CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Proportional, Integral and Derivative (PID) control is a significant area of research due to its widespread industrial use. Majority of process control loops are of PID and are often combined with other technologies to build the complex automation systems that are used in many industries. Chemical and petrochemical control strategies are often organised in a hierarchy of functions, with scheduling and optimization functions running on top of the hierarchy, multivariable predictive controllers in the middle and PID controllers at the lower level, directly sending control signals to actuators. Tuning of a PID controller implies, setting its adjustable parameters to appropriate values that provide good quality control performance and the optimal operation of the PID controller-design methods is of significant interest.

Automatic tuning is a method by which a controller can be tuned on demand. There are several auto-tuning techniques classified usually as model-based or rule-based methods. Auto-tuning is a combination of a procedure for characterizing process dynamics with controller parameters. Auto-tuning is obviously an attractive feature as it relieves plant operators of manual-tuning duties, and has been present in commercial PID controllers since early 1980’s. The auto-tuning method using relay feedback technique is used and classified as a model-based method, was first introduced by Astrom and Hagglund (1984).
Transfer function models are used to design a PID controller for nonlinear systems. However, for highly nonlinear systems, the PID controller design based on the linear model is not adequate. This is due to significant changes in the steady state gain and time constant of the process. In such cases, the PID controller will not give a satisfactory performance. To overcome this difficulty, a suitable nonlinear model representation of the process is desirable. The dynamics of industrial chemical processes such as heat exchangers and pH neutralization can be easily modelled with the Hammerstein or the Wiener-type. These two types of model comprise a nonlinear static element followed or preceded by a linear dynamic one and are usually given in a block-oriented form. These block-oriented nonlinear processes are controlled by nonlinear control strategy, so that the controllers can be the PID.

1.2 LITRATURE REVIEW

The literature review is given area wise. Three control strategies like Nonlinear Proportional Integral Derivative (NPID) controller based on Wiener model, neural inverse control and Wiener model based identification and control using relay feedback were inspected to propose identification and control method for Wiener-type nonlinear systems.

1.2.1 Continuous Stirred Tank Reactor (CSTR)

The Continuous Stirred Tank Reactor (CSTR) demonstrated for Van de Vusse (1964) is considered as a plant. The problems considered at the control stage are input multiplicities and process inherent limitations such as dead time and non-minimum phase behavior. Morari (1992) has discussed the same problems that should be considered at the design stage.
The term 'input multiplicity' implies the existence of more than one steady state solution when the output is specified. For nonlinear Single Input Single Output (SISO) systems the input multiplicity exists when the steady state gain changes its sign through zero somewhere in the operating range. This phenomenon is identified by Balakotaiah and Luss (1985) in chemical reactors. In some cases there exists a connection between models with input multiplicities and models with non-minimum phase behavior. Both characteristics are caused by competing physical effects on one output variable (Fox et al 1984).

The term 'non-minimum phase', as applied to stable linear systems are defined through the existence of Right Half Plane (RHP) zeros or time delays in the transfer function. The name 'non-minimum' phase refers to the additional phase lag that is contributed by RHP zeros and time delays. The phase of a system with these characteristics is not minimal because there exists another transfer function with the same gain but with a smaller phase lag. Isidori (1995) studied the stable nonlinear systems without time delays and the term 'non-minimum phase' implies unstable zero dynamics.

Gopaluni et al (2003) apply the idea of back-stepping to a benchmark CSTR by using a simple transformation of the original nonlinear model of the chemical reactor. A robust adaptive nonlinear controller is also designed by introducing uncertainty into all of the estimated parameters. The dynamics and control of a number of chemical reactors have been studied in the literature Luyben (1990). In recent times, there has been a growing interest in nonlinear process control, especially with the advent of new techniques to address nonlinear control design problems. The most commonly used approaches are feedback linearization, input-output decoupling, and disturbance decoupling. These techniques obviously form a small portion of methods that can be applied in the area of nonlinear control (Isidori 1995).
1.2.2 Nonlinear PID Controller based on Wiener Model

The control difficulties imposed on PID controllers with integral action have been studied by Fox et al (1984) and Reddy and Chidambaram (1994). Chidambaram also (1998) discussed on analytical equation to represent the gain for isothermal CSTR. Nonlinear Proportional and Integral (PI) controller based on Wiener model for pH process is implemented in real-time by Arvind Kumar et al (2004). Hammerstein model based nonlinear PI controller for CSTR is designed by Jyothi and Chidambaram (2003).

1.2.3 Neural controllers for CSTR

Neural Network (NN) have been used in the recent years to avoid the problems associated with deterministic approaches, and to approximate the nonlinear functions up to any desired level of accuracy. Development of mathematical analysis has led to the discovery of a class of approximation functions includes polynomials, trigonometric series, orthogonal functions, splines, and NN. Nonlinear Auto Regressive Moving Average (NARMA) models provide a unified representation for a wide class of nonlinear systems, as stated in Leontaritis and Billings (1985). In a NARMA description the system is modeled in terms of a nonlinear functional expansion of lagged inputs and outputs. This function is complex and its explicit form is usually unknown.

The use of NNs in chemical engineering area offers a potentially effective means of handling three difficult problems: complexity, nonlinearity and uncertainty. The variety of available NN architectures permits to deal with a wide range of process control problems in comparison with other empirical models. NN is relatively less sensitive to noise but it experience the higher levels of uncertainty when applied in process control problems as stated in Baughman and Liu (1995). Narendra and Pathasarthy (1990) have
developed NN schemes for identification and control of nonlinear process to number of control applications.


Psaltis et al (1988) has discussed the generalised learning method which is trained to learn the total inverse dynamics of the plant. In the specialised learning method, the learning of the controller is carried out using the difference between present and desired output of the system. These numerous versions and applications of this method have been studied by Seng et al (1993).

1.2.4 Identification of Wiener model using Relay Feedback Test


Relay feedback has wide applications in engineering world and has been studied for three decades. Astrom and Hagglund (1984) successfully
applied the relay feedback method to auto-tune PID controllers for process control and triggered a resurgence of interest from both academics and industry to investigate relay feedback systems, which is still far from complete. Luyben and Eskinat (1994) have used consecutive Relay Feedback Test (RFT) to identify the block oriented model structures and suggested that the relay is to be displaced vertically or horizontally to identify the Wiener or Hammerstein-type.

Huang et al (1998) has proposed a method to identify the Wiener model using symmetric and asymmetric RFT. Huang et al (2002) have also proposed a consecutive relay test to select the structure of the model among block-oriented ones. Lee et al (2004) have determined the parameters of the inverse static nonlinear function via a simple optimization procedure which aims to obtain a symmetric cycling output.

Luyben (2001) determined information from the shape of RFT which is particular about the small or large dead time processes. Sung and Lee (2004) have used a modified RFT to identify the Wiener model for simulated pH process. Park et al (2004) have conducted a RFT and estimated the linear dynamic subsystem for simulated example. Then, the model parameters of the nonlinear static function are estimated from the subsequent triangular-type input test. Sung (2002) also estimate the static nonlinearity analytically without any iterative optimization for Hammerstein by simulating polynomial plus second and fourth order transfer function. Systematic approach to identifying Hammerstein and Wiener models, including the model structure and the parameters, for nonlinear process is presented in Jeng et al (2005).

Yoneya (2005) presents identification method of the linear part of the plant which has nonlinearity in its input. The method is simulated for fourth order transfer function in the noisy environment. Lin et al (2006) have studied the reactive distillation and proved that the consistent high-frequency
information can be obtained by RFT. Wang et al (2007) introduced the concept of phase deviation to compensate for the span between the critical point and the oscillation point of Nyquist plot so that the ultimate gain and the ultimate frequency can be accurately obtained. Atherton and Majhi (1998) have also estimated the parameters of open-loop stable and unstable First Order Plus Dead Time (FOPDT) and two FOPDTs in series.

1.2.5 Experimental heat exchanger process using RFT

Giulio D’Emilia (2007) evaluated the accuracy of methods for auto-tuning of PID. In particular, a theoretical and experimental approach is described to evaluate the adequateness of new methods for auto-tuning of PID. This method is able to significantly reduce the time duration for auto-tuning with respect to traditional ones. Leva et al (2006) proposes a novel tuning approach based on relationship between model and relay based tuning. This method also couples the advantages of model-based methods and the simplicity and clarity of relay experiments. Some of simple synthesis procedures are derived for PI, PID form his novel approach. Three simulation examples and temperature control of two transistors heat a metal plate and rotational speed control laboratory tests are reported.

1.2.6 Experimental three-tank system using RFT

Monjea et al (2007) discussed an auto-tuning method for fractional order PID controller and experimental results are given to illustrate the effectiveness of this method. Visioli (2007) has tuned PI controller automatically to implement a modified version of a plug and control strategy, its effectiveness has been discussed by applying it to a level control system. A single run of a biased relay feedback test is carried out to obtain parameters of the model without any prior information about the time delay or the steady-
state gain (Gu, 2006). According to the estimated model, an analytical procedure for PI/PID controller design is developed based on $H_\infty$ optimization and Internal Model Control (IMC) theory. Laboratory tank system shows the effectiveness of the proposed method.

1.3 **ISSUES FOR NEW CONTROL METHOD**

The aim of the thesis is to propose a simple and effective method for identification and control of Wiener-type nonlinear systems. The following issues are considered as worthy

(i) Most of the control loops are of PID type. The use of PID for the control of Wiener-type process is given importance.

(ii) A new method must be developed to implement real-time identification and control.

(iii) The method must be simple with lesser mathematical complexities for effective identification and control of Wiener-type process without practical difficulties.

(iv) The methodology is to be adaptable for the systems in the robust condition as required for chemical and petrochemical industries.

1.4 **CHALLENGES OF THE THESIS**

Formulate a nonlinear PID controller to improve the dynamic performance of the concentration-control in CSTR process. Develop neural controllers such as model predictive and Nonlinear Auto Regressive Moving Average Exogenous Feedback Linearization Control (NARMA-L2) to enhance the concentration control in CSTR process.
Analyse and validate the effectiveness of the Huang (1998) method with real-time heat exchanger process. The existing methods suffer to identify and control the Wiener-type process in single test. Also on-line computations of real-time process are not advisable for the chemical processes when the operating conditions changes. Propose a simple method that has single run of RFT on real-time process and comparatively few computations for the identification and control of Wiener-type process. Validate the proposed method with simulated stable and unstable systems and experimental heat exchanger and three-tank process.

1.5 OVERVIEW OF THE THESIS

The work reported in the thesis is organised into six Chapters. In Chapter 2 the linear PID and Wiener model based nonlinear PID controller are designed and tested for a simulated-isothermal CSTR.

In Chapter 3 the CSTR process is controlled by the ANN based model predictive and inverse model control.

Chapter 4 discusses the Huang et al (1998) and Lee et al (2004) methods to identify and control the real-time heat exchanger as Wiener-type process. Genetic Algorithm based optimization is proposed to avoid the initial value problem during static nonlinearity identification stage.

Chapter 5 proposes a new method for identification and control of Wiener-type system. This method is designed in such a way to adapt the real-time process identification and control. The proposed method is also validated for real-time heat exchanger and three-tank system. Both processes are controlled by Wiener model based nonlinear control strategy.

Chapter 6 presents the overview of work done and the scope for further research in this direction.