1 Introduction to process design

D.L. PYLE

Introduction

At the core of chemical engineering is design, frequently of continuous processes. A food process plant will consist of a series of process units, each of which carries out some specific job, such as mixing, fermentation, sterilization, or separation. Each of these units is designed using physical and chemical principles; later chapters of this book will consider the principles which underpin these designs. However, to produce an efficient process it is necessary to consider the whole process, to understand the way in which material moves around the plant and to calculate the heating and cooling duties needed.

Chemical engineers begin design by constructing a flowsheet for a plant, on which a Material Balance can be carried out to define all the flows in and out of the system and individual units. This balance enables a preliminary idea of the best flowsheet to be obtained; for example, if only 5% of the inputs in a process unit are actually used, then it will probably be necessary to add a recycle stream to return unreacted material to the unit. In addition to the mass balance, an estimate of the heating and cooling loads on the plant, the Thermal Balance, can be developed. Material and thermal balances can be carried out before going into detail about the sizes of individual units; the preliminary flowsheet incorporates all the key elements of the process without specifying the details of the design, such as the size of any pumps, pipes and heat exchangers needed.

This chapter introduces techniques for the analysis of flowsheets and processes which will be used throughout this book. It also introduces the key problem of food process engineering, of ensuring that the process is economically viable. The profitability of a given process is, in practice, very difficult to estimate. However, the use of ideas such as the net present value of a project can be used both to estimate the success of the project and to compare it to possible other investments. A series of examples are provided to illustrate the concepts developed in this chapter; these will be taken up and developed in depth in the rest of the book.

The aim of design is to arrive at a precise specification of all the material and energy requirements, and the equipment, pipework, instrumentation and control schemes necessary for a process to be constructed and operated efficiently, safely and economically. This involves consideration of the whole process and of the individual units that comprise it. The first stage in process design is to generate possible schemes that might meet the requirements of the process in question. This involves considering alternative **operations** (such as direct or indirect sterilization, filtration or centrifugation, co- or counter-current spray drying) and **sequences** of these operations. It results in a qualitative process description, which is usually presented as a schematic diagram, or flowsheet, of the whole process. For example, Fig. 1.1 shows a simplified outline of a hypothetical process for semi-batch extraction from a solid using supercritical carbon dioxide. In this case, the engineer would certainly consider other alternatives with a view to improving energy efficiency and process economics.

In many ways flowsheet development is the most creative part of the design process and the most difficult to pin down in terms of standard or rote procedures. Here, we won’t focus on this preliminary phase of overall process design, although we shall consider some alternatives, and how to evaluate them, on the basis of selected examples. First, however, consider how alternative flowsheets could be evaluated. The first point, clearly, is to determine whether the process is technically feasible. It may not be feasible for a variety of reasons: for example, one of the process operations might be fraught with difficulties, or require unrealistically large material or energy inputs. Invariably there will be several technically feasible options, but some will certainly be more efficient – in technical terms – than others, and in order to discriminate between them it is necessary, in the next stages of evaluation, to estimate the flows of materials and energy. A further stage in the appraisal process would be to consider the relative economic merits of the various alternatives. All these stages of process design and evaluation are quantitative, even if they do not involve very accurate calculations early on in the design process. Some of the methods that underpin these stages

Fig. 1.1 Simplified flowsheet of semi-batch extraction with supercritical carbon dioxide.