FUZZY MODELLING AND CONTROL FOR A NONLINEAR REBOILER SYSTEM OF A DISTILLATION COLUMN

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In The Name of Allah, Most Gracious and Most Merciful

To my beloved

Abah and Mama;

Ibrahim bin Md Saleh & Jahani binti Ali

and

brothers and sister;

Mohd Hafiz Ikhwan, Mohd Farhan Fitri & Nurul Fathiah

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ABSTRACT

Most process control systems are complex and nonlinear in nature. To design a good controller for these systems, accurate models are needed. Most of the available conventional plant modelling techniques cater linear plants and therefore in most cases, inaccurate nonlinear plant models are obtained which in turn resulted in poor control performance. In view of this, the thesis explored the Fuzzy modelling technique based on Takagi-Sugeno (TS) method for modelling a reboiler system of a distillation column. Model parameters are tuned using Genetic algorithm (GA) and Recursive least square (RLS). The Unbiasedness criterion (UC) is applied for structure identification. Data from simulation system that represents the actual plant is used in model development. Fuzzy model obtained using the proposed technique is compared with various other modelling techniques such as the conventional Fuzzy model and linear model. The result shows that the technique proposed gives a more accurate model as compared to the other methods. The optimized Fuzzy model obtained is used to design a Fuzzy controller for the temperature control of the vessel of the distillation column. Manipulated variables for the Fuzzy controller are heat from electrical heater and flowrate of silicon oil in the reboiler system. Genetic algorithm (GA) is used to tune the parameters of the Fuzzy controller. The performance of the Fuzzy controller using the optimized Fuzzy model is better than using the linear model.

ABSTRAK

Kebanyakan sistem kawalan proses adalah kompleks dan tidak lurus. Bagi merekabentuk pengawal yang baik untuk proses tersebut, model yang tepat adalah diperlukan. Kebanyakan teknik permodelan konvensional yang sedia ada hanya sesuai untuk sistem lurus. Oleh itu, dalam kebanyakan kes, model sistem tidak lurus yang tidak tepat diperolehi di mana ia akan menghasilkan prestasi pengawal yang buruk. Berasaskan fakta ini, tesis ini menyelidik teknik permodelan *Fuzzy* berdasarkan metod Takagi-Sugeno (TS) bagi memodelkan sebuah sistem pemanas kolum penyejatan. Parameter-parameter model diselaras menggunakan teknik *Genetic algorithm* (GA) dan *Recursive least square* (RLS). Teknik *Unbiasedness criterion* (UC) diaplikasikan untuk pengenalpastian struktur model. Data daripada sistem simulasi yang mewakili loji sebenar digunakan dalam proses pembinaan model. Model *Fuzzy* yang diperolehi kemudiannya dibandingkan dengan pelbagai teknik permodelan yang lain seperti model *Fuzzy* konvensional dan model lelurus. Keputusan menunjukkan teknik yang dicadangkan dapat menghasilkan model yang lebih tepat berbanding teknik-teknik lain. Model *Fuzzy* yang optimum ini juga digunakan untuk merekabentuk pengawal *Fuzzy* bagi mengawal suhu tangki di dalam kolum penyejatan. Pembolehubah yang dimanipulasi bagi pengawal *Fuzzy* adalah haba daripada pemanas elektrik dan kadar aliran minyak silikon di dalam sistem pemanas. *Genetic algorithm* (GA) digunakan untuk melaraskan parameter-parameter pengawal *Fuzzy*. Prestasi yang ditunjukkan oleh pengawal *Fuzzy* yang dibina berdasarkan model *Fuzzy* yang optimum adalah lebih baik daripada model lurus.

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LIST OF SYMBOLS AND ABBREVIATIONS

GA	-	Genetic algorithm
MIMO	-	Multi input multi output
MISO	-	Multi input single output
MSE	-	Mean squared error
RLS	-	Recursive least square
BLS	-	Batch least square
UC	-	Unbiasedness criterion
FM – SPO	-	Fuzzy model with structure and parameter optimization
FM – PO	-	Fuzzy model with parameter optimization
FM – C	-	Conventional Fuzzy model
LM	-	Linear model
c	-	Center of membership function
σ	-	Width of membership function
μ	-	membership value
ρ_c	-	probability of crossover
ρ_m	-	probability of mutation

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CHAPTER 1

INTRODUCTION

1.1 Overview

Modelling of process plant is a challenging task as most process plants are nonlinear, time varying and complex in nature. Accurate plant models are necessary in order to develop good control system. In most industrial applications, linear models are more popularly used for control system development. This is because the linear approach for modelling and control is easier to develop. However, since most industrial plants are complex and nonlinear, the linear model is usually over simplistic and therefore a good performance controller is non-achievable. This resulted in a non-optimized plant control.

With the establishment of artificial intelligence techniques, alternative strategies have been introduced, developed and applied to overcome the problems of nonlinear and complex plant system modelling and control. The techniques make use of deductive process with learning capabilities by adapting or combining several intelligence techniques such as Fuzzy logic, Genetic algorithm or Neural network.

This thesis presents such study that implements the principle and concept of artificial intelligence especially Fuzzy logic to solve the problems of modelling and control of a reboiler system for a distillation column. The nonlinearity nature of a distillation column makes it difficult for an accurate model to be obtained. There are many variables to be manipulated and controlled in a distillation column control

system. These variables are interacting and therefore to achieve control objective of each variable is not an easy task. This thesis attempts to develop an accurate model of a reboiler system for a distillation column using artificial intelligence techniques such than a good controller can be designed to improve the performance of the system.

1.2 Problem statement

The process of separating mixture of liquids is probably the most common and important process in process control industries. The example of the process can be found in petroleum industry where crude oil is separated into several components such as petrol, diesel, tar and bitumen. The process plant used for this purpose is a distillation column.

The objective of a distillation column process is to separate mixture substances into several components in order to acquire useful component. The basic idea behind the process lies on the concept of different component has different boiling point. To separate a mixture, the liquid in the column can be heated at certain temperature to force components transform into the gas phase. The gas is then condensed back into liquid form and after a certain period, an amount of desired pure component can be collected.

There are many types of distillation columns where each plant is designed to perform specific types of separation and also depends on the complexity of the process. Commonly, the distillation column type is classified by looking at how the plant is operated. There are two types of distillation column operation namely:-

1) Batch distillation column.
2) Continuous distillation column.

Obviously, the difference between these two types of distillation column lies on the volume of the mixture that going to be separated. In batch operation, the mixture is introduced batch-wise where there will be no more mixture to be added

during distillation or extraction process. The next batch of mixture will only be introduced when the desired distillation task is achieved. Batch distillation column is frequently used for small-volume products.

In contrast, continuous distillation column processes a continuous feed stream of mixture. A certain amount of mixture is continuously fed into the column during the distillation process. Continuous distillation column is capable of handling high throughputs.

In this research, the process plant used as the reference system is the pilot plant distillation column located at Centre of Lipids Engineering and Applied Research (CLEAR), Universiti Teknologi Malaysia (UTM), Kuala Lumpur. This plant is a batch type of distillation column. Thus, based on this plant, a simulation system is developed in this thesis.

The plant is mainly used to extract and distillate ginger oleoresin from *Zingiber officinale Roscoe* or commonly known as solid ginger using ethanol as the solvent. Ginger oleoresin is the final product to be collected for further application. Generally, in industry, the oleoresin is gaining popularity as a component which is widely used in herbal-based medicine product. The ginger oleoresin also has widespread uses as a flavouring agent in food and odour in perfume. A schematic diagram of the distillation column is as shown in figure 1.1.

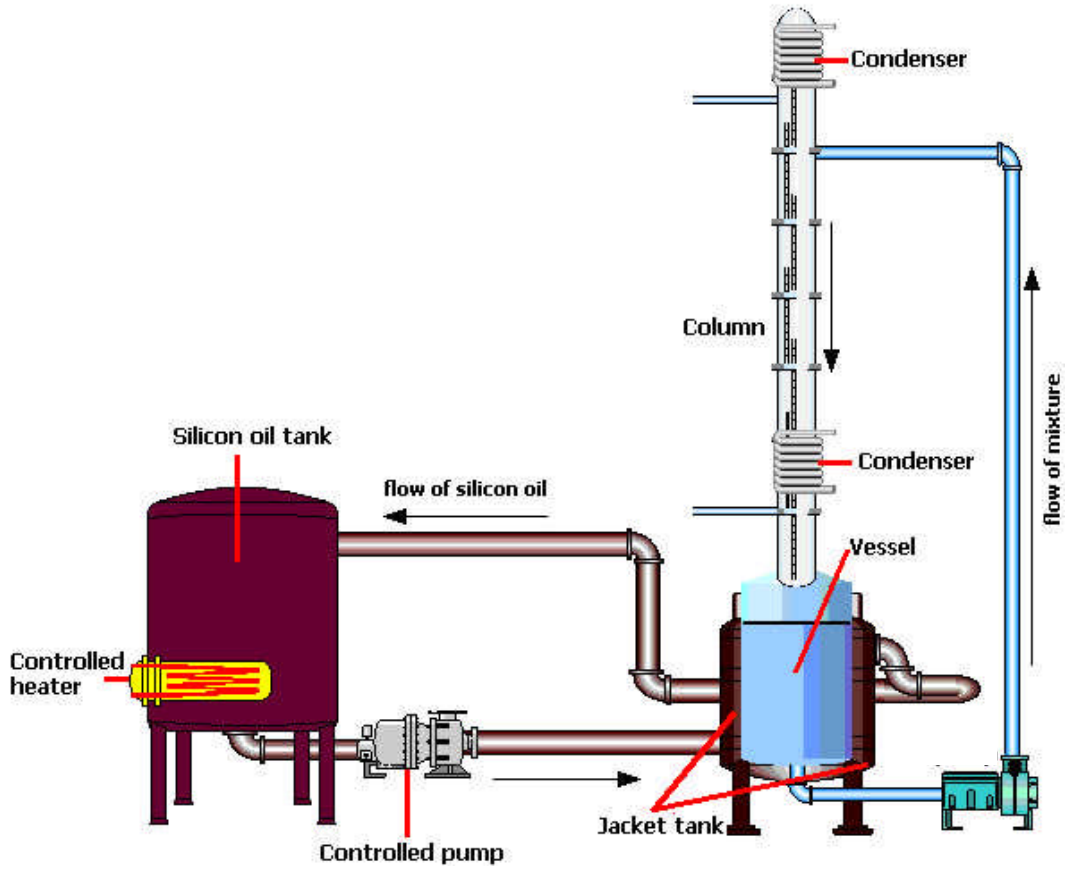

Figure 1.1 A schematic diagram of distillation column plant

From the control perspective of the pilot plant distillation column, the temperature of the vessel that contains extraction mixture needs to be controlled and maintained at certain setpoint. The heat which causes the temperature to increase is supplied from the reboiler part of the distillation column. There are two elements that can be controlled in the reboiler part: electrical heater and pump.

The main objective is to control these elements so that the temperature in the vessel that contained mixture to be separated can reach the setpoint value and at the same time the power consumption and heat loss can be reduced. In order to achieve these objectives, it is very important to make sure that heat from the heater and flowrate of silicon oil controlled by the pump have a balance relationship. Incorrect values of the output from one of these elements can affect the temperature behaviour which finally will give poor result. For example, if the maximum heater power is set and minimum flowrate is selected, the temperature inside the vessel increases very slowly meanwhile temperature at other part increases quickly. This causes a power

waste whereby heat is used to increase the temperature of different part of the reboiler.

To optimally control two interacting variables is not an easy task in the absence of accurate plant model. Therefore, it is essential that a good and accurate plant model is obtained for the pilot plant distillation column in order for a good performance controller to be designed.

1.3 Objective of the thesis

The objectives of the thesis can be divided into two main parts:-

Part 1: Fuzzy modelling for reboiler system of distillation column.

1) To develop models for nonlinear system namely reboiler system of distillation column using Fuzzy modelling technique.
2) To develop an algorithm for tuning Takagi-Sugeno (TS) Fuzzy model structure and parameter using numerical data.
3) To compare the performance of the optimized Fuzzy model with conventional Fuzzy models and linear model as well.

Part 2: Designing Fuzzy controller of distillation column based on Fuzzy model.

1) To design Fuzzy controller for the distillation column plant based on its Fuzzy model.
2) To apply an algorithm for tuning Fuzzy control parameter.
3) To compare the performance index of the Fuzzy model-based Fuzzy control with the linear model-based Fuzzy control.

1.4 Scope of the thesis

In order to ensure the objectives of the thesis can be achieved, scope of the research has been determined so that the work done in this research will be clearly understood. The scope of this thesis covers:-

1) To focus on a part of distillation column called reboiler system as the reference system for model development. The reboiler system is the critical part in the distillation column plant that will determine the performance of the extraction process.
2) To use the mathematical model based on energy balance principle to represent the reboiler system of distillation column plant. This simulation plant will be stated as the reference plant.
3) Implementation of artificial intelligence concept and principle especially Fuzzy logic as the core subject in the development of intelligence model and control of the plant.
4) Application of software namely LabView as the computational platform for developing plant's simulation, data acquisition and training of Fuzzy model and control.

1.5 Contribution of the thesis

Previous work on Fuzzy modelling concentrates on using Genetic algorithm (GA) for tuning the parameters of the model (Setnes and Roubus, 2000; Wong et al., 2000; Teng et al.,2002). However, studies have shown that by modifying the model structure of Takagi-Sugeno Fuzzy model, some improvement of the accuracy of the model can be achieved (Sugeno and Kang, 1988).

In this thesis, we proposed to combine the use of GA for optimizing the parameters of the antecedent part, Recursive least square (RLS) method for obtaining the consequent part of the Fuzzy model and Unbiasedness criterion (UC) steps, as such forming a hybrid method of optimizing the structure and parameter of Fuzzy model.

The method is used to have accurate model of the distillation column. A Fuzzy logic controller is designed offline using GA to optimize the tuning of its parameters. Through the comparisons with several methods, namely conventional Fuzzy model, Fuzzy model with optimum parameter and linear model, the results show that the proposed method gives a more accurate model.

Below are some of the expected contributions of this thesis:-

i) Fuzzy model for the reboiler system of distillation column plant that is more accurate to represent the plant.
ii) Based on Fuzzy model, Fuzzy controller for the distillation column plant is developed which is well-performed when being applied to the model and the plant.
iii) Provide reliable method to optimize the structure and parameter of Fuzzy model which will improve the accuracy and exactness of the model compared to the reference system.
iv) Provide method to tune parameter of Fuzzy control that will guide the controller to be set up so that it can meet the control specification.

1.6 Thesis layout

This thesis is organized with eight chapters. Chapter 1 describes the general introduction of this thesis, objective, scope and contribution of the research. Followed by chapter 2 with literature review on modelling of distillation column system, Fuzzy modelling technique and Fuzzy control technique. In chapter 3 and 4, a detail explanation on Fuzzy modelling and Fuzzy control will be presented, separately. Starting with general overview on Takagi-Sugeno Fuzzy model, then the tuning algorithm to find optimum structure and parameter will be discussed. This includes the explanation on Genetic algorithm (GA), recursive least square (RLS) method and Unbiasedness criterion (UC). Comprehensive description on Fuzzy control is then presented including overview on standard Fuzzy control and parameter tuning using Genetic algorithm (GA).

Chapter 5 will give detail explanation on the reboiler system of distillation column plant. The derivation on differential equation mathematical model of the system will first been described. Next, the discrete time variant model will be expressed. The implementation of Fuzzy modelling technique and Fuzzy control technique on the distillation column are then illustrated in chapter 6 and 7 respectively. Procedures, results and discussion will be explained in both chapters. Finally the conclusion and further development will be given in chapter 8.

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