# Chapter 2

# Transport Phenomena vs Unit Operations Approach

The history of Unit Operations is interesting. As indicated in the previous chapter, chemical engineering courses were originally based on the study of unit processes and/or industrial technologies. However, 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 mass transfer 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 discussed earlier, and has, with varying degrees and emphasis, dominated the profession to this day.

The Unit Operations approach was adopted by the profession soon after its inception. During the 130 years (since 1880) that the profession has been in existence as a branch of engineering, society's needs have changed tremendously and so has chemical engineering.

The teaching of Unit Operations at the undergraduate level has remained relatively unchanged 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* or, more simply, engineering science. The focal point of this science is the rigorous mathematical description of all physical rate processes in terms of mass, heat, or momentum crossing phase boundaries. This approach took hold of the education/curriculum of the profession with the publication of the 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 than traditional chemical engineers. There has fortunately been a return to the traditional approach to chemical engineering, primarily as a result of the efforts of ABET (Accreditation Board for Engineering and Technology). Detractors to this pragmatic approach argue that this type of theoretical education experience provides answers to what and how, but not necessarily why, i.e., it provides a greater understanding of both fundamental physical and chemical processes. However, in terms

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of reality, nearly all chemical engineers are now presently involved with the why questions. Therefore, 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.

The following paragraphs attempt to qualitatively describe the differences between the above two approaches. Both deal with the transfer of certain quantities (momentum, energy, and mass) from one point in a system to another. There are three basic transport mechanisms which can potentially be involved in a process. They are:

**1** Radiation

**2** Convection

**3** Molecular Diffusion

The first mechanism, radiative transfer, arises as a result of wave motion and is not considered, since it may be justifiably neglected in most engineering applications. The second mechanism, convective transfer, occurs simply because of bulk motion. The final mechanism, molecular diffusion, can be defined as the transport mechanism arising as a result of gradients. For example, momentum is transferred in the presence of a velocity gradient; energy in the form of heat is transferred because of a temperature gradient; and, mass is transferred in the presence of a concentration gradient. These molecular diffusion effects are described by phenomenological laws.[1]

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

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

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 Fig. 2.1) 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 a system, the conservation law is applied on a "macroscopic" level to the entire system. The resultant equation (usually algebraic) describes the overall changes occurring to the system (or equipment). This approach is usually applied in the Unit Operation

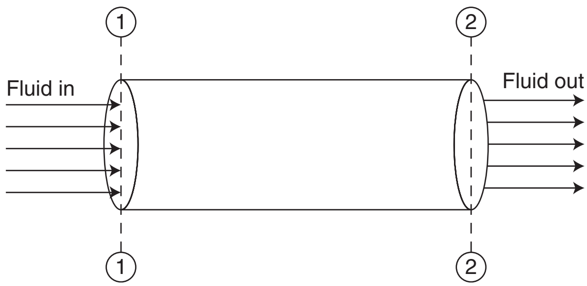


**Figure 2.1** Flow system.

(or its equivalent) courses, an approach which is highlighted in this text and its two companion texts.[2,3]

In the *microscopic/transport phenomena approach*, detailed information concerning the behavior within a system is required; this is occasionally requested of and by the engineer. The conservation law is then applied to a differential element within the system that is large compared to an individual molecule, but small compared to the entire system. The resulting differential equation is then expanded via an integration in order to describe the behavior of the entire system.

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 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 attempting to kill 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 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 have come to be referred to by many as the transport equations. In recent years, the trend toward expressing these equations in vector form has gained momentum (no pun intended). However, the shell-balance approach has been retained in most texts where the equations are presented in componential form, i.e., 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, re-expanded into other coordinate systems. This information is available in the literature.[1,4]

**ILLUSTRATIVE EXAMPLE 2.1**

Explain why the practicing engineer/scientist invariably employs the macroscopic approach in the solution of real world problems.

***SOLUTION*:** The macroscopic approach involves examining the relationship between changes occurring at the inlet and the outlet of a system. This approach attempts to identify and solve problems found in the real world, and is more straightforward than and preferable to the more involved microscopic approach. The microscopic approach, which requires an understanding of all internal variations taking place within the system that can lead up to an overall system result, simply may not be necessary. ■

## REFERENCES

1. R. Bird, W. Stewart, and E. Lightfoot, "*Transport Phenomena*," John Wiley & Sons, Hoboken, NJ, 1960.
2. L. Theodore, "*Heat Transfer for the Practicing Engineer*," John Wiley & Sons, Hoboken, NJ, 2011 (in preparation).
3. P. Abulencia and L. Theodore, "*Fluid Flow for the Practicing Engineer*," John Wiley & Sons, Hoboken, NJ, 2009.
4. L. Theodore, "*Introduction to Transport Phenomena*," International Textbook Co., Scranton, PA, 1970.

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