ADVANCED PROCESS CONTROL OF FATTY ACID DISTILLATION COLUMN USING ARTIFICIAL NEURAL NETWORKS

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ABSTRACT

This thesis discusses the application of neural networks in a fatty acids distillation process control. The objective was to fulfill product purity specifications under varying feed compositions and large process disturbances. The research activities were divided into four main parts. First, a fatty acids distillation process was simulated using HYSYS.Plant™ software. The simulation model was able to closely match the actual process plant data. The model was therefore considered as a reasonable representation of the actual process. Second, a neural network estimator was formulated for a product composition. Here, secondary variables as well as their past values were carefully selected to formulate an accurate and parsimonious model. Third, the inferential model was implemented as an integral part of an inferential control scheme in the distillation column. Simulation results obtained affirmed the potentials of the proposed inferential strategy for composition control. Significant improvements were obtained compared to the widely used strategy of controlling a column temperature. Finally, a neural network based model predictive control scheme was investigated. The implementation on composition control of the distillation process also produced promising results. In conclusion, the works undertaken here have exposed the potentials of neural network models in solving industrial control problems, particularly for composition control in a distillation column.

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CHAPTER I

INTRODUCTION

1.1 Motivation

The control of fatty acid distillation process is challenging due to several process related reasons. Among others, intricate issues include the process nonlinearity, frequent process changes and disturbances as well as lack of measurements. Process measurements are particularly important because these measurements are used to monitor and control process operations. Reliable measurements provide opportunities for efficient monitoring of process states as well as implementation of control and optimisation procedures. These facilitate consistent and effective production especially if regular and reliable measurements can be made available at the appropriate frequency. Difficulties in measuring some of the primary variables inevitably lead to poor control. In more serious condition, such weaknesses may even lead to no control at all. As a result, process performance is degraded.

The measurement of product quality is one of the most serious. In practice, most product property variables are analysed off-line in the laboratories. Although on-line sensors may be available, their usage is often limited due to long measurement delays (*e.g.*, gas chromatographs) which can take up to 20 minutes. On-line sensors are also susceptible to factors that affect their reliability such as fouling in the sampling line. As a result, frequent maintenance and calibration are required to ensure the efficiency of the system. This again, limits the use of such devices in industrial process control.

In a typical palm oil distillation process, the product quality is maintained by controlling the appropriate temperature of the distillation column. This is normally supported by off-line laboratory analysis of the product, carried out at one- or two-hour interval. Although this has almost been the standard practice in the oleochemical industries, it is by no means the best solution. In fact, the main reason for this approach to dominate is the lack of cost effective and reliable on-line analysers as mentioned in the above. Assuming the laboratory analysis is reliable and accurate and the process is well-behaved and not subjected to serious disturbances, the unique relationships between the product composition and temperature as defined by the thermodynamic equilibrium provide the necessary inference. However, this ideal situation does not always transpire. Many processes are exposed to difficulties such as frequent changes in quality of raw materials and interruption of utilities. Changes of feedstock composition alter the thermodynamic relationships between temperatures and product composition in the column. The unique relation between the setpoint temperature and the product composition needed for the success of the indirect strategy is now questionable, thus subjecting the operation to considerable uncertainty. At times, this can even results in excessive off-specification products, especially when the operation is changing from one operating region to another. Although these difficulties can be addressed by experienced plant operators or engineers, dependence on human intervention subjects the plant to unnecessary uncertainty.

One way to tackle this problem is to apply inferential measurement strategy. Inferential measurement is a powerful methodology that allows difficult-to-measure primary variables be inferred from other easily measured secondary variables. An example of application is to use secondary measurements such as pressure, flow or temperature to estimate the product composition in a distillation column. If the model is sufficiently accurate, the estimated values of the product composition can be used as feedback for automatic control and optimisation. In essence, inferential measurement systems mimic what experienced process operators and engineers do in running process plants without subjecting the plants to human inconsistencies.

The work is founded on this idea. Here, neural network modelling strategy is employed to capture the process dynamics in the form of compact estimation model.

On-line inferential estimation and control is implemented on the pre-cut column of a fatty acid distillation plant. Here, the intention is to control one of the fatty acid compositions at some desired values. In addition, this work also explored the application of neural-network-based model predictive control (MPC) of the product composition. MPC has attracted widespread interest by the academia and industry alike due to its ability to deal with constraints and convenience for extension into multivariable implementation. However, in this work, only single variable control is considered.

1.2 Objective of Work

The aim of this work is to investigate the application of two model-based strategies, *i.e.*, the inferential strategy and model predictive strategy in the monitoring and control of product quality in an industrial fatty acid distillation column. A data based (empirical) modelling approach is used, where multilayer perceptron (MLP) neural networks are exploited to capture the intended process characteristic. To facilitate this study, a rigorous simulation of the distillation column is first developed in a commercial process simulator, HYSYS.Plant™ and used to test the performance of the proposed strategies.

1.3 Scope of Work

The scope of work addressed in this project is as follows:

(i) Simulation of a fatty acid distillation column

(ii) Estimation of fatty acid composition using neural networks

(iii) Inferential control of a fatty acid composition

(iv) Model predictive control of a fatty acid composition

1.4 Layout of Thesis

Chapter II begins with a process description of an industrial fatty acid distillation process focussing on the first unit, the pre-cut column. After that, the development of the simulation flowsheet of the column applying HYSYS.Plant^{TM} (a commercial dynamic simulator) is provided. The subjects of thermodynamic property models selection, unit operations sizing and controller design are discussed. This is followed by the validation of the simulation with actual industrial data. The investigation on the process dynamic response is then provided. The simulation flowsheet will be the test bed for implementing and testing the proposed control strategies.

Chapter III commences with the discussion on the inferential estimation strategy and a survey on early works. This is followed by the introduction of neural networks. Here, description of the neural network's structure and basic algorithm is provided. Discussion on the procedure and stages in neural network modelling, *i.e.*, data generation and pre-processing, network topology design, neural network training and validation, and network performance evaluation are described next. Chapter III also discusses the actual application of the inferential estimation strategy on the distillation test bed. The implementation process, which follows the neural network modelling procedure explained earlier, is described. The chapter concludes with a discussion on the results obtained.

In Chapter IV, inferential control is implemented to the distillation test bed to control a product composition, employing the estimator developed in Chapter III. The chapter first briefly discusses composition control strategies in industry, followed by the description of the existing composition control strategy employed by the selected distillation test bed. Inferential control is then introduced, along with a survey of previous works and the implementation of the inferential control strategy in the fatty acid column.

Chapter V discusses the implementation of model predictive control (MPC). The chapter commences with an overview that includes discussions on the strengths, weaknesses and implementation of MPC. Next, the description on some of the wellknown MPC schemes is provided. This is followed by the elaboration on the neural-network-based MPC (NNMPC) approach. A survey of previous works on NNMPC is also provided, along with a discussion on the integration of neural networks in MPC. Finally, the implementation of an NNMPC scheme on the fatty acid distillation column is provided. The performance of the NNMPC scheme is compared to the previously developed inferential control scheme. The thesis is concluded by Chapter VI where the conclusions drawn from the study as well as some recommendations for future works are presented.

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