.3 CURRENT STATUS OF RESEARCH IN CSTR OPTIMIZATION

Conventional approaches suffer from serious limitations like more oscillatory behavior, high overshoot and settling time, hence the motivation for researchers to seek more flexible and powerful algorithms. A recent approach is bio-inspired intelligent computing that is continuously installed in various schemes of applications. Genetic Algorithm (GA), Neural Network (NN) and Fuzzy Logic (FL) have come as the powerful tools to overcome the limitations mentioned (Krishnand and Nayak 2009). The global interest in fuzzy logic demonstrates the academic and industrial performances of an approximate reasoning over crisp assumption models in real time applications in the field of control (Ketata et al. 1995). The fuzzy controllers are employed as intelligent controllers in real time control applications. With low computational cost, fuzzy logic is highly flexible to deal with complex non-linear problems. The performances of the plant are strictly based on the expertise of the developer that generates rule basis. Therefore, it is a subject of interest for most of the researchers.

Adaptive approach (Astrom & Wittenmark 1995) used for controlling the CSTR system is dependent partly on the selection of External Linear Model (ELM) for non-linear process and plant parameters are defined according to the system’s actual state during control (Bobal et al. 1995). Though the identification is expelled in a discrete time frame, ELM focuses
on the implementation of delta model parameters where the sampling periods are closer to continuous ones (Stericker & Sinha 1993). The estimation of the state could be produced through a number of identification schemes like pole placement method, moving horizon estimation, but the most employed methods are based on Recursive Least Square (RLS) methods. RLS method is easy with low computation and is open for further advancements based on exponential and directional forgetting (Fikar and Mikles 1999) for better identification of outputs.

Polynomial approaches are confronted for the design of controller and the satisfaction of initial control requirements are taken into account. Moreover, for the systems with negative properties like non-minimum phase behavior (If a transfer function has poles and/or zeros in the right half plane then this system shows non-minimum phase behaviour) or process that consumes additional time, the polynomial approach provides more accurate outputs. The subsidiary pole placement method also furnishes with the requirements such as stability, asymptotic tracking of reference signals and compensation of disturbances (Kucera 1993). The control configuration with 1 Degree of Freedom (1DOF) installed with the controller on feedback and reference signals from exponential functions are taken into account for design purpose.

It looks apparent that the conventional approaches may not give the best solution for improving the transient response of the CSTR plant. Better performance of which can be achieved only by optimizing adaptive PID controller and fuzzy controllers using optimization algorithms like GA and ABC. The plant response can also be improved by using the performance indices like Mean Square Error (MSE) and Integral of Square Error (ITAE) with proper weights as the objective function.
1.4 ORGANIZATION OF THE THESIS

Chapter 1 has presented the introduction to CSTR plant and various control techniques that are commonly used to control the plant. The remaining parts of the thesis are organized as below. Chapter 2 presents the literature survey on the existing control techniques that are classified based on linear and non-linear domains. Based on these techniques, the research objective is presented. Chapter 3 deals with the mathematical modelling, state variable equations and process description of CSTR plant. The performances of the CSTR plant are analyzed by using the conventional PID and adaptive control techniques. Chapter 4 elaborates the implementation of PID controller for controlling the temperature in CSTR plant. The PID controller is optimized using the optimization techniques like GA and ABC. Chapter 5 describes the implementation of adaptive controller for CSTR. This adaptive PID control is also optimized using GA and ABC. Chapter 6 provides the implementation of fuzzy control for the CSTR plant. This fuzzy control is also optimized using GA and ABC. Chapter 7 gives the conclusion and directions for future research.

1.5 SUMMARY

This chapter has focused on the importance of controlling the CSTR plant. It also has highlighted different control techniques used in addition to presenting the current status of research in CSTR optimization and the organization of the thesis.