National Program on Technology Enhanced Learning (NPTEL)

Plantwide Control of Integrated Chemical Processes

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TABLE OF CONTENTS

MODULE II: Control of Common Unit Operations

MODULE III: Issues in Plantwide Control System Design

Chapter 0. Introduction to Course

0.1. Background and Motivation

Chemical processes are designed and operated for manufacturing value added chemicals, the value addition providing the economic incentive for the existence of the process. The fiercely competitive business environment constantly drives research and innovation for significantly improving existing process technologies and for developing new technologies to satisfy man's ever growing needs. On the operation side, the processes are operated to meet key production objectives that include process safety, product specifications (production rate and quality) and environmental regulations. These key production objectives must be satisfied even as the process is subjected to disturbances such as changes in the fresh feed composition, variation in the ambient temperature, equipment fouling, sensor noise / bias etc. In other words, the process operation must ensure proper management of the process variability so that the key production objectives are met even in the presence of the process variability. This naturally leads to the idea of proper management of process variability, the task accomplished by a well designed automatic process control system.

Consider the heat exchanger in Figure 0.1. Steam is used to heat a process stream to a certain temperature. Due to variations in the process stream flow rate and inlet temperature, the stream outlet temperature varies over a large range. From the process operation perspective, this is unacceptable since the large variation in the process stream temperature disturbs the downstream unit (eg. a reactor). The installation of a temperature controller that manipulates the steam flow rate to hold the outlet stream temperature constant mitigates this problem to a very large extent. This is illustrated in the outlet stream temperature and steam flow rate profiles in Figure 0.2. For open loop operation (no temperature control), the temperature varies over a large range while the steam flow rate remains constant. On the other hand, for closed loop operation (with temperature control), the variation in the outlet stream temperature is significantly lower with the steam flow rate showing large variability. The temperature controller thus transforms the variability in the outlet stream temperature to the steam flow rate. This simple example illustrates the action of a control loop as an agent for transformation of process variability.

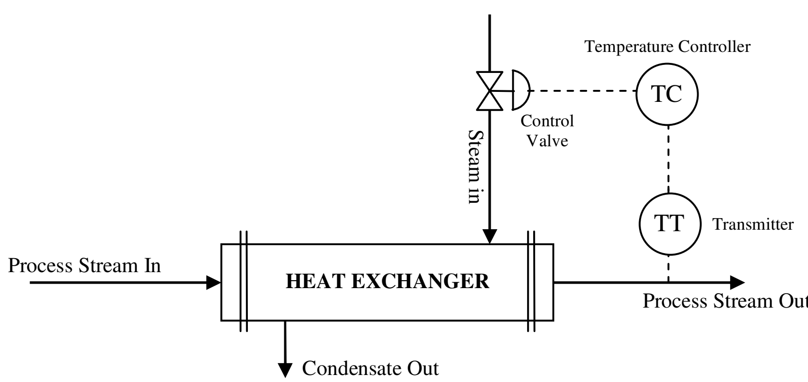

Figure 0.1. Heat exchanger with temperature controller

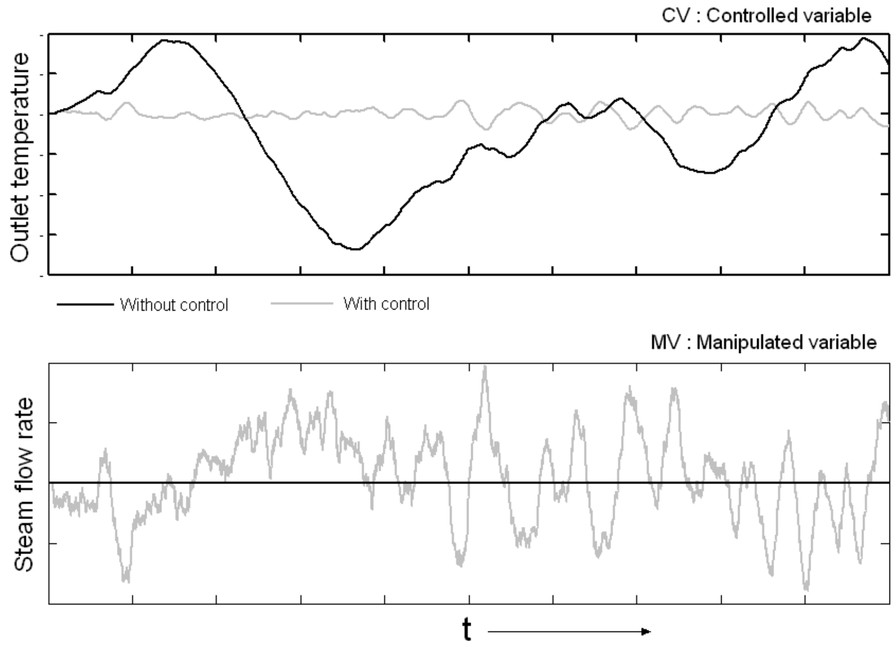

Figure 0.2. The manipulated (steam flow rate) and controlled variable (outlet temperature of process stream) with and without control

A chemical process consists of various interconnected units with material and energy recycle. Controlling a process variable by adjusting the flow rate of a process stream necessarily disturbs the downstream / upstream process due to the interconnection. Material and energy recycle can cause the variability to be propagated through the entire plant. Considering the plant-wide propagation / transformation of process variability, the choice of the variables that are controlled (held at / close to their set-points), the corresponding variables that are manipulated and the degree of tightness of control (loose / tight control) are then key determinants of safe and stable process operation. The choice of the controlled and manipulated variables is also sometimes referred to as the control structure. Modern control text books provide very little guidance to the practicing engineer on the key issue of control structure selection for individual unit operations and the complete process, choosing instead to focus on the control algorithms and their properties with typical mathematical elegance. How does one go about choosing the most appropriate plant-wide control structure for a given set of production objectives? This work attempts to provide an engineering common sense approach to the practicing engineer for answering this key question.

Given a control system that ensures safe and stable process operation in the face of ever present disturbances, crucial economic variables must be maintained to ensure economically efficient or optimum process operation. Depending on the prevailing economic circumstances, optimality may require process operation at the maximum achievable throughput or lower throughputs. At the optimum steady state, multiple process constraints are usually active such as reactor operation at maximum cooling duty/level/temperature/pressure or column operation at its flooding level etc. How close can the process operate to these constraint limits is intimately tied with the basic plant-wide control strategy implemented. The converse problem is that of designing the regulatory plantwide control system such that the back-off from the constraint limits is the least possible. In this work, we also develop a systematic procedure for designing such an economic plantwide control system.

In summary, this book is targeted at the practicing engineer to help him design effective plant-wide control systems through an appreciation of the major issues the control system must address. It is hoped that the targeted audience finds the work of practical utility. The author invites suggestions, comments and criticisms for improving upon the work.

0.2. Organization of the Course

The course is organized into four modules, excluding this Introduction. In Module 1, the reader is introduced to the essentials of process control. Only the most practical aspects of process control theory are presented. Mathematical rigor is deliberately done away with in favour of a more colloquial style to keep the discussion focused on the most essential and practical aspects of process control theory. Module 2 is devoted to the control of common unit operations found in the process industry. The control of distillation columns is exhaustively dealt with and includes simple, heat integrated and complex column configurations. The control of industrially common reactor configurations and heat exchangers is covered next. Finally common control configurations for miscellaneous systems such as furnaces, heat refrigeration systems and compressors are discussed. Module 3 elaborates upon the key issues in the design of a plant-wide control system. The need for balancing the reactant inventory and the interaction between the reaction and separation section of a plant are described. We then go about developing a systematic procedure for economic plantwide control system design. Three elaborate case studies on realistic chemical processes are then presented to demonstrate the application of the methodology. Comparisons with conventional plantwide control structures show that an economic plantwide control structure can significantly improve (2-20%) the achievable profit (or maximum throughput) for a given process. Proper design of the plantwide control system is thus shown to be crucial to achieving economically optimal process operation.