4

TRANSPORT PHENOMENA VERSUS UNIT OPERATIONS

4.1 INTRODUCTION

As indicated in Chapter 1, 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 Unit Operations. This approach to chemical engineering was promulgated in the Little report as discussed earlier in Chapter 1 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 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 remained relatively static since the publication of several early-to-mid 1900 texts. 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

Fluid Flow for the Practicing Chemical Engineer. By J. Patrick Abulencia and Louis Theodore

first edition of the Bird *et al.* book.[1] Some, including both authors 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 that 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 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 (including chemical 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.

4.2 THE DIFFERENCES

This section attempts to 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. Three basic transport mechanisms are involved in a process. They are:

1. Radiation.
2. Convection.
3. Molecular diffusion.

The first mechanism, radiative transfer, arises due to wave motion and is not considered since it may be justifiably neglected in most engineering applications. Convective transfer occurs simply due to bulk motion. One may define molecular diffusion as the transport mechanism arising due to gradients. For example, momentum is transferred in the presence of a velocity gradient; energy in the form of heat is transferred due to a temperature gradient; mass is transferred in the presence of a concentration gradient. These molecular diffusion effects are described by phenomenological laws.

Momentum, energy, and mass are all conserved. As such, each quantity obeys the conservation law within a system:

$$\left\{\begin{matrix}\text{quantity}\\ \text{into}\\ \text{system}\end{matrix}\right\} - \left\{\begin{matrix}\text{quantity}\\ \text{out of}\\ \text{system}\end{matrix}\right\} + \left\{\begin{matrix}\text{quantity}\\ \text{generated in}\\ \text{system}\end{matrix}\right\} = \left\{\begin{matrix}\text{quantity}\\ \text{accumulated}\\ \text{in system}\end{matrix}\right\} \tag{4.1}$$

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

$$\left\{\begin{matrix}\text{rate}\\ \text{into}\\ \text{system}\end{matrix}\right\} - \left\{\begin{matrix}\text{rate}\\ \text{out of}\\ \text{system}\end{matrix}\right\} + \left\{\begin{matrix}\text{rate}\\ \text{generated in}\\ \text{system}\end{matrix}\right\} = \left\{\begin{matrix}\text{rate}\\ \text{accumulated}\\ \text{in system}\end{matrix}\right\} \tag{4.2}$$

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 Fig. 4.1) and define the system as the fluid contained with 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. 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 and 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 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 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.

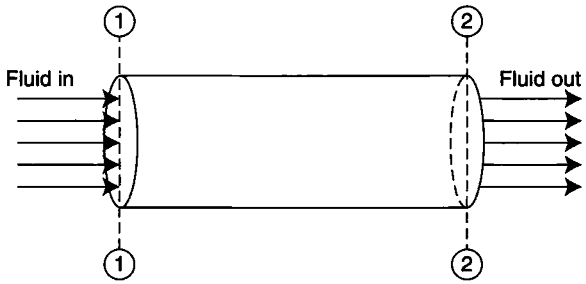

Figure 4.1 Flow through cylinder.

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 be in turn be re-expanded into other coordinate systems. This information is available in the literature.[2,3]

As noted above, the microscopic approach receives limited treatment in this text. It is introduced in the next chapter and again in Chapter 9 (Conservation Law for Momentum) and Chapter 14 (Turbulent Flow).

4.3 WHAT IS ENGINEERING?

A discussion on chemical engineering is again warranted before proceeding to the fluid flow 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 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 (hence the name of the topic and book) 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 (see Chapter 1). Today, that definition has changed. Although it is still based on chemical fundamentals and physical principles, these principles have been deemphasized in order to allow the expansion of the profession to other areas (biotechnology, semiconductors, fuel cells, environmental, 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 one of the authors is simply, "chemical engineers solve problems." This definition can be extended to all engineers and state "engineers solve problems."

REFERENCES

1. R. N. Bird, W. Stewart, and E. Lightfoot, "Transport Phenomena", John Wiley & Sons, Hoboken, NJ, 1960.
2. L. Theodore, "Transport Phenomena for Engineers", International Textbook Company, Scranton, PA, 1971 (with permission).
3. R. N. Bird, W. Stewart, and E. Lightfoot, "Transport Phenomena", 2nd edition, John Wiley & Sons, Hoboken, NJ, 2002.

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