CHEMICAL PROCESS ENGINEERING

Design and Economics

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Preface

Chemical engineers develop, design, and operate processes that are vital to our society. Hardigg* states: “I consider engineering to be understandable by the general public by speaking about the four great ideas of engineering: structures, machines, networks, and processes." Processes are what distinguish chemical from other engineering disciplines. Nevertheless, designing chemical plants requires contributions from other branches of engineering. Before taking process design, students’ thinking has been compartmentalized into several distinct subjects. Now, they must be trained to think more globally than before. This is not an easy transition. One of my students said that process design is a new way of thinking for him. I have found it informative to read employment ads to keep abreast of skills required of process engineers. An ad from General Dynamics† in San Diego, CA, states, “We are interested in chemical engineers with plant operations and/or process engineering experience because they develop the total process perspective and problem-solving skill we need.”

The book is designed mostly for a senior course in process design. It could be used for entry-level process engineers in industry or for a refresher course. The book could also be used before learning to use process simulation software. Before enrolling in process design, the student must have some knowledge of chemical engineering prerequisites: mass and energy balances, thermodynamics, transport

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* Hardigg, V, ASEE Prism, p.26, April 1999.

† Chemical and Engineering News, January 29, 1990.

phenomena, separator design, and reactor design. I encourage students to refer to their textbooks during their process design, but there is need for a single source, covering the essentials of these subjects. One reason for a single source is the turnover in instructors and texts. Besides, it is difficult to teach a course using several texts, even if the students are familiar with the texts. Another objective of a process design course is to fill the holes in their education. This book contains many examples. In many cases, the examples are familiar to the student. Sources of process-design case studies are: the American Institute of Chemical Engineers (AIChE) student contest problems; the Department of Chemical Engineering, Washington University, at St. Louis, Missouri; and my own experience.

I am fortunate to have worked with skilled engineers during my beginning years in chemical engineering. From them I learned to design, troubleshoot, and construct equipment. This experience gave me an appreciation of the mechanical details of equipment. Calculating equipment size is only the beginning. The next step is translating design calculations into equipment selection. For this task, process engineers must know what type and size of equipment are available. At the process design stage, the mechanical details should be considered. An example is seals, which impacts on safety. I have not attempted to include discussion of all possible equipment in my text. If I had, I would still be writing.

The book emphasizes approximate shortcut calculations needed for a preliminary design. For most of the calculations, a pocket calculator and mathematics software, such as Polymath, is sufficient. When the design reaches the final stages, requiring more exact designs, then process simulators must be used. Approximate, quick calculations have their use in industry for preparing proposals, for checking more exact calculations, and for sizing some equipment before completing the process design. In many example problems, the calculated size is rounded off to the next highest standard size. To reduce the completion time, the approach used is to purchase immediately equipment that has a long delivery time, such as pumps and compressors. Once the purchase has been made the rest of the process design is locked into the size of this equipment. Although any size equipment – within reason – could be built, it is less costly to select a standard size, which varies from manufacturer to manufacturer. Using approximate calculations is also an excellent way of introducing students to process design before they get bogged down in more complex calculations.

Units are always a problem for chemical engineers. It is unfortunate that the US has not converted completely from English units to SI (Système International) units. Many books have adopted SI units. Most equipment catalogs use English units. Companies having overseas operations and customers must use SI units. Thus, engineers must be fluent in both sets of units. It could be disastrous not to be fluent. I therefore decided to use both systems. In most cases, the book contains units in both systems, side-by-side. The appendix contains a discussion of SI units with a table of conversion factors.

Chapter 1, The Structure of Processes and Process Engineering, introduces the student to processes and the use of the flow diagram. The flow diagram is the way chemical engineers describe a process and communicate. This chapter contains some of the more common flow-diagram symbols. To reduce the complexity of the flow diagram, this chapter divides a process into nine process operations. There may be more than one process operation contained in a process unit (the equipment). This chapter also describes the chemical-engineering tasks required in a project.

Chapter 2, Production and Capital Cost Estimation, only contains the essentials of chemical-engineering economics. Many students learn other aspects of engineering economics in a separate course. Rather than placing this chapter later in the book, it is placed here to show the student how equipment influences the production cost. Chapter 2 describes cash flow and working capital in a corporation. This chapter also describes the components of the production cost and how to calculate this cost. Finally, this chapter describes the components of capital cost and outlines a procedure for calculating the cost. Most of the other chapters discuss equipment selection and sizing needed for capital cost estimation.

Chapter 3, Process-Circuit Analysis, first discusses the strategy of problem solving. Next, the chapter summarizes the relationships for solving design problems. The approach to problem solving followed throughout most of the book is to first list the appropriate design equations in a table for quick reference and checking. The numbering system for equations appearing in the text is to show the chapter number followed by the equation number. For example, Equation 5.7 means Equation 7 in Chapter 5. For equations listed in tables, the numbering system is to number the chapter, then the table and the equation. Thus, 3.8.12 would be Equation 12 in Table 8 and Chapter 3. Following this table another table outlines a calculating procedure. Then, the problem-sizing method is applied to four single-process units, and to a segment of a process consisting of several units.

Heat transfer is one of the more frequently-occurring process operations. Chapter 4, Process Heat Transfer, discusses shell-and-tube heat exchangers, and Chapter 7, Reactor Design, discusses jacket and coil heat exchangers. Chapter 4 describes how to select a heat-transfer fluid and a shell-and-tube heat-exchanger design. This chapter also shows how to make an estimate of heat-exchanger area and rate heat exchangers.

Transferring liquids and gases from one process unit to another is also a frequently occurring process operation. Heat exchangers and pumps are the most frequently used equipment in many processes. Chapter 5, Compressors, Pumps, and Turbines, discusses the two general types of machines, positive displacement and dynamic, for both liquids and gases. The discussion of pumps also could logically be included in Chapter 8, Design of Flow Systems. Instead, Chapter 5 includes pumps to emphasize the similarities in the design of pumps and compressors. This chapter shows how to calculate the power required for compressors and pumps. Chapter 5 also discusses electric motor and turbine drives for these machines.

Chapter 6, Separator Design, considers only the most common phase and component separators. Because plates and column packings are contained in vessels, this chapter starts with a brief discussion of the mechanical design of vessels. Although chemical engineers rarely design vessels, a working knowledge of the subject is needed to communicate with mechanical engineers. The phase separators considered are: gas-liquid, liquid-liquid, and solid-liquid. The common component separators are: fractionators, absorbers, and extractors. This chapter shows how to approximately calculate the length and diameter of separators. Flowrate fluctuations almost always occur in processes. To dampen these fluctuations requires installing accumulators at appropriate points in the process. Accumulators are sized by using a surge time (residence time) to calculate a surge volume. Frequently, a phase separator and a component separator include the surge volume. This chapter also discusses vortex formation in vessels and how to prevent it. Vortexes may form in a vessel, drawing a gas into the discharge line and forming a two-phase mixture. Then, the two-phase mixture flows into a pump, damaging the pump.

Chapter 7, Reactor Design, discusses continuous and batch stirred-tank reactors and the packed-bed catalytic reactor, which are frequently used. Heat exchangers for stirred-tank reactors described are the: simple jacket, simple jacket with a spiral baffle, simple jacket with agitation nozzles, partial pipe-coil jacket, dimple jacket, and the internal pipe coil. The amount of heat removed or added determines what jacket is selected. Other topics discussed are jacket pressure drop and mechanical considerations. Chapter 7 also describes methods for removing or adding heat in packed-bed catalytic reactors. Also considered are flow distribution methods to approach plug flow in packed beds.

Designing flow systems is a frequently occurring design problem confronted by the process engineer, both in a process and in research. Chapter 8 discusses selecting and sizing, piping, valves, and flow meters. Chapter 5 considered pump selection. Chapter 8 also describes pump sizing, using manufacturer's performance curves. Cavitation in pumps is a frequently occurring problem and this chapter also discusses how to avoid it. After completing the chapter, the students work on a two week problem selecting and sizing control valves and a pump from manufacturers' literature. Many of these problems are drawn from industrial experience.

Most things in life are not possible without the help of others. I am grateful to the following individuals:

the many students who used my class notes during the development of the senior course in process design, and who critiqued my class notes by the questions they asked

Otto Frank, formally Process Supervisor at Allied Signal Co., Morristown, NJ, who critiqued a draft of my book from an industrial point of view.