Chapter 27

Economics and Finance

INTRODUCTION

Chapter 27 is concerned with Economics and Finance. These two topics can ultimately dictate the decisions made by the practicing engineer and his/her company. For example, a company may decide that due to the rising price of fuel they will explore the possibility of recovering the energy in a hot process stream instead of discharging it to the environment. A decision will then be based on whether it makes sense economically in the short- and long-term to purchase and install a heat exchange. Furthermore, economic evaluations are a major part of process and plant design.

This chapter provides introductory material, including the need for economic analyses, to this vast field within engineering. The next section discusses the need for economic analyses. The following section is devoted to 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 fitted into any rigid set of formulas. The material presented falls into roughly three parts: namely, general principles, practical information, and applications. The presentation starts with simple situations and proceeds to more complicated formulations and techniques that may be employed if there are sufficient data available. Other texts in the literature provide further details on the subject.

THE NEED FOR ECONOMIC ANALYSES

A company or individual hoping to increase its profitability must carefully assess a range of investment opportunities and select the most profitable options from those available. Increasing competitiveness also requires that efforts be expended to reducing 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.

Heat Transfer Applications for the Practicing Engineer. Louis Theodore

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 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 shortsighted attitude is surprising in a group of professionals who normally go to great lengths to get 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 economic prospects on 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 economic design and operation. This applies to both equipment (e.g., heat exchangers) and also 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 all too often must 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 equipment and 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 which 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.

Finally, 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 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; in effect, 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 nonprofit organizations, it is still important to determine the effect of various policies on profit.[2]

As noted above, the next section is devoted to definitions. This is followed with an overview of accounting principles and applications. The chapter concludes with applications.

DEFINITIONS

Before proceeding to the applications, it would be wise to provide the reader with certain key definitions in the field. Fourteen concepts that often come into play in an economic analysis are given below. The definitions have been drawn from the literature.[3]

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:

$$S = P(1 + ni) \tag{27.1}$$

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 often 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 semiannually, 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:

$$S = P(1 + i)^n \tag{27.2}$$

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:

$$S = P\left(1 + \frac{i'}{m}\right)^{mn} \tag{27.3}$$

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

$$i = \left(1 + \frac{i'}{m}\right)^{m} - 1 \tag{27.4}$$

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 some later time n and at interest rate i. This equation is the compound interest equation solved for the present worth term, P.

$$P = S(1 + i)^{-n} \tag{27.5}$$

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 when discussing 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

$$S = R[(1 + i)^n - 1]/i \tag{27.6}$$

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

$$D = (\text{Original cost} - \text{Salvage value})/(\text{Estimated life in years}) \tag{27.7}$$

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 UAP = (Original cost − Salvage value)(SFDF) where SFDF is the sinking fund deposit factor and is given by

$$\text{SFDF} = i/[(1+i)^n - 1] \tag{27.8}$$

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 UAP by the compound amount factor (CAF) where

$$\text{CAF} = [(1+i)^n - 1]/i \tag{27.9}$$

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):

$$\text{Cost}_{\text{year B}} = \text{Cost}_{\text{year A}}\left(\frac{\text{FECI}_{\text{year B}}}{\text{FECI}_{\text{year A}}}\right) \tag{27.10}$$

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. Similar methods for estimating the cost of equipment (e.g., heat exchangers), are available in the literature. However, actual quotes from vendors is preferred and should be used if greater accuracy is required.

Capital Recovery Factor

In comparing alternative 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 (or heat exchanger, etc). 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:

$$\mathrm{CRF} = i(1+i)^n/[(1+i)^n - 1] = i/[1-(1+i)^{-n}] \tag{27.11}$$

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:

$$\mathrm{ACC} = (\mathrm{TCC})(\mathrm{CRF}) \tag{27.12}$$

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. For each alternative in the present net worth (PNW) method of economic selection, a single sum is calculated that would provide for all expenditures over a common time period. The alternative having the least PNW of expenditures is selected as the most economical. The equation to employ is

$$\mathrm{PNW} = \mathrm{CC} + \mathrm{PN} + \mathrm{PWD} - \mathrm{PWS} \tag{27.13}$$

where CC = capital cost
PN = future renewals
PWD = other disbursements
PWS = salvage value

If the estimated lifetimes differ for the various alternatives, one should employ a period of time equal to the least common multiple of the different lifetimes for review 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 (fractional basis) 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 (P) is therefore,

$$P = I - C \tag{27.14}$$

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), denoted by some as p, may be estimated from the equation below:

$$p = \text{ARR} = \text{Average annual profit or earnings/Initial total investment} \tag{27.15}$$

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 interpolation calculations 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 usually listed without the last zero) in 10 years, with interest payable semiannually would be entitled to semiannual 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% 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:

$$V = C(1+i)^{-n} + R[1-(1+i)^{-n}]/i \tag{27.16}$$

where V = purchase price

C = redemption price

R = periodic interest payment

n = time in periods to maturity

i = yield rate (fractional basis)

Incremental Cost

By definition, the average unit increment cost is the increase in cost divided by the increase in production. Only those cost factors which 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.

Optimization

As noted in the previous chapter, optimization is often applied in several areas of engineering science and technology. The two key areas involve process design and plant operation. The term “optimization” may be viewed as a process involving the selection of the best option among different solutions. Optimization in process design involves maximizing annual profit, while minimizing total annual cost and environmental degradation. Optimization in plant operation generally involves maximizing product and product quality subject to economic, environmental, and energy constraints. Two heat transfer illustrative examples dealing with optimization are provided at the end of the Applications Section.

PRINCIPLES OF ACCOUNTING[3]

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 on financial information from the company accountants, especially information regarding 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 flow for that project. (Note: *Cash flow* is an algebraic monitary quantity whose numerical value represents the amount of money transferred. If money is received (inflow), the cash flow is positive; if the money is disbursed, the cash flow is negative.) Since these cash flows are often used to assess profitability by such methods as PNW, 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:

$$\text{Capital} = \text{Assets} - \text{Liabilities} \tag{27.17}$$

or

$$\text{Assets} = \text{Capital} + \text{Liabilities} \tag{27.18}$$

Capital, often referred to as net worth, is the money value of the business, since assets are the money value 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 aforementioned business makes a profit of \$5000, the liability is increased to \$15,000. With this concept in mind Equation (27.18) can be expanded to:

$$\text{Assets} = \text{Capital} + \text{Liabilities} + \text{Profit} \tag{27.19}$$

where the capital is considered 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 (27.19) can be further expanded to:

$$\begin{aligned}\text{Assets} + \text{Expenses} &= \text{Capital} + \text{Liabilities} + \text{Profit}\\ &\quad + \text{Revenue (from sales)}\end{aligned} \tag{27.20}$$

Some engineers have the greatest difficulty in regarding an expense as being equivalent to an asset, as is implied by Equation (27.20). 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 made 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 Heating Oil Account." This account would list the cost of each purchase of heating 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 also 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 heat transfer related applications have been drawn from the National Science Foundation (NSF) literature[4–8] and two other key sources.[9,10]

ILLUSTRATIVE EXAMPLE 27.1

List the major *fixed* capital costs for the chemical process industry.

***SOLUTION*:**

1. Major process equipment (i.e., heat exchangers, reactors, tanks, pumps, filters, distillation columns, etc.).
2. Installation of major process equipment.
3. Process piping.
4. Insulation.
5. Instrumentation.
6. Auxiliary facilities (i.e., power substations, transformers, boiler houses, fire-control equipment, etc.).

7. Outside lines (i.e., piping external to buildings, supports and posts for overhead piping, electric feeders from power substations, etc.).
8. Land and site improvements.
9. Building and structures.
10. Consultant fees.
11. Engineering and construction (design and engineering fees plus supervision of plant erection).
12. Contractors' fees (administrative). ■

ILLUSTRATIVE EXAMPLE 27.2

List the major *working* capital costs for the chemical process industry.

***SOLUTION*:**

1. Raw materials for plant startup.
2. Raw material, intermediate and finished product inventories.
3. Cost of handling and transportation of materials to and from sites.
4. Cost inventory control, warehouse(s), associated insurance, security arrangements, etc.
5. Money to carry accounts receivable (i.e., credit extended to customers) less accounts payable (i.e., credit extended by suppliers).
6. Money to meet payrolls when starting up.
7. Readily available cash for emergency.
8. Any additional cash required to operate the process or business.
9. Expenses associated with new hirees.
10. Startup consultant fees. ■

ILLUSTRATIVE EXAMPLE 27.3

Answer the following three questions:

1. Define the straight-line method of analysis that is employed in calculating depreciation allowances.
2. Define the double-declining balance (DDB) method of analysis.
3. Define the sum-of-the-year's digits (SYD) method of analysis.

***SOLUTION*:** 1. The straight-line rate of depreciation is a constant equal to $1/n$ where n is the life of the facility for tax purposes. Thus, if the life of the plant is 10 yr, the straight-line rate of depreciation is 0.1. This rate, applied over each of the 10 yr, will result in a depreciation reserve equal to the initial investment.

2. A declining balance rate is obtained by first computing the straight-line rate and then applying some multiple of that rate to each year's unrecovered cost rather than to the original investment. Under the double-declining balance method, twice the straight-line rate is applied to each year's remaining unrecovered cost. Thus, if the life of a facility is 10 years, the

straight-line rate will be 0.1, and the first year's double-declining balance will be 0.2. If the original investment is I, the depreciation allowance the first year will be $0.2I$. For the second year, it will be $0.16I$, or 0.2 of the unrecovered cost of $0.8I$. The depreciation allowances for the remaining years are calculated in a similar manner until the tenth year has been completed. Since this method involves taking a fraction of an unrecovered cost each year, it will never result in the complete recovery of the investment. To overcome this objection, the U.S. Internal Revenue Service, allowed the taxpayer in the past to shift from the DDB depreciation method to the straight-line method any time after the start of the project.

3. The rate of depreciation for the sum-of-the-year's digits method is a fraction. The numerator of this fraction is the remaining useful life of the project at the beginning of the tax year, while the denominator is the sum of the individual digits corresponding to the total years of life of the project. Thus, with a project life, n, of 10 years, the sum of the year's digits will be $10 + 9 + 8 + 7 + 6 + 5 + 4 + 3 + 2 + 1 = 55$. The depreciation rate the first year will be $10/55 = 0.182$. If the initial cost of the facility is I, the depreciation for the first year will be $0.182I$, $9/55 = 0.164I$ for the second year, and so on until the last year. The SYD method will recover 100% of the investment at the end of n years. However, shift from SYD to straight-line depreciation cannot be made once the SYD method has been started. ■

ILLUSTRATIVE EXAMPLE 27.4

Compare the results of the three methods discussed in Illustrative Example 27.3.

***SOLUTION*:** A tabular summary of the results of depreciation according to the straight-line, double-declining, and sum-of-the-year's digits methods are shown in Table 27.1. ■

ILLUSTRATIVE EXAMPLE 27.5

A heat exchanger costing $60,000 has an estimated lifetime of 9 years and a salvage value of $500. What uniform annual payment must be made into a fund at the end of the year to replace

Table 27.1 Comparative Methods of Analysis

Year	Straight-line	Double-declining	Sum-of-the-year's digits
0	1.000	1.000	1.000
1	0.900	0.800	0.818
2	0.800	0.640	0.655
3	0.700	0.512	0.510
4	0.600	0.410	0.383
5	0.500	0.328	0.274
6	0.400	0.262	0.183
7	0.300	0.210	0.110
8	0.200	0.168	0.056
9	0.100	0.134	0.018
10	0.000	0.108	0.000

the exchanger if the fund earns 3.375%? What would be the appraisal value of the exchanger at the end of the fifth year based on straight line depreciation?

***SOLUTION*:** Write the equation for the uniform annual payment (UAP) in terms of the cost (P) and salvage value (L), using a sinking fund model. See Equation (27.8).

$$\text{UAP} = (P - L)(\text{SFDF})$$

Calculate the sinking fund depreciation factor, SFDF

$$\text{SFDF} = \frac{i}{(1+i)^n - 1} \tag{27.8}$$

$$= \frac{0.03375}{(1+0.03375)^9 - 1} = 0.0969$$

Thus,

$$\text{UAP} = (\$60{,}000 - \$500)(0.0969) = \$5765$$

In determining the appraisal value B where the straight line method of depreciation is used, the following equation applies:

$$B = P - \left(\frac{P-L}{n}\right)x \tag{27.21}$$

The term n refers to the years to the end of life, and x refers to any time (in years) from the present before the end of usable life. One can employ this equation for the appraisal value and solve for B_5 after five years.

$$B_5 = \$60{,}000 - \left(\frac{\$60{,}000 - \$500}{9}\right)(5) = \$26{,}945$$

This problem assumed that the depreciation of the heat exchanger followed a sinking fund method, while the appraisal value of the exchanger followed a straight line depreciation trend. For the depreciation calculation, it is assumed that the exchanger will remain in operation for all of its nine years of usable life. For this reason, the depreciable amount of the exchanger may be thought of as being deposited into a sinking fund to be applied toward the replacement of the heat exchanger after nine years.

The appraisal value of the exchanger after the fifth year is calculated as part of the appraisal calculation. This value takes into account the fact that the heat exchanger, even one year after it is purchased, is no longer worth what was paid for it. Since the appraisal had little to do with the fund for its replacement, the exchanger was assumed to follow a straight line depreciation model. ■

ILLUSTRATIVE EXAMPLE 27.6

The annual operation costs of an outdated heat exchanger/boiler system is \$75,000. Under a proposed new design, the installation of a new system will require an initial cost of \$150,000 and an annual operating cost of \$15,000 for the first five years. Determine the annualized cost for the new heating system by assuming the system has only five years (n) operational life. The interest rate (i) is 7%. The capital recovery factor (CRF) or annual payment of a capital investment can be calculated as follows:

$$\mathrm{CRF} = \left(\frac{A}{P}\right)_{i,n} = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{27.11}$$

where A is the annual cost and P is the present worth.

Compare the costs for both the outdated and proposed operations.

***SOLUTION*:** The annualized cost for the new system is determined based on the following input data:

Capital cost = \$150,000
Interest, $i = 7\%$
Term, $n = 5$ yr

For $i = 0.07$ and $n = 5$, the CRF is

$$\begin{aligned}\mathrm{CRF} &= \frac{0.07(1+0.07)^5}{(1+0.07)^5 - 1}\\ &= 0.2439\end{aligned}$$

The total annualized cost for the heat exchanger is then

$$\begin{aligned}AC &= IC + OC\\ &= (0.2439)(\$150{,}000) + \$15{,}000 = \$51{,}585\end{aligned}$$

Since this cost is lower than the annual cost of \$75,000 for the old process, the proposed plan should be implemented. ■

ILLUSTRATIVE EXAMPLE 27.7

Plans are underway to construct and operate a commercial hazardous waste facility in Dumpsville in the sate of Egabrag. The company is still undecided as to whether to install a double pipe or shell-and-tube heat exchanger at the plant site to recover energy. The double pipe (DP) unit is less expensive to purchase and operate than a comparable shell-and-tube (ST) system. However, projected energy recover income from the ST unit is higher since it will handle a larger quantity and different temperature steam.

Based on economic and financial data provided in Table 27.2, select the heat exchanger or 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 exchangers.

Table 27.2 Costs/Credits Data

Costs/credits	Double pipe (DP)	Shell-and-tube (ST)
Capital ($)	2,625,000	2,975,000
Installation ($)	1,575,000	1,700,000
Operation ($/yr)	400,000	550,000
Maintenance ($/yr)	650,000	775,000
Income ($/yr)	2,000,000	2,500,000

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

$$\begin{aligned} \text{CRF} &= i/[1-(1+i)^{-n}] \qquad (27.11) \\ &= 0.12/[1-(1+0.12)^{-12}] \\ &= 0.1614 \end{aligned}$$

Determine the annual capital and installation costs for the DP unit:

$$\begin{aligned} \text{DP costs} &= (\text{Capital} + \text{Installation})(\text{CRF}) \\ &= (2{,}625{,}000 + 1{,}575{,}000)(0.1614) \\ &= \$677{,}880/\text{yr} \end{aligned}$$

Determine the annual capital and installation costs for the ST unit:

$$\begin{aligned} \text{ST costs} &= (\text{Capital} + \text{Installation})(\text{CRF}) \\ &= (2{,}975{,}000 + 1{,}700{,}000)(0.1614) \\ &= \$754{,}545/\text{yr} \end{aligned}$$

The information below in Table 27.3 provides a comparison of the costs and credits for both exchangers.

The profit is the difference between the total annual cost and the income credit.

$$\begin{aligned} \text{DP(profit)} &= 2{,}000{,}000 - 1{,}728{,}000 = \$272{,}000/\text{yr} \\ \text{ST(profit)} &= 2{,}500{,}000 - 2{,}080{,}000 = \$420{,}000/\text{yr} \end{aligned}$$

A shell-and-tube heat exchanger should therefore be selected based on the above economic analysis.

Table 27.3 Comparison of Results; Illustrative Example 27.7

	Double pipe	Shell-and-tube
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

■

ILLUSTRATIVE EXAMPLE 27.8

Based on an outgrowth of a 2011 energy audit study for a new process, it is necessary to heat 50,000 lb/h of an organic liquid form 150 to 330°F. The liquid is at a pressure of 135 psia. A simple steam-heated shell-and-tube foating-head carbon steel exchanger is the preferred equipment choice. Steam is available at 150 psia (135 psig) and 300 psia (285 psig). The higher pressure steam should result in a smaller heat exchanger but the steam will cost more. Which steam choice would be better?

Data:

The heat capacity of the organic liquid is 0.6 Btu/lb · °F.

The plant on-stream operation factor is expected to be 90%.

Steam properties are:

	150 psia	300 psia
Saturation temperature, °F	358.0	417.0
Latent heat (enthalpy), Btu/lb	863.6	809.0
Cost, $/1000 lb	5.20	5.75

Heat exchanger cost correlation (1998 basis):

Base cost (BC) = 117 $A^{0.65}$

Installation factor (IF) = 3.29

Pressure factors (PF):

100 to 200 psig = 1.15

200 to 300 psig = 1.20

Cost indexes (CI):

1998 = 230

2011 = 360

Capital cost (C) = (BC)(IF)(PF)(CI)

***SOLUTION*:** Calculate the overall heat duty:

$$\dot{Q} = \dot{m}c_p(T_2 - T_1) = (50{,}000\,\text{lb/h})(0.6\,\text{Btu/lb}\cdot{}^\circ\text{F})(330 - 150^\circ\text{F})$$
$$= 5{,}400{,}000\,\text{Btu/h}$$

Calculate the log-mean temperature difference for each case:

	150 psia case	300 psia case
ΔT_1	358 − 150 = 208	417 − 150 =267
ΔT_2	358 − 330 = 28	417 − 330 = 87
LMTD	89.8°F	160.5°F

Calculate the required heat transfer area for each case:

$$A_{150} = (5{,}400{,}000)/[(138)(89.8)] = 436\ \text{ft}^2$$
$$A_{300} = (5{,}400{,}000)/[(138)(160.5)] = 244\ \text{ft}^2$$

Determine the capital cost for each case:

$$\text{Cost}_{150} = (117)(436)^{0.65}(360/230)(3.29)(1.15) = \$36{,}000$$
$$\text{Cost}_{300} = (117)(244)^{0.65}(360/230)(3.29)(1.20) = \$25{,}800$$

Obtain the steam requirement for each case in lb/yr:

$$\begin{aligned}\text{St}_{150} &= (5{,}400{,}000\ \text{Btu/h})(8760 \times 0.9\ \text{h/yr})/(863.6\ \text{Btu/lb})\\ &= 49.3\ \text{million lb/yr}\\ \text{St}_{300} &= (5{,}400{,}000\ \text{Btu/h})(8760 \times 0.9\ \text{h/yr})/(809.0\ \text{Btu/lb})\\ &= 52.6\ \text{million lb/yr}\end{aligned}$$

Use the above calculation to determine the annual steam cost for each case:

$$\text{StCost}_{150} = (49.3 \times 10^6\ \text{lb/yr})(0.00520\ \$/\text{lb}) = \$256{,}000/\text{yr}$$
$$\text{StCost}_{300} = (52.6 \times 10^6\ \text{lb/yr})(0.00575\ \$/\text{lb}) = \$303{,}000/\text{yr}$$

The 300-psia exchanger costs \$10,200 less to purchase and install, but it costs \$47,000 per year more to operate. Choosing the more expensive, 150-psia exchanger is the obvious choice. ■

ILLUSTRATIVE EXAMPLE 27.9

Two small commercial power plant designs are under consideration. The first design involves a traditional boiler (TB) and the second a fluidized fed (FB). For the TB system, the total capital cost (TCC) is \$2.5 million, the annual operating costs (AOC) are \$1.2 million, and the annual revenue generated from the facility (*R*) is \$3.6 million. For the FB system, TCC, AOC and R are \$3.5, 1.4 and 5.3 million, respectively. Using straight-line depreciation and the discounted cash flow method, which unit is more attractive? Assume a 10-yr facility lifetime and a 2 yr construction period. Note that the solution involves the calculation of the rate of return for each of the two proposals.(11)

***SOLUTION*:** For TB system, calculate the depreciation *D*, the working capital WC, the taxable income TI, the income tax to be paid IT, and the annual after tax cash flow *A*. The depreciation is (straight-line):

$$\begin{aligned}D &= 0.1(\text{TCC})\\ &= (0.1)(\$2{,}500{,}000)\\ &= \$250{,}000\end{aligned}$$

The WC is set at 10% of the TCC:

$$\begin{aligned}\text{WC} &= 0.1(\text{TCC})\\ &= (0.1)(\$2{,}500{,}000)\\ &= \$250{,}000\end{aligned}$$

In addition,

$$\begin{aligned}\text{TI} &= R - \text{AOC} - D\\ &= \$3{,}600{,}000 - \$1{,}200{,}000 - \$250{,}000\\ &= \$2{,}150{,}000\end{aligned}$$

and one may estimate that

$$\begin{aligned}\text{IT} &= (0.5)\text{TI}\\ &= (05)(\$2{,}150{,}000)\\ &= \$1{,}075{,}000\end{aligned}$$

The after-tax cash flow is calculated using

$$\begin{aligned}A &= R - \text{AOC} - \text{IT}\\ &= \$3{,}600{,}000 - \$1{,}200{,}000 - \$1{,}075{,}000\\ &= \$1{,}325{,}000\end{aligned}$$

The rate of return, i, for the TB unit is also calculated. This rate of return can be computed by solving the equation below:

$$\begin{aligned}&\left[\frac{(1+i)^{10}-1}{I(1+i)^{10}}\right]A + \left[\frac{1}{(1+i)^{10}}\right]\text{WC}\\ &\quad = \text{WC} + (0.5)\text{TCC} + (0.5)\text{TCC}(1+i)^1\end{aligned}$$

or

$$\begin{aligned}&\left[\frac{(1+i)^{10}-1}{I(1+i)^{10}}\right](1.325\times 10^6) + \left[\frac{1}{(1+i)^{10}}\right](0.250\times 10^6)\\ &= (0.250\times 10^6) + (0.5)(1.250\times 10^6) + (0.5)(1.250\times 10^6)(1+i)^1\end{aligned}$$

By trial and error (assume i),

$$i = 39.6\% \simeq 40\%$$

For the FB system,

$$\begin{aligned}\text{WC} = D &= (0.1)(\$3{,}500{,}000)\\ &= \$350{,}000\\ \text{TI} &= \$5{,}300{,}000 - \$1{,}400{,}000 - \$350{,}000\\ &= \$3{,}550{,}000\\ \text{IT} &= (0.5)(\$3{,}550{,}000)\\ &= \$1{,}775{,}000\end{aligned}$$

The annual after-tax cash flow is

$$\begin{aligned} A &= \$5{,}300{,}000 - \$1{,}400{,}000 - \$1{,}775{,}000 \\ &= \$2{,}125{,}000 \end{aligned}$$

The rate of return equation for the FB unit becomes

$$\left[\frac{(1+i)^{10}-1}{i(1+i)^{10}}\right](2.125 \times 10^6) + \left[\frac{1}{(1+i)^{10}}\right](0.3650 \times 10^6)$$
$$= (0.350 \times 10^6) + (0.5)(1.750 \times 10^6) + (0.5)(1.750 \times 10^6)(1+i)^1$$

By trial and error,

$$i = 44.8\%$$

Hence, by the discounted cash flow method, the rate of return on the initial capital investment is approximately 5% greater for the FB system than the TB system. From a purely financial standpoint, the FB system is the more attractive option. ■

ILLUSTRATIVE EXAMPLE 27.10

A stream of 100,000 acfm flue gas from a utility facility is to be cooled in an air preheater. You have been requested to find the best unit to install to cool the flue gas and preheat the combustion air feed to the boiler. A reputable vendor has provided information on the cost of three units, as well as installation, operating, and maintenance costs. Table 27.4 summarizes all the data you have collected. Determine what preheater you would select in order to minimize costs on an annualized basis.

***SOLUTION*:** The first step is to convert the equipment, installation, and operating costs to total costs by multiplying each by the total gas flow, 100,000 acfm. Hence, for the finned exchanger, the total costs are

$$\begin{aligned} \text{Equipment cost} &= 100{,}000 \text{ acfm } (\$3.1/\text{acfm}) = \$310{,}000 \\ \text{Installation cost} &= 100{,}000 \text{ acfm } (\$0.80/\text{acfm}) = \$80{,}000 \\ \text{Operating cost} &= 100{,}000 \text{ acfm } (\$0.06/\text{acfm} \cdot \text{yr}) = \$6000/\text{yr} \end{aligned}$$

Table 27.4 Preheater Cost Data

	Finned	4-pass	2-pass
Equipment cost	\$3.1/acfm	\$1.9/acfm	\$2.5/acfm
Installation cost	\$0.80/acfm	\$1.4/acfm	\$1.0/acfm
Operating cost	\$0.06/acfm-yr	\$0.06/acfm-yr	\$0.095/acfm-yr
Maintenance cost	\$14,000/yr	\$28,000/yr	\$9500/yr
Lifetime of equipment	20 yr	15 yr	20 yr

Costs are based on comparable performance. Interest rate is 10% and there is zero salvage value.

Table 27.5 Preheater Cost Calculations

	Finned	4-pass	2-pass
Equipment cost	\$310,000	\$190,000	\$250,000
Installation cost	\$80,000	\$140,000	\$100,000
CRF	0.11746	0.13147	0.11746
Annual equipment cost	\$36,412	\$24,980	\$29,365
Annual installation cost	\$9397	\$18,405	\$11,746
Annual operating cost	\$6000	\$6000	\$9500
Annual maintenance cost	\$14,000	\$28,000	\$9500
Total annual cost	\$65,809	\$77,385	\$60,111

Note that the operating costs are on an annualized basis. The equipment cost and the installation cost must then be converted to an annual basis using the CRF. From Equation (27.11)

$$\begin{aligned}\text{CRF} &= (0.1)(1+0.1)^{20}/[(1+0.1)^{20}-1]\\ &= 0.11746\end{aligned}$$

The annual costs for the equipment and the installation is given by the product of the CRF and the total costs of each:

$$\begin{aligned}\text{Equipment annual cost} &= \$310{,}000(0.11746)\\ &= \$36{,}412/\text{yr}\\ \text{Installation annual cost} &= \$80{,}000(0.11746)\\ &= \$9397/\text{yr}\end{aligned}$$

The calculations for the 4-pass and the 2-pass exchangers are performed in the same manner. The three preheaters can be compared after all the annual costs are added. The tabulated results are provided in Table 27.5. According to the analysis, the 2-pass exchanger is the most economically attractive device since the annual cost is the lowest. ■

ILLUSTRATIVE EXAMPLE 27.11

A new large diameter steam line, carrying steam at 450 K is being designed. It is desired to calculate the optimal insulation thickness for this line. Outline the calculations required.

***SOLUTION*:** The optimum thickness of insulation is arrived at by employing an economic approach. If a bare pipe were to carry a hot fluid, there would be a certain hourly loss of heat whose value could be determined from the cost of producing the energy. The lower the heat loss the greater the thickness and initial cost of the insulation and the greater the annual fixed charges (maintenance and depreciation) which must be added to the annual heat loss. Assuming a number of thicknesses of insulation and adding the fixed charges to the value of the heat lost, a minimum cost can be obtained and the thickness corresponding to it will represent the optimum economic thickness of the insulation. The form of a graphical solution is provided in Figure 27.1. ■

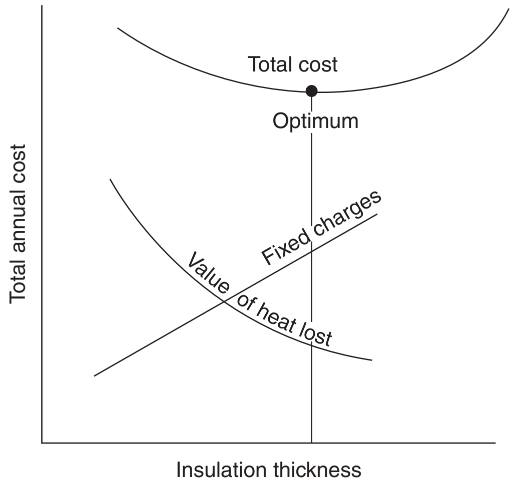

Figure 27.1 Optimum thickness of insulation.

ILLUSTRATIVE EXAMPLE 27.12

Shannon O'Brien, a recent graduate from Manhattan College's prestigious chemical engineering program was given an assignment to design the most cost-effective heat exchanger to recover energy from a hot flue gas at 500°F. The design is to be based on pre-heating 100°F incoming air (to be employed in the boiler) to a temperature that will result in the maximum annual profit to the utility. A line diagram of the proposed countercurrent exchanger is provided in Figure 27.2.

Having just completed a heat transfer course with Dr. Flynn and a thermodynamics course with the infamous Dr. Theodore, Shannon realizes that their are two costs that need to be considered:

1. the heat exchanger employed for energy recovery, and
2. the "quality" (from an entropy perspective) of the recovered energy—refer to Chapter 20 for additional details.

She also notes that the higher the discharge temperature of the heated air, t, the smaller will be the temperature difference driving force, and the higher the area requirement of the exchanger and the higher the equipment cost. Alternatively, with a higher t, the "quality" of the recovered energy is higher, thus leading to an increase in recovered profits (by reducing fuel costs).

Based on similar system designs, Ricci Consultants (RC) has provided the following annual economic models:

$$\text{Recovered energy profit:}\quad A(t - t_c); \qquad A = \$/\text{yr}\cdot{}^\circ\text{F}$$
$$\text{Exchange cost:}\quad B/(T_H - t); \quad B = \$\cdot{}^\circ\text{F/yr}$$

For the above system, RC suggests a value for the coefficients in the cost model be set at:

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

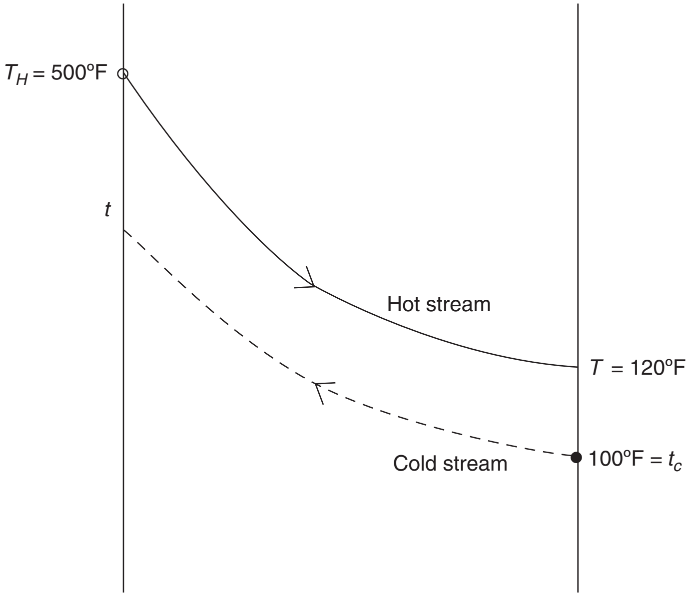

Figure 27.2 Proposed countercurrent exchanger.

Employing the above information, Shannon has been asked to calculate a t that will

1. provide breakeven operation
2. maximize profits

She is also required to perform the calculation if $A = 10$, $B = 4000$, and $A = 10$, $B = 400{,}000$. Finally, an analysis of the results is requested.

***SOLUTION*:** Since there are two contributing factors to the cost model, one may write the following equation for the profit, P

$$P = A(t - t_c) - B/(T_H - t); \quad T_H = 500 \quad \text{and} \quad t_c = 100$$

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

$$(t - t_c)(T_H - t) = B/A$$

This may be rewritten as

$$t^2 - (T_H + t_c)T + [(B/A) + T_H t_c] = 0$$

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

$$\begin{aligned} t &= \frac{600 \pm \sqrt{(600)^2 - (4)(1)(10{,}000 + 50{,}000)}}{2} \\ &= \frac{600 \pm 346}{2} \\ &= 473^\circ\text{F},\ 127^\circ\text{F} \end{aligned}$$

To maximize the profit, take the first deriative of P with respect to t and set it equal to zero, i.e.,

$$\frac{dP}{dt} = A - \frac{B}{(T_H - t)^2} = 0$$

Solving,

$$\begin{aligned}(T_H - t)^2 &= B/A \\ T_H - t &= \sqrt{B/A} \\ &= \sqrt{10{,}000} \\ &= 100 \\ t &= 400^\circ\mathrm{F}\end{aligned}$$

Upon analyzing the first derivative with t values greater than and less than 400°F, Shannon observes that the derivative changes sign from $+ \rightarrow -$ about $t = 400$, indicating a relative maximum.

Similarly, for $A = 10$, $B = 4000$,

$$\begin{aligned}t_{\mathrm{BE}} &= 499^\circ\mathrm{F},\ 101^\circ\mathrm{F} \\ t_{\max} &= 480^\circ\mathrm{F}\end{aligned}$$

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

$$\begin{aligned}t_{\mathrm{BE}} &= 300^\circ\mathrm{F} \\ t_{\max} &= 300^\circ\mathrm{F}\end{aligned}$$

Graphical results for the three scenarios is shown in Figure 27.3. ■

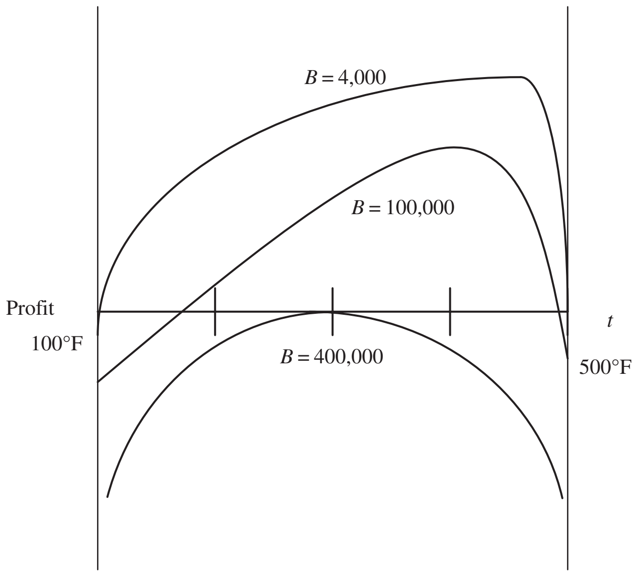

Figure 27.3 Heat exchanger results.

ILLUSTRATIVE EXAMPLE 27.13

Two hot liquid (essentially water) process streams are discharged from sources *A* and *B* in a plant. A young engineer has proposed to recover energy from the two streams by employing two heat exchangers that are currently available on site: a double pipe (DP) exchanger and a shell-and-tube (ST) exchanger. Due to diameter differences in the two lines that discharge the hot liquid from source *A*, there is a 60/40 split (mass basis) of the flowrate. There are also two lines discharging liquid from source *B* with a 75/25 split to the ST/TB exchangers. Due to the location of the exchangers relative to the two sources, the 40% flow from *A* and 75% flow from *B* can be diverted (fed) to the ST exchanger. The remaining discharge can only be sent to the DP exchanger.

The young engineer has obtained additional information. The maximum flowrate that exchanger ST and DP can accommodate to 12,000 ft^3/day and 6000 ft^3/day respectively. In addition, the maximum flow that be drawn from sources *A* and *B* is 8000 ft^3/day and 6000 ft^3/day respectively.

Prepare a line diagram of a system to recover the energy from sources $A + B$.

***SOLUTION*:** The line diagram is provided in Figure 27.4. ■

ILLUSTRATIVE EXAMPLE 27.14

Refer to Illustrative Example 27.13. The profit value of the recovered energy from sources *A* and *B* are \$1.70/ft^3 and \$2.00/ft^3, respectively. *Develop* the describing equations that will provide values of the (volumetic) flowrates from *A* and *B*, i.e., q_A and q_B, that will maximize the profit *P* for the proposed process.

***SOLUTION*:** The discribing equations are as follows. The objective function of the profit is

$$P = (1.70)q_A + (2.00)q_B$$

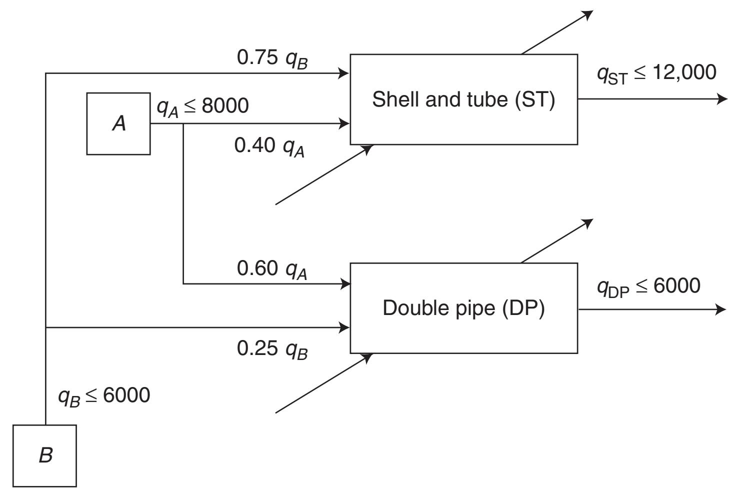

Figure 27.4 Shell-and-tube and double pipe exchangers.

The constraints are

$$q_A \leq 8000$$
$$q_B \leq 6000$$
$$0.75q_A + 0.40q_B = q_{ST} \leq 12{,}000$$
$$0.60q_A + 0.25q_B = q_{DP} \leq 6000$$
$$q_A \geq 0,\ q_B \geq 0$$

■

ILLUSTRATIVE EXAMPLE 27.15

Refer to the two previous examples. Calculate values of q_A and q_B that will maximize the profit from this process. Also calculate the annual (365 day basis) profit based on this condition.

***SOLUTION*:** Employing a suitable optimization program gives:

$$q_A = 7500\ \text{ft}^3/\text{day}$$
$$q_B = 6000\ \text{ft}^3/\text{day}$$
$$P = 24{,}750\ \$/\text{day}$$
$$= \$8{,}910{,}000\ \$/\text{yr}$$

Note that operating, maintenance, depreciation, etc., costs have not been included in the analysis. ■

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