Chapter 18

Economics and Finance

INTRODUCTION

Chapter 18 is concerned with economics and finance. These two topics can ultimately dictate the decisions made by practicing engineers and their companies. As noted in the Introduction of Part Three, a company may decide that because of the rising price of the feedstock to a distillation column, they will explore the possibility of producing the raw material from a cheaper raw material. A decision will then be based on whether it makes sense economically in the short- and long-term. Furthermore, economic evaluations are a major part of process and plant design.

This chapter provides introductory material to this vast field within engineering. The next two sections are devoted to a discussion on the need for economic analyses and definitions. This is followed with an overview of accounting principles. The chapter concludes with Illustrative Examples in the Applications section.

Both the qualitative and quantitative viewpoint is emphasized in this chapter although it is realized that the broad subject of engineering economics cannot be fit into any rigid set of formulas. The material presented falls into roughly three parts: general principles, practical information, and applications. The presentation starts with the simplest situations and proceeds to more complicated formulations and techniques that may be employed if there are sufficient data available. Other texts referenced in the literature provide further details on the subject.

THE NEED FOR ECONOMIC ANALYSES

A company or individual hoping to increase profitability must carefully assess a range of investment opportunities and select the most profitable options from those available. Increasing competitiveness also requires that efforts need to be made to reduce the costs of existing processes. In order to accomplish this, engineers should be fully aware of not only technical factors but also economic factors, particularly those that have the largest effect on profitability.

In earlier years, engineers concentrated on the technical side of projects and left the financial studies to the economist. In effect, engineers involved in making

Mass Transfer Operations for the Practicing Engineer. By Louis Theodore and Francesco Ricci

estimates of the capital and operating costs have often left the overall economic analysis and investment decision-making to others. This approach is no longer acceptable.

Some engineers are not equipped to perform a financial and/or economic analysis. Furthermore, many engineers already working for companies have never taken courses in this area. This short-sighted attitude is surprising in a group of people who normally go to great lengths to obtain all the available technical data before making an assessment of a project or study. The attitude is even more surprising when one notes that data are readily available to enable an engineer to assess the prospects of both his/her own company and those of his/her particular industry.(1)

As noted above, the purpose of this chapter is to provide a working tool to assist the student or engineer in not only understanding economics and finance but also in applying technical information to the economic design and operation of processes and plants. The material to follow will often focus on industrial and/or plant applications. Hopefully, this approach will provide the reader with a better understanding of some of the fundamentals and principles.

Bridging the gap between theory and practice is often a matter of experience acquired over a number of years. Even then, methods developed from experience must all too often be re-evaluated in the light of changing economic conditions if optimum designs are to result. The approach presented here therefore represents an attempt to provide a consistent and reasonably concise method for the solution of these problems involving economic alternatives.(2)

The term *economic analysis* in engineering problems generally refers to calculations made to determine the conditions for realizing maximum financial return for a design or operation. The same general principles apply whether one is interested in the choice of alternatives for completing projects, in the design of plants so that the various components are economically proportioned, or in the economical operation of existing plants. General considerations that form the framework on which sound decisions must be made are often simple. Sometimes their application to the problems encountered in the development of a commercial enterprise involves too many intangibles to allow exact analysis; in that case, judgment must be intuitive. Often, however, such calculations may be made with a considerable degree of exactness. This chapter will attempt to develop a relatively concise method for applying these principles.

Concern with maximum financial return implies that the criterion for judging projects involved is profit. While this is usually true, there are many important objectives which, though aimed at ultimate profit increase, cannot be immediately evaluated in quantitative terms. Perhaps the most significant of these is the recent increased concern with environmental degradation and sustainability. Thus, there has been some tendency in recent years to regard management of commercial organizations as a profession with social obligations and responsibilities; considerations other than the profit motive may govern business decisions. However, these additional social objectives are, for the most part, often not inconsistent with the economic goal of satisfying human wants with the minimum effort. In fact, even in the operation of primarily non-profit organizations, it is still important to determine the effect of various policies on profit.(2)

The next section is devoted to definitions. This is followed with an overview of accounting principles and,finally, a section or applications.

DEFINITIONS

Before proceeding to the applications, it would be wise to provide the reader with certain key definitions in the field. Fourteen (there are of course more) concepts that often come into play in an economic analysis are given below. The definitions have been drawn from the literature.[1–3] Note that some overlap of notations, e.g., P, exists in the material to follow.

Simple Interest

The term interest can be defined as the money paid for the use of money. It is also referred to as the value or worth of money. Two terms of concern are simple interest and compound interest. Simple interest is always computed on the original principal. The basic formula to employ in simple interest calculations is:

$$S = P(1 + ni) \tag{18.1}$$

where P = original principal
n = time in years
i = annual interest rate
S = sum of interest and principal after n years

Normally, the interest period is one year, in which case i is referred to as the effective interest rate.

Compound Interest

Unlike simple interest, with compound interest, interest is added periodically to the original principal. The term conversion or compounding of interest simply refers to the addition of interest to the principal. The interest period or conversion period in compound interest calculations is the time interval between successive conversions of interest and the interest period is the ratio of the stated annual rate to this number of interest periods in one year. Thus, if the given interest rate is 10% compounded semi-annually, the interest period is 6 months and the interest rate per interest period is 5%. Alternately, if the given interest rate is 10% compounded quarterly, then the interest period is 3 months and the interest rate per interest period is 2.5%. One should always assume the interest is compounded annually unless otherwise stated. The basic formula to employ for compound interest is:

$$S = P(1 + i)^n \tag{18.2}$$

If interest payments become due m times per year at compound interest, $(m)(n)$ payments are required in n years. A nominal annual interest rate, i', may be defined by:

$$S = P\left(1 + \frac{i'}{m}\right)^{mn} \tag{18.3}$$

In this case, the effective annual interest, i, is:

$$i = \left(1 + \frac{i'}{m}\right)^{m} - 1 \tag{18.4}$$

In the limit (as m approaches infinity), such payments may be considered to be required at infinitesimally short intervals, in which case, the interest is said to be compounded continuously. Numerically, the difference between continuous and annual compounding is small. However, annual compounding may be significant when applied to very large sums of money.

Present Worth

The present worth is the current value of a sum of money due at time n and at interest rate i. This equation is the compound interest equation solved for the present worth term, P

$$P = S(1 + i)^{-n} \tag{18.5}$$

Evaluation of Sums of Money

The value of a sum of money changes with time because of interest considerations. \$1000 today, \$1000 ten years from now, and \$1000 ten years ago all have different meanings when interest is taken into account. \$1000 today would be worth more ten years from now because of the interest that could be accumulated in the interim. *On the other hand, \$1000 today would have been worth less ten years ago because a smaller sum of money could have been invested then so as to yield \$1000 today.* Therefore, one must refer to the date as well as the sum of money.

Summarizing, evaluating single sums of money requires multiplying by $(1 + i)^n$ if the required date of evaluation is after the date associated with the obligation or multiplying by $(1 + i)^{-n}$ if the required date of evaluation is before the date associated with the obligation. The term n is always the time in periods between the date associated with the obligation and the date of evaluation.

The evaluation of sums of money may be applied to the evaluation of a uniform series of payments. A uniform series is a series of equal payments made at equal intervals. Suppose R is invested at the end of every interest period for n periods. The total value of all these payments, S, as of the date of the last payment, may be calculated from the equation

$$S = R[(1 + i)^n - 1]/i \tag{18.6}$$

The term S is then called the amount of the uniform series.

Depreciation

The term depreciation refers to the decrease in the value of an asset. Two approaches that can be employed are the straight line and sinking fund method. In the straight line method of depreciation, the value of the asset is decreased each year by a constant amount. The annual depreciation amount, D, is given by

$$D = (\text{Original cost} - \text{Salvage value})/(\text{Estimated life in years}) \tag{18.7}$$

In the sinking fund method of depreciation, the value of the asset is determined by first assuming that a sinking fund consisting of uniform annual payments had been set up for the purpose of replacing the asset at the end of its estimated life. The uniform annual payment (UAP) may be calculated from the equation

$$\text{UAP} = (\text{Original cost} - \text{Salvage value})(\text{SFDF})$$

where SFDF is the sinking fund deposit factor and is given by

$$\text{SFDF} = i/[(1+i)^n - 1] \tag{18.8}$$

The value of the asset at any time is estimated to be the difference between the original cost and the amount that would have accumulated in the sinking fund. The amount accumulated in the sinking fund is obtained by multiplying the SFDF by the compound amount factor (CAF) where

$$\text{CAF} = [(1+i)^n - 1]/i \tag{18.9}$$

Fabricated Equipment Cost Index

A simple process is available to estimate the equipment cost from past cost data. The method consists of adjusting the earlier cost data to present values using factors that correct for inflation. A number of such indices are available; one of the most commonly used is the fabricated equipment cost index (FECI).

$$\text{Cost}_{\text{year B}} = \text{Cost}_{\text{year A}}\left(\frac{\text{FECI}_{\text{year B}}}{\text{FECI}_{\text{year A}}}\right) \tag{18.10}$$

Given the cost and FECI for year A, as well as the FECI for year B, the cost of the equipment in year B can be estimated.

Capital Recovery Factor

In comparing alternative mass transfer processes or different options for a particular process from an economic point-of-view, one recommended procedure to follow is that the total capital cost can be converted to an annual basis by distributing it over the projected lifetime of the facility. The sum of both the annualized capital cost (ACC), including installation, and the annual operating cost (AOC), is called the total annualized cost (TAC) for the project or facility. The economic merit of the proposed facility, process, or scheme can be examined once the total annual cost is available.

The conversion of the total capital cost (TCC) to an ACC requires the determination of an economic parameter known as the capital recovery factor (CRF). This parameter can be found in any standard economics textbook or calculated directly from the following equation:

$$\mathrm{CRF} = i(1+i)^n/[(1+i)^n - 1] \tag{18.11}$$

where n = projected lifetime of the system

i = annual interest rate (as a fraction)

The CRF is a positive, fractional number. Once this factor has been determined, the ACC can be calculated from the following equation:

$$\mathrm{ACC} = (\mathrm{TCC})(\mathrm{CRF}) \tag{18.12}$$

The annualized capital cost reflects the cost associated with recovering the initial capital expenditure over the depreciable life of the system.

Present Net Worth

There are various approaches that may be employed in the economic selection of the best of several alternatives. A single sum is calculated that would provide for all expenditures over a common time period for each alternative in the present net worth (PNW) method of economic selection. The alternative having the least PNW of expenditures is selected as the most economical. The equation to employ is

$$\mathrm{PNW} = \mathrm{CC} + \mathrm{PN} + \mathrm{PWD} - \mathrm{PWS} \tag{18.13}$$

where CC = capital cost

PN = future renewals

PWD = other disbursements

PWS = salvage value

If the estimated lifetimes differ for the various alternatives, employ a period of time equal to the least common multiple of the different lifetimes for renewal purposes.

Perpetual Life

Capitalized cost can be viewed as present worth under the assumption of perpetual life. Computing capitalized cost involves, in a very real sense, finding the present worth of an infinite series of payments. To obtain the present worth of an infinite series of payments of $\$R$ at the end of each interest period forever, one needs simply to divide R by i, where i is the interest rate per interest period. Thus, to determine what sum of money, P, would have to be invested at 8.0% to provide payments of \$100,000 at the end of each year forever, P would have to be such that the interest on it each period would be \$100,000. Withdrawal of the interest at the end of each period would leave the original sum intact to again draw \$100,000 interest at the end of the next period. For this example,

$$\begin{aligned} P &= 100{,}000/0.08 \\ &= \$1{,}250{,}000 \end{aligned}$$

The \$1,250,000 would be the present worth of an infinite series of payments of \$100,000 at the end of each year forever, assuming money is worth 8%.

To determine the present worth of an infinite series of payments of \$$R$ at the end of each n periods forever, first multiply by the SFDF to convert to an equivalent single period payment and then divide by i to obtain the present worth.

Break-Even Point

From an economic point-of-view, the break-even point of a process operation is defined as that condition when the costs (C) exactly balance the income (I). The profit (PR) is therefore,

$$PR = I - C \tag{18.14}$$

At break-even, the profit is zero.

Approximate Rate of Return

Rate of return can be viewed as the interest that will make the present worth of net receipts equal to the investment. The approximate rate of return (ARR) (defined by some as p), may be estimated from the equation below:

$$p = \text{ARR} = \text{Average annual profit or earnings/Initial total investment} \tag{18.15}$$

To determine the average annual profit, simply divide the difference between the total money receipts (income) and the total money disbursements (expenses) by the number of years in the period of the investment.

Exact Rate of Return

Using the approximate rate of return as a guide, one can generate the exact rate of return (ERR). This is usually obtained by trial-and-error and an interpolation calculation of the rate of interest that makes the present worth of net receipts equal to the investment. The approximate rate of return will tend to overestimate the exact rate of return when all or a large part of the receipts occur at the end of a period of investment.

The approximate rate will tend to underestimate the exact rate when the salvage value is zero and also when the salvage value is a high percentage of the investment.

Bonds

A bond is a written promise to pay both a certain sum of money (redemption price) at a future date (redemption date) and equal interest payments at equal intervals in the interim. The holder of a \$1000, 5% bond, redeemable at 105 (bond prices are listed without the last zero) in 10 years, with interest payable semi-annually would be entitled to semi-annual payments of \$1000 × 0.025 or \$25 for 10 years and 105% of \$1000, that is \$1050, at the end of 10 years when the bond is redeemed.

The interest payment on a bond is found by multiplying the face value of the bond by the bond interest rate per period. From above, the face value is \$1000 and the bond interest rate per period is 0.025. Therefore, the periodic interest payment is \$25. Redeemable at 105 means that the redemption price is 105% (1.05) of the face value of the bond.

The purchase price of a bond depends on the yield rate, i.e., the actual rate of return on the investment represented by the bond purchase. Therefore, the purchase price of a bond is the present worth of the redemption price plus the present worth of future interest payments, all computed at the yield rate. The bond purchase price formula is:

$$V = C(1+i)^{-n} + R[1-(1+i)^{-n}]/i \tag{18.16}$$

where V = purchase price
C = redemption price
R = periodic interest payment
n = time in periods to maturity
i = yield rate

Incremental Cost

By definition, the average unit increment cost is the increase in cost divided by the increase in production. Only those cost factors that vary with production can affect the average unit increment cost. In problems involving decisions as to whether to stay in production or temporarily shut down, the average unit increment cost may be compared with the unit increment cost or the unit selling price.

PRINCIPLES OF ACCOUNTING[4]

Accounting is the science of recording business transactions in a systematic manner. Financial statements are both the basis for and the result of management decisions.

Such statements can tell a manager or an engineer a great deal about a company, provided that one can interpret the information correctly.

Since a fair allocation of costs requires considerable technical knowledge of operations in the chemical process industries, a close liaison between the senior process engineers and the accountants in a company is desirable. Indeed, the success of a company depends on a combination of financial, technical, and managerial skills.

Accounting is also the language of business, and the different departments of management use it to communicate within a broad context of financial and cost terms. The engineer who does not take the trouble to learn the language of accountancy denies oneself the most important means available for communicating with top management. He/she may be thought by them to lack business acumen. Some engineers have only themselves to blame for their lowly status within the company hierarchy since they seem determined to displace themselves from business realities behind the screen of their specialized technical expertise. However, more and more engineers are becoming involved in decisions that are business related.

Engineers involved in feasibility studies and detailed process evaluations are dependent for financial information on the company accountants, especially for information on the way the company intends to allocate its overhead costs. It is vital that the engineer should correctly interpret such information and that he/she can, if necessary, make the accountant understand the effect of the chosen method of allocation.

The method of allocating overheads can seriously affect the assigned costs of a project and, hence, the apparent cash flows for that project. Since these cash flows are often used to assess profitability by such methods as the NPV (net present value), unfair allocation of overhead costs can result in a wrong choice between alternative projects.

In addition to understanding the principles of accountancy and obtaining a working knowledge of its practical techniques, the engineer should be aware of possible inaccuracies of accounting information in the same way that he/she allows for errors in any technical data.

At first acquaintance, the language of accountancy appears illogical to most engineers. Although the accountant normally expresses information in tabular form, the basis of all practice can be simply expressed by:

$$\text{Capital} = \text{Assets} - \text{Liabilities} \tag{18.17}$$

or

$$\text{Assets} = \text{Capital} + \text{Liabilities} \tag{18.18}$$

Capital, often referred to as net worth, is the money value of the business, since assets are the money values of things the business owns while liabilities are the money value of the things the business owes.

Most engineers have great difficulty in thinking of capital (also known as ownership) as a liability. This is easily overcome once it is realized that a business is a legal entity in its own right, owing money to the individuals who own it. This realization is absolutely essential when considering large companies with stockholders, and is used for consistency even for sole ownerships and partnerships. If a person, say FR, puts up \$10,000 capital to start a business, then that business has a liability to repay \$10,000 to that person.

It is even more difficult to think of profit as being a liability. Profit is the increase in money available for distribution to the owners and effectively represents the interest obtained on the capital. If the profit is not distributed, it represents an increase in capital by the normal concept of compound interest. Thus, if the business makes a profit of \$5000, the liability is increased to \$15,000. With this concept in mind, Equation (18.18) can be expanded to:

$$\text{Assets} = \text{Capital} + \text{Liabilities} + \text{Profit} \tag{18.19}$$

where the capital is considered as the cash investment in the business and is distinguished from the resultant profit in the same way that principal and interest are separated.

Profit (as referred to above) is the difference between the total cash revenue from sales and the total of all costs and other expenses incurred in making those sales. With this definition, Equation (18.19) can be further expanded to:

$$\begin{aligned}\text{Assets} + \text{Expenses} = \text{Capital} &+ \text{Liabilities} + \text{Profit} \\ &+ \text{Revenue from sales}\end{aligned} \tag{18.20}$$

Some engineers have the greatest difficulty in regarding an expense as being equivalent to an asset, as is implied by Equation (18.20). However, consider FR's earnings. During the period in which he made a profit of \$5000, his total expenses excluding his earnings were \$8000. If he assessed the worth of his labor to the business at \$12,000, then the revenue required from sales would be \$25,000. Effectively, FR has a personal income of \$17,000 in the year, but he has apportioned it to the business as \$12,000 expense for his labor and \$5000 return on his capital. In larger businesses, there will also be those who receive salaries but do not hold stock and therefore, receive no profits, and stockholders who receive profits but no salaries. Thus, the difference between expenses and profits is very practical.

The period covered by the published accounts of a company is usually one year, but the details from which these accounts are compiled are often entered daily in a journal. The journal is a chronological listing of every transaction of the business, with details of the corresponding income or expenditure. For the smallest businesses, this may provide sufficient documentation but, in most cases, the unsystematic nature of the journal can lead to computational errors. Therefore, the usual practice is to keep accounts that are listings of transactions related to a specific topic such as "Purchase of Distillation Crude." This account would list the cost of each purchase of crude oil, together with the date of purchase, as extracted from the journal.

The traditional work of accountants has been to prepare balance sheets and income statements. Nowadays, accountants are becoming increasingly concerned with forward planning. Modern accountancy can roughly be divided into two branches: financial accountancy and management or cost accountancy.

Financial accountancy is concerned with stewardship. This involves the preparation of balance sheets and income statements that represent the interest of stockholders and are consistent with the existing legal requirements. Taxation is an important element of financial accounting.

Management accounting is concerned with decision-making and control. This is the branch of accountancy closest to the interest of most process engineers. Management accounting is concerned with standard costing, budgetary control, and investment decisions.

Accounting statements only present facts that can be expressed in financial terms. They do not indicate whether a company is developing new products that will ensure a sound business future. A company may have impressive current financial statements and yet may be heading for bankruptcy in a few years' time if provision is not being made for the introduction of sufficient new products or services.

APPLICATIONS

The remainder of the chapter is devoted to Illustrative Examples, many of which contain technical developmental material. A good number of these mass transfer related applications have been drawn from the National Science Foundation (NSF) literature[4–8] and two other key sources.[9,10]

ILLUSTRATIVE EXAMPLE 18.1

A plant manager spends \$10,000 on new packing for a tower that recovers a valuable product in a liquid stream from a distillation column. The manager decides to depreciate the equipment at \$1430/yr (7-yr straight-line method depreciation) and estimates that the equipment will generate \$1500/yr in annual profit. Define the commonly accepted formula for payout time and calculate the payout time for this system.

***SOLUTION*:** The payout time is calculated as the fixed capital investment divided by the sum of the annual profit plus the annual depreciation

$$\text{Payout time} = \frac{\text{Fixed capital investment}}{\text{Annual profit} + \text{Annual depreciation}}$$

When the formula is applied to the data, the following result is obtained:

$$\begin{aligned}\text{Payout time} &= \frac{\$10{,}000}{\$1500 + \$1430}\\ &= 3.44\ \text{yr}\end{aligned}$$

■

ILLUSTRATIVE EXAMPLE 18.2

A mass transfer process emits 50,000 acfm of gas containing metal particulate at a loading of 2.0 gr/ft^3. A particulate recovery device is employed for particle capture and the metal captured from the unit is worth \$0.03/lb. Experimental data have shown that the collection efficiency, E, is related to the system pressure drop, ΔP, by the formula:

$$E = \frac{\Delta P}{\Delta P + 15.0}$$

where E = fractional collection efficiency

ΔP = pressure drop $\mathrm{lb_f/ft^2}$

If the overall fan is 55% efficient (overall) and electric power costs \$0.18/kWh, at what collection efficiency is the cost of power equal to the value of the recovered material? What is the pressure drop in inches of water (in. H_2O) at this condition?

***SOLUTION*:** The value of the recovered material (RV) may be expressed in terms of the collection efficiency E, the volumetric flow rate q, the inlet metal loading w, and the value of the metal (MV):

$$\mathrm{RV} = (q)(w)(\mathrm{MV})(E)$$

Substituting yields

$$\mathrm{RV} = \left(\frac{50{,}000\ \mathrm{ft^3}}{\mathrm{min}}\right)\left(\frac{2.0\ \mathrm{gr}}{\mathrm{ft^3}}\right)\left(\frac{1\ \mathrm{lb}}{7000\ \mathrm{gr}}\right)\left(\frac{0.03\$}{\mathrm{lb}}\right)(E) = 0.429E\ \$/\mathrm{min}$$

The recovered value can be expressed in terms of pressure drop by replacing E by ΔP:

$$\mathrm{RV} = \frac{(0.429)(\Delta P)}{\Delta P + 15.0}\ \$/\mathrm{min}$$

The cost of power (CP) in terms of ΔP, q, the cost of electricity (CE) and the fan efficiency, E_f, is

$$\mathrm{CP} = (q)(\Delta P)(\mathrm{CE})/(E_f)$$

Substitution yields

$$\mathrm{CP} = \left(\frac{50{,}000\ \mathrm{ft^3}}{\mathrm{min}}\right)\left(\frac{\Delta P\ \mathrm{lb_f}}{\mathrm{ft^2}}\right)\left(\frac{0.18\$}{\mathrm{kWh}}\right)\left(\frac{1\ \mathrm{min}\cdot\mathrm{kW}}{44{,}200\ \mathrm{ft}\cdot\mathrm{lb_r}}\right)\left(\frac{1}{0.55}\right)\left(\frac{1\ \mathrm{h}}{60\ \mathrm{min}}\right)$$

$$= 0.006\Delta P\ \$/\mathrm{min}$$

The pressure drop at which the cost of power is equal to the value of the recovered material is found by equating RV with CP:

$$\mathrm{RV} = \mathrm{CP}$$

Solving gives

$$\begin{aligned}\Delta P &= 66.5\ \mathrm{lb_f/ft^2}\\ &= 12.8\ \mathrm{in.}\ \mathrm{H_2O}\end{aligned}$$

Figure 18.1 shows the variation of RV, CP, and profit with pressure drop.

The collection efficiency corresponding to the above calculated ΔP is

$$\begin{aligned}E &= \frac{\Delta P}{\Delta P + 15.0}\\ &= \frac{66.5}{66.5 + 15.0}\\ &= 0.82\\ &= 82.0\%\end{aligned}$$

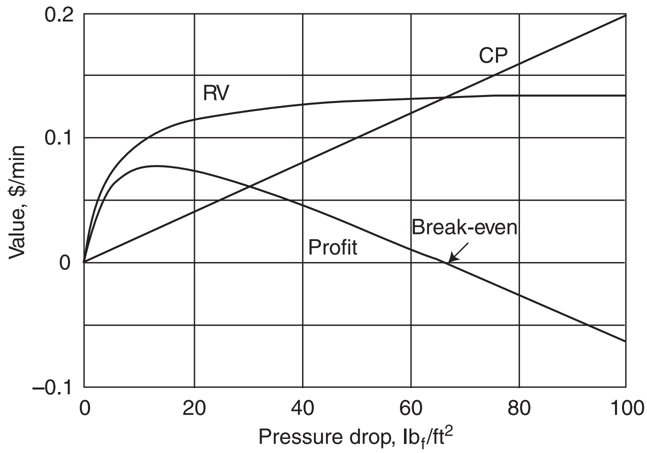

Figure 18.1 Profit as a function of pressure drop.

The reader should note that operating below this efficiency (or the corresponding pressure drop) will produce a profit; operating above this value leads to a loss.

The operating condition for maximum profit can be estimated from Figure 18.1. Calculating this value is left as an exercise for the reader. [*Hint:* Set the first derivative of the profit (i.e., RV − CP) with respect to ΔP equal to zero. The answer is 13.9 lb_f/ft^2.] ■

ILLUSTRATIVE EXAMPLE 18.3

Three different mass transfer devices are available for the recovery of a valuable chemical from a stream. The service life is 10 years for each device. Their capital and annual operating costs are shown in Table 18.1. Which is the most economical unit? Employ a straight-line depreciation method of analysis.

***SOLUTION*:** To select the most economical recovery device, a comparison can be performed among the three units based on the total annualized cost (TAC). Table 18.2 can be used to simplify these calculations.

A comparison among units A, B, and C indicates that unit C has the lowest TAC and should be selected as the most economical unit of the three being evaluated. A similar result would be obtained if a return on investment (ROI) method of analysis were employed. ■

Table 18.1 Initial and Operating Cost

Device	Initial cost	Annual operating cost	Salvage value in year 10
A	\$300,000	\$50,000	0
B	\$400,000	\$35,000	0
C	\$450,000	\$25,000	0

Table 18.2 Total Annual Cost

Unit	A	B	C
Capital investment	\$300,000	\$400,000	\$450,000
Depreciation	\$30,000	\$40,000	\$45,000
Operating costs	\$50,000	\$35,000	\$25,000
Total annual cost	\$80,000	\$75,000	\$70,000

ILLUSTRATIVE EXAMPLE 18.4

As noted earlier, the break-even point of a process operation is defined as that condition when the costs (C) exactly balance the income (I). The profit (P) is therefore $P = I - C$. At break-even, the profit is zero.

The cost and income (in dollars) for a mass transfer operation are given by the following equations:

$$I = \$60{,}000 + 0.021N$$
$$C = \$78{,}000 + 0.008N$$

where N is the yearly production units of mass of the chemical being manufactured.

Calculate the break-even point for this operation.

***SOLUTION*:** Write the equation relating C to I. Note that at break-even operation, $P = 0$.

$$I = C$$

Substitute for C and I in terms of N:

$$\$60{,}000 + 0.021N = \$78{,}000 + 0.008N$$

Solving for N at the break-even point:

$$N = 1{,}384{,}600$$

Calculating the cost at the break-even point:

$$\begin{aligned} C &= \$78{,}000 + 0.008N \\ &= \$78{,}000 + 0.008(1{,}384{,}600) \\ &= \$89{,}077 \end{aligned}$$

The reader should note that as N decreases below 1,384,600 units of mass, P is negative (there is a loss). Higher values of N lead to a profit. ■

ILLUSTRATIVE EXAMPLE 18.5

A small packed absorption tower is being designed to remove ammonia from air by scrubbing with water at 68°F and one atmosphere. It was decided that either 1 inch Raschig rings or 1 inch

Tellerettes will be used as the packing in the tower. The value of N_{OG} is 6.0 for either packing, but H_{OG} is 2.5 ft for Raschig rings and 1.0 ft for the Tellerettes. The cost of 1-inch Raschig rings is $\$7.56/\mathrm{ft}^3$ and for Tellerettes is $\$26.40/\mathrm{ft}^3$. The installed cost of the tower shell is \$83 per foot of tower height. Determine which of the packings will be the more economical for the system. Assume a tower diameter of 20 inches for both cases.

***SOLUTION*:** Calculate the required packing height, Z (ft), for a Raschig ring (RR) tower:

$$\begin{aligned} Z(\mathrm{RR}) &= N_{OG}H_{OG} \\ &= (6.0)(2.5) \\ &= 15.0 \text{ ft} \end{aligned}$$

Calculate the RR packed volume in ft^3 and the packing cost PC:

$$\begin{aligned} V(\mathrm{RR}) &= (\pi D^2/4)(Z) \\ &= (\pi/4)(20/12)^2(15) \\ &= 32.7 \text{ ft}^3 \\ PC(\mathrm{RR}) &= (32.7)(7.56) \\ &= \$247 \end{aligned}$$

Calculate the RR tower shell cost TC in \$:

$$\begin{aligned} TC(\mathrm{RR}) &= (15)(83) \\ &= \$1245 \end{aligned}$$

Calculate the total TCC cost of the RR tower:

$$\begin{aligned} TCC(\mathrm{RR}) &= 247 + 1245 \\ &= \$1492 \end{aligned}$$

Repeat the calculation for the required packing height, Z (ft), for a Tellerette (T) tower:

$$\begin{aligned} Z(\mathrm{T}) &= N_{OG}H_{OG} \\ &= (6.0)(1.0) \\ &= 6.0 \text{ ft} \\ V(\mathrm{T}) &= (\pi/4)(20/12)^2(6.0) \\ &= 13.1 \text{ ft}^3 \\ PC(\mathrm{T}) &= (26.40)(13.1) \\ &= \$346 \\ TC(\mathrm{T}) &= (83)(6.0) \\ &= \$498 \\ TCC(\mathrm{T}) &= 346 + 498 \\ &= \$844 \end{aligned}$$

The cost of a Raschig ring tower is 1.77 times the cost of a Tellerette packed tower in this service. Select the Tellerette tower. ■

ILLUSTRATIVE EXAMPLE 18.6

An adsorber cost \$852,644 in 1982. A company intends to install a similar type of unit in its facility in 2010. Estimate the cost of the new adsorber. If the total (direct plus indirect) installation cost is 60% of the adsorber cost, what is the annualized capital cost of this unit? The expected life of the unit is 10 years. Assume an interest rate of 10%.

Data: 1982 FECI = 306.2
2010 FECI = 418.2 (estimated)

***SOLUTION*:** Estimate the capital cost, CC, of the adsorber in 2010:

$$\begin{aligned}\text{Cost}_{2010} &= \text{Cost}_{1982}(2010\ \text{FECI}/1982\ \text{FECI})\\ \text{CC} &= (852{,}644)(418.2/306.2)\\ &= \$1{,}165{,}000\end{aligned}$$

Calculate the installation cost, IC:

$$\begin{aligned}\text{IC} &= (0.60)(1{,}165{,}000)\\ &= \$698{,}700\end{aligned}$$

Calculate the total capital cost, TCC:

$$\begin{aligned}\text{TCC} &= 1{,}165{,}000 + 698{,}700\\ &= \$1{,}863{,}700\end{aligned}$$

Obtain the capital recovery factor, CRF:

$$\begin{aligned}\text{CRF} &= i(1+i)^n/[(1+i)^n - 1]; \quad i = 0.1 \quad \text{and} \quad n = 10\\ &= (0.1)(1.1)^{10}/[(1.1)^{10} - 1]\\ &= 0.16275\end{aligned}$$

Finally, calculate the annualized capital cost, ACC, of the adsorber in \$/yr:

$$\begin{aligned}\text{ACC} &= (\text{TCC})(\text{CRF})\\ &= (1{,}863{,}700)(0.16275)\\ &= 303{,}300\ \$/\text{yr}\end{aligned}$$

■

ILLUSTRATIVE EXAMPLE 18.7

Prior to being processed in an adsorber, a 200,000 acfm stream of particulate contaminated air is to be treated using one of three devices: an electrostatic precipitator, a venturi scrubber, or a baghouse. The data contained in Table 18.3 were obtained from a reliable vendor. Which air pollution control device should be selected for this operation?

Table 18.3 Economic Data for Illustrative Example 18.7

	ESP	Venturi scrubber	Baghouse
Total capital cost	\$17.5/acfm	\$14.0/acfm	\$16.0/acfm
Operating cost	\$0.30/acfm-yr	\$0.35/acfm-yr	\$0.40/acfm-yr
Maintenance cost	\$120,000/yr	\$150,000/yr	\$130,000/yr
Equipment lifetime	10 yr	10 yr	12 yr
Interest	10%	10%	10%

***SOLUTION*:** Obtain the total capital costs, TCC, for each control device by multiplying by the acfm:

$$\begin{aligned}\text{TCC(ESP)} &= (200{,}000)(17.5)\\ &= \$3{,}500{,}000\\ \text{TCC(VEN)} &= (200{,}000)(14.0)\\ &= \$2{,}800{,}000\\ \text{TCC(BAG)} &= (200{,}000)(16.0)\\ &= \$3{,}200{,}000\end{aligned}$$

Calculate the capital recovery factor for each control device:

$$\text{CRF} = (i)(1+i)^n/[(1+i)^n - 1]$$

$$\begin{aligned}\text{CRF(ESP)} &= (0.1)(1+0.1)^{10}/[(1+0.1)^n - 1]\\ &= 0.16275\\ \text{CRF(VEN)} &= 0.16275\\ \text{CRF(BAG)} &= 0.14676\end{aligned}$$

Calculate the annual capital cost, ACC, for each control device:

$$\begin{aligned}\text{ACC(ESP)} &= (3{,}500{,}000)(0.16275)\\ &= 569{,}625\ \$/\text{yr}\\ \text{ACC(VEN)} &= (2{,}800{,}000)(0.16275)\\ &= 455{,}700\ \$/\text{yr}\\ \text{ACC(BAG)} &= (3{,}200{,}000)(0.14676)\\ &= 469{,}632\ \$/\text{yr}\end{aligned}$$

Calculate the annual operating cost, AOC, for each device:

$$\begin{aligned}\text{AOC(ESP)} &= (200{,}000)(0.30)\\ &= 60{,}000\ \$/\text{yr}\\ \text{AOC(VEN)} &= (200{,}000)(0.35)\\ &= 70{,}000\ \$/\text{yr}\\ \text{AOC(BAG)} &= (200{,}000)(0.40)\\ &= 80{,}000\ \$/\text{yr}\end{aligned}$$

Calculate the total annual cost, TAC, for each device. See Table 18.4.

Table 18.4 Total Annual Cost

	ESP	VEN	BAG
ACC ($/yr)	569,600	455,700	469,600
AOC ($/yr)	60,000	70,000	80,000
AMC ($/yr)	120,000	150,000	130,000
TAC ($/yr)	749,600	675,700	679,600

Finally, select the most economically attractive control device. According to this analysis, either the venturi scrubber or the baghouse is the most attractive economically; the difference in the TAC is marginal. ■

ILLUSTRATIVE EXAMPLE 18.8

Plans are underway to construct and operate some type of mass transfer unit that will serve to purify a product stream from a chemical reactor. The company is still undecided as to whether to install a distillation column or an extraction unit. The extraction unit is less expensive to purchase and operate than a comparable distillation system, primarily because of energy costs. However, projected income from the distillation unit is higher since it will handle a larger quantity of process liquid and provide a purer product. Based on the economic and financial data given in Table 18.5, select the mass transfer unit that will yield the higher annual profit. Calculations should be based on an interest rate of 12% and a process lifetime of 12 years for both units.

***SOLUTION*:** Calculate the capital recovery factor, CRF:

$$\begin{aligned} \text{CRF} &= (0.12)(1+0.12)^{12}/[(1+0.12)^{12}-1] \\ &= 0.1614 \end{aligned}$$

Determine the annual capital and installation costs for the extraction (EXT) unit:

$$\begin{aligned} \text{COST(EXT)} &= (2{,}625{,}000 + 1{,}575{,}000)(0.1614) \\ &= \$677{,}880/\text{yr} \end{aligned}$$

Table 18.5 Economic Data for Illustrative Example 18.8

Costs/credits	Extraction	Distillation
Mass transfer unit	$750,000	$800,000
Peripherals	$1,875,000	$2,175,000
Total capital	$2,625,000	$2,975,000
Installation	$1,575,000	$1,700,000
Operation	$400,000/yr	$550,000/yr
Maintenance	$650,000/yr	$775,000/yr
Income	$2,000,000/yr	$2,500,000/yr

Table 18.6 Cost Analysis

	Extraction	Distillation
Total installed ($/yr)	678,000	755,000
Operation ($/yr)	400,000	550,000
Maintenance ($/yr)	650,000	775,000
Total annual cost ($/yr)	1,728,000	2,080,000
Income credit ($/yr)	2,000,000	2,500,000

Determine the annual capital and installation costs for the distillation (DST) unit:

$$\begin{aligned}\text{COST(DST)} &= (2{,}975{,}000 + 1{,}700{,}000)(0.1614)\\ &= \$754{,}545/\text{yr}\end{aligned}$$

See Table 18.6 for a comparison of costs and credits for both devices.

Finally, calculate the profit for each unit on an annualized basis:

$$\text{PROFIT(EXT)} = 2{,}000{,}000 - 1{,}728{,}000 = +272{,}000\ \$/\text{yr}$$
$$\text{PROFIT(DST)} = 2{,}500{,}000 - 2{,}080{,}000 = +420{,}000\ \$/\text{yr}$$

A distillation unit should be selected based on the above economic analysis.

Detailed cost estimates are beyond the scope of this text. Such procedures are capable of producing accuracies in the neighborhood of $\pm 5\%$. However, such estimates generally require many months of engineering work. This type of analysis is designed to give the reader a basis for a preliminary cost analysis only. ■

ILLUSTRATIVE EXAMPLE 18.9[10]

Karen Tschinkel, an undergraduate student from Manhattan College's prestigious chemical engineering program was given the assignment to design and operate a liquid extraction unit in the most cost-effective manner. The design is to be based on an outlet solute concentration in the solvent that will result in the maximum annual profit for the process. A line diagram of the proposed countercurrent unit is provided in Figure 18.2.

Having completed a mass transfer course, Karen realized that there are two costs which need to be considered:

1 the extraction unit employed for solvent recovery

2 the value of solvent recovered

She also notes that the higher the concentration C (mg/L) of the solvent recovery stream, the smaller will be the concentration difference driving force, and the higher the size requirement of the extractor (resulting in higher equipment cost). Alternatively, with a higher C, the concentration of recovered solute is higher, thus leading to an increase in profits.

Based on a similar system design, Ricci and Theodore Consultants (RAT) have provided the following annual economic models:

Recovered solute profit: $A(C-100)$; $A = \$/\text{yr(mg/L)}$

Liquid extraction unit cost: $B/(500-C)$; $B = \$\text{(mg/L)/yr}$

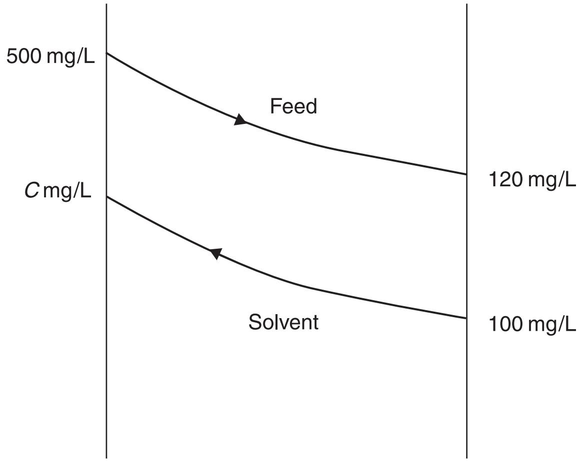

Figure 18.2 Proposed liquid extraction unit.

For the above system, RAT suggest values for the coefficients in the model be set at:

$$A = 10$$
$$B = 100,000$$

Employing the above information, Karen has been asked to calculate an outlet concentration, C, that will

1 provide breakeven (BE) operation, and
2 maximize profits (MP).

***SOLUTION*:** Since there are two contributing factors to the cost model, one may write the following equation for the profit as a function of exit solvent concentration:

$$P = A(C - 100) - \frac{B}{500 - C}$$

For breakeven operation, set $P = 0$, so that

$$(500 - C)(C - 100) = B/A$$

This may be expanded and rewritten as

$$C^2 - (500 + 100)C + [(B/A) + (500)(100)] = 0$$
$$C^2 - 600C + (10{,}000 + 50{,}000) = 0$$

The solution to this quadratic equation for $A = 10$ and $B = 100{,}000$ is

$$C = \frac{-(-600) \pm \sqrt{(-600)^2 - (4)(1)(60{,}000)}}{2(1)}$$
$$= \frac{600 \pm 342}{2}$$

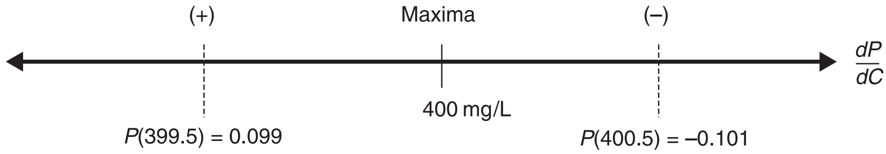

Figure 18.3 First derivative test.

The two solutions for BE operation are:

$$C = \{473\,\text{mg/L},\ 127\,\text{mg/L}\}$$

To maximize (or minimize) the profit, take the first derivative of P with respect to C and set it equal to zero, i.e.,

$$\frac{dP}{dC} = A - \frac{B}{(500 - C)^2} = 0$$

Solving:

$$\begin{aligned}(500 - C)^2 &= B/A \\ 500 - C &= \pm\sqrt{B/A} \\ C &= \{400\,\text{mg/L},\ 600\,\text{mg/L}\}\end{aligned}$$

However, based on the physical interpretation of these roots, it is readily apparent that the exit solvent concentration, C, cannot be greater than the inlet feed concentration. Hence, the root $C = 600\,\text{mg/L}$ has no physical meaning and may be neglected.

In order to determine if this root is the relative maxima, the *first derivative test* must be employed. By qualitatively examining the value of the derivative $(+/-)$ on both sides of each root, an inference can be made as to whether the original function contained a relative maxima or relative minima at the root. For instance, if the value of the derivative changes in sign from positive to negative as the concentration is increasing at the root, the slope of the line tangent to the original function changes from positive to negative at this point, and hence the root is a relative maxima in the original function (this assumes continuity about the point of interest in the original function). Inversely, should the sign change from negative to positive in the derivative, then the original function realizes a relative minima at the root. In this particular example, the values of the derivative arbitrarily close to each root have the following sign shown in Figure 18.3. A relative maxima in the *profit equation*, $P(C)$, is realized at $C = 400\,\text{mg/L}$. Thus, for MP, the exit concentration is equal to 400 mg/L. Alternatively, the *second derivative test* may be employed, which examines a function's change about its point(s) of inflection. This test would yield the same result. ■

ILLUSTRATIVE EXAMPLE 18.10

Refer to Illustrative Example 18.9. Karen has also been asked to perform the calculations if $A = 10$, $B = 400$ and $A = 10$, $B = 400{,}000$. Finally, an analysis of all the results is requested.

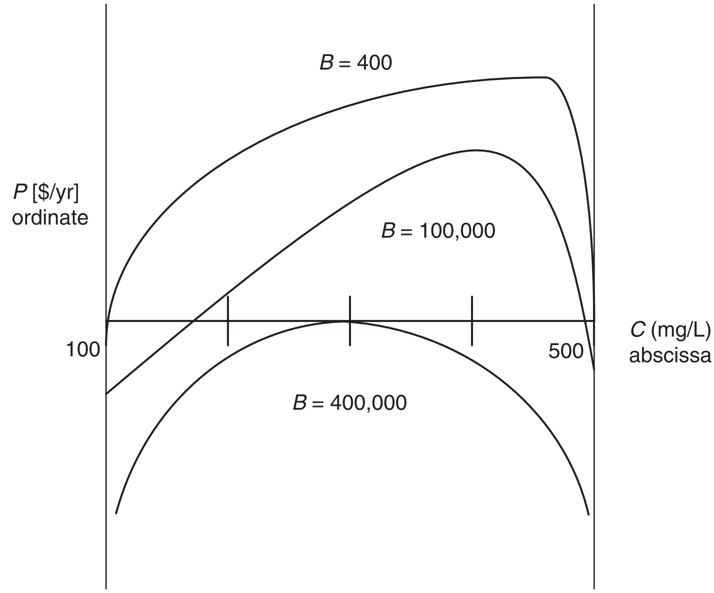

Figure 18.4 Profit-discharge concentration plot.

***SOLUTION*:** Using a similar procedure as in Illustrative Example 18.9, Karen determined that:

for $A = 10$, $B = 400$

$$C = \{499\,\text{mg/L},\ 101\,\text{mg/L}\}\ \text{for BE}$$
$$C = 480\,\text{mg/L for MP}$$

for $A = 10$, $B = 400{,}000$

$$C = 300\,\text{mg/L for BE}$$
$$C = 300\,\text{mg/L for MP}$$

In terms of analysis, a qualitative sketch of the three scenarios are provided in Figure 18.4. ■

ILLUSTRATIVE EXAMPLE 18.11

A distillation column processes two types of crude oil streams: North Texas and Venezuelan. Because of consumer demand, the production of diesel fuel, home heating oil, and gasoline must be limited. Based on the information in Table 18.7, estimate the optimum daily usage rate of each crude oil to maximize the profit, P.

The profit generated on processing North Texas (A) and Venezuelan Crude (B) is $2.00/gal and $1.60/gal, respectively.

Table 18.7 Crude Oil Usage and Production Information

	North Texas, %	Venezuelan, %	Maximum production rate, gal/day
Diesel fuel	8	11	1500
Home heating oil	29	54	5500
Gasoline	63	35	11,000

***SOLUTION*:** Set N_A and N_B equal to the daily usage rate of North Texas and Venezuelan crude. One may then write the following based on the problem statement:

$$P = 2.00N_A + 1.60N_B; \quad N = \text{gal/day}$$

Constraints:

$$0.08N_A + 0.11N_B \le 1500$$
$$0.29N_A + 0.54N_B \le 5500$$
$$0.63N_A + 0.35N_B \le 11{,}000$$

By trial-and-error, or from an optimization program, one obtains (approximately):

$$N_A = 16{,}800\ \text{gal/day}$$
$$N_B = 1150\ \text{gal/day}$$
$$P = \$35{,}500/\text{day}$$

■

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