Chapter 2

History of Chemical Engineering: Transport Phenomena vs Unit Operations

INTRODUCTION

Although the chemical engineering profession is usually thought to have originated shortly before 1900, many of the processes associated with this discipline were developed in antiquity. For example, filtration operations were carried out 5000 years ago by the Egyptians. During this period, chemical engineering evolved from a mixture of craft, mysticism, incorrect theories, and empirical guesses.

In a very real sense, the chemical industry dates back to prehistoric times when people first attempted to control and modify their environment. The chemical industry developed as any other trade or craft. With little knowledge of chemical science and no means of chemical analysis, the earliest "chemical engineers" had to rely on previous art and superstition. As one would imagine, progress was slow. This changed with time. The chemical industry in the world today is a sprawling complex of raw-material sources, manufacturing plants, and distribution facilities which supplies society with thousands of chemical products, most of which were unknown over a century ago. In the latter half of the 19th century, an increased demand arose for engineers trained in the fundamentals of chemical processes. This demand was ultimately met by chemical engineers.

Three sections complement the presentation for this chapter. They are:

History of Chemical Engineering

Transport Phenomena vs Unit Operations

What is Engineering?

Heat Transfer Applications for the Practicing Engineer. Louis Theodore

HISTORY OF CHEMICAL ENGINEERING

The first attempt to organize the principles of chemical processing and to clarify the professional area of chemical engineering was made in England by George E. Davis. In 1880, he organized a Society of Chemical Engineers and gave a series of lectures in 1887 which were later expanded and published in 1901 as "A Handbook of Chemical Engineering." In 1888, the first course in chemical engineering in the United States was organized at the Massachusetts Institute of Technology (MIT) by Lewis M. Norton, a professor of industrial chemistry. The course applied aspects of chemistry and mechanical engineering to chemical processes.(1)

Chemical engineering began to gain professional acceptance in the early years of the 20th century. The American Chemical Society was founded in 1876 and, in 1908, organized a Division of Industrial Chemists and Chemical Engineers while authorizing the publication of the *Journal of Industrial and Engineering Chemistry*. Also in 1908, a group of prominent chemical engineers met in Philadelphia and founded the American Institute of Chemical Engineers.(1)

The mold for what is now called chemical engineering was fashioned at the 1922 meeting of the American Institute of Chemical Engineers when A. D. Little's committee presented its report on chemical engineering education. The 1922 meeting marked the official endorsement of the unit operations concept and saw the approval of a "declaration of independence" for the profession.(1) A key component of this report included the following:

> Any chemical process, on whatever scale conducted, may be resolved into a coordinated series of what may be termed "unit operations," as pulverizing, mixing, heating, roasting, absorbing, precipitation, crystallizing, filtering, dissolving, and so on. The number of these basic unit operations is not very large and relatively few of them are involved in any particular process . . . An ability to cope broadly and adequately with the demands of this (the chemical engineer's) profession can be attained only through the analysis of processes into the unit actions as they are carried out on the commercial scale under the conditions imposed by practice.

The key unit operations were ultimately reduced to three: Fluid Flow,(2) Heat Transfer (the subject title of this text), and Mass Transfer.(3) The Little report also went on to state that:

> Chemical Engineering, as distinguished from the aggregate number of subjects comprised in courses of that name, is not a composite of chemistry and mechanical and civil engineering, but is itself a branch of engineering, . . .

A time line diagram of the history of chemical engineering between the profession's founding to the present day is shown in Figure 2.1. As can be seen from the time line, the profession has reached a crossroads regarding the future education/curriculum for chemical engineers. This is highlighted by the differences of Transport Phenomena and Unit Operations, a topic that is discussed in the next section.

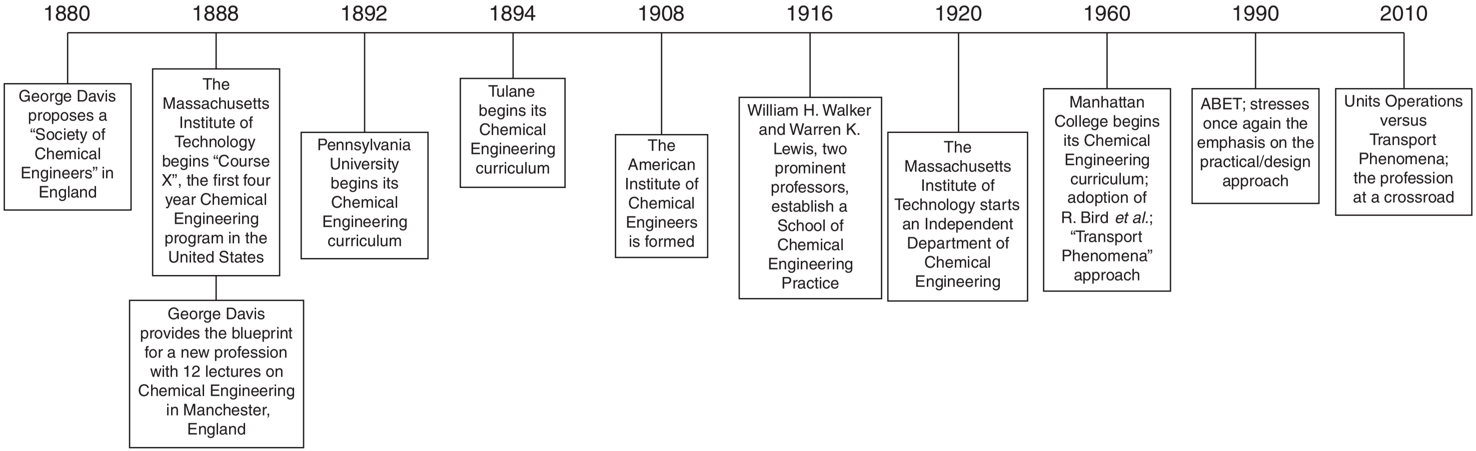

Figure 2.1 Chemical engineering time-line.

TRANSPORT PHENOMENA VS UNIT OPERATIONS

As indicated in the previous section, chemical engineering courses were originally based on the study of unit processes and/or industrial technologies. It soon became apparent that the changes produced in equipment from different industries were similar in nature (i.e., there was a commonality in the fluid flow operations in the petroleum industry as with the utility industry). These similar operations became known as the aforementioned Unit Operations. This approach to chemical engineering was promulgated in the Little report, as discussed earlier in the previous section, and to varying degrees and emphasis, has dominated the profession to this day.

The Unit Operations approach was adopted by the profession soon after its inception. During the many years since 1880 that the profession has been in existence as a branch of engineering, society's needs have changed tremendously and, in turn, so has chemical engineering.

The teaching of Unit Operations at the undergraduate level has remained relatively static since the publication of several early-to-mid 1900 texts. Prominent among these was one developed as a result of the recommendation of an advisory committee of more than a dozen educators and practicing engineers who recognized the need for a chemical engineering handbook. Dr. John H. Perry of Grasselli Chemical Co. was persuaded to undertake this tremendous compilation. The first edition of this classic work was published in 1934; the latest edition (eighth) was published in 2008. (The author of this text has served as an editor and author of the section on Environment Management for the past three editions). However, by the middle of the 20th century, there was a slow movement from the unit operation concept to a more theoretical treatment called transport phenomena. The focal point of this science was the rigorous mathematical description of all physical rate processes in terms of mass, heat, or momentum crossing boundaries. This approach took hold of the education/curriculum of the profession with the publication of the first edition of the Bird *et al.*(5) book. Some, including the author of this text, feel that this concept set the profession back several decades since graduating chemical engineers, in terms of training, were more applied physicists than traditional chemical engineers.

There has fortunately been a return to the traditional approach of chemical engineering in recent years, primarily due to the efforts of the Accreditation Board for Engineering and Technology (ABET). Detractors to this approach argue that this type of practical education experience provides the answers to 'what' and 'how' but not 'why' (i.e., a greater understanding of both physical and chemical processes). However, the reality is that nearly all practicing engineers are in no way presently involved with the 'why' questions; material normally covered here has been replaced, in part, with a new emphasis on solving design and open-ended problems. This approach is emphasized in this text.

One can qualitatively describe the differences between the two approaches discussed above. Both deal with the transfer of certain quantities (momentum, energy, and mass) from one point in a system to another. Momentum, energy, and mass are all conserved (see Chapter 4). As such, each quantity obeys the conservation law within a system:

$$\left\{\begin{matrix}\text{quantity}\\ \text{into}\\ \text{system}\end{matrix}\right\} - \left\{\begin{matrix}\text{quantity}\\ \text{out of}\\ \text{system}\end{matrix}\right\} + \left\{\begin{matrix}\text{quantity}\\ \text{generated in}\\ \text{system}\end{matrix}\right\} = \left\{\begin{matrix}\text{quantity}\\ \text{accumulated}\\ \text{in system}\end{matrix}\right\} \tag{2.1}$$

This equation may also be written on a time rate basis:

$$\left\{\begin{matrix}\text{rate}\\ \text{into}\\ \text{system}\end{matrix}\right\} - \left\{\begin{matrix}\text{rate}\\ \text{out of}\\ \text{system}\end{matrix}\right\} + \left\{\begin{matrix}\text{rate}\\ \text{generated in}\\ \text{system}\end{matrix}\right\} = \left\{\begin{matrix}\text{rate}\\ \text{accumulated}\\ \text{in system}\end{matrix}\right\} \tag{2.2}$$

The conservation law may be applied at the macroscopic, microscopic, or molecular level. One can best illustrate the differences in these methods with an example. Consider a system in which a fluid is flowing through a cylindrical tube (see Figure 2.2), and define the system as the fluid contained within the tube between points 1 and 2 at any time.

If one is interested in determining changes occurring at the inlet and outlet of the system, the conservation law is applied on a "macroscopic" level to the entire system. The resultant equation describes the overall changes occurring *to* the system (or equipment). This approach is usually applied in the Unit Operation (or its equivalent) courses, an approach which is highlighted in this text. The resulting equations are almost always algebraic.

In the microscopic approach, detailed information concerning the behavior within a system is required and this is occasionally requested of or by the engineer. The conservation law is then applied to a differential element within the system which is large compared to an individual molecule, but small compared to the entire system. The resulting equation is usually differential, and is then expanded via an integration to describe the behavior of the entire system. This has been defined as the transport phenomena approach.

The molecular approach involves the application of the conservation laws to individual molecules. This leads to a study of statistical and quantum mechanics—both of

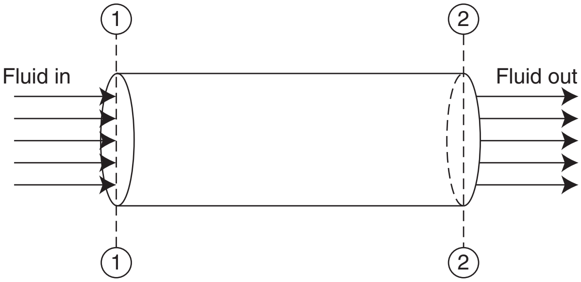

Figure 2.2 Flow through a cylinder.

which are beyond the scope of this text. In any case, the description of individual particles at the molecular level is of little value to the practicing engineer. However, the statistical averaging of molecular quantities in either a differential or finite element within a system can lead to a more meaningful description of the behavior of a system.

Both the microscopic and molecular approaches shed light on the physical reasons for the observed macroscopic phenomena. Ultimately, however, for the practicing engineer, these approaches may be valid but are akin to killing a fly with a machine gun. Developing and solving these equations (in spite of the advent of computer software packages) is typically not worth the trouble.

Traditionally, the applied mathematician has developed the differential equations describing the detailed behavior of systems by applying the appropriate conservation law to a differential element or shell within the system. Equations were derived with each new application. The engineer later removed the need for these tedious and error-prone derivations by developing a general set of equations that could be used to describe systems. These are referred to as the transport equations. In recent years, the trend toward expressing these equations in vector form has also gained momentum (no pun intended). However, the shell-balance approach has been retained in most texts, where the equations are presented in componential form—in three particular coordinate systems—rectangular, cylindrical, and spherical. The componential terms can be "lumped" together to produce a more concise equation in vector form. The vector equation can in turn, be re-expanded into other coordinate systems. This information is available in the literature.(5,6)

WHAT IS ENGINEERING?

A discussion on chemical engineering is again warranted before proceeding to the heat transfer material presented in this text. A reasonable question to ask is: What is Chemical Engineering? An outdated but once official definition provided by the American Institute of Chemical Engineers (AIChE) is:

> Chemical Engineering is that branch of engineering concerned with the development and application of manufacturing processes in which chemical or certain physical changes are involved. These processes may usually be resolved into a coordinated series of unit physical operation and chemical processes. The work of the chemical engineer is concerned primarily with the design, construction, and operation of equipment and plants in which these unit operations and processes are applied. Chemistry, physics, and mathematics are the underlying sciences of chemical engineering, and economics is its guide in practice.

The above definition has been appropriate up until a few decades ago since the profession grew out of the chemical industry. Today, that definition has changed. Although it is still based on chemical fundamentals and physical principles, these principles have been de-emphasized in order to allow the expansion of the profession to other areas (biotechnology, semiconductors, fuel cells, environment, etc.). These areas include environmental management, health and safety, computer applications, and economics and finance. This has led to many new definitions of chemical engineering, several of which are either too specific or too vague. A definition proposed by the author is simply "chemical engineers solve problems." This definition can be extended to all engineers and thus "engineers solve problems."

Obviously, the direction of the engineering profession, and chemical engineering in particular, has been a moving target over the past 75 years. For example, a distinguished AIChE panel in 1952 gave answers to the question: "Whither, chemical engineering as a science?" The panel concluded that the profession must avoid freezing concepts into a rigid discipline that leaves no room for growth and development. The very fluidity of chemical engineering must continue to be one of its most distinguishing aspects. In 1964, J. Hedrick of Cornell University (at an AIChE Tri-Section Symposium in Newark, NJ) posed the question "Will there still be a distinct profession of chemical engineering twenty years from now?" The dilemma has surfaced repeatedly in the past 50 years. More recently Theodore(7) addressed the issue; here is part of his comments:

> One of my goals is to keep in touch with students following graduation. What I have learned from graduates in the workforce is surprising—approximately 75% of them use little to nothing of what was taught in class. Stoichiometry? Sometimes. Unit operations? Sometimes. Kinetics? Not often. Thermodynamics? Rarely. Transport Phenomena? Forget about it. It is hard to deny that the chemical engineering curriculum is due for an overhaul.
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> The traditional chemical engineers who can design a heat exchanger, predict the performance of an adsorber, specify a pump, etc., have become a dying breed. What really hurts is that I consider myself in this category. Fortunately (or perhaps unfortunately), I'm in the twilight of my career.
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> Change won't come easy. Although several universities in the U.S. are pioneering new programs and course changes aimed at the chemical engineer of the furture, approval by the academic community is not unanimous. Rest assured that most educators will do everything in their power to protect their "turf".
>
> But change really does need to come. Our profession owes it to the students.

The main thrust of these comments can be applied to other engineering and science disciples.

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