CHAPTER

6

COST ESTIMATION

An acceptable plant design must present a process that is capable of operating under conditions which will yield a profit. Since net profit equals total income minus all expenses, it is essential that the chemical engineer be aware of the many different types of costs involved in manufacturing processes. Capital must be allocated for direct plant expenses, such as those for raw materials, labor, and equipment. Besides direct expenses, many other indirect expenses are incurred, and these must be included if a complete analysis of the total cost is to be obtained. Some examples of these indirect expenses are administrative salaries, product-distribution costs, and costs for interplant communications.

A capital investment is required for any industrial process, and determination of the necessary investment is an important part of a plant-design project. The total investment for any process consists of fixed-capital investment for physical equipment and facilities in the plant plus working capital which must be available to pay salaries, keep raw materials and products on hand, and handle other special items requiring a direct cash outlay. Thus, in an analysis of costs in industrial processes, capital-investment costs, manufacturing costs, and general expenses including income taxes must be taken into consideration.

CASH FLOW FOR INDUSTRIAL OPERATIONS

Figure 6-1 shows the concept of cash flow for an overall industrial operation based on a support system serving as the source of capital or the sink for capital* receipts. Input to the capital sink can be in the form of loans, stock issues, bond releases, and other funding sources including the net cash flow returned to the

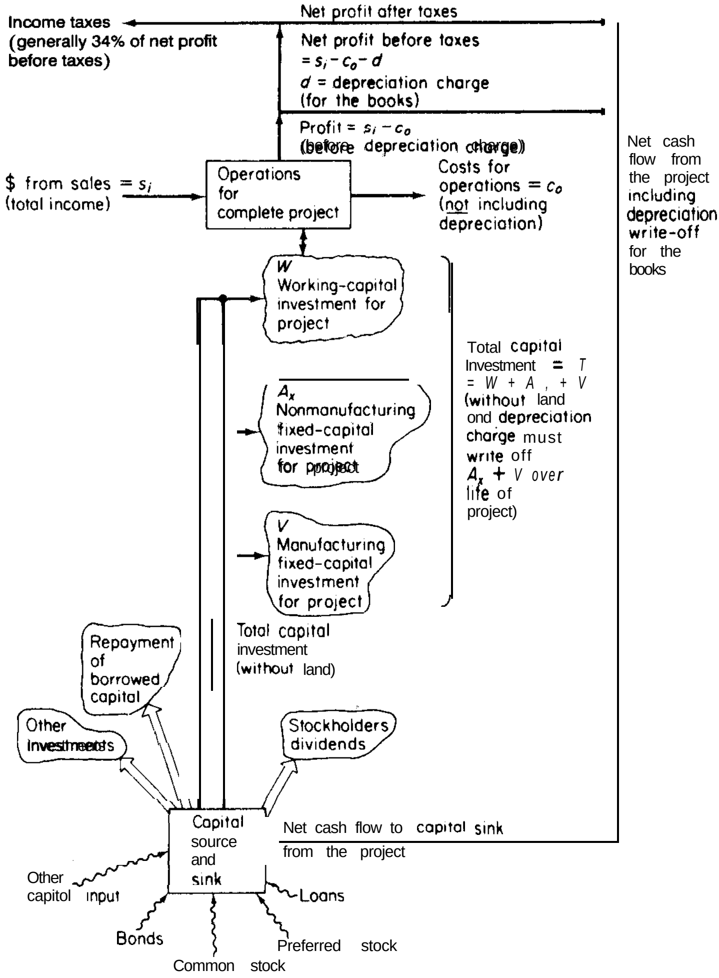

FIGURE 6-1
Tree diagram showing cash flow for industrial operations.

capital sink from each project. Output from the capital source is in the form of total capital investments for each of the company's industrial operations, dividends to stockholders, repayment of debts, and other investments.

The tree-growth concept, as shown in Fig. 6-1, depicts a trunk output to start the particular industrial operation designated as the total capital investment. This total capital investment includes all the funds necessary to get the project underway. This encompasses the regular manufacturing fixed-capital investment and the working-capital investment along with the investment required for all necessary auxiliaries and nonmanufacturing facilities. The cash flow for the capital investments can usually be considered as in a lump sum or in-an-instant such as for the purchase of land with a lump-sum payment or the provision of working capital as one lump sum at the start of the operation of the completed plant. Fixed capital for equipment ideally can be considered as in-an-instant for each piece of equipment although the payments, of course, can be spread over the entire construction period when considering the fixed-capital investment for a complete plant. Because income from sales and necessary operating costs can occur on an irregular time basis, a constant reservoir of working capital must be kept on hand continuously to draw from or add to as needed.

The rectangular box in Fig. 6-1 represents the overall operations for the complete project with working-capital funds moving in and out as needed but maintaining a constant fund as available working capital. Cash flows into the operations box as total dollars of income (s_i) from all sales while actual costs for the operations, such as for raw materials and labor, are shown as outflow costs (c_o). These cash flows for income and operating expenses can be considered as continuous and represent rates of flow at a given point in time using the same time basis, such as dollars per day or dollars per year. Because depreciation charges to allow eventual replacement of the equipment are in effect costs which are paid back to the company capital sink, these charges are not included in the costs for operations shown in Fig. 6-1. The difference between the income (s_i) and operating costs (c_o) represents gross profits before depreciation or income-tax charges ($s_i - c_o$) and is represented by the vertical line rising out of the operations box.

Depreciation, of course, must be recognized as a cost before income-tax charges are made and before net profits are reported to the stockholders. Consequently, removal of depreciation in the cash-flow diagram as a charge against profit is accomplished at the top of the tree diagram in Fig. 6-1 with the depreciation charge (d) entering the cash-flow stream for return to the capital sink. The resulting new profit of $s_i - c_o - d$ is taxable, and the income-tax charge is shown as a cash-flow stream deducted at the top of the diagram. The remainder, or net profit after taxes, is now clear profit which can be returned to the capital sink, along with the depreciation charge, to be used for new investments, dividends, or repayment of present investment as indicated by the various trunks emanating from the capital source in Fig. 6-1.

Cumulative Cash Position

The cash flow diagram shown in Fig. 6-1 represents the steady-state situation for cash flow with s_i, c_o, and d all based on the same time increment. Figure 6-2 is for the same type of cash flow for an industrial operation except that it depicts the situation over a given period of time as the ***cumulative cash position.*** The time period chosen is the estimated life period of the project, and the time value of money is neglected.

In the situation depicted in Fig. 6-2, land value is included as part of the total capital investment to show clearly the complete sequence of steps in the

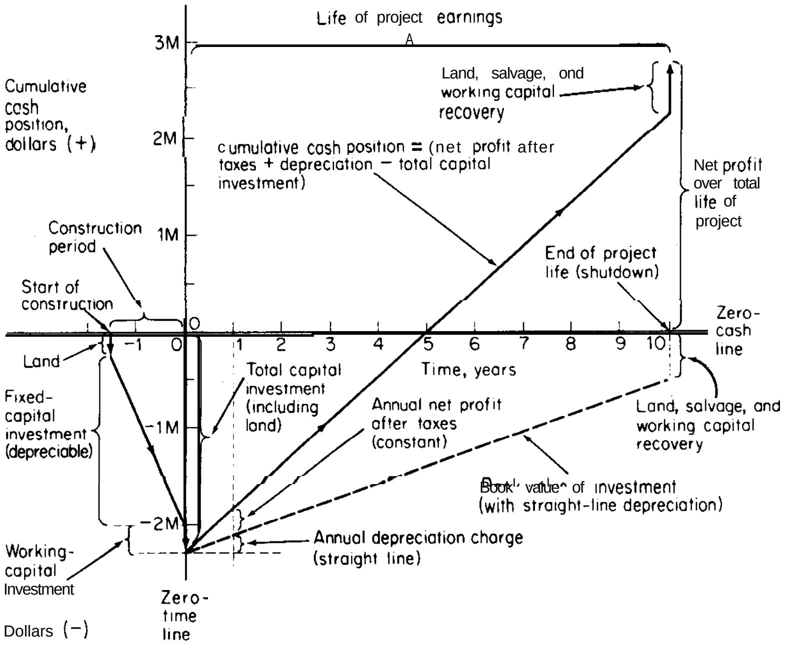

FIGURE 6-2
Graph of cumulative cash position showing effects of cash flow with time for an industrial operation neglecting time value of money.

full life cycle for an industrial process. The zero point on the abscissa represents that time at which the plant has been completely constructed and is ready for operation. The total capital investment at the zero point in time includes land value, fixed-capital and auxiliaries investment, and working capital. The cash position is negative by an amount equivalent to the total capital investment at zero time, but profits in the ideal situation come in from the operation as soon as time is positive. Cash flow to the company, in the form of net profits after taxes and depreciation charges, starts to accumulate and gradually pays off the full capital investment. For the conditions shown in Fig. 6-2, the full capital investment is paid off in five years. After that time, profits accumulate on the positive side of the cumulative cash position until the end of the project life at which time the project theoretically is shut down and the operation ceases. At that time, the working capital is still available, and it is assumed that the land can still be sold at its original value. Thus, the final result of the cumulative cash position is a net profit over the total life of the project, or a cash flow into the company capital sink (in addition to the depreciation cash flow for investment payoff) over the ten-year period, as shown in the upper right-hand bracket in Fig. 6-2.

The relationships presented in Fig. 6-2 are very important for the understanding of the factors to be considered in cost estimation. To put emphasis on the basic nature of the role of cash flow, including depreciation charges, Fig. 6-2 has been simplified considerably by neglecting the time value of money and using straight-line relationships of constant annual profit and constant annual depreciation. In the chapters to follow, more complex cases will be considered in detail.

FACTORS AFFECTING INVESTMENT AND PRODUCTION COSTS

When a chemical engineer determines costs for any type of commercial process, these costs should be of sufficient accuracy to provide reliable decisions. To accomplish this, the engineer must have a complete understanding of the many factors that can affect costs. For example, many companies have reciprocal arrangements with other concerns whereby certain raw materials or types of equipment may be purchased at prices lower than the prevailing market prices. Therefore, if the chemical engineer bases the cost of the raw materials for the process on regular market prices, the result may be that the process is uneconomical. If the engineer had based the estimate on the actual prices the company would have to pay for the raw materials, the economic picture might have been altered completely. Thus the engineer must keep up-to-date on price fluctuations, company policies, governmental regulations, and other factors affecting costs.

Sources of Equipment

One of the major costs involved in any chemical process is for the equipment. In many cases, standard types of tanks, reactors, or other equipment are used, and a substantial reduction in cost can be made by employing idle equipment or by purchasing second-hand equipment. If new equipment must be bought, several independent quotations should be obtained from different manufacturers. When the specifications are given to the manufacturers, the chances for a low cost estimate are increased if the engineer does not place overly strict limitations on the design.

Price Fluctuations

In our modern economic society, prices may vary widely from one period to another, and this factor must be considered when the costs for an industrial process are determined. It would obviously be ridiculous to assume that plant operators or supervisors could be hired today at the same wage rate as in 1975. The same statement applies to comparing prices of equipment purchased at different times. The chemical engineer, therefore, must keep up-to-date on price and wage fluctuations. One of the most complete sources of information on existing price conditions is the *Monthly Labor Review* published by the U.S. Bureau of Labor Statistics. This publication gives up-to-date information on present prices and wages for different types of industries.

Company Policies

Policies of individual companies have a direct effect on costs. For example, some concerns have particularly strict safety regulations and these must be met in every detail. Accounting procedures and methods for determining depreciation costs vary among different companies. The company policies with reference to labor unions should be considered, because these will affect overtime labor charges and the type of work the operators or other employees can do. Labor-union policies may even dictate the amount of wiring and piping that can be done on a piece of equipment before it is brought into the plant, and, thus, have a direct effect on the total cost of installed equipment.

Operating Time and Rate of Production

One of the factors that has an important effect on the costs is the fraction of the total available time during which the process is in operation. When equipment stands idle for an extended period of time, the labor costs are usually low; however, other costs, such as those for maintenance, protection, and depreciation, continue even though the equipment is not in active use.

Operating time, rate of production, and sales demand are closely interrelated. The ideal plant should operate under a time schedule which gives the maximum production rate while maintaining economic operating methods. In this way, the total cost per unit of production is kept near a minimum because the fixed costs are utilized to the fullest extent. This ideal method of operation is based on the assumption that the sales demand is sufficient to absorb all the material produced. If the production capacity of the process is greater than the sales demand, the operation can be carried on at reduced capacity or periodically at full capacity.

Figure 6-3 gives a graphical analysis of the effect on costs and profits when the rate of production varies. As indicated in this figure, the fixed costs remain constant and the total product cost increases as the rate of production increases. The point where the total product cost equals the total income is known as the *break-even point*. Under the conditions shown in Fig. 6-3, an ideal production rate for this chemical processing plant would be approximately 450,000 kg/month, because this represents the point of maximum net earnings.

The effects of production rate and operating time on costs should be recognized. By considering sales demand along with the capacity and operating characteristics of the equipment, the engineer can recommend the production rate and operating schedules that will give the best economic results.

Governmental Policies

The national government has many regulations and restrictions which have a direct effect on industrial costs. Some examples of these are import and export tariff regulations, restrictions on permissible depreciation rates, income-tax rules, and environmental regulations.

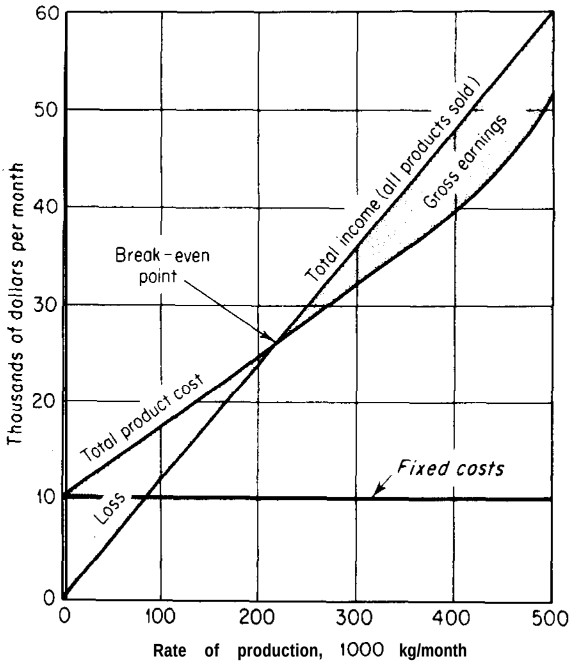

FIGURE 6-3
Break-even chart for chemical processing plant.

Prior to 1951, the United States had strict governmental regulations against rapid write-offs for industrial equipment. These restrictions increased the income-tax load for new companies during their first few years of existence and tended to discourage new enterprises. Therefore, during the Korean war, a fast amortization policy for certain defense installations was authorized. This policy permitted at least part of the value of the installation to be written off in 5 years as compared to an average of 10 to 15 years under the old laws. In 1954, a new law was passed permitting approximately two-thirds of the total investment for any process to be written off as depreciation during the first half of the useful life. A rapid write-off of this type can be very desirable for some concerns because it may reduce income taxes during the early years of the plant life.

In 1971 and again in 1981 and 1986, there were major changes in Federal income-tax regulations relative to acceptable methods for determining depreciation write-offs. Other changes have from time to time been adopted by Congress, and the cost engineer must keep up-to-date on these changes.†

Governmental policies with reference to capital gains and gross-earnings taxes should be understood when costs are determined. Suppose a concern decides to sell some valuable equipment before its useful life is over. The equipment has a certain *asset* or unamortized value, but the offered price may

†For a discussion of depreciation write-off methods, see Chap. 9 (Depreciation).

be more than the unamortized value. This profit over the unamortized value would have been taxable as long-term capital gain at 28 to 30 percent if it had been held for nine months in 1977, one year from 1978 to mid 1984, and six months from mid 1984 through 1987. Starting in 1988, the period for long-term capital gain was one year and the tax rate on both short-term and long-term capital gains was generally the same as that for ordinary income. Therefore, in the example referred to above where a long-term capital gain would be realized by selling equipment, the capital gain would have been fairly large if a fast depreciation method had been used by the company. Prior to 1988, this gain would probably have been taxed at a low rate (perhaps as low as 28 percent) while the amount saved through fast depreciation allowance could have been at an income-tax rate of nearly 50 percent. However, after 1987, new Federal tax rules have been enacted which could make the capital-gains tax the same as the income tax on ordinary income of about 34 percent.?

The preceding examples illustrate why the chemical engineer should understand the effects of governmental regulations on costs. Each company has its own methods for meeting these regulations, but changes in the laws and alterations in the national and company economic situation require constant surveillance if optimum cost conditions are to be maintained.

CAPITAL INVESTMENTS

Before an industrial plant can be put into operation, a large sum of money must be supplied to purchase and install the necessary machinery and equipment. Land and service facilities must be obtained, and the plant must be erected complete with all piping, controls, and services. In addition, it is necessary to have money available for the payment of expenses involved in the plant operation.

The capital needed to supply the necessary manufacturing and plant facilities is called the *fixed-capital investment,* while that necessary for the operation of the plant is termed the *working capital.* The sum of the fixed-capital investment and the working capital is known as the *total capital investment.* The fixed-capital portion may be further subdivided into *manufacturing fixed-capital investment* and *nonmanufacturing fixed-capital investment.*

Fixed-Capital Investment

Manufacturing fixed-capital investment represents the capital necessary for the installed process equipment with all auxiliaries that are needed for complete process operation. #Expenses for piping, instruments, insulation, foundations, and site preparation are typical examples of costs included in the manufacturing fixed-capital investment.

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†For a discussion of income-tax rates, see Chap. 8 (Taxes and Insurance).

Fixed capital required for construction overhead and for all plant components that are not directly related to the process operation is designated as the nonmanufacturing fixed-capital investment. These plant components include the land, processing buildings, administrative, and other offices, warehouses, laboratories, transportation, shipping, and receiving facilities, utility and waste-disposal facilities, shops, and other permanent parts of the plant. The construction overhead cost consists of field-office and supervision expenses, home-office expenses, engineering expenses, miscellaneous construction costs, contractor's fees, and contingencies. In some cases, construction overhead is proportioned between manufacturing and nonmanufacturing fixed-capital investment.

Working Capital

The working capital for an industrial plant consists of the total amount of money invested in (1) raw materials and supplies carried in stock, (2) finished products in stock and semifinished products in the process of being manufactured, (3) accounts receivable, (4) cash kept on hand for monthly payment of operating expenses, such as salaries, wages, and raw-material purchases, (5) accounts payable, and (6) taxes payable.

The raw-materials inventory included in working capital usually amounts to a l-month supply of the raw materials valued at delivered prices. Finished products in stock and semifinished products have a value approximately equal to the total manufacturing cost for 1 month's production. Because credit terms extended to customers are usually based on an allowable 30-day payment period, the working capital required for accounts receivable ordinarily amounts to the production cost for 1 month of operation.

The ratio of working capital to total capital investment varies with different companies, but most chemical plants use an initial working capital amounting to 10 to 20 percent of the total capital investment. This percentage may increase to as much as 50 percent or more for companies producing products of seasonal demand because of the large inventories which must be maintained for appreciable periods of time.

ESTIMATION OF CAPITAL INVESTMENT

Of the many factors which contribute to poor estimates of capital investments, the most significant one is usually traceable to sizable omissions of equipment, services, or auxiliary facilities rather than to gross errors in costing. A check list of items covering a new facility is an invaluable aid in making a complete estimation of the fixed-capital investment. Table 1 gives a typical list of these items.

TABLE 1
Breakdown of fixed-capital investment items for a chemical process

Direct Costs

1. *Purchased equipment*
   - All equipment listed on a complete flow sheet
   - Spare parts and noninstalled equipment spares
   - Surplus equipment, supplies, and equipment allowance
   - Inflation cost allowance
   - Freight charges
   - Taxes, insurance, duties
   - Allowance for modifications during startup
2. *Purchased-equipment installation*
   - Installation of all equipment listed on complete flow sheet
   - Structural supports, insulation, paint
3. *Instrumentation and controls*
   - Purchase, installation, calibration, computer tie-in
4. *Piping*
   - Process piping-carbon steel, alloy, cast iron, lead, lined, aluminum, copper, ceramic, plastic, rubber, reinforced concrete
   - Pipe hangers, fittings, valves
   - Insulation-piping, equipment
5. *Electrical equipment and materials*
   - Electrical equipment -switches, motors, conduit, wire, fittings, feeders, grounding, instrument and control wiring, lighting, panels
   - Electrical materials and labor
6. *Buildings (including services)*
   - Process buildings-substructures, superstructures, platforms, supports, stairways, ladders, access ways, cranes, monorails, hoists, elevators
   - Auxiliary buildings-administration and office, medical or dispensary, cafeteria, garage, product warehouse, parts warehouse, guard and safety, fire station, change house, personnel building, shipping office and platform, research laboratory, control laboratory
   - Maintenance shops-electric, piping, sheet metal, machine, welding, carpentry, instrument
   - Building services-plumbing, heating, ventilation, dust collection, air conditioning, building lighting, elevators, escalators, telephones, intercommunication systems, painting, sprinkler systems, fire alarm
7. *Yard improvements*
   - Site development-site clearing, grading, roads, walkways, railroads, fences, parking areas, wharves and piers, recreational facilities, landscaping
8. *Service facilities*
   - Utilities-steam, water, power, refrigeration, compressed air, fuel, waste disposal
   - Facilities-boiler plant incinerator, wells, river intake, water treatment, cooling towers, water storage, electric substation, refrigeration plant, air plant, fuel storage, waste disposal plant, environmental controls, fire protection
   - Nonprocess equipment-office furniture and equipment, cafeteria equipment, safety and medical equipment, shop equipment, automotive equipment, yard material-handling equipment, laboratory equipment, locker-room equipment, garage equipment, shelves, bins, pallets, hand trucks, housekeeping equipment, fire extinguishers, hoses, fire engines, loading stations
   - Distribution and packaging-raw-material and product storage and handling equipment, product packaging equipment, blending facilities, loading stations

(Continued)

TABLE 1
Breakdown of fixed-capital investment items for a chemical process *(Continued)*

Direct **Costs**

9. *Land*
   Surveys and fees
   Property cost

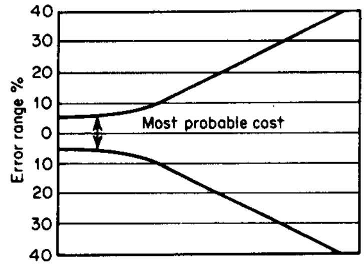
Indirect costs

1. *Engineering and supervision*
   Engineering costs-administrative, process, design and general engineering, drafting, cost engineering, procuring, expediting, reproduction, communications, scale models, consultant fees, travel
   Engineering supervision and inspection
2. *Construction expenses*
   Construction, operation and maintenance of temporary facilities, offices, roads, parking lots, railroads, electrical, piping, communications, fencing
   Construction tools and equipment
   Construction supervision, accounting, timekeeping, purchasing, expediting
   Warehouse personnel and expense, guards
   Safety, medical, fringe benefits
   Permits, field tests, special licenses
   Taxes, insurance, interest
3. *Contractor's fee*
4. *Contingency*

Types of Capital Cost Estimates

An estimate of the capital investment for a process may vary from a predesign estimate based on little information except the size of the proposed project to a detailed estimate prepared from complete drawings and specifications. Between these two extremes of capital-investment estimates, there can be numerous other estimates which vary in accuracy depending upon the stage of development of the project. These estimates are called by a variety of names, but the following five categories represent the accuracy range and designation normally used for design purposes:

1. Order-of-magnitude estimate (ratio estimate) based on similar previous cost data; probable accuracy of estimate over ± 30 percent.
2. Study estimate (factored estimate) based on knowledge of major items of equipment; probable accuracy of estimate up to ± 30 percent.
3. Preliminary estimate (budget authorization estimate; scope estimate) based on sufficient data to permit the estimate to be budgeted; probable accuracy of estimate within ± 20 percent.



	Required information	Detailed estimate ±5% range	Definitive estimate ±10% range	Preliminary estimate ±20% range	Study estimate ±30% range	Order-of-magnitude estimate > ±30% range
Site	Location	●	●	●	●	
	General description	●	●	●		
	Soil bearing	●	●	●		
	Location & dimensions R.R., roads, impounds, fences	●	●	●		
	Well-developed site plot plan & topographical map	●	●			
	Well-developed site facilities					
Process flow sheet	Rough sketches				●	
	Preliminary			●		
	Engineered	●	●			
Equipment list	Preliminary sizing & material specifications			●	●	
	Engineered specifications	●	●			
	Vessel sheets	●	●			
	General arrangement					
	(a) Preliminary		●	●		
	(b) Engineered	●				
Building and structures	Approximate sizes & type of construction			●	●	
	Foundation sketches		●	●		
	Architectural & construction	●	●	●		
	Preliminary structural design			●		
	General arrangements & elevations	●	●			
	Detailed drawings	●				
Utility requirements	Rough quantities (steam, water, electricity, etc.)				●	
	Preliminary heat balance			●		
	Preliminary flow sheets			●		
	Engineered heat balance	●	●			
	Engineered flow sheets	●	●			
	Well-developed drawings	●				
Piping	Preliminary flow sheet & specifications			●	●	
	Engineered flow sheet	●	●			
	Piping layouts & schedules	●				
Insulation	Rough specifications			●		
	Preliminary list of equipment & piping to be insulated		●			
	Insulation specifications & schedules	●				
	Well-developed drawings or specifications					
Instrumentation	Preliminary instrument list					
	Engineered list & flow sheet	●	●			
	Well-developed drawings	●				
Electrical	Preliminary motor list-approximate sizes			●	●	
	Engineered list & sizes	●	●			
	Substations, number & sizes, specifications	●	●	●		
	Distribution specifications	●				
	Preliminary lighting specifications			●		
	Preliminary interlock, control, & instrument wiring specs.		●			
	Engineered single-line diagrams (power & light)	●	●			
	Well-developed drawings	●				
Man-hours	Engineering & drafting	●	●	●	●	
	Labor by craft	●				
	Supervision	●				
Project scope standard processes	Product, capacity, location & site requirements. Utility & service requirements. Building & auxiliary requirements. Raw materials & finished product handling & storage requirements					●

FIGURE 6-4
Cost-estimating information guide.

TABLE 2
Typical average costs for making estimates (1990)†

Cost of project	Less than $2,000,000	$2,000,000 to $10,000,000	$10,000,000 to $100,000,000
Order-of-magnitude estimate	$ 3,000	$ 6,000	$ 13,000
Study estimate	20,000	40,000	60,000
Preliminary estimate	50,000	80,000	130,000
Definitive estimate	80,000	160,000	320,000
Detailed estimate	200,000	520,000	1,000,000

† Adapted from A. Pikulik and H. E. Diaz, Cost Estimating for Major Process Equipment, *Chem. Eng.*, **84**(21):106 (Oct. 10, 1977).

4. Definitive estimate (project control estimate) based on almost complete data but before completion of drawings and specifications; probable accuracy of estimate within ± 10 percent.
5. Detailed estimate (contractor's estimate) based on complete engineering drawings, specifications, and site surveys; probable accuracy of estimate within ±5 percent.

Figure 6-4 shows the relationship between probable accuracy and quantity and quality of information available for the preparation of these five levels of estimates.? The approximate limits of error in this listing are plotted and show an envelope of variability. There is a large probability that the actual cost will be more than the estimated cost where information is incomplete or in time of rising-cost trends. For such estimates, the positive spread is likely to be wider than the negative, e.g., +40 and − 20 percent for a study estimate. Table 2 illustrates the wide variation that can occur in the cost of making a capital-investment estimate depending on the type of estimate.

Predesign cost estimates (defined here as order-of-magnitude, study, and preliminary estimates) require much less detail than firm estimates such as the definitive or detailed estimate. However, the predesign estimates are extremely important for determining if a proposed project should be given further consideration and to compare alternative designs. For this reason, most of the information presented in this chapter is devoted to predesign estimates, although it should be understood that the distinction between predesign and firm estimates gradually disappears as more and more detail is included.

It should be noted that the predesign estimates may be used to provide a basis for requesting and obtaining a capital appropriation from company management. Later estimates, made during the progress of the job, may indicate that the project will cost more or less than the amount appropriated. Management is then asked to approve a ***variance*** which may be positive or negative.

†Adapted from a method presented by W. T. Nichols, *Znd. Eng. Chem.*, **43**(10):2295 (1951).

TABLE 3
Cost indexes as annual averages

Year	Marshall and Swift installed-equipment indexes, 1926 = 100: All-industry	Marshall and Swift installed-equipment indexes, 1926 = 100: Process-industry	*Eng. News-Record* construction index: 1913 = 100	*Eng. News-Record* construction index: 1949 = 100	*Eng. News-Record* construction index: 1967 = 100	Nelson-Farrar refinery construction index, 1946 = 100	Chemical engineering plant cost index 1957-1959 = 100
1975	444	452	2412	464	207	576	182
1976	472	479	2401	503	224	616	192
1977	505	514	2576	540	241	653	204
1978	545	552	2776	582	259	701	219
1979	599	607	3003	630	281	757	239
1980	560	675	3237	679	303	823	261
1981	721	745	3535	741	330	904	297
1982	746	774	3825	802	357	977	314
1983	761	786	4066	852	380	1026	317
1984	780	806	4146	869	387	1061	323
1985	790	813	4195	879	392	1074	325
1986	798	817	4295	900	401	1090	318
1987	814	830	4406	924	412	1122	324
1988	852	870	4519	947	422	1165	343
1989	895	914	4606	965	429	1194	355
1990 (Jan.)	904†	924	4673	979	435	1203	356

† All costs presented in this text are based on this value of the Marshall and Swift index unless otherwise indicated.

COST INDEXES

Most cost data which are available for immediate use in a preliminary or predesign estimate are based on conditions at some time in the past. Because prices may change considerably with time due to changes in economic conditions, some method must be used for updating cost data applicable at a past date to costs that are representative of conditions at a later time.† This can be done by the use of cost indexes.

A cost index is merely an index value for a given point in time showing the cost at that time relative to a certain base time. If the cost at some time in the past is known, the equivalent cost at the present time can be determined by multiplying the original cost by the ratio of the present index value to the index value applicable when the original cost was obtained.

†See Chap. 11 for a discussion of the strategy to use in design estimates to consider the effects of inflation or deflation on costs and profits in the future.

$$\text{Present cost} = \text{original cost}\left(\frac{\text{index value at present time}}{\text{index value at time original cost was obtained}}\right)$$

Cost indexes can be used to give a general estimate, but no index can take into account all factors, such as special technological advancements or local conditions. The common indexes permit fairly accurate estimates if the time period involved is less than 10 years.

Many different types of cost indexes are published regularly. Some of these can be used for estimating equipment costs; others apply specifically to labor, construction, materials, or other specialized fields. The most common of these indexes are the *Marshall and Swift all-industry and process-industry equipment indexes,* the *Engineering News-Record construction index,* the *Nelson-Farrar refinery construction index,* and the *Chemical Engineering plant cost index.* Table 3 presents a list of values for various types of indexes over the past 15 years.

Marshall and Swift Equipment Cost Indexes†

The Marshall and Swift (formerly known as Marshall and Stevens) equipment indexes are normally divided into two categories. The all-industry equipment index is simply the arithmetic average of individual indexes for 47 different types of industrial, commercial, and housing equipment. The process-industry equipment index is a weighted average of eight of these, with the weighting based on the total product value of the various process industries. The percentages used for the weighting in a typical year are as follows: cement 2; chemicals, 48; clay products, 2; glass, 3; paint, 5; paper, 10; petroleum, 22; and rubber, 8.

The Marshall and Swift indexes are based on an index value of 100 for the year 1926. These indexes take into consideration the cost of machinery and major equipment plus costs for installation, fixtures, tools, office furniture, and other minor equipment. All costs reported in this text are based on a Marshall and Swift all-industry index of 904 as reported for January 1, 1990 unless indicated otherwise.

Engineering News-Record Construction Cost Index‡

Relative construction costs at various dates can be estimated by the use of the *Engineering News-Record* construction index. This index shows the variation in

†Values for the Marshall and Swift equipment cost indexes are published each month in *Chemical Engineering.* For a complete description of these indexes, see R. W. Stevens, *Chem. Eng.*, **54**(11):124 (Nov., 1947). See also *Chem. Eng.*, **85**(11):189 (May 8, 1978) and **92**(9):75 (April 29, 1985).

‡The *Engineering News-Record* construction cost index appears weekly in the *Engineering News-Record.* For a complete description of this index and the revised basis, see *Eng. News-Record,* **143**(9):398 (1949); **178**(11):87 (1967). History is in March issue each year; for example, see *Eng. News-Record,* **220**(11):54 (March 15, 1988).

labor rates and materials costs for industrial construction. It employs a composite cost for 2500 lb of structural steel, 1088 fbm of lumber, 2256 lb of concrete, and 200 h of common labor. The index is usually reported on one of three bases: an index value of 100 in 1913, 100 in 1949, or 100 in 1967.

Nelson-Farrar Refinery Construction Cost Index†

Construction costs in the petroleum industry are the basis of the Nelson-Farrar construction index. The total index percentages are weighted as follows: skilled labor, 30; common labor, 30; iron and steel, 20; building materials, 8; and miscellaneous equipment, 12. An index value of 100 is used for the base year of 1946.

Chemical Engineering Plant Cost Index‡

Construction costs for chemical plants form the basis of the *Chemical Engineering* plant cost index. The four major components of this index are weighted by percentage in the following manner: equipment, machinery, and supports, 61; erection and installation labor, 22; buildings, materials, and labor, 7; and engineering and supervision, 10. The major component, equipment, is further subdivided and weighted as follows: fabricated equipment, 37; process machinery, 14; pipe, valves, and fittings, 20; process instruments and controls, 7; pumps and compressors, 7; electrical equipment and materials, 5; and structural supports, insulation, and paint, 10. All index components are based on 1957-1959 = 100.

Other Indexes and Analysis

There are numerous other indexes presented in the literature which can be used for specialized purposes. For example, cost indexes for materials and labor for various types of industries are published monthly by the U.S. Bureau of Labor Statistics in the *Monthly Labor Review*. These indexes can be useful for special kinds of estimates involving particular materials or unusual labor conditions. Another example of a cost index which is useful for world-wide comparison of cost charges with time is published periodically in *Engineering Costs and*

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†The Nelson-Farrar refinery construction index is published the first week of each month in the *Oil and Gas Journal*. For a complete description of this index, see *Oil Gas J.*, **63**(14):185 (1965); **74**(48):68 (1976); and **83**(52):145 (1985).

‡The *Chemical Engineering* plant cost index is published each month in *Chemical Engineering*. A complete description of this index is in *Chem. Eng.*, **70**(4):143 (Feb. 18, 1963) with recapping and updating in issues of **73**(9):184 (April 25, 1966); **76**(10):134 (May 5, 1969); **79**(25):168 (Nov. 13, 1972); **82**(9):117 (April 28, 1975); **85**(11):189 (May 8, 1978); **89**(8):153 (April 19, 1982); and **92**(9):75 (April 29, 1985).

Production Economics. This presents cost indexes for plant costs for various countries in the world including Australia, Belgium, Canada, Denmark, France, Germany, Italy, Netherlands, Norway, Japan, Sweden, the United Kingdom, and the United States.?

Unfortunately, all cost indexes are rather artificial; two indexes covering the same types of projects may give results that differ considerably. The most that any index can hope to do is to reflect average changes. The latter may at times have little meaning when applied to a specific case. For example, a contractor may, during a slack period, accept a construction job with little profit just to keep his construction crew together. On the other hand, if there are current local labor shortages, a project may cost considerably more than a similar project in another geographical location.

For use with process-equipment estimates and chemical-plant investment estimates, the *Marshall and Swift* equipment cost indexes and the *Chemical Engineering* plant cost indexes are recommended. These two cost indexes give very similar results, while the *Engineering News-Record* construction cost index, relative with time, has increased much more rapidly than the other two because it does not include a productivity improvement factor. Similarly, the *Nelson-Farrar* refinery construction index has shown a very large increase with time and should be used with caution and only for refinery construction.

COST FACTORS IN CAPITAL INVESTMENT

Capital investment, as defined earlier, is the total amount of money needed to supply the necessary plant and manufacturing facilities plus the amount of money required as working capital for operation of the facilities. Let us now consider the proportional costs of each major component of fixed-capital investment as outlined previously in Table 1 of this chapter. The cost factors presented here are based on a careful study by Bauman and associates plus additional data and interpretations from other more recent sources‡ with input based on modern industrial experience.

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†For methods used, see *Eng. Costs Prod. Econ.*, **6**(1):267 (1982).

‡H. C. Bauman, "Fundamentals of Cost Engineering in the Chemical Industry," Reinhold Publishing Corporation, New York, 1964; K. M. Guthrie, "Process Plant Estimating, Evaluation, and Control," Craftsman Book Company of America, Solana Beach, CA, 1974; D. H. Allen and R. C. Page, Revised Techniques for Predesign Cost Estimating. *Chem. Eng.*, **82**(5):142 (Mar. 3, 1975); W. D. Baasel, "Preliminary Chemical Engineering Plant Design," American Elsevier Publishing Company, Inc., New York, 1976; R. H. Perry and D. W. Green, "Chemical Engineers' Handbook," 6th ed., McGraw-Hill Book Company, Inc., New York, 1984; G. D. Ulrich, "A Guide to Chemical Engineering Process Design and Economics," Wiley, New York, 1984; R. K. Sinnott, "An Introduction to Chemical Engineering Design," Pergamon Press, Oxford, England, 1983; P. F. Ostwald, "AM Cost Estimator," McGraw-Hill Book Company, Inc., New York, 1988.

TABLE 4
Typical percentages of fixed-capital investment values for direct and indirect cost segments for multipurpose plants or large additions to existing facilities

Component	Range, %
Direct costs	
Purchased equipment	15-40
Purchased equipment installation	6-14
Instrumentation and controls (installed)	2-8
Piping (installed)	3-20
Electrical (installed)	2-10
Buildings (including services)	3-18
Yard improvements	2-5
Service facilities (installed)	8-20
Land	1-2
Total direct costs	
Indirect costs	
Engineering and supervision	4-21
Construction expense	4-16
Contractor's fee	2-6
Contingency	5-15
Total fixed-capital investment	

Table 4 summarizes this typical variation in component costs as percentages of fixed-capital investment for multiprocess grass-roots plants or large *battery-limit* additions. A *grass-roots* plant is defined as a complete plant erected on a new site. Investment includes all costs of land, site development, battery-limit facilities, and auxiliary facilities. A geographical boundary defining the coverage of a specific project is a *battery limit.* Usually this encompasses the manufacturing area of a proposed plant or addition, including all process equipment but excluding provision of storage, utilities, administrative buildings, or auxiliary facilities unless so specified. Normally this excludes site preparation and therefore, may be applied to the extension of an existing plant.

Example 1 Estimation of fixed-capital investment using ranges of process-plant component costs. Make a study estimate of the fixed-capital investment for a process plant if the purchased-equipment cost is $100,000. Use the ranges of process-plant component cost outlined in Table 4 for a process plant handling both solids and fluids with a high degree of automatic controls and essentially outdoor operation.

Solution

Components	Assumed % of total	Cost	Ratioed % of total
Purchased equipment	25	$100,000	23.0
Purchased-equipment installation	9	36,000	8.3
Instrumentation (installed)	7	28,000	6.4
Piping (installed)	8	32,000	7.3
Electrical (installed)	5	20,000	4.6
Buildings (including services)	5	20,000	4.6
Yard improvements	2	8,000	1.8
Service facilities (installed)	15	60,000	13.8
Land	1	4,000	0.9
Engineering and supervision	10	40,000	9.2
Construction expense	12	48,000	11.0
Contractor's fee	2	8,000	1.8
Contingency	8	32,000	7.3
		$436,000	100.0

Range will vary from $371,000 to $501,000 for normal conditions; if economy is inflationary, it may vary from $436,000–$566,000.

Purchased Equipment

The cost of purchased equipment is the basis of several predesign methods for estimating capital investment. Sources of equipment prices, methods of adjusting equipment prices for capacity, and methods of estimating auxiliary process equipment are therefore essential to the estimator in making reliable cost estimates.

The various types of equipment can often be divided conveniently into (1) processing equipment, (2) raw-materials handling and storage equipment, and (3) finished-products handling and storage equipment. The cost of auxiliary equipment and materials, such as insulation and ducts, should also be included.

The most accurate method for determining process equipment costs is to obtain firm bids from fabricators or suppliers. Often, fabricators can supply quick estimates which will be very close to the bid price but will not involve too much time. Second best in reliability are cost values from the file of past purchase orders. When used for pricing new equipment, purchase-order prices must be corrected to the current cost index. Limited information on process-equipment costs has also been published in various engineering journals. Costs, based on January 1, 1990 prices, for a large number of different types and capacities of equipment are presented in Chaps. 14 through 16. A convenient reference to these various cost figures is given in the Table of Contents and in the subject index.

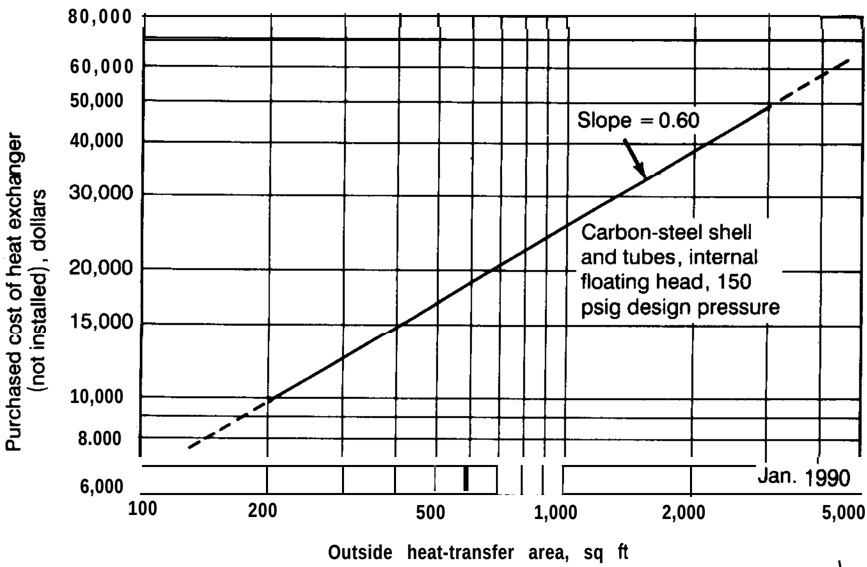

FIGURE 6-5
Application of "six-tenth-factor" rule to costs for shell-and-tube heat exchangers.

Estimating Equipment Costs by Scaling

It is often necessary to estimate the cost of a piece of equipment when no cost data are available for the particular size of operational capacity involved. Good results can be obtained by using the logarithmic relationship known as the ***six-tenths-factor*** rule, if the new piece of equipment is similar to one of another capacity for which cost data are available. According to this rule, if the cost of a given unit at one capacity is known, the cost of a similar unit with X times the capacity of the first is approximately $(X)^{0.6}$ times the cost of the initial unit.

$$\text{Cost of equip. } a = \text{cost of equip. } b\left(\frac{\text{capac. equip. } a}{\text{capac. equip. } b}\right)^{0.6} \tag{1}$$

The preceding equation indicates that a log-log plot of capacity versus equipment cost for a given type of equipment should be a straight line with a slope equal to 0.6. Figure 6-5 presents a plot of this sort for shell-and-tube heat exchangers. However, the application of the 0.6 rule of thumb for most purchased equipment is an oversimplification of a valuable cost concept since the actual values of the cost capacity factor vary from less than 0.2 to greater than 1.0 as shown in Table 5. Because of this, the 0.6 factor should only be used in the absence of other information. In general, the cost-capacity concept should not be used beyond a tenfold range of capacity, and care must be taken to make certain the two pieces of equipment are similar with regard to type of construction, materials of construction, temperature and pressure operating range, and other pertinent variables.

TABLE 5
Typical exponents for equipment cost vs. capacity

Equipment	Siie range	Exponent
Blender, double cone rotary, c.s.	SO-250 ft^3	0.49
Blower, centrifugal	10^3–10^4 ft^3/min	0.59
Centrifuge, solid bowl, c.s.	10–10^2 hp drive	0.67
Crystallizer, vacuum batch, c.s.	500-7000 ft^3	0.37
Compressor, reciprocating, air cooled, two-stage, 150 psi discharge	10–400 ft^3/min	0.69
Compressor, rotary, single-stage, sliding vane, 150 psi discharge	10^2–10^3 ft^3/min	0.79
Dryer, drum, single vacuum	10–10^2 ft^2	0.76
Dryer, drum, single atmospheric	10–10^2 ft^2	0.40
Evaporator (installed), horizontal tank	10^2–10^4 ft^2	0.54
Fan, centrifugal	10^3–10^4 ft^3/min	0.44
Fan, centrifugal	2×10^4–7×10^4 ft^3/min	1.17
Heat exchanger, shell and tube, floating head, c.s.	100-400 ft^2	0.60
Heat exchanger, shell and tube, fixed sheet, c.s.	100-400 ft^2	0.44
Kettle, cast iron, jacketed	250-800 gal	0.27
Kettle, glass lined, jacketed	200-800 gal	0.31
Motor, squirrel cage, induction, 440 volts, explosion proof	5-20 hp	0.69
Motor, squirrel cage, induction, 440 volts, explosion proof	20-200 hp	0.99
Pump, reciprocating, horizontal cast iron (includes motor)	2–100 gpm	0.34
Pump, centrifugal, horizontal, cast steel (includes motor)	10^4–10^5 gpm × psi	0.33
Reactor, glass lined, jacketed (without drive)	50–600 gal	0.54
Reactor, s.s, 300 psi	10^2–10^3 gal	0.56
Separator, centrifugal, c.s.	50-250 ft^3	0.49
Tank, flat head, c.s.	10^2–10^4 gal	0.57
Tank, c.s., glass lined	10^2–10^3 gal	0.49
Tower, c.s.	10^3–2×10^6 lb	0.62
Tray, bubble cup, c.s.	3-10 ft diameter	1.20
Tray, sieve, c.s.	3-10 ft diameter	0.86

Example 2 Estimating cost of equipment using scaling factors and cost index. The purchased cost of a 50-gal glass-lined, jacketed reactor (without drive) was $8350 in 1981. Estimate the purchased cost of a similar 300-gal, glass-lined, jacketed reactor (without drive) in 1986. Use the annual average Marshall and Swift equipment-cost index (all industry) to update the purchase cost of the reactor.

Solution. Marshall and Swift equipment-cost index (all industry)

(From Table 3) For 1981 721

(From Table 3) For 1986 798

From Table 5, the equipment vs. capacity exponent is given as 0.54:

$$\text{In 1986, cost of reactor} = (\$8350)\left(\frac{798}{721}\right)\left(\frac{300}{50}\right)^{0.54}$$
$$= \$24{,}300$$

Purchased-equipment costs for vessels, tanks, and process- and materials-handling equipment can often be estimated on the basis of weight. The fact that a wide variety of types of equipment have about the same cost per unit weight is quite useful, particularly when other cost data are not available. Generally, the cost data generated by this method are sufficiently reliable to permit order-of-magnitude estimates.

Purchased-Equipment Installation

The installation of equipment involves costs for labor, foundations, supports, platforms, construction expenses, and other factors directly related to the erection of purchased equipment. Table 6 presents the general range of installation cost as a percentage of the purchased-equipment cost for various types of equipment.

Installation labor cost as a function of equipment size shows wide variations when scaled from previous installation estimates. Table 7 shows exponents varying from 0.0 to 1.56 for a few selected pieces of equipment.

TABLE 6
Installation cost for equipment as a percentage of the purchased-equipment cost†

Type of equipment	Installation cost, %
Centrifugal separators	20-60
Compressors	30-60
Dryers	25-60
Evaporators	25-90
Filters	65-80
Heat exchangers	30-60
Mechanical crystallizers	30-60
Metal tanks	30-60
Mixers	20-40
Pumps	25-60
Towers	60-90
Vacuum crystallizers	40-70
Wood tanks	30-60

† Adapted from K. M. Guthrie, "Process Plant Estimating, Evaluation, and Control," Craftsman Book Company of America, Solana Beach, California, 1974.

TABLE 7
Typical exponents for equipment installation labor vs. size

Equipment	Size range	Exponent
Conduit, aluminum	0.5-2-in. diam.	0.49
Conduit, aluminum	2-4-in. diam.	1.11
Motor, squirrel cage, induction, 440 volts	1-10 hp	0.19
Motor, squirrel cage, induction, 440 volts	10-50 hp	0.50
Pump, centrifugal, horizontal	0.5-1.5 hp	0.63
Pump, centrifugal, horizontal	1.5-40 hp	0.09
Tower, c.s.	Constant diam.	0.88
Tower, c.s.	Constant height	1.56
Transformer, single phase, dry	9-225 kva	0.58
Transformer, single phase, oil, class A	15-225 kva	0.34
Tubular heat exchanger	Any size	0.00

Tubular heat exchangers appear to have zero exponents, implying that direct labor cost is independent of size. This reflects the fact that such equipment is set with cranes and hoists, which, when adequately sized for the task, recognize no appreciable difference in size of weight of the equipment. The higher labor exponent for installing carbon-steel towers indicates the increasing complexity of tower internals (trays, downcomers, etc.) as tower diameter increases.

Analyses of the total installed costs of equipment in a number of typical chemical plants indicate that the cost of the purchased equipment varies from 65 to 80 percent of the installed cost depending upon the complexity of the equipment and the type of plant in which the equipment is installed. Installation costs for equipment, therefore, are estimated to vary from 25 to 55 percent of the purchased-equipment cost.

Insulation Costs

When very high or very low temperatures are involved, insulation factors can become important, and it may be necessary to estimate insulation costs with a great deal of care. Expenses for equipment insulation and piping insulation are often included under the respective headings of equipment-installation costs and piping costs.

The total cost for the labor and materials required for insulating equipment and piping in ordinary chemical plants is approximately 8 to 9 percent of the purchased-equipment cost. This is equivalent to approximately 2 percent of the total capital investment.

Instrumentation and Controls

Instrument costs, installation-labor costs, and expenses for auxiliary equipment and materials constitute the major portion of the capital investment required for instrumentation. This part of the capital investment is sometimes combined with the general equipment groups. Total instrumentation cost depends on the amount of control required and may amount to 6 to 30 percent of the purchased cost for all equipment. Computers are commonly used with controls and have the effect of increasing the cost associated with controls.

For the normal solid-fluid chemical processing plant, a value of 13 percent of the purchased equipment is normally used to estimate the total instrumentation cost. This cost represents approximately 3 percent of the total capital investment. Depending on the complexity of the instruments and the service, additional charges for installation and accessories may amount to 50 to 70 percent of the purchased cost, with the installation charges being approximately equal to the cost for accessories.

Piping

The cost for piping covers labor, valves, fittings, pipe, supports, and other items involved in the complete erection of all piping used directly in the process. This includes raw-material, intermediate-product, finished-product, steam, water, air, sewer, and other process piping. Since process-plant piping can run as high as 80 percent of purchased-equipment cost or 20 percent of tied-capital investment, it is understandable that accuracy of the entire estimate can be seriously affected by the improper application of estimation techniques to this one component.

Piping estimation methods involve either some degree of piping take-off from detailed drawings and flow sheets or using a factor technique when neither detailed drawings nor flow sheets are available. Factoring by percent of purchased-equipment cost and percent of fixed-capital investment is based strictly on experience gained from piping costs for similar previously installed chemical-process plants. Table 8 presents a rough estimate of the piping costs for various types of chemical processes. Additional information for estimating

TABLE 8
Estimated cost of piping

Type of process plant	Percent of purchased-equipment			Percent of fixed-capital investment
	Material	Labor	Total	Total
Solid †	9	7	16	4
Solid-fluid ‡	17	14	31	7
Fluid §	36	30	66	13

† A coal briquetting plant would be a typical solid-processing plant.
‡ A shale oil plant with crushing, grinding, retorting, and extraction would be a typical solid-fluid processing plant.
§ A distillation unit would be a typical fluid-processing plant.

TABLE 9
Component electrical costs as percent of total electrical cost

Component	Range, %	Typical value, %
Power wiring	25-50	40
Lighting	I-25	12
Transformation and service	9-65	40
Instrument control wiring	3-8	5

The lower range is generally applicable to grass-roots single-product plants; the higher percentages apply to complex chemical plants and expansions to major chemical plants.

piping costs is presented in Chap. 14. Labor for installation is estimated as approximately 40 to 50 percent of the total installed cost of piping. Material and labor for pipe insulation is estimated to vary from 15 to 25 percent of the total installed cost of the piping and is influenced greatly by the extremes in temperature which are encountered in the process streams.

Electrical Installations

The cost for electrical installations consists primarily of installation labor and materials for power and lighting, with building-service lighting usually included under the heading of building-and-services costs. In ordinary chemical plants, electrical-installations cost amounts to 10 to 15 percent of the value of all purchased equipment. However, this may range to as high as 40 percent of purchased-equipment cost for a specific process plant. There appears to be little relationship between percent of total cost and percent of equipment cost, but there is a better relationship to fixed-capital investment. Thus, the electrical installation cost is generally estimated between 3 and 10 percent of the fixed-capital investment.

The electrical installation consists of four major components, namely, power wiring, lighting, transformation and service, and instrument and control wiring. Table 9 shows these component costs as ratios of the total electrical cost.

Buildings Including Services

The cost for buildings including services consists of expenses for labor, materials, and supplies involved in the erection of all buildings connected with the plant. Costs for plumbing, heating, lighting, ventilation, and similar building services are included. The cost of buildings, including services for different types of process plants, is shown in Tables 10 and 11 as a percentage of purchased-equipment cost and tied-capital investment.

TABLE 10
Cost of buildings including services based on purchased-equipment cost

Type of process plant†	Percentage of purchased-equipment cost: New plant at new site (Grass roots)	New unit at existing site (Battery limit)	Expansion at an existing site
Solid	68	25	15
Solid-fluid	47	29	7
Fluid	45	5–18‡	6

† See Table 8 for definition of types of process plants.
‡ The lower figure is applicable to petroleum refining and related industries.

TABLE 11
Cost of buildings and services as a percentage of fixed-capital investment for various types of process plants

Type of process plant†	New plant at new site	New unit at existing site	Expansion at an existing site
Solid	18	1	4
Solid-fluid	12	7	2
Fluid	10	2–4‡	2

† See Table 8 for definition of types of process plants.
‡ The lower figure is applicable to petroleum refining and related industries.

Yard Improvements

Costs for fencing, grading, roads, sidewalks, railroad sidings, landscaping, and similar items constitute the portion of the capital investment included in yard improvements. Yard-improvements cost for chemical plants approximates 10 to 20 percent of the purchased-equipment cost. This is equivalent to approximately 2 to 5 percent of the fixed-capital investment. Table 12 shows the range in variation for various components of yard improvements in terms of the fixed-capital investment.

Service Facilities

Utilities for supplying steam, water, power, compressed air, and fuel are part of the service facilities of an industrial plant. Waste disposal, fire protection, and miscellaneous service items, such as shop, first aid, and cafeteria equipment and facilities, require capital investments which are included under the general heading of service-facilities cost.

The total cost for service facilities in chemical plants generally ranges from 30 to 80 percent of the purchased-equipment cost with 55 percent representing

TABLE 12
Typical variation in percent of fixed-capital investment for yard improvements

Yard improvement	Range, %	Typical value, %
Site clearing	0.4-1.2	0.8
Roads and walks	0.2-1.2	0.6
Railroads	0.3-0.9	0.6
Fences	0.1-0.3	0.2
Yard and fence lighting	0.1-0.3	0.2
Parking areas	0.1-0.3	0.2
Landscaping	0.1-0.2	0.1
Other improvements	0.2-0.6	0.3

an average for a normal solid-fluid processing plant. For a single-product, small, continuous-process plant, the cost is likely to be in the lower part of the range. For a large, new, multiprocess plant at a new location, the costs are apt to be near the upper limit of the range. The cost of service facilities, in terms of capital investment, generally ranges from 8 to 20 percent with 13 percent considered as an average value. Table 13 lists the typical variations in percentages of fixed-capital investment that can be encountered for various components of service facilities. Except for entirely new facilities, it is unlikely that all service facilities will be required in all process plants. This accounts to a large degree for the wide variation range assigned to each component in Table 13. The range also reflects the degree to which utilities which depend on heat balance are used in the process. Service facilities largely are functions of plant physical size and will be present to some degree in most plants. However, not always will there be a need for each service-facility component. The omission of these utilities would tend to increase the relative percentages of the other service facilities actually used in the plant. Recognition of this fact, coupled with a careful appraisal as to the extent that service facilities are used in the plant, should result in selecting from Table 13 a reasonable cost ratio applicable to a specific process design.

Land

The cost for land and the accompanying surveys and fees depends on the location of the property and may vary by a cost factor per acre as high as thirty to fifty between a rural district and a highly industrialized area. As a rough average, land costs for industrial plants amount to 4 to 8 percent of the purchased-equipment cost or 1 to 2 percent of the total capital investment. Because the value of land usually does not decrease with time, this cost should not be included in the fixed-capital investment when estimating certain annual operating costs, such as depreciation.

TABLE 13
Typical variation in percent of fixed-capital investment for service facilities

Service facilities	Range, %	Typical value, %
Steam generation	2.6-6.0	3.0
Steam distribution	0.2-2.0	1.0
Water supply, cooling, and pumping	0.4-3.7	1.8
Water treatment	0.5-2.1	1.3
Water distribution	0.1-2.0	0.8
Electric substation	0.9-2.6	1.3
Electric distribution	0.4-2.1	1.0
Gas supply and distribution	0.2-0.4	0.3
Air compression and distribution	0.2-3.0	1.0
Refrigeration including distribution	1.0-3.0	2.0
Process waste disposal	0.6-2.4	1.5
Sanitary waste disposal	0.2-0.6	0.4
Communications	0.1-0.3	0.2
Raw-material storage	0.3-3.2	0.5
Finished-product storage	0.7-2.4	1.5
Fire-protection system	0.3-1.0	0.5
Safety installations	0.2-0.6	0.4

Engineering and Supervision

The costs for construction design and engineering, drafting, purchasing, accounting, construction and cost engineering, travel, reproductions, communications, and home office expense including overhead constitute the capital investment for engineering and supervision. This cost, since it cannot be directly charged to equipment, materials, or labor, is normally considered an indirect cost in fixed-capital investment and is approximately 30 percent of the purchased-equipment cost or 8 percent of the total direct costs of the process plant. Typical percentage variations of tied-capital investment for various components of engineering and supervision are given in Table 14.

Construction Expense

Another expense which is included under indirect plant cost is the item of construction or field expense and includes temporary construction and operation, construction tools and rentals, home office personnel located at the construction site, construction payroll, travel and living, taxes and insurance, and other construction overhead. This expense item is occasionally included under equipment installation, or more often under engineering, supervision, and construction. If construction or field expenses are to be estimated separately, then Table 15 will be useful in establishing the variation in percent of fixed-capital investment for this indirect cost. For ordinary chemical-process

TABLE 14
Typical variation in percent of fixed-capital investment for engineering and services

Component	Range, %	Typical value, %
Engineering	1.5-6.0	2.2
Drafting	2.0-12.0	4.8
Purchasing	0.2-0.5	0.3
Accounting, construction. and cost engineering	0.2-1.0	0.3
Travel and living	0.1-1.0	0.3
Reproductions and communications	0.2-0.5	0.2
Total engineering and supervision (including overhead)	4.0-21.0	8.1

plants the construction expenses average roughly 10 percent of the total direct costs for the plant.

Contractor's Fee

The contractor's fee varies for different situations, but it can be estimated to be about 2 to 8 percent of the direct plant cost or 1.5 to 6 percent of the fixed-capital investment.

Contingencies

A contingency factor is usually included in an estimate of capital investment to compensate for unpredictable events, such as storms, floods, strikes, price

TABLE 15
Typical variation in percent of fixed-capital investment for construction expenses

Component	Range, %	Typical value, %
Temporary construction and operations	1.0-3.0	1.7
Construction tools and rental	1.0-3.0	1.5
Home office personnel in field	0.2-2.0	0.4
Field payroll	0.4-4.0	1.0
Travel and living	0.1-0.8	0.3
Taxes and insurance	1.0-2.0	1.2
Startup materials and labor	0.2-1.0	0.4
overhead	0.3-0.8	0.5
Total construction expanses	4.2-16.6	7.0

changes, small design changes, errors in estimation, and other unforeseen expenses, which previous estimates have statistically shown to be of a recurring nature. This factor may or may not include allowance for escalation. Contingency factors ranging from 5 to 15 percent of the direct and indirect plant costs are commonly used, with 8 percent being considered a fair average value.

Startup Expense

After plant construction has been completed, there are quite frequently changes that have to be made before the plant can operate at maximum design conditions. These changes involve expenditures for materials and equipment and result in loss of income while the plant is shut down or is operating at only partial capacity. Capital for these startup changes should be part of any capital appropriation because they are essential to the success of the venture. These expenses may be as high as 12 percent of the fixed-capital investment. In general, however, an allowance of 8 to 10 percent of the fixed-capital investment for this item is satisfactory.

Startup expense is not necessarily included as part of the required investment; so it is not presented as a component in the summarizing Table 26 for capital investment at the end of this chapter. In the overall cost analysis, startup expense may be represented as a one-time-only expenditure in the first year of the plant operation or as part of the total capital investment depending on the company policies.

Methods for estimating capital investment

Various methods can be employed for estimating capital investment. The choice of any one method depends upon the amount of detailed information available and the accuracy desired. Seven methods are outlined in thischapter, with each method requiring progressively less detailed information and less preparation time. Consequently, the degree of accuracy decreases with each succeeding method. A maximum accuracy within approximately ± 5 percent of the actual capital investment can be obtained with method A.

METHOD A DETAILED-ITEM ESTIMATE. A detailed-item estimate requires careful determination of each individual item shown in Table 1. Equipment and material needs are determined from completed drawings and specifications and are priced either from current cost data or preferably from firm delivered quotations. Estimates of installation costs are determined from accurate labor rates, efficiencies, and employee-hour calculations. Accurate estimates of engineering, drafting, field supervision employee-hours, and field-expenses must be detailed in the same manner. Complete site surveys and soil data must be available to minimize errors in site development and construction cost estimates. In fact, in this type of estimate, an attempt is made to firm up as much of the estimate as possible by obtaining quotations from vendors and suppliers. Because of the extensive data necessary and the large amounts of engineering time required to prepare such a detailed-item estimate, this type of estimate is almost exclusively only prepared by contractors bidding on lump-sum work from finished drawings and specifications.

METHOD B UNIT-COST ESTIMATE. The unit-cost method results in good estimating accuracies for fixed-capital investment provided accurate records have been kept of previous cost experience. This method, which is frequently used for preparing definitive and preliminary estimates, also requires detailed estimates of purchased price obtained either from quotations or index-corrected cost records and published data. Equipment installation labor is evaluated as a fraction of the delivered-equipment cost. Costs for concrete, steel, pipe, electricals, instrumentation, insulation, etc., are obtained by take-offs from the drawings and applying unit costs to the material and labor needs. A unit cost is also applied to engineering employee-hours, number of drawings, and specifications. A factor for construction expense, contractor's fee, and contingency is estimated from previously completed projects and is used to complete this type of estimate. A cost equation summarizing this method can be given as†

$$C_n = \left[\Sigma(E + E_L) + \Sigma(f_x M_x + f_y M_L') + \Sigma f_e H_e + \Sigma f_d d_n\right](f_F) \tag{2}$$

where C_n = new capital investment
E = purchased-equipment cost
E_L = purchased-equipment labor cost
f_x = specific material unit cost, e.g., f_p = unit cost of pipe
M_x = specific material quantity in compatible units
f_y = specific material labor unit cost per employee-hour
M_L' = labor employee-hours for specific material
f_e = unit cost-for engineering
H_e = engmeermg employee-hours
f_d = unit cost per drawing or specification
d_n = number of drawings or specifications
f_F = construction or field expense factor always greater than 1

Approximate corrections to the base equipment cost of complete, main-plant items for specific materials of construction or extremes of operating pressure and temperature can be applied in the form of factors as shown in Table 16.

METHOD C PERCENTAGE OF DELIVERED-EQUIPMENT COST. This method for estimating the fixed or total-capital investment requires determination of the delivered-equipment cost. The other items included in the total direct plant cost are then estimated as percentages of the delivered-equipment cost. The additional components of the capital investment are based on average percentages of the total direct plant cost, total direct and indirect plant costs, or total capital

†H. C. Bauman, "Fundamentals of Cost Engineering in the Chemical Industry," Reinhold Publishing Corporation, New York, 1964.

TABLE 16
Correction factors for operating pressure, operating temperature, and material of construction to apply for fixed-capital investment of major plant items†‡

Operating pressure, psia (atm)	Correction factor
0.08 (0.005)	1.3
0.2 (0.014)	1.2
0.7 (0.048)	1.1
700.54 (48) 100 (6.8)	1.0 (base)
3000 (204)	1.21.1
6000 (408)	1.3

Operating temperature, °C	Correction factor
-80	1.3
0	1.0 (base)
100	1.05
600	1.1
5,000	1.2
10,000	1.4

Material of construction	Correction factor
Carbon steel-mild	1.0 (base)
Bronze	1.05
Carbon/molybdenum steel	1.065
Aluminum	1.075
Cast steel	1.11
Stainless steel	1.28 to 1.5
Worthite alloy	1.41
Hastelloy C alloy	1.54
Monel alloy	1.65
Nickel/inconel alloy	1.71
Titanium	2.0

† Adapted from D. H. Allen and R. C. Page, Revised Techniques for Predesign Cost Estimating, *Chem. Eng.*, **82(5)**: 142 (March 3, 1975).

‡ It should be noted that these factors are to be used *only* for complete, main-plant items and serve to correct from the base case to the indicated conditions based on pressure or temperature extremes that may be involved or special materials of construction that may be required. For the case of small or single pieces of equipment which are completely dedicated to the extreme conditions, the factors given in this table may be far too low and factors or methods given in other parts of this book must be used.

investment. This is summarized in the following cost equation:

$$C_n = [\Sigma E + \Sigma(f_1 E + f_2 E + f_3 E + \ldots)](f_I) \tag{3}$$

where $f_1, f_2 \ldots$ = multiplying factors for piping, electrical, instrumentation, etc.
f_I = indirect cost factor always greater than 1.

The percentages used in making an estimation of this type should be determined on the basis of the type of process involved, design complexity, required materials of construction, location of the plant, past experience, and other items dependent on the particular unit under consideration. Average values of the various percentages have been determined for typical chemical plants, and these values are presented in Table 17.

Estimating by percentage of delivered-equipment cost is commonly used for preliminary and study estimates. It yields most accurate results when applied to projects similar in configuration to recently constructed plants. For comparable plants of different capacity, this method has sometimes been reported to yield definitive estimate accuracies.

Example 3 Estimation of fixed-capital investment by percentage of delivered-equipment cost. Prepare a study estimate of the tied-capital investment for the process plant described in Example 1 if the delivered-equipment cost is $100,000.

Solution. Use the ratio factors outlined in Table 17 with modifications for instrumentation and outdoor operation.

Components	***cost***
Purchased equipment (delivered), *E*	$100,000
Purchased equipment installation, 39% *E*	39,000
Instrumentation (installed), 28% *E*	28,000
Piping (installed), 31% *E*	31,000
Electrical (installed), 10% *E*	10,000
Buildings (including services), 22% *E*	22,000
Yard improvements, 10% *E*	10,000
Service facilities (installed), 55% *E*	55,000
Land, 6% *E*	6,000
Total direct plant cost *D*	301,000
Engineering and supervision, 32% *E*	32,000
Construction expenses, 34% *E*	34,000
Total direct and indirect cost $(D+I)$	367,000
Contractor's fee, 5% $(D+I)$	18,000
Contingency, 10% $(D+I)$	37,000
Fixed-capital investment	$422,000

METHOD D "LANG" FACTORS FOR APPROXIMATION OF CAPITAL INVESTMENT. This technique, proposed originally by Lang† and used quite frequently to obtain order-of-magnitude cost estimates, recognizes that the cost of a

†H. J. Lang, *Chem. Eng.*, **54**(10):117 (1947); H. J. Lang, *Chem. Eng.*, **55**(6):112 (1948).

TABLE 17

Ratio factors for estimating capital-investment items based on delivered-equipment cost

Values presented are applicable for major process plant additions to an existing site where the necessary land is available through purchase or present ownership.? The values are based on fixed-capital investments ranging from under $1 million to over $20 million.

Item	Percent of delivered-equipment cost for: Solid-processing plant‡	Solid-fluid-processing plant ‡	Fluid-processing plant ‡
Direct costs			
Purchased equipment-delivered (including fabricated equipment and process machinery) §	100	100	100
Purchased-equipment installation	45	39	47
Instrumentation and controls (installed)	9	13	18
Piping (installed)	16	31	66
Electrical (installed)	10	10	11
Buildings (including services)	25	29	18
Yard improvements	13	10	10
Service facilities (installed)	40	55	70
Land (if purchase is required)	6	6	6
Total direct plant cost	264	293	346
Indirect costs			
Engineering and supervision	33	32	33
Construction expenses	39	34	41
Total direct and indirect plant costs	336	359	420
Contractor's fee (about 5% of direct and indirect plant costs)	17	18	21
Contingency (about 10% of direct and indirect plant costs)	34	36	42
Fixed-capital investment	387	413	483
Working capital (about 15% of total capital investment)	68	74	86
Total capital investment	455	487	569

† Because of the extra expense involved in supplying service facilities, storage facilities, loading terminals, transportation facilities, and other necessary utilities at a completely undeveloped site, the fved-capital investment for a new plant located at an undeveloped site may be as much as 100 percent greater than for an equivalent plant constructed as an addition to an existing plant.

‡ See Table 8 for definition of types of process plants.

§ Includes pumps and compressors.

TABLE 18
Lang multiplication factors for estimation of fixed-capital investment or total capital investment

Factor x delivered-equipment cost = fixed-capital investment or total capital investment for major additions to an existing plant.

Type of plant	Factor for	
	Fixed-capital investment	Total capital investment
Solid-processing plant	3.9	4.6
Solid-fluid-processing plant	4.1	4.9
Fluid-processing plant	4.8	5.7

process plant may be obtained by multiplying the basic equipment cost by some factor to approximate the capital investment. These factors vary depending upon the type of process plant being considered. The percentages given in Table 17 are rough approximations which hold for the types of process plants indicated. These values, therefore, may be combined to give Lang multiplication factors that can be used for estimating the total direct plant cost, the fixed-capital investment, or the total capital investment. Factors for estimating the fixed-capital investment or the total capital investment are given in Table 18. It should be noted that these factors include costs for land and contractor's fees.

Greater accuracy of capital investment estimates can be achieved in this method by using not one but a number of factors. One approach is to use different factors for different types of equipment. Another approach is to use separate factors for erection of equipment, foundations, utilities, piping, etc., or even to break up each item of cost into material and labor factors.? With this approach, each factor has a range of values and the chemical engineer must rely on past experience to decide, in each case, whether to use a high, average, or low figure.

Since tables are not convenient for computer calculations it is better to combine the separate factors into an equation similar to the one proposed by Hirsch and Glazier‡

$$C_n = f_I\left[E(1 + f_F + f_p + f_m) + E_i + A\right] \tag{4}$$

†Further discussions on these methods may be found in W. D. Baasel, "Preliminary Chemical Engineering Plant Design," American Elsevier Publishing Company, Inc., New York, 1976; S. G. Kirkham, Preparation and Application of Refined Lang Factor Costing Techniques, *AACE Bul.*, **15**(5):137 (Oct., 1972); C. A. Miller, Capital Cost Estimating-A Science Rather Than an Art, Cost *Engineers' Notebook,* ASCE A-1666 (June, 1978).

‡J. H. Hirsch and E. M. Glazier, *Chem. Eng. Progr.*, **56**(12):37 (1960).

where the three installation-cost factors are, in turn, defined by the following three equations:

$$\log f_F = 0.635 - 0.154 \log 0.001E - 0.992; + 0.506 \frac{f_v}{E} \quad (5)$$

$$\log f_p = -0.266 - 0.014 \log 0.001E - 0.156; + 0.556 \frac{p}{E} \quad (6)$$

$$\log f_m = 0.344 + 0.033 \log 0.001E + 1.194; \quad (7)$$

and the various parameters are defined accordingly:

E = purchased-equipment on an f.o.b. basis
f, = indirect cost factor always greater than 1 (normally taken as 1.4)
f_F = cost factor for field labor
f_p = cost factor for piping materials
f_m = cost factor for miscellaneous items, including the materials cost for insulation, instruments, foundations, structural steel, building, wiring, painting, and the cost of freight and field supervision
E_i = cost of equipment already installed at site
A = incremental cost of corrosion-resistant alloy materials
e = total heat exchanger cost (less incremental cost of alloy)
f_v = total cost of field-fabricated vessels (less incremental cost of alloy)
p = total pump plus driver cost (less incremental cost of alloy)
t = total cost of tower shells (less incremental cost of alloy)

Note that Eq. (4) is designed to handle both purchased equipment on an f.o.b. basis and completely installed equipment.

METHOD E POWER FACTOR APPLIED TO PLANT-CAPACITY RATIO. This method for study or order-of-magnitude estimates relates the fixed-capital investment of a new process plant to the fixed-capital investment of similar previously constructed plants by an exponential power ratio. That is, for certain similar process plant configurations, the fixed-capital investment of the new facility is equal to the fixed-capital investment of the constructed facility C multiplied by the ratio R, defined as the capacity of the new facility divided by the capacity of the old, raised to a power x. This power has been found to average between 0.6 and 0.7 for many process facilities. Table 19 gives the capacity power factor (x) for various kinds of processing plants.

$$C_n = C(R)'' \quad (8)$$

A closer approximation for this relationship which involves the direct and indirect plant costs has been proposed as

$$C_n = f\left[D(R)^x + I\right] \quad (9)$$

TABLE 19

Capital-cost data for processing plants (1990)†

Product or process	Process remarks	Typical plant size, 1000 tons / yr	Fixed-capital investment, million $	$ of fixed-capital investment per annual ton of product	Power factor (*x*)‡ for plant-capacity ratio
		Chemical plants			
Acetic acid	CH_3OH and CO-catalytic	10	6	650	0.68
Acetone	Propylene-copper chloride catalyst	100	32	320	0.45
Ammonia	Steam reforming	100	24	240	0.53
Ammonium nitrate	Ammonia and nitric acid	100	5	50	0.65
Butanol	Propylene, CO, and H_2O—catalytic	50	40	800	0.40
Chlorine	Electrolysis of NaCl	50	28	550	0.45
Ethylene	Refinery gases	50	13	260	0.83
Ethylene oxide	Ethylene-catalytic	50	50	1000	0.78
Formaldehyde (37%)	Methanol-catalytic	10	16	1600	0.55
Glycol	Ethylene and chlorine	5	15	2900	0.75
Hydrofluoric acid	Hydrogen fluoride and H_2O	10	8	800	0.68
Methanol	CO,, natural gas, and steam	60	13	200	0.60
Nitric acid (high strength)	Ammonia-catalytic	100	6	65	0.60
Phosphoric acid	Calcium phosphate and H_2SO_4	5	3	650	0.60
Polyethylene (high density)	Ethylene-catalytic	5	16	3200	0.65
Propylene	Refinery gases	10	3	320	0.70
Sulfuric acid	Sulfur-catalytic	100	3	32	0.65
Urea	Ammonia and CO,	60	8	130	0.70

TABLE 19
Capital-cost data for processing plants (1990) (*Continued*)

Product or process	Process remarks	Typical plant size, 1000 bbl / day	Fixed-capital investment, million $	$ of fixed-capital investment per bbl / day	Power factor (*x*)‡ for plant-capacity ratio
		Refinery units			
Alkylation (H_2SO_4)	Catalytic	10	19	1900	0.60
Coking (delayed)	Thermal	10	26	2600	0.38
Coking (fluid)	Thermal	10	16	1600	0.42
Cracking (fluid)	Catalytic	10	16	1600	0.70
Cracking	Thermal	10	5	500	0.70
Distillation (atm.)	65% vaporized	100	32	3m	0.90
Distillation (vac.)	65% vaporized	100	19	200	0.70
Hydrotreating	Catalytic desulfurization	10	3	320	0.65
Reforming	Catalytic	10	29	2900	0.60
Polymerization	Catalytic	10	5	500	0.58

† Adapted from K. M. Guthrie, Capital and Operating Costs for 54 Chemical Processes, *Chem. Eng.*, 77(13):140 (June 15, 1970) and K. M. Guthrie, "Process Plant Estimating, Evaluation, and Control," Craftsman Book Company of America, Solana Beach, California. 1974. See also J. E. Haselbarth, Updated Investment Costs for 60 Chemical Plants, *Chem. Eng.*, 74(25):214 (Dec. 4, 1967) and D. Drayer, How to Estimate Plant Cost-Capacity Relationship, *Petro/Chem Engr.*, 42(5):10 (1970).

‡ These power factors apply within roughly a three-fold ratio extending either way from the plant size as given.

TABLE 20
Relative labor rate and productivity indexes in the chemical and allied products industries for the United States (1989)†

Geographical area	Relative labor rate	Relative productivity factor
New England	1.14	0.95
Middle Atlantic	1.06	0.96
South Atlantic	0.84	0.91
Midwest	1.03	1.06
Gulf	0.95	1.22
Southwest	0.88	1.04
Mountain	0.88	0.97
Pacific Coast	1.22	0.89

† Adapted from J. M. Winton, Plant Sites, *Chem. Week*, 121(24):49 (Dec. 14, 1977), and updated with data from M. Kiley, ed., "National Construction Estimator," 37th ed., Craftsman Book Company of America, Carlsbad, CA, 1989. Productivity, as considered here, is an economic term that gives the value added (products minus raw materials) per dollar of total payroll cost. Relative values were determined by taking the average of Kiley's weighted state values in each region divided by the weighted average value of all the regions. See also Tables 23 and 24 of this chapter; H. Popper and G. E. Weismantel, Costs and Productivity in the Inflationary 1970's, *Chem. Eng.*, 77(1):132 (Jan. 12, 1970); and C. H. Edmondson, *Hydrocarbon Process.*, 53(7):167 (1974).

where f is a lumped cost-index factor relative to the original installation cost. D is the direct cost and Z is the total indirect cost for the previously installed facility of a similar unit on an equivalent site. The value of x approaches unity when the capacity of a process facility is increased by adding identical process units instead of increasing the size of the process equipment. The lumped cost-index factor f is the product of a geographical labor cost index, the corresponding area labor productivity index, and a material and equipment cost index. Table 20 presents the relative median labor rate and productivity factor for various geographical areas in the United States.

Example 4 Estimating relative costs of construction labor as a function of geographical area. If a given chemical process plant is erected near Dallas (Southwest area) with a construction labor cost of $100,000 what would be the construction labor cost of an identical plant if it were to be erected at the same time near Los Angeles (Pacific Coast Area) for the time when the factors given in Table 20 apply?

Solution

Relative median labor rate-Southwest 0.88 from Table 20
Relative median labor rate-Pacific Coast 1.22 from Table 20

$$\text{Relative labor rate ratio} = \frac{1.22}{0.88} = 1.3864$$

Relative productivity factor-Southwest 1.04 from Table 20
Relative productivity factor-Pacific Coast 0.89 from Table 20

$$\text{Relative productivity factor ratio} = \frac{0.89}{1.04} = 0.8558$$

Construction labor cost of Southwest to Pacific Coast = (1.3864)/(0.8558) = 1.620
Construction labor cost at Los Angeles = (1.620)($100,000) = $162,000

To determine the fixed-capital investment required for a new similar single-process plant at a new location with a different capacity and with the same number of process units, the following relationship has given good results:

$$C_n = R^x\left[f_E E + f_M M + f_L f_F e_L\left(E_L + f_y M_L'\right)\right](f_I)\frac{C}{C-I} \tag{10}$$

where f_E = current equipment cost index relative to cost of the purchased equipment
f_M = current material cost index relative to cost of material
M = material cost
f_L = current labor cost index in new location relative to E_L and M_L' at old location
e_L = labor efficiency index in new location relative to E_L and M_L' at old location
E_L = purchased-equipment labor cost
M_L' = labor employee-hours for specific material
f_y = specific material labor cost per employee-hour
C = original capital investment

In those situations where estimates of fixed-capital investment are desired for a similar plant at a new location and with a different capacity, but with multiples of the original process units, Eq. (11) often gives results with somewhat better than study-estimate accuracy.

$$C_n = \left[R f_E E + R^x f_M M + R^x f_L f_F e_L\left(E_L + f_y M_L\right)\right](f_I)\frac{C}{C-I} \tag{11}$$

More accurate estimates by this method are obtained by subdividing the process plant into various process units, such as crude distillation units, reformers, alkylation units, etc., and applying the best available data from similar previously installed process units separately to each subdivision. Table 19 lists some typical process unit capacity-cost data and exponents useful for making this type of estimate.

Example 5 Estimation of fixed-capital investment with power factor applied to plant-capacity ratio. If the process plant, described in Example 1, was erected in the Dallas area for a fixed-capital investment of $436,000 in 1975, determine what the estimated fixed-capital investment would have been in 1980 for a similar process plant located near Los Angeles with twice the process capacity but with an equal number of process units? Use the power-factor method to evaluate the new fixed-capital investment and assume the factors given in Table 20 apply.

Solution. If Eq. (8) is used with a 0.6 power factor and the Marshall and Swift all-industry index (Table 3), the fixed-capital investment is

$$C_n = Cf_E(R)^x$$

$$C_n = (436{,}000)\left(\frac{660}{444}\right)(2)^{0.6} = \$982{,}000$$

If Eq. (8) is used with a 0.7 power factor and the Marshall and Swift all-industry index (Table 3), the fixed-capital investment is

$$C_n = (436{,}000)\left(\frac{660}{444}\right)(2)^{0.7} = \$1{,}053{,}000$$

If Eq. (9) is used with a 0.6 power factor, the Marshall and Swift all-industry index (Table 3), and the relative labor and productivity indexes (Table 20), the fixed-capital investment is

$$C_n = f\left[D(R)^x + I\right]$$

where $f = f_E f_L e_L$, and D and Z are obtained from Example 1,

$$C_n = \left(\frac{660}{444}\right)\left(\frac{1.22}{0.88}\right)\left(\frac{1.04}{0.89}\right)\left[(308{,}000)(2)^{0.6} + 128{,}000\right]$$

$$C_n = (1.486)(1.620)(467.000 + 128{,}000)$$

$$C_n = \$1{,}432{,}000$$

If Eq. (9) is used with a 0.7 power factor, the Marshall and Swift all-industry index (Table 3), and the relative labor and productivity indexes (Table 20), the fixed-capital investment is

$$C_n = \$1{,}513{,}000$$

Results obtained using this procedure have shown high correlation with fixed-capital investment estimates that have been obtained with more detailed techniques. Properly used, these factoring methods can yield quick fixed-capital investment requirements with accuracies sufficient for most economic-evaluation purposes.

METHOD F INVESTMENT COST PER UNIT OF CAPACITY. Many data have been published giving the fixed-capital investment required for various processes per unit of annual production capacity such as those shown in Table 19. Although these values depend to some extent on the capacity of the individual plants, it is possible to determine the unit investment costs which apply for average conditions. An order-of-magnitude estimate.of the fixed-capital investment for a given process can then be obtained by multiplying the appropriate investment cost per unit of capacity by the annual production capacity of the proposed plant. The necessary correction for change of costs with time can be made with the use of cost indexes.

METHOD G TURNOVER RATIOS. A rapid evaluation method suitable for order-of-magnitude estimates is known as the "turnover ratio" method. Turnover ratio is defined as the ratio of gross annual sales to the fixed-capital investment,

$$\text{Turnover ratio} = \frac{\text{gross annual sales}}{\text{fixed-capital investment}} \tag{12}$$

where the product of the annual production rate and the average selling price of the commodities is the gross annual sales figures. The reciprocal of the turnover ratio is sometimes defined as the *capital ratio* or the *investment ratio*.† Turnover ratios of up to 5 are common for some business establishments and some are as low as 0.2. For the chemical industry, as a very rough rule of thumb, the ratio can be approximated as 1.

ORGANIZATION FOR PRESENTING CAPITAL INVESTMENT ESTIMATES BY COMPARTMENTALIZATION

The methods for estimating capital investment presented in the preceding sections represent the fundamental approaches that can be used. However, the direct application of these methods can often be accomplished with considerable improvement by considering the fixed-capital investment requirement by parts. With this approach, each identified part is treated as a separate unit to obtain the total investment cost directly related to it. Various forms of compartmentalization for this type of treatment have been proposed. Included in these are (1) the *modular estimate*,‡ (2) the *unit-operations estimate*,§ (3) the *functional-unit estimate*,¶ and (4) the *average-unit-cost estimate*.††

The same principle of breakdown into individual components is used for each of the four approaches. For the *modular estimate*, the basis is to consider individual modules in the total system with each consisting of a group of similar items. For example, all heat exchangers might be included in one module, all furnaces in another, all vertical process vessels in another, etc. The total cost estimate is considered under six general groupings including chemical processing, solids handling, site development, industrial buildings, offsite facilities, and

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†When the term *investment ratio* is used, the investment is usually considered to be the total capital investment which includes working capital as well as other capitalized costs.

‡W. J. Dodge *et* al., Metropolitan New York Section of AACE, The Module Estimating Technique as an Aid in Developing Plant Capital Costs, *Trans. AACE* (1962); K. M. Guthrie, Capital Cost Estimating, *Chem. Eng.*, **76(6):114** (March 24, 1969); K. M. Guthrie, "Process Plant Estimating, Evaluation, and Control," Craftsman Book Company of America, Solana Beach, CA, 1974; A. Pikulik and H. E. Diaz, *Chem. Eng.*, **84(21):106** (Oct. 10, 1977); R. H. Perry and D. H. Green, "Chemical Engineers' Handbook," 6th ed., McGraw-Hill Book Company, Inc., New York, 1984.

§E. F. Hensley, "The Unit-Operations Approach," American Association of Cost Engineers, Paper presented at Annual Meeting, 1967; E. W. Merrow, K. E. Phillips, and C. W. Meyers, "Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants," Rand Corporation, Santa Monica, CA, 1981; see also *Chem. Eng.*, **88(3):41** (Feb. 9, 1981).

¶A. V. Bridgewater, The Functional-Unit Approach to Rapid Cost Estimation, *AACE Bull.*, **18(5):153** (1976).

††C. A. Miller, New Cost Factors Give Quick Accurate Estimates, *Chem. Eng.*, **72(19):226** (Sept. 13, 1965); C. A. Miller, Current Concepts in Capital Cost Forecasting, *Chem. Eng. Progr.*, **69(5):77** (1973); 0. P. Charbanda, "Process Plant and Equipment Cost Estimation," Craftsman Book Company of America, Solana Beach, CA, 1979; S. Cran, Improved Factored Method Gives Better Preliminary Cost Estimates," *Chem. Eng.*, **88(7):79** (Apr. 6, 1981).

project indirects. As an example of an equipment cost module for heat exchangers, the module would include the basic delivered cost of the piece of equipment with factors similar to Lang factors being presented for supplemental items needed to get the equipment ready for use such as piping, insulation, paint,- labor, auxiliaries, indirect costs, and contingencies.

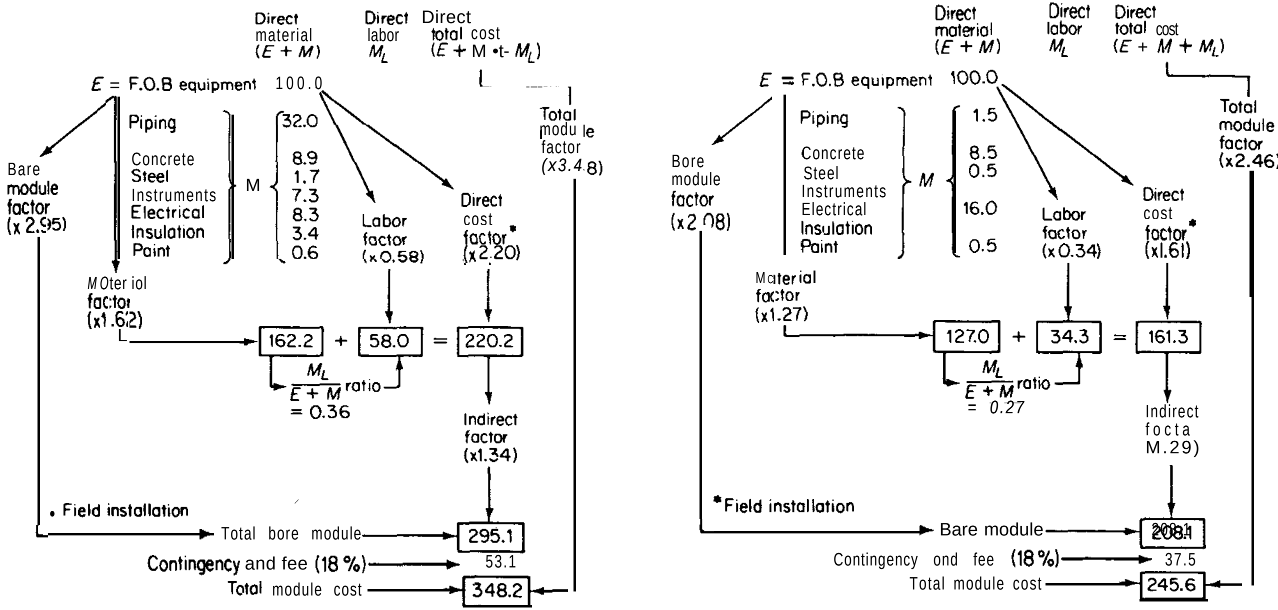
In presenting the basic data for the module factors, the three critical variables are size or capacity of the equipment, materials of construction, and operating pressure with temperature often being given as a fourth critical variable. It is convenient to establish the base cost of all equipment as that constructed of carbon steel and operated at atmospheric pressure. Factors, such as are presented in Table 16, are then used to change the estimated costs of the equipment to account for variation in the preceding critical variables. Once the equipment cost for the module is determined, various factors are applied to obtain the final fixed-capital investment estimate for the item completely installed and ready for operation. Figure 6-6 shows two typical module approaches with Fig. **6-6*a*** representing a module that applies to a "normal" chemical process where the overall Lang factor for application to the f.o.b. cost of the original equipment is 3.482 and Fig. **6-6*b*** representing a "normal" module for a piece of mechanical equipment where the Lang factor has been determined to be 2.456.

The modules referred to in the preceding can be based on combinations of equipment that involve similar types of operations requiring related types of auxiliaries. An example would be a distillation operation requiring the distillation column with the necessary auxiliaries of reboiler, condenser, pumps, holdup tanks, and structural supports. This type of compartmentalization for estimating purposes can be considered as resulting in a so-called *unit-operations estimate.* Similarly, the *functional-unit estimate* is based on the grouping of equipment by function such as distillation or filtration and including the fundamental pieces of equipment as the initial basis with factors applied to give the final estimate of the capital investment.

The *average-unit-cost* method puts special emphasis on the three variables of size of equipment, materials of construction, and operating pressure as well as on the type of process involved. In its simplest form, all of these variables and the types of process can be accounted for by one number so that a given factor to convert the process equipment cost to total fixed-capital investment can apply for each "average unit cost." The latter is defined as the total cost of the process equipment divided by the number of equipment items in that particular process. As the "average unit cost" increases, the size of the factor for converting equipment cost to total fixed-capital investment decreases with a range of factor values applicable for each "average unit cost" depending on the particular type of process, operating conditions, and materials of construction.

ESTIMATION OF TOTAL PRODUCT COST

Methods for estimating the total capital investment required for a given plant are presented in the first part of this chapter. Determination of the necessary



(a) "Normal" module for a chemical process unit with resultant Lang factor of 3.482

(b) "Normal" module for a mechanical equipment unit with resultant Lang factor of 2.456

FIGURE **6-6**
Example of a "normal" module as applied for estimating capital investment for a chemical process and a mechanical equipment unit. [Adapted from K. M. Guthrie, Capital Cost Estimating, *Chem. Eng.*, **76**(6):114 (March 24, 1969).]

- **Total product cost**
  - **Manufacturing costs**
    - **Direct production costs**
      - Raw materials
      - Operating labor
      - Operating supervision
      - Power and utilities
        - Steam
        - Electricity
        - Fuel
        - Refrigeration
        - Water
      - Maintenance and repairs
      - Operating supplies
      - Laboratory charges
      - Royalties (if not on lump-sum basis)
      - Catalysts and solvents
    - **Fixed charges**
      - Depreciation
      - Taxes (property)
      - Insurance
      - Rent
    - **Plant overhead costs**
      - Medical
      - Safety and protection
      - General plant overhead
      - Payroll overhead
      - Packaging
      - Restaurant
      - Recreation
      - Salvage
      - Control laboratories
      - Plant superintendence
      - Storage facilities
  - **General expenses**
    - **Administrative expenses**
      - Executive salaries
      - Clerical wages
      - Engineering and legal costs
      - Office maintenance
      - Communications
    - **Distribution and marketing expenses**
      - Sales offices
      - Salesmen expenses
      - Shipping
      - Advertising
      - Technical sales service
    - Research and development
    - Financing (interest) (often considered a fixed charge)
    - Gross-earnings expense

FIGURE 6-7
Costs involved in total product cost for a typical chemical process plant.

capital investment is only one part of a complete cost estimate. Another equally important part is the estimation of costs for operating the plant and selling the products. These costs can be grouped under the general heading of ***totalproduct cost.*** The latter, in turn, is generally divided into the categories of ***manufacturing costs*** and ***general expenses.*** Manufacturing costs are also known as ***operating*** or ***production costs.*** Further subdivision of the manufacturing costs is somewhat dependent upon the interpretation of direct and indirect costs.

Accuracy is as important in estimating total product cost as it is in estimating capital investment costs. The largest sources of error in total-product-cost estimation are overlooking elements of cost. A tabular form is very useful for estimating total product cost and constitutes a valuable checklist to preclude omissions. Figure 6-7 provides a suggested checklist which is typical of the costs involved in chemical processing operations.

Total product costs are commonly calculated on one of three bases: namely, daily basis, unit-of-product basis, or annual basis, The annual cost basis is probably the best choice for estimation of total cost because (1) the effect of seasonal variations is smoothed out, (2) plant on-stream time or equipment-operating factor is considered, (3) it permits more-rapid calculation of operating costs at less than full capacity, and (4) it provides a convenient way of considering infrequently occurring but large expenses such as annual turnaround costs in a refinery.

The best source of information for use in total-product-cost estimates is data from similar or identical projects. Most companies have extensive records of their operations, so that quick, reliable estimates of manufacturing costs and general expenses can be obtained from existing records. Adjustments for increased costs as a result of inflation must be made, and differences in plant site and geographical location must be considered.

Methods for estimating total product cost in the absence of specific information are discussed in the following paragraphs. The various cost elements are presented in the order shown in Fig. 6-7.

Manufacturing Costs

All expenses directly connected with the manufacturing operation or the physical equipment of a process plant itself are included in the manufacturing costs. These expenses, as considered here, are divided into three classifications as follows: (1) direct production costs, (2) fixed charges, and (3) plant-overhead costs.

Direct production costs include expenses directly associated with the manufacturing operation. This type of cost involves expenditures for raw materials (including transportation, unloading, etc.,); direct operating labor; supervisory and clerical labor directly connected with the manufacturing operation; plant maintenance and repairs; operating supplies; power; utilities; royalties; and catalysts.

It should be recognized that some of the variable costs listed here as part of the direct production costs have an element of fixed cost in them. For instance, maintenance and repair decreases, but not directly, with production level because a maintenance and repair cost still occurs when the process plant is shut down.

Fixed charges are expenses which remain practically constant from year to year and do not vary widely with changes in production rate. Depreciation, property taxes, insurance, and rent require expenditures that can be classified as fixed charges.

Plant-overhead costs are for hospital and medical services; general plant maintenance and overhead; safety services; payroll overhead including pensions, vacation allowances, social security, and life insurance; packaging, restaurant and recreation facilities, salvage services, control laboratories, property protection, plant superintendence, warehouse and storage facilities, and special employee benefits. These costs are similar to the basic fixed charges in that they do not vary widely with changes in production rate.

General Expenses

In addition to the manufacturing costs, other general expenses are involved in any company's operations. These general expenses may be classified as (1) administrative expenses, (2) distribution and marketing expenses, (3) research and development expenses, (4) financing expenses, and (5) gross-earnings expenses.

Administrative expenses include costs for executive and clerical wages, office supplies, engineering and legal expenses, upkeep on office buildings, and general communications.

Distribution and marketing expenses are costs incurred in the process of selling and distributing the various products. These costs include expenditures for materials handling, containers, shipping, sales offices, salesmen, technical sales service, and advertising.

Research and development expenses are incurred by any progressive concern which wishes to remain in a competitive industrial position. These costs are for salaries, wages, special equipment, research facilities, and consultant fees related to developing new ideas or improved processes.

Financing expenses include the extra costs involved in procuring the money necessary for the capital investment. Financing expense is usually limited to interest on borrowed money, and this expense is sometimes listed as a fixed charge.

Gross-earnings expenses are based on income-tax laws. These expenses are a direct function of the gross earnings made by all the various interests held by the particular company. Because these costs depend on the company-wide picture, they are often not included in predesign or preliminary cost-estimation figures for a single plant, and the probable returns are reported as the gross earnings obtainable with the given plant design. However, when considering net profits, the expenses due to income taxes are extremely important, and this cost must be included as a special type of general expense.

DIRECT PRODUCTION COSTS

Raw Materials

In the chemical industry, one of the major costs in a production operation is for the raw materials involved in the process. The amount of the raw materials which must be supplied per unit of time or per unit of product can be determined from process material balances. In many cases, certain materials act only as an agent of production and may be recoverable to some extent. Therefore, the cost should be based on the amount of raw materials actually consumed as determined from the overall material balances.

Direct price quotations from prospective suppliers are preferable to published market prices. For preliminary cost analyses, market prices are often used for estimating raw-material costs. These values are published regularly in journals such as the ***Chemical Marketing Reporter*** (formerly the ***Oil, Paint, and Drug Reporter***).

Freight or transportation charges should be included in the raw-material costs, and these charges should be based on the form in which the raw materials are to be purchased for use in the final plant. Although bulk shipments are cheaper than smaller-container shipments, they require greater storage facilities and inventory. Consequently, the demands to be met in the final plant should be considered when deciding on the cost of raw materials.

The ratio of the cost of raw materials to total plant cost obviously will vary considerably for different types of plants. In chemical plants, raw-material costs are usually in the range of 10 to 50 percent of the total product cost.

Operating Labor

In general, operating labor may be divided into skilled and unskilled labor. Hourly wage rates for operating labor in different industries at various locations can be obtained from the U.S. Bureau of Labor ***Monthly Labor Review.*** For chemical processes, operating labor usually amounts to about 15 percent of the total product cost.

In preliminary costs analyses, the quantity of operating labor can often be estimated either from company experience with similar processes or from published information on similar processes. Because the relationship between labor requirements and production rate is not always a linear one, a 0.2 to 0.25 power of the capacity ratio when plant capacities are scaled up or down is often used.

If a flow sheet and drawings of the process are available, the operating labor may be estimated from an analysis of the work to be done. Consideration

TABLE 21
Typical labor requirements for process equipment

Type of equipment	Workers/unit/shift
Dryer, rotary	$\frac{1}{2}$
Dryer, spray	1
Dryer, tray	$\frac{1}{2}$
Centrifugal separator	$\frac{1}{4}$–$\frac{1}{2}$
Crystallizer, mechanical	$\frac{1}{6}$
Filter, vacuum	$\frac{1}{8}$–$\frac{1}{4}$
Evaporator	$\frac{1}{4}$
Reactor, batch	1
Reactor, continuous	$\frac{1}{2}$
Steam plant (100,000 lb/h)	3

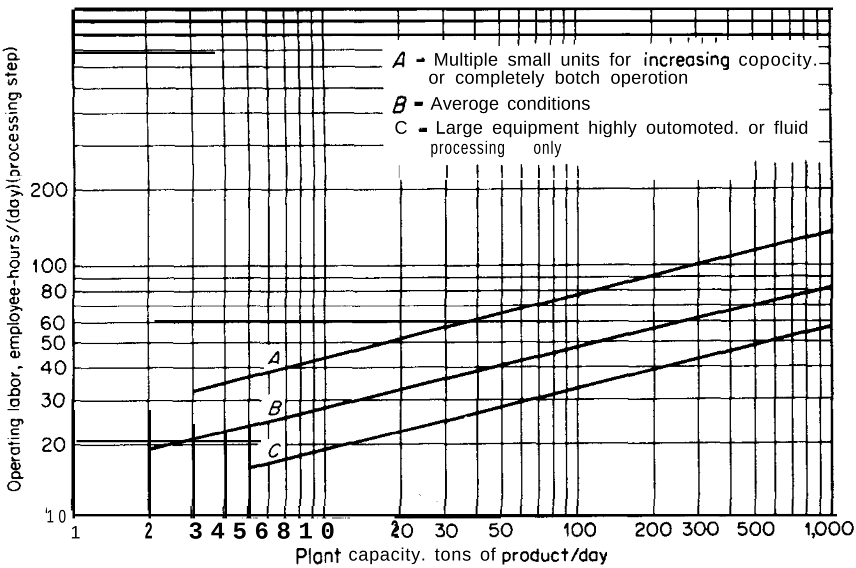


FIGURE 6-8
Operating labor requirements for chemical process industries.

must be given to such items as the type and arrangement of equipment, multiplicity of units, amount of instrumentation and control for the process, and company policy in establishing labor requirements. Table 21 indicates some typical labor requirements for various types of process equipment.

Another method of estimating labor requirements as a function of plant capacity is based on adding up the various principal processing steps on the flow

TABLE 22
Operating labor, fuel, steam, power, and water requirements for various processes†

	Capacity thousand ton/yr	Operating labor and supervision workhours/ton	Maintenance labor and supervision workhours/ton	Power and utilities, per ton/yr or bbl/day capacity: Fuel MM Btu/h	Steam lb/h	Power kWh	Water gph
			Chemical plants				
Acetone	100	0.518	0.315	.. ..	1.73	310	5.18
Acetic acid	10	1.483	0.984	. ..	......	180	0.58
Butadiene	100	0.345	0.285	...	0.012	130	0.73
Ethylene oxide	100	0.232	0.104	.. .	4.88	140	0.148
Formaldehyde	100	0.259	0.328	....	34.6	200	0.029
Hydrogen peroxide	100	0.288	0.352	.. ..	2.62	160	0.186
Isoprene	100	0.230	0.325	....	0.81	710	0.001
Phosphoric acid	10	1.85	0.442	.	0.18	40	0.03
Polyethylene	100	0.259	0.295	...	0.23	450	0.0004
Urea	100	0.238	0.215	.. ..	0.33	135	0.0002
Vinyl acetate	100	0.432	0.528	.. ..	1.34	275	0.27
			Refinery units				
	Thousand bbl/day	Workhours/bbl	Workhours/bbl				
Alkylation	10	0.007	0.0895	.....	10.83	0.07	1.48
Coking (delayed)	10	0.011‡	0.0096	0.007	1.85	0.07	....
Coking (fluid)	10	0.0096	0.0058	0.012	2.55	0.06	0.64
Cracking (fluid)	10	0.0122	0.0115	. . .	(4.73)§	0.02	0.33
Cracking (thermal)	10	0.0096	0.0025	0.012	(2.55)§	0.06	0.64
Distillation (atm)	10	0.0048	0.0042	0.004	0.25	0.03	0.16
Distillation (VAC)	10	0.0024	0.0154	0.003	0.95	0.04	0.18
Hydrotreating	10	0.0048	0.0028	0.006	0.92	0.01	0.14
Reforming, catalyt.	10	0.0048	0.0078	0.002	1.38	0.23	0.28
Polymerization	10	0.0024	0.0158	. . .	4.85	0.07	0.43

† Based on information from K. M. Guthrie, Capital and Operating Costs for 54 Chemical Processes, *Chem. Eng.*, **77(13)**: 140 (June 15, 1970).

‡ Includes two coke cutters (1 shift/day).

§ Net steam generated.

TABLE 23
Cost tabulation for selected utilities and labor†‡
1989 costs based on U.S. Gulf Coast location

	cost
Steam costs	
Exhaust, \$/1000 lb	1.10
Pressure of 100 psig, \$/1000 lb	2.40
Pressure of 500 psig, \$/1000 lb	3.60
Fuel **costs**	
Gas at well head including gathering-system costs:	
Existing contracts, \$/million Btu	2.40
New contracts, \$/million Btu	3.00
Fuel oil in \$/million Btu with 6.25 million Btu/bbl	3.00
Gas transmission costs in ¢/100 miles	7.30
Plant fuel gas in \$/million Btu	3.20
Purchased power for midcontinent USA in ¢/kWh	7.00
Water costs	
Process water (treated) in ¢/1000 gal	80
Cooling water in ¢/1000 gal (tower or river)	10
Labor rates	
Supervisor, \$/h	28.00
Operators, \$/h	21.00
Helpers, \$/h	17.40
Chemists, \$/h	20.00
Labor burden as % of direct labors	25
Plant general overhead as % of total labor + burden	40

† Based on information updated from C. C. Johnnie and D. K. Aggarwal, Calculating Plant Utility Costs, *Chem. Eng. Progr.*, 73(11):84 (1977) and M. Kiley, "National Construction Estimator," 37th ed., Craftsman Book Company of America, Carlsbad, CA, 1989.

‡ See Appendix B for a more detailed listing of utility and related costs.

§ Labor burden refers to costs the company must pay associated with and above the base labor rate, such as for Social Security, insurance, and other benefits.

sheets.¶ In this method, a process step is defined as any unit operation, unit process, or combination thereof, which takes place in one or more units of integrated equipment on a repetitive cycle or continuously, e.g., reaction, distillation, evaporation, drying, filtration, etc. Once the plant capacity is fixed, the number of employee-hours per ton of product per step is obtained from Fig. 6-8 and multiplied by the number of process steps to give the total employee-hours per ton of production. Variations in labor requirements from highly automated processing steps to batch operations are provided by selection of the appropriate curve on Fig. 6-8.

¶Method originally proposed by H. E. Wessel, New Graph Correlates Operating Labor for Chemical Processes, *Chem. Eng.*, 59(7):209 (July, 1952).

TABLE 24
Engineering ***News-Record*** **labor indexes to permit estimation of prevailing wage rates by location†**

(See table 23 for values of labor rates as $/h)

Location	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
	ENB Skilled Labor Index (December values). (Based on 1967 = 100)									
Atlanta	256	304	330	312	312	312	330	335	348	392
Baltimore	281	304	333	337	329	339	355	377	395	478
Birmingham	289	309	320	332	343	343	338	355	368	422
Boston	265	2%	353	378	396	413	433	462	490	542
Chicago	289	314	349	355	358	361	381	401	417	442
Cincinnati	314	342	359	378	377	378	378	386	397	481
Cleveland	294	315	349	382	395	406	419	419	426	439
Dallas	302	352	386	409	385	364	357	353	335	434
Denver	281	324	366	406	406	359	373	373	347	386
Detroit	314	350	356	369	369	377	3%	412	433	441
Kansas City	307	340	372	394	397	404	410	427	436	498
Los Angeles	336	375	375	452	445	433	457	465	472	541
Minneapolis	276	314	351	388	372	397	407	417	426	461
New Orleans	297	325	350	376	376	311	376	3%	372	469
New York	250	274	303	334	361	381	408	427	456	470
Philadelphia	267	307	324	354	374	393	418	431	454	559
Pittsburgh	282	304	324	342	370	370	372	373	383	428
St Louis	262	297	306	318	350	362	378	382	400	448
San Francisco	307	330	381	400	407	411	442	455	464	508
Seattle	327	363	386	387	389	397	401	405	414	450

† Published in *Engineering* News Record monthly in the second issue of the month with summaries in the third issue of the March and December issues.

Example 6 Estimation of labor requirements. Consider a highly automated processing plant having a capacity of 100 tons/day of product and requiring principal processing steps of heat transfer, reaction, and distillation. What are the average operating labor requirements for an annual operation of 300 days?

Solution. The process plant is considered to require three process steps. From Fig. 6-8, for a capacity of 100 tons product/day, the highly automated process plant requires 33 employee-hours/day/processing step. Thus, for 300 days annual operation, operating labor required = (3)(33)(300) = 29,700 employee-hours/year.

Because of new technological developments including computerized controls and long-distance control arrangements, the practice of relating employee-hour requirements directly to production quantities for a given product can give inaccurate results unless very recent data are used. As a general rule of thumb,? the labor requirements for a fluids-processing plant, such as an ethylene oxide plant or others as shown in Table 22, would be in the low range of $\frac{1}{3}$ to 2 employee-hours per ton of product; for a solid-fluids plant, such as a polyethylene plant, the labor requirement would be in the intermediate range of 2 to 4 employee-hours per ton of product; for plants primarily engaged in solids processing such as a coal briquetting plant, the large amount of materials handling would make the labor requirements considerably higher than for other types of plants with a range of 4 to 8 employee-hours per ton of product being reasonable. The data shown in Fig. 6-8 and Table 22, where plant capacity and specific type of process are taken into account, are much more accurate than the preceding rule of thumb if the added necessary information is available.

In determining costs for labor, account must be taken of the type of worker required, the geographical location of the plant, the prevailing wage rates, and worker productivity. Table 20 presents data that can be used as a guide for relative median labor rates and productivity factors for workers in various geographical areas of the United States. Tables 23 and 24 provide data on labor rates in dollars per hour for the U.S. Gulf Coast region and average labor indexes to permit estimation of prevailing wage rates.

Direct Supervisory and Clerical Labor

A certain amount of direct supervisory and clerical labor is always required for a manufacturing operation. The necessary amount of this type of labor is closely related to the total amount of operating labor, complexity of the operation, and product quality standards. The cost for direct supervisory and clerical labor averages about 15 percent of the cost for operating labor. For reduced capacities, supervision usually remains fixed at the MO-percent-capacity rate.

Utilities

The cost for utilities, such as steam, electricity, process and cooling water, compressed air, natural gas, and fuel oil, varies widely depending on the amount of consumption, plant location, and source. For example, costs for a few selected utilities in the U.S. Gulf Coast region are given in Table 23. A more detailed list of average rates for various utilities is presented in Appendix B. The required utilities can sometimes be estimated in preliminary cost analyses from available information about similar operations as shown in Table 22. If such information is unavailable, the utilities must be estimated from a preliminary design. The utility may be purchased at predetermined rates from an outside source, or the service may be available from within the company. If the company supplied its own service and this is utilized for just one process, the entire cost of the service installation is usually charged to the manufacturing process. If the service is utilized for the production of several different products,

†J. E. Haselbarth, Updated Investment Costs for 60 Chemical Plants, *Chem. Eng.*, 74(25):214 (Dec. 4, 1967).

the service cost is apportioned among the different products at a rate based on the amount of individual consumption.

Steam requirements include the amount consumed in the manufacturing process plus that necessary for auxiliary needs. An allowance for radiation and line losses must also be made.

Electrical power must be supplied for lighting, motors, and various process-equipment demands. These direct-power requirements should be increased by a factor of 1.1 to 1.25 to allow for line losses and contingencies. As a rough approximation, utility costs for ordinary chemical processes amount to 10 to 20 percent of the total product cost.

Maintenance and Repairs

A considerable amount of expense is necessary for maintenance and repairs if a plant is to be kept in efficient operating condition. These expenses include the cost for labor, materials, and supervision.

Annual costs for equipment maintenance and repairs may range from as low as 2 percent of the equipment cost if service demands are light to 20 percent for cases in which there are severe operating demands. Charges of this type for buildings average 3 to 4 percent of the building cost. In the process industries, the total plant cost per year for maintenance and repairs is roughly equal to an average of 6 percent of the fixed-capital investment. Table 25 provides a guide for estimation of maintenance and repair costs as a function of process conditions.

For operating rates less than plant capacity, the maintenance and repair cost is generally estimated as 85 percent of that at 100 percent capacity for a 75 percent operating rate, and 75 percent of that at 100 percent capacity for a 50 percent operating rate.

TABLE 25
Estimation of costs for maintenance and repairs

Type of operation	Maintenance cost as percentage of fixed-capital investment (on annual basis)		
	Wages	Materials	Total
Simple chemical processes	1-3	1-3	2-6
Average processes with normal operating conditions	2-4	3-5	5-9
Complicated processes, severe corrosion operating conditions, or extensive instrumentation	3-5	4-6	7-11

Operating Supplies

In any manufacturing operation, many miscellaneous supplies are needed to keep the process functioning efficiently. Items such as charts, lubricants, test chemicals, custodial supplies, and similar supplies cannot be considered as raw materials or maintenance and repair materials, and are classified as operating supplies. The annual cost for this type of supplies is about 15 percent of the total cost for maintenance and repairs.

Laboratory Charges

The cost of laboratory tests for control of operations and for product-quality control is covered in this manufacturing cost. This expense is generally calculated by estimating the employee-hours involved and multiplying this by the appropriate rate. For quick estimates, this cost may be taken as 10 to 20 percent of the operating labor.

Patents and Royalties

Many manufacturing processes are covered by patents, and it may be necessary to pay a set amount for patent rights or a royalty based on the amount of material produced. Even though the company involved in the operation obtained the original patent, a certain amount of the total expense involved in the development and procurement of the patent rights should be borne by the plant as an operating expense. In cases of this type, these costs are usually amortized over the legally protected life of the patent. Although a rough approximation of patent and royalty costs for patented processes is 0 to 6 percent of the total product cost, the engineer must use judgement because royalties vary with such factors as the type of product and the industry.

Catalysts and Solvents

Costs for catalysts and solvents can be significant and depend upon the specific manufacturing processes chosen.

FIXED CHARGES

Certain expenses are always present in an industrial plant whether or not the manufacturing process is in operation. Costs that are invariant with the amount of production are designated as ***fixed*** costs or ***fixed** charges*. These include costs for depreciation, local property taxes, insurance, and rent. Expenses of this type are a direct function of the capital investment. As a rough approximation, these charges amount to about 10 to 20 percent of the total product cost.

Depreciation

Equipment, buildings, and other material objects comprising a manufacturing plant require an initial investment which must be written off as a manufacturing expense. In order to write off this cost, a decrease in value is assumed to occur throughout the usual life of the material possessions. This decrease in value is designated as ***depreciation.***

Since depreciation rates are very important in determining the amount of income tax, the Internal Revenue Service has established allowable depreciation rates based on the probable useful life of various types of equipment and other fixed items involved in manufacturing operations. While several alternative methods may be used for determining the rate of depreciation, a straight-line method is usually assumed for engineering projects. In applying this method, a useful-life period and a salvage value at the end of the useful life are assumed, with due consideration being given to possibilities of obsolescence and economic changes. The difference between initial cost and the salvage value divided by the total years of useful life gives the annual cost due to depreciation.

The annual depreciation rate for machinery and equipment ordinarily is about 10 percent of the tied-capital investment, while buildings are usually depreciated at an annual rate of about 3 percent of the initial cost.

Local Taxes

The magnitude of local property taxes depends on the particular locality of the plant and the regional laws. Annual property taxes for plants in highly populated areas are ordinarily in the range of 2 to 4 percent of the fixed-capital investment. In less populated areas, local property taxes are about 1 to 2 percent of the tied-capital investment.

Insurance

Insurance rates depend on the type of process being carried out in the manufacturing operation and on the extent of available protection facilities. On an annual basis, these rates amount to about 1 percent of the fixed-capital investment.

Rent

Annual costs for rented land and buildings amount to about 8 to 12 percent of the value of the rented property.

PLANT OVERHEAD COSTS

The costs considered in the preceding sections are directly related with the production operation. In addition, however, many other expenses are always involved if the complete plant is to function as an efficient unit. The expenditures required for routine plant services are included in ***plant-overhead*** costs. Nonmanufacturing machinery, equipment, and buildings are necessary for many of the general plant services, and the fixed charges and direct costs for these items are part of the plant-overhead costs.

Expenses connected with the following comprise the bulk of the charges for plant overhead:

Hospital and medical services
General engineering
Safety services
Cafeteria and recreation facilities
General plant maintenance and overhead
Payroll overhead including employee benefits
Control laboratories
Packaging
Plant protection
Janitor and similar services
Employment offices
Distribution of utilities
Shops
Lighting
Interplant communications and transportation
Warehouses
Shipping and receiving facilities

These charges are closely related to the costs for all labor 'directly connected with the production operation. The plant-overhead cost for chemical plants is about 50 to 70 percent of the total expense for operating labor, supervision, and maintenance.

ADMINISTRATIVE COSTS

The expenses connected with top-management or administrative activities cannot be charged directly to manufacturing costs; however, it is necessary to include the ***administrative costs*** if the economic analysis is to be complete. Salaries and wages for administrators, secretaries, accountants, stenographers, typists, and similar workers are part of the administrative expenses, along with costs for office supplies and equipment, outside communications, administrative buildings, and other overhead items related with administrative activities. These costs may vary markedly from plant to plant and depend somewhat on whether the plant under consideration is a new one or an addition to an old plant. In the absence of more-accurate cost figures from company records, or for a quick estimate, the administrative costs may be approximated as 20 to 30 percent of the operating labor.

DISTRIBUTION AND MARKETING COSTS

From a practical viewpoint, no manufacturing operation can be considered a success until the products have been sold or put to some profitable use. It is necessary, therefore, to consider the expenses involved in selling the products. Included in this category are salaries, wages, supplies, and other expenses for sales offices; salaries, commissions, and traveling expenses for salesmen; shipping expenses; cost of containers; advertising expenses; and technical sales service.

Distribution and marketing costs vary widely for different types of plants depending on the particular material being produced, other products sold by the company, plant location, and company policies. These costs for most chemical plants are in the range of 2 to 20 percent of the total product cost. The higher figure usually applies to a new product or to one sold in small quantities to a large number of customers. The lower figure applies to large-volume products, such as bulk chemicals.

RESEARCH AND DEVELOPMENT COSTS

New methods and products are constantly being developed in the chemical industries. These accomplishments are brought about by emphasis on research and development. ***Research and development costs*** include salaries and wages for all personnel directly connected with this type of work, fixed and operating expenses for all machinery and equipment involved, costs for materials and supplies, direct overhead expenses, and miscellaneous costs. In the chemical industry, these costs amount to about 2 to 5 percent of every sales dollar.

FINANCING

Interest

Interest is considered to be the compensation paid for the use of borrowed capital. A fixed rate of interest is established at the time the capital is borrowed; therefore, interest is a definite cost if it is necessary to borrow the capital used to make the investment for a plant. Although the interest on borrowed capital is a fixed charge, there are many persons who claim that interest should not be considered as a manufacturing cost. It is preferable to separate interest from the other fixed charges and list it as a separate expense under the general heading of management or financing cost. Annual interest rates amount to 5 to 10 percent of the total value of the borrowed capital.

When the capital investment is supplied directly from the existing funds of a company, it is a debatable point whether interest should be charged as a cost.

For income-tax calculations, interest on owned money cannot be charged as a cost. In design calculations, however, interest can be included as a cost unless there is assurance that the total capital investment will be supplied from the company's funds and the company policies permit exclusion of interest as a cost.

GROSS-EARNINGS COSTS

The total income minus the total production cost gives the *gross earnings* made by the particular production operation, which can then be treated mathematically by any of several methods to measure the profitably of the proposed venture or project. These methods will be discussed later in Chaps. 7 and 10.

Because of income-tax demands, the final ***net profit*** is often much less than the gross earnings. Income-tax rates are based on the gross earnings received from all the company interests. Consequently, the magnitude of these costs varies widely from one company to another.

On an annual basis, the corporate income-tax laws for the United States in 1979 required payment of a 17, 20, 30, and 40 percent normal tax on the lst, 2nd, 3rd, and 4th $25,000, respectively, of the annual gross earnings of a corporation plus 46 percent of all annual gross earnings above $100,000. In addition, if other levies, such as state income taxes, were included, the overall tax rate could have been even higher. By 1988, the corporate income-tax laws had been changed to 15 percent on the first $50,000 of annual gross earnings, 25 percent on annual gross earnings of $50,000 to $75,000, and 34 percent on annual gross earnings above $75,000 plus a special graduated-tax phase-out of 5 percent on the gross earnings from $100,000 to $335,000. Tax rates vary from year to year depending on Federal and state regulations as is shown in the following example where 1988 Federal-tax rates are considered.

Example 7 Break-even point, gross earnings, and net profit for a process plant. The annual direct production costs for a plant operating at 70 percent capacity are $280,000 while the sum of the annual fixed charges, overhead costs, and general expenses is $200,000. What is the break-even point in units of production per year if total annual sales are $560,000 and the product sells at $40 per unit? What were the annual gross earnings and net profit for this plant at 100 percent capacity in 1988 when corporate income taxes required a 15 percent tax on the first $50,000 of annual gross earnings, 25 percent on annual gross earnings of $50,000 to $75,000, 34 percent on annual gross earnings above $75,000, and 5 percent on gross earnings from $100,000 to $335,000?

Solution. The break-even point (Fig. 6-3) occurs when the total annual product cost equals the total annual sales. The total annual product cost is the sum of the fixed costs (including fixed charges, overhead, and general expenses) and the direct production costs for n units per year. The total annual sales is the product of the number of units and the selling price per unit. Thus

$$\text{Direct production cost/unit} = \frac{280{,}000}{(560{,}000/40)} = \$20/\text{unit}$$

and the number of units needed for a break-even point is given by

$$200{,}000 + 20n = 40n$$

$$n = \frac{200{,}000}{20} = 10{,}000 \text{ units/year}$$

This is $[(10{,}000)/(14{,}000/0.7)]100 = 50\%$ of the present plant operating capacity.

$$\begin{aligned}
\text{Gross annual earnings} &= \text{total annual sales} - \text{total annual product cost}\\
&= \frac{14{,}000}{0.7}\,\text{units}\ (\$40/\text{unit})\\
&\quad - \left[200{,}000 + \frac{14{,}000}{0.7}\,\text{units}\ (\$20/\text{unit})\right]\\
&= 800{,}000 - 600{,}000\\
&= \$200{,}000\\
\text{Net annual earnings} &= \text{gross annual earnings} - \text{income taxes}\\
&= 200{,}000 - [(0.15)(50{,}000) + (0.25)(25{,}000)\\
&\qquad + (0.34)(200{,}000 - 75{,}000)\\
&\qquad + (0.05)(200{,}000 - 100{,}000)]\\
&= 200{,}000 - 61{,}250\\
&= \$138{,}750
\end{aligned}$$

CONTINGENCIES

Unforeseen events, such as strikes, storms, floods, price variations, and other contingencies, may have an effect on the costs for a manufacturing operation. When the chemical engineer predicts total costs, it is advisable to take these factors into account. This can be accomplished by including a contingency factor equivalent to 1 to 5 percent of the total product cost.

SUMMARY

This chapter has outlined the economic considerations which are necessary when a chemical engineer prepares estimates of capital investment cost or total product cost for a new venture or project. Methods for obtaining predesign cost estimates have purposely been emphasized because the latter are extremely important for determining the feasibility of a proposed investment and to compare alternative designs. It should be remembered, however, that predesign estimates are often based partially on approximate percentages or factors that are applicable to a particular plant or process under consideration. Tables 26 and 27 summarize the predesign estimates for capital investment costs and total product costs, respectively. The percentages indicated in both tables give the ranges encountered in typical chemical plants. Because of the wide variations in different types of plants, the factors presented should be used only when more accurate data are not available.

TABLE 26
Estimation of capital investment cost (showing individual components)

The percentages indicated in the following summary of the various costs constituting the capital investment are approximations applicable to ordinary chemical processing plants. It should be realized that the values given can vary depending on many factors, such as plant location, type of process, complexity of instrumentation, etc.

I. **Direct** costs = **material** and labor involved in actual installation of complete facility **(70–85%** of fixed-capital investment)
  A. Equipment + installation + instrumentation + piping + electrical + insulation + painting **(50–60%** of **fixed-capital** investment)
    1. Purchased equipment **(15–40%** of fixed-capital investment)
    2. Installation, including insulation and painting **(25–55%** of **purchased-equipment** cost)
    3. Instrumentation **and** controls, installed (6-30% of **purchased-equipment** cost)
    4. Piping, installed **(10–80%** of purchased-equipment cost)
    5. Electrical, installed **(10–40%** of **purchased-equipment** cost)
  B. Buildings, process and auxiliary **(10–70%** of purchasedequipment cost)
  C. Service facilities and yard improvements **(40–100%** of **purchased-equipment** cost)
  D. Land (I-2% of fixed-capital investment or 4-8% of purchased-equipment cost)

II. Indict costs = expenses which are not directly involved with material and labor of actual installation of complete facility **(15–30%** of **fixed-capital** investment)
  A. Engineering and supervision **(5–30%** of direct costs)
  B. Construction expense and contractor's fee (6-30% of direct costs)
  C. Contingency **(5–15%** of fixed-capital investment)

Ill. Fixed-capital investment = direct costs + indirect costs

IV. Working capital **(10–20%** of total capital investment)

V. Total **capital** investment = fixed-capital investment + working capital

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TABLE 27
Estimation of total product cost (showing individual components)

The percentages indicated in the following summary of the various costs involved in the complete operation of manufacturing plants are approximations applicable to ordinary chemical processing plants. It should be realized that the values given can vary depending on many factors, such as plant location, type of process, and company policies.

Percentages are expressed on an annual **basis.**

I. Manufacturing cost = **direct** production costs + **fixed** charges + plant overhead costs
  A. Direct production costs (about 60% of total product cost)
    1. Raw materials **(10–50%** of total product cost)
    2. Operating labor **(10–20%** of total product cost)
    3. Direct supervisory and clerical labor **(10–25%** of operating labor)
    4. *Utilities* ***(10–20% of*** total ***product*** cost)
    5. ***Maintenance and repairs (2–10% of fixed-capital investment)***
    6. Operating supplies **(10–20%** of cost for maintenance and repairs, or **0.5–1%** of **fixed-**capital investment)
    7. Laboratory charges (IO-20% of operating labor)
    8. Patents and royalties **(0–6%** of total product cost)
  B. Fixed charges **(10–20%** of total product cost)
    1. Depreciation (depends on **life** period, salvage **value,** and method of calculation-about 10% of **fixed-capital** investment for machinery and equipment and **2–3%** of building value for buildings)
    2. Local taxes **(1–4%** of fixed-capital investment)
    3. Insurance **(0.4–1%** of **fixed-capital** investment)
    4. Rent **(8–12%** of **value** of rented **land** and buildings)

TABLE 27
Estimation of total product cost (showing individual components) (Continued)

C. Plant-overhead costs (SO-70% of cost for operating labor, supervision, and maintenance, or **5–15%** of total product cost); includes costs for the following: general plant upkeep and overhead, payroll overhead, packaging, medical services, safety and protection, restaurants, recreation, salvage, laboratories, and storage facilities.

II. General expenses = administrative costs + distribution and selling costs + research and development costs

A. Administrative costs (about 15% of costs for operating labor, supervision, and maintenance, or **2–6%** of total product cost); includes costs for executive salaries, clerical wages, legal fees, office supplies, and communications

B. Distribution and selling costs (**2–20%** of total product cost); includes costs for sales offices, salesmen, shipping, and advertising

C. Research and development costs (**2–5%** of every sales **dollar** or about 5% of total product cost)

D. Financing (interest)? (**0–10%** of total capital investment)

III. Total product **cost‡ =** manufacturing cost + general expenses

IV. **Gross-earnings cost** (gross earnings = total income total product cost; amount of **gross-**earnings cost depends on amount of gross earnings for entire company and income-tax regulations; a general range for gross-earnings cost is **30–40%** of gross earnings)

† Interest on borrowed money is often considered as a fiied charge.

‡ If desired, a contingency factor can be included by increasing the total product cost by 1-5%.

NOMENCLATURE FOR CHAPTER 6

A = incremental cost of corrosion-resistant alloy materials
A, = nonmanufacturing fixed-capital investment
c_o = costs for operations (*not* including depreciation)
C = original capital investment
C_n = new capital investment
d = depreciation charge
d_n = number of drawings and specifications
D = total direct cost of plant
e = total heat exchanger cost (less incremental cost of alloy)
e_L = labor efficiency index in new location relative to cost of E_L and M_L'
E = purchased-equipment cost (installation cost not included) on f.o.b. basis
E_i = installed-equipment cost (purchased and installation cost included)
E_L = purchased-equipment labor cost (base)
f = lumped cost index relative to original installation cost
f_1, f_2 = multiplying factors for piping, electrical, instrumentation, etc.
f_d = unit cost per drawing and specification
f_e = unit cost for engineering
f_E = current equipment cost index relative to cost of *E*
f_F = construction or field-labor expense factor always greater than 1
f, = indirect cost factor always greater than 1

f_L = current labor cost index in new location relative to cost of E_L and M_L'
f_M = current material cost index relative to cost of M
f_m = cost factor for miscellaneous items
f_p = cost factor for piping materials
f_v = total cost of field-fabricated vessels (less incremental cost of alloy)
f_x = specific material unit cost, e.g., f_p = unit cost of pipe
f_y = specific material labor unit cost per employee-hour
H_e = engineering employee-hours
I = total indirect cost of plant
M = material cost
M_L' = labor employee-hours for specific material
M_L = direct labor cost for equipment installation and material handling
M_x = specific material quantity in compatible units
p = total pump plus driver cost (less incremental cost of alloy)
R = ratio of new to original capacity
s_i = total income from sales
t = total cost of tower shells (less incremental cost of alloy)
T = total capital investment
V = manufacturing fixed-capital investment
W = working-capital investment
x = exponential power for cost-capacity relationships

PROBLEMS

1. The purchased cost of a shell-and-tube heat exchanger (floating head and carbon-steel tubes) with 100 ft^2 of heating surface was \$3000 in 1980. What will be the purchased cost of a similar heat exchanger with 200 ft^2 of heating surface in 1980 if the purchased-cost-capacity exponent is 0.60 for surface area ranging from 100 to 400 ft^2? If the purchased-cost-capacity exponent for this type of exchanger is 0.81 for surface areas ranging from 400 to 2000 ft^2, what will be the purchased cost of a heat exchanger with 1000 ft^2 of heating surface in 1985?
2. Plot the 1985 purchased cost of the shell-and-tube heat exchanger outlined in the previous problem as a function of the surface area from 100 to 2000 ft^2. Note that the purchased-cost-capacity exponent is not constant over the range of surface area requested.
3. The purchased and installation costs of some pieces of equipment are given as a function of weight rather than capacity. An example of this is the installed costs of large tanks. The 1980 cost for an installed aluminum tank weighing 100,000 lb was \$390,000. For a size range from 200,000 to 1,000,000 lb, the installed cost-weight exponent for aluminum tanks is 0.93. If an aluminum tank weighing 700,000 lb is required, what is the present capital investment needed?
4. What weight of installed stainless-steel tank could have been obtained for the same capital investment as in the previous problem? The 1980 cost for an installed 304 stainless-steel tank weighing 300,000 lb was \$670,000. The installed cost-weight exponent for stainless tanks is 0.88 for a size range from 300,000 to 700,000 lb.
5. The purchased cost of a 1400-gal stainless-steel tank in 1980 was \$7500. The tank is cylindrical with flat top and bottom, and the diameter is 6 ft. If the entire outer

surface of the tank is to be covered with 2 in. thickness of magnesia block, estimate the present total cost for the installed and insulated tank. The Jan. 1, 1980 cost for the 2-in. magnesia block was \$2.20 per ft^2 while the labor for installing the insulation was \$5.00 per ft^2.

6. A one-story warehouse 120 by 60 ft is to be added to an existing plant. An asphalt-pavement service area 60 by 30 ft will be added adjacent to the warehouse. It will also be necessary to put in 500 lin ft of railroad siding to service the warehouse. Utility service lines are already available at the warehouse site. The proposed warehouse has a concrete floor and steel frame, walls, and roof. No heat is necessary, but lighting and sprinklers must be installed. Estimate the total cost of the proposed addition. Consult App. B for necessary cost data.

7. The purchased cost of equipment for a solid-processing plant is \$500,000. The plant is to be constructed as an addition to an existing plant. Estimate the total capital investment and the tied-capital investment for the plant. What percentage and amount of the fixed-capital investment is due to wst for land and contractor's fee?

8. The purchased-equipment cost for a plant which produces pentaerythritol (solid-fuel-processing plant) is \$300,000. The plant is to be an addition to an existing formaldehyde plant. The major part of the building cost will be for indoor construction, and the contractor's fee will be 7 percent of the direct plant cost. All other costs are close to the average values found for typical chemical plants. On the basis of this information, estimate the following:
(a) The total direct plant cost.
(*b*) The fixed-capital investment.
(*c*) The total capital investment.

9. Estimate by the turnover-ratio method the fixed-capital investment required for a proposed sulfuric acid plant (battery limit) which has a capacity of 140,000 tons of 100 percent sulfuric acid per year (contact-catalytic process) using the data from Table 19 for 1990 with sulfuric acid cost at \$72 per ton. The plant may be considered as operating full time. Repeat using the cost-capacity-exponent method with data from Table 19.

10. The total capital investment for a chemical plant is \$1 million, and the working capital is \$100,000. If the plant can produce an average of 8000 kg of final product per day during a 365-day year, what selling price in dollars per kilogram of product would be necessary to give a turnover ratio of 1.0?

11. A process plant was constructed in the Philadelphia area (Middle Atlantic) at a labor cost of \$200,000 in 1980. What would the average costs for the same plant to be in the Miami, Florida area (South Atlantic) if it were constructed in late 1988? Assume, for simplicity, that the relative labor rate and relative productivity factor remain essentially constant.

12. A company has been selling a soap containing 30 percent by weight water at a price of \$10 per 100 lb f.o.b. (i.e., freight on board, which means the laundry pays the freight charges). The company offers an equally effective soap containing only 5 percent water. The water content is of no importance to the laundry, and it is willing to accept the soap containing 5 percent water if the delivered costs are equivalent. If the freight rate is 70 cents per 100 lb, how much should the company charge the laundry per 100 lb f.o.b. for the soap containing 5 percent water?

13. The total capital investment for a conventional chemical plant is \$1,500,000, and the plant produces 3 million kg of product annually. The selling price of the product is

\$0.82/kg. Working capital amounts to 15 percent of the total capital investment. The investment is from company funds, and no interest is charged. Raw-materials costs for the product are \$0.09/kg, labor \$0.08/kg, utilities \$0.05/kg, and packaging \$0.008/kg. Distribution costs are 5 percent of the total product cost. Estimate the following:

(*a*) Manufacturing cost per kilogram of product.
(*b*) Total product cost per year.
(*c*) Profit per kilogram of product before taxes.
(*d*) Profit per kilogram of product after taxes (use current rate).

14. Estimate the manufacturing cost per 100 lb of product under the following conditions:

    Fixed-capital investment = \$2 million
    Annual production output = 10 million lb of product
    Raw materials cost = \$0.12/lb of product
    Utilities
      100 psig steam = 50 lb/lb of product
      Purchased electrical power = 0.4 kWh/lb of product
      Filtered and softened water = 10 gal/lb of product
    Operating labor = 20 men per shift at \$12.00 per employee-hour
    Plant operates three hundred 24-h days per year
    Corrosive liquids are involved
    Shipments are in bulk carload lots
    A large amount of direct supervision is required
    There are no patent, royalty, interest, or rent charges
    Plant-overhead costs amount to 50 percent of the cost for operating labor, supervision, and maintenance

15. A company has direct production costs equal to 50 percent of total annual sales and fixed charges, overhead, and general expenses equal to \$200,000. If management proposes to increase present annual sales of \$800,000 by 30 percent with a 20 percent increase in fixed charges, overhead, and general expenses, what annual sales dollar is required to provide the same gross earnings as the present plant operation? What would be the net profit if the expanded plant were operated at full capacity with an income tax on gross earnings fixed at 34 percent? what would be the net profit for the enlarged plant if total annual sales remained the same as at present? What would be the net profit for the enlarged plant if the total annual sales actually decreased to \$700,000?

16. A process plant making 2000 tons per year of a product selling for \$0.80 per lb has annual direct production costs of \$2 million at 100 percent capacity and other fixed costs of \$700,000. What is the fixed cost per pound at the break-even point? If the selling price of the product is increased by 10 percent, what is the dollar increase in net profit at full capacity if the income tax rate is 34 percent of gross earnings?

17. A rough rule of thumb for the chemical industry is that \$1 of annual sales requires \$1 of fixed-capital investment. In a chemical processing plant where this rule applies, the total capital investment is \$2,500,000 and the working capital is 20 percent of the total capital investment. The annual total product cost amounts to \$1,500,000. If the national and regional income-tax rates on gross earnings total 36 percent, determine the following:

    (a) Percent of total capital investment returned annually as gross earnings.
    (*b*) Percent of total capital investment returned annually as net profit.

18. The total capital investment for a proposed chemical plant which will produce $1,500,000 worth of goods per year is estimated to be $1 million. It will be necessary to do a considerable amount of research and development work on the project before the final plant can be constructed, and management wishes to estimate the permissible research and development costs. It has been decided that the net profits from the plant should be sufficient to pay off the total capital investment plus all research and development costs in 7 years. A return after taxes of at least 12 percent of sales must be obtained, and 34 percent of the research and development cost is tax-free (i.e., income-tax rate for the company is 34 percent of the gross earnings). Under these conditions, what is the total amount the company can afford to pay for research and development?
19. A chemical processing unit has a capacity for producing 1 million kg of a product per year. After the unit has been put into operation, it is found that only 500,000 kg of the product can be disposed of per year. An analysis of the existing situation shows that all fixed and other invariant charges, which must be paid whether or not the unit is operating, amount to 35 percent of the total product cost when operating at full capacity. Raw-material costs and other production costs that are directly proportional to the quantity of production (i.e., constant per kilogram of product at any production rate) amount to 40 percent of the total product cost at full capacity. The remaining 25 percent of the total product cost is for variable overhead and miscellaneous expenses, and the analysis indicates that these costs are directly proportional to the production rate during operation raised to the 1.5 power. What will be the percent change in total cost per kilogram of product if the unit is switched from the l-million-kg-per-year rate to a time and rate schedule which will produce 500,000 kg of product per year at the least total cost? All costs referred to above are on a per-kilogram basis.
20. Estimate the total operating cost per day for labor, power, steam, and water in a plant producing 100 tons of acetone per day from the data given in Table 22 and using utility costs from Table 23. Consider all water as treated city water. The steam pressure may be assumed to be 100 psig. Labor costs average $20 per employee-hour. Electricity must be purchased. Plant operates 365 days per year.

CHAPTER 7

INTERESTAND INVESTMENT COSTS

A considerable amount of confusion exists among engineers over the role of interest in determining costs for a manufacturing operation. The confusion is caused by the attempt to apply the classical economist's definition of interest. According to the classical definition, interest is the money returned to the owners of capital for use of their capital. This would mean that any profit obtained through the uses of capital could be considered as interest. Modern economists seldom adhere to the classical definition. Instead, they prefer to substitute the term ***return on capital*** or ***return on investment*** for the classical ***interest.***

Engineers define interest as the ***compensation paid for the use of borrowed capital.*** This definition permits distinction between profit and interest. The rate at which interest will be paid is usually fixed at the time the capital is borrowed, and a guarantee is made to return the capital at some set time in the future or on an agreed-upon pay-off schedule.

TYPES OF INTEREST

Simple Interest

In economic terminology, the amount of capital on which interest is paid is designated as the ***principal,*** and ***rate of interest*** is defined as the amount of interest earned by a unit of principal in a unit of time. The time unit is usually taken as one year. For example, if $100 were the compensation demanded for giving someone the use of $1000 for a period of one year, the principal would be $1000, and the rate of interest would be 100/1000 = 0.1 or 10 percent/year.

The simplest form of interest requires compensation payment at a constant interest rate based only on the original principal. Thus, if $1000 were loaned for a total time of 4 years at a constant interest rate of 10 percent/year, the simple interest earned would be

$$\$1000 \times 0.1 \times 4 = \$400$$

If P represents the principal, n the number of time units or interest periods, and i the interest rate based on the length of one interest period, the amount of simple interest Z during n interest periods is

$$Z = Pin \tag{1}$$

The principal must be repaid eventually; therefore, the entire amount S of principal plus simple interest due after n interest periods is

$$S = P + Z = P(1 + in) \tag{2}$$

Ordinary and Exact Simple Interest

The time unit used to determine the number of interest periods is usually 1 year, and the interest rate is expressed on a yearly basis. When an interest period of less than 1 year is involved, the ***ordinary*** way to determine simple interest is to assume the year consists of twelve 30-day months, or 360 days. The ***exact*** method accounts for the fact that there are 365 days in a normal year. Thus, if the interest rate is expressed on the regular yearly basis and d represents the number of days in an interest period, the following relationships apply:

$$\text{Ordinary simple interest} = Pi\frac{d}{360} \tag{3}$$

$$\text{Exact simple interest} = Pi\frac{d}{365} \tag{4}$$

Ordinary interest is commonly accepted in business practices unless there is a particular reason to use the exact value.

Compound Interest

In the payment of simple interest, it makes no difference whether the interest is paid at the end of each time unit or after any number of time units. The same total amount of money is paid during a given length of time, no matter which method is used. Under these conditions, there is no incentive to pay the interest until the end of the total loan period.

Interest, like all negotiable capital, has a time value. If the interest were paid at the end of each time unit, the receiver could put this money to use for earning additional returns. Compound ***interest*** takes this factor into account by stipulating that interest is due regularly at the end of each interest period. If payment is not made, the amount due is added to the principal, and interest is charged on this converted principal during the following time unit. Thus, an initial loan of $1000 at an annual interest rate of 10 percent would require payment of $100 as interest at the end of the first year. If this payment were not made, the interest for the second year would be ($1000 + $100)(0.10) = $110, and the total ***compound amount*** due after 2 years would be

$$\$1000 + \$100 + \$110 = \$1210$$

The compound amount due after any discrete number of interest periods can be determined as follows:

Period	Principal at start of period	Interest earned during period (i = interest rate based on length of one period)	Compound amount S at end of period
1	P	Pi	$P + Pi = P(1 + i)$
2	$P(1 + i)$	$P(1 + i)(i)$	$P(1 + i) + P(1 + i)(i) = P(1 + i)^2$
3	$P(1 + i)^2$	$P(1 + i)^2(i)$	$P(1 + i)^2 + P(1 + i)^2(i) = P(1 + i)^3$
n	$P(1 + i)^{n-1}$	$P(1 + i)^{n-1}(i)$	$P(1 + i)^n$

Therefore, the total amount of principal plus compounded interest due after n interest periods and designated as S is†

$$S = P(1 + i)^n \tag{5}$$

The term $(1 + i)^n$ is commonly referred to as the ***discrete single-payment compound-amount factor.*** Values for this factor at various interest rates and numbers of interest periods are given in Table 1.

Figure 7-1 shows a comparison among the total amounts due at different times for the cases where simple interest, discrete compound interest, and continuous interest are used.

NOMINAL AND EFFECTIVE INTEREST RATES

In common industrial practice, the length of the discrete interest period is assumed to be 1 year and the fixed interest rate i is based on 1 year. However, there are cases where other time units are employed. Even though the actual interest period is not 1 year, the interest rate is often expressed on an annual basis. Consider an example in which the interest rate is 3 percent per period

†For the analogous equation for continuous interest compounding, see Eq. (12).

TABLE 1

Discrete compound-interest factor $(1 + i)^n$ at various values of i and n†

Number of interest periods, n	Value of $(1 + i)^n$ at indicated percent interest													
	1%	2%	3%	4 %	5%	6 %	7 %	8%	10%	12%	14%	16%	18%	20%
1	1.0100	1.0200	1.0300	1.0400	1.0500	1.0600	1.0709	1.0800	1.100C	1.1209	1.1409	1.1600)	1.180(	1.2000
2	1.0201	1.0404	1.0609	1.0816	1.1025	1.1236	1.1449	1.1664	1.210C	1.2544	1.2996	1.3456(3	1.392’	1.4400
3	1.0363	1.0612	1.0927	1.1249	1.1576	1.1910	1.2250	1.2597	1.331C	1.4040	1.4815	1.5609)	1.643(	1.7280
4	1.0406	1.0824	1.1256	1.1699	1.2155	1.2625	1.3108	1.3605	1.4641	1.5735	1.6890	1.810(	1.938	2.0736
5	1.0510	1.1041	1.1593	1.2167	1.2763	1.3382	1.4026	1.4693	1.6105	1.7623	1.9264	2.100:	2.2871	2.4883
6	1.0615	1.1262	1.1041	1.2653	1.3401	1.4185	1.5007	1.5869	1.7716	1.9738	2.1950	2.4364	2.699(	2.9860
7	1.0721	1.1487	1.2299	1.3159	1.4071	1.5036	1.6058	1.7138	1.9487	2.2107	2.5023	2.826:	3.185	3.6832
8	1.0829	1.1717	1.2668	1.3686	1.4775	1.6838	1.7182	1.8509	2.1438	2.4766	2.8592	3.278’	3.758	4.2998
9	1.0937	1.1961	1.3048	1.4233	1.5513	1.6895	1.8386	1.9990	2.3579	2.7731	3.2620	3.8030	4.4351	5.1598
10	1.1046	1.2190	1.3439	1.4802	1.6289	1.7908	1.9672	2.1589	2.5931	3.1058	3.7072	4.4114	5.2331	6.1917
11	1.1157	1.2434	1.3842	1.6395	1.7103	1.8983	2.1049	2.3316	2.8531	3.4785	4.2262	5.1173	6.1751	7.4301
12	1.1268	1.2662	1.4258	1.6010	1.7959	2.0122	2.2522	2.5182	3.1384	3.8960	4.8179	5.9360	7.287(	8.9161
13	1.1381	1.2936	1.4685	1.6651	1.8856	2.1329	2.4098	2.7196	3.4623	4.3635	6.4924	6.885	8.599’	10.699
14	1.1495	1.3195	1.5126	1.7317	1.9799	2.2609	2.5785	2.9372	3.7975	4.8871	6.2614	7.9875	10.147	12.839
15	1.1610	1.3459	1.5580	1.8009	2.0789	2.3966	2.7590	3.1722	4.1771	5.4736	7.1380	9.265	11.974	15.407
16	1.1726	1.3728	1.6047	1.8730	2.1829	2.5404	2.9522	3.4259	4.595C	6.1304	8.1373	10.748	14.129	18.488
17	1.1843	1.4002	1.6528	1.9479	2.2920	2.6928	3.1588	3.7000	5.0546	6.8660	9.2765	12.468	16.672	22.186
18	1.1961	1.4282	1.7024	2.0258	2.4066	2.8543	3.3799	3.9960	5.5599	7.6900	10.575	14.462	19.673	26.623
19	1.2081	1.4568	1.7535	2.1068	2.5270	3.0256	3.6166	4.3157	6.115	8.6128	12.056	16.777	23.214	31.948
20	1.2202	1.4859	1.8061	2.1911	2.6533	3.2071	3.8697	4.6610	6.727	9.6463	13.744	19.461	27.393	38.338
21	1.2324	1.5157	1.8603	2.2788	2.7800	3.3996	4.1406	5.0338	7.400	10.304	15.668	22.574	32.324	46.005
22	1.2447	1.5460	1.9161	2.3699	2.9263	3.6035	4.4304	5.4365	8.1402	12.100	17.861	26.186	38.142	55.206
23	1.2522	1.5769	1.9736	2.4647	3.0715	3.8197	4.7408	5.8715	8.954	13.552	20.362	30.376	45.008	66.247
24	1.2697	1.6084	2.0328	2.5633	3.2251	4.0489	5.0724	6.3412	9.849	15.179	23.212	35.236	53.109	79.497
25	1.2824	1.6406	2.0938	2.6658	3.3864	4.2919	5.4274	6.8485	10.835	17.000	26.462	40.874	62.669	95.396
30	1.3478	1.8114	2.4273	3.2434	4.3219	5.7435	7.6123	10.063	17.449	29.960	50.950	87.044	143.37	237.38
35	1.4166	1.9999	2.8139	3.9461	6.5160	7.6861	10.677	14.785	28.102	52.800	98.101	180.31	328.00	590.67
40	1.4889	2.2080	3.2620	4.8010	7.0400	10.286	14.974	21.725	45.259	93.051	188.88	378.72	750.38	469.8
46	1.5648	2.4379	3.7816	5.8412	8.9850	13.765	21.002	31.920	72.891	163.99	163.68	795.44	1716.7	657.2
so	1.6446	2.6916	4.3839	7.1067	11.467	18.420	29.457	46.902	17.39	289.09	100.24	670.7	927.3	1100.4

† Percent interest = (i)(100).

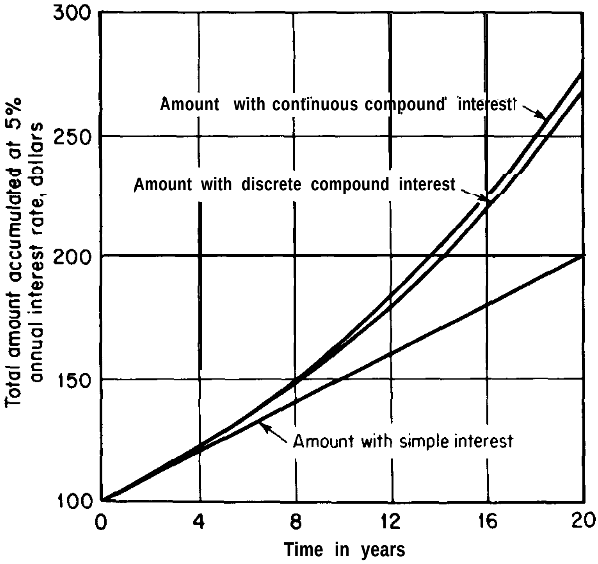

FIGURE 7-1
Comparison among total amounts accumulated with simple interest, discrete compound interest, and continuous compound nominal interest.

and the interest is compounded at half-year periods. A rate of this type would be referred to as "6 percent compounded semiannually." Interest rates stated in this form are known as nominal interest *rates*. The actual annual return on the principal would not be exactly 6 percent but would be somewhat larger because of the compounding effect at the end of the semiannual period.

It is desirable to express the exact interest rate based on the original principal and the convenient time unit of 1 year. A rate of this type is known as the *effective interest rate.* In common engineering practice, it is usually preferable to deal with effective interest rates rather than with nominal interest rates. The only time that nominal and effective interest rates are equal is when the interest is compounded annually.

Nominal interest rates should always include a qualifying statement indicating the compounding period. For example, using the common annual basis, \$100 invested at a nominal interest rate of 20 percent compounded annually would amount to \$120.00 after 1 year; if compounded semiannually, the amount would be \$121.00; and, if compounded continuously, the amount would be \$122.14. The corresponding effective interest rates are 20.00 percent, 21.00 percent, and 22.14 percent, respectively.

If nominal interest rates are quoted, it is possible to determine the effective interest rate by proceeding from Eq. (5).

$$S = P(1 + i)^n \tag{5}$$

In this equation, S represents the total amount of principal plus interest due after n periods at the periodic interest rate i. Let r be the nominal interest rate under conditions where there are m conversions or interest periods per year.

Then the interest rate based on the length of one interest period is r/m, and the amount S after 1 year is

$$S_{\text{after 1 year}} = P\left(1 + \frac{r}{m}\right)^m \tag{6}$$

Designating the effective interest rate as i_{eff}, the amount S after 1 year can be expressed in an alternate form as

$$S_{\text{after 1 year}} = P(1 + i_{\text{eff}}) \tag{7}$$

By equating Eqs. (6) and (7), the following equation can be obtained for the effective interest rate in terms of the nominal interest rate and the number of periods per year:

$$\text{Effective annual interest rate} = i_{\text{eff}} = \left(1 + \frac{r}{m}\right)^m - 1 \tag{8}$$

Similarly, by definition,

$$\textbf{Nominal annual interest rate} = m\left(\frac{r}{m}\right) = r \tag{9}$$

Example 1 Applications of different types of interest. It is desired to borrow \$1000 to meet a financial obligation. This money can be borrowed from a loan agency at a monthly interest rate of 2 percent. Determine the following:

(a) The total amount of principal plus simple interest due after 2 years if no intermediate payments are made.
(*b*) The total amount of principal plus compounded interest due after 2 years if no intermediate payments are made.
(*c*) The nominal interest rate when the interest is compounded monthly.
(*d*) The effective interest rate when the interest is compounded monthly.

Solution

(a) Length of one interest period = 1 month
Number of interest periods in 2 years = 24
For simple interest, the total amount due after n periods at periodic interest rate i is

$$S = P(1 + in) \tag{2}$$

P = initial principal = \$1000
i = 0.02 on a monthly basis
n = 24 interest periods in 2 years

$$S = \$1000(1 + 0.02 \times 24) = \$1480$$

(*b*) For compound interest, the total amount due after n periods at periodic interest rate i is

$$S = P(1 + i)^n \tag{5}$$

$$S = \$1000(1 + 0.02)^{24} = \$1608$$

(*c*) Nominal interest rate = 2 x 12 = 24% per year compounded monthly

(*d*) Number of interest periods per year = m = 12
Nominal interest rate = r = 0.24

$$\text{Effective interest rate} = \left(1 + \frac{r}{m}\right)^m - 1 \tag{8}$$

$$\text{Effective interest rate} = \left(1 + \frac{0.24}{12}\right)^{12} - 1 = 0.268 = 26.8\%$$

CONTINUOUS INTEREST

The preceding discussion of types of interest has considered only the common form of interest in which the payments are charged at periodic and discrete intervals, where the intervals represent a finite length of time with interest accumulating in a discrete amount at the end of each interest period. Although in practice the basic time interval for interest accumulation is usually taken as one year, shorter time periods can be used as, for example, one month, one day, one hour, or one second. The extreme case, of course, is when the time interval becomes infinitesimally small so that the *interest is compounded continuously*.

The concept of continuous interest is that the cost or income due to interest flows regularly, and this is just as reasonable an assumption for most cases as the concept of interest accumulating only at discrete intervals. The reason why continuous interest has not been used widely is that most industrial and financial practices are based on methods which executives and the public are used to and can understand. Because normal interest comprehension is based on the discrete-interval approach, little attention has been paid to the concept of continuous interest even though this may represent a more realistic and idealized situation.

The Basic Equations for Continuous Interest Compounding

Equations (6), (7), and (8) represent the basic expressions from which continuous-interest relationships can be developed. The symbol r represents the nominal interest rate with m interest periods per year. If the interest is compounded continuously, m approaches infinity, and Eq. (6) can be written as

$$S_{\text{after } n \text{ years}} = P \lim_{m \to \infty} \left(1 + \frac{r}{m}\right)^{mn} = P \lim_{m \to \infty} \left(1 + \frac{r}{m}\right)^{(m/r)(rn)} \tag{10}$$

The fundamental definition for the base of the natural system of logarithms (e = 2.71828) is†

$$\lim_{m \to \infty} \left(1 + \frac{r}{m}\right)^{m/r} = e = 2.71828\ldots \tag{11}$$

†See any book on advanced calculus. For example, W. Fulks, "Advanced Calculus," 3d ed., pp. 55-56, John Wiley & Sons, Inc., New York, 1978.

Thus, with continuous interest compounding at a nominal annual interest rate of r, the *amount* S an initial *principal* P will compound to in n years is†‡

$$S = Pe^{rn} \tag{12}$$

Similarly, from Eq. (8), the effective annual interest rate i_{eff}, which is the conventional interest rate that most executives comprehend, is expressed in terms of the nominal interest rate r compounded continuously as

$$i_{\text{eff}} = e^r - 1 \tag{13}$$

$$r = \ln(i_{\text{eff}} + 1) \tag{14}$$

Therefore,

$$e^{rn} = (1 + i_{\text{eff}})^n \tag{15}$$

and

$$S = Pe^{rn} = P(1 + i_{\text{eff}})^n \tag{16}$$

As is illustrated in the following example, a conventional interest rate (i.e., effective annual interest rate) of 22.14 percent is equivalent to a 20.00 percent nominal interest rate compounded continuously. Note, also, that a nominal interest rate compounded daily gives results very close to those obtained with continuous compounding.

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†The same result can be obtained from calculus by noting that, for the case of continuous compounding, the differential change of S with time must equal the nominal continuous interest rate times S, or $dS/dn = rS$. This expression can be integrated as follows to give Eq. (12):

$$\int_P^S \frac{dS}{S} = r\int_0^n dn$$

$$\ln \frac{S}{P} = rn \quad \text{or} \quad S = Pe^{rn} \tag{12}$$

‡A generalized way to express both Eq. (12) and Eq. (5), with direct relationship to the other interest equations in this chapter, is as follows:

$$\text{Future worth} = \text{present worth} \times \text{compound interest factor}$$

$$S = PC$$

or

$$\text{Future worth} \times \text{discount factor} = \text{present worth}$$

$$SF = P$$

$$\text{Discount factor} = F = \frac{1}{\text{compound interest factor}} = \frac{1}{C}$$

Although the various factors for different forms of interest expressions are derived in terms of interest rate in this chapter, the overall concept of interest evaluations is simplified by the use of the less-complicated nomenclature where designated factors are applied. Thus, expressing both Eqs. (12) and (5) as $SF = P$ would mean that F is e^{-rn} for the continuous interest case of Eq. (12) and $(1 + i)^{-n}$ for the discrete interest case of Eq. (5). See Table 4 for further information on this subject.

Example 2 Calculations with continuous interest compounding. For the case of a nominal annual interest rate of 20.00 percent, determine:

(*a*) The total amount to which one dollar of initial principal would accumulate after one 365-day year with daily compounding.

(*b*) The total amount to which one dollar of initial principal would accumulate after one year with continuous compounding.

(*c*) The effective annual interest rate if compounding is continuous.

Solution

(*a*) Using Eq. (6). $P = \$1.0$, $r = 0.20$, $m = 365$,

$$S_{\text{after 1 year}} = P\left(1 + \frac{r}{m}\right)^m = (1.0)\left(1 + \frac{0.20}{365}\right)^{365} = \$1.2213$$

(*b*) Using Eq. (12),

$$S = Pe^{rn} = (1.0)(e)^{(0.20)(1)} = \$1.2214$$

(*c*) Using Eq. (13),

$$i_{\text{eff}} = e^r \quad 1 = 1.2214 \quad 1 = 0.2214 \text{ or } 22.14\%$$

Tabulated values of i_{eff} and the corresponding r with continuous interest compounding are shown in Table 2.

TABLE 2
Effective annual interest rates compared to equivalent nominal interest rates with continuous interest

Effective annual rate of return, %	Nominal continuous rate of return, %	Effective annual rate of return, %	Nominal continuous rate of return, %
1	0.99504	35	30.010
2	1.9803	40	33.647
3	2.9559	45	37.156
4	3.9221	50	40.547
5	4.8790	60	47.000
6	5 8269	70	53.063
7	6.7659	80	58.779
8	7.6961	90	64.185
9	8.6178	100	69.315
10	9.5310	110	74.194
15	13.976	120	78.846
20	18.232	130	83.291
25	22.314	140	87.547
30	26.236	150	91.629

Example 3 Use of digital computer to give tabulated values of amount accumulated with continuous interest compounding. Present the digital computer program and the tabulated printout to six significant figures giving the amount to which an initial principal of $100 will accumulate year by year from 1 to 20 years with continuous interest compounding based on a nominal interest rate of 20 percent.

Solution. The equation to be solved on the digital computer is

$$S = Pe^{rn}$$

where S will be evaluated to six significant figures for

$$n = 1, 2, 3, \ldots, 20$$
$$P = \$100$$
$$r = 0.20$$

The Fortran IV program and the computer print-out follow:

```
$IBJOB MAP
$IBFTC DECK 1
      DO 1 N = 1,20
      AN=N
      S = 100.*EXP(.20*AN)
1     WRITE(6, 2)N, S
2     FORMAT(I4,F12.3)
      END
$ENTRY
```

Printout

1	122.140	11	902.501
2	149.182	12	1102.318
3	182.212	13	1346.374
4	222.554	14	1644.465
5	271.828	15	2008.554
6	332.012	16	2453.253
7	405.520	17	2996.410
8	495.303	18	3659.823
9	604.965	19	4470.118
10	738.906	20	5459.815

(NOTE: *The preceding illustrates the method used to prepare tabulated results of factors and emphasizes the simplicity of the procedure with a digital computer. This set of results represents a standard exponential function available in tabulated form in standard mathematical tables. See Prob. 8 at the end of this chapter for a requested computer solution for a more complicated continuous-interest case.)*

PRESENT WORTH AND DISCOUNT

It is often necessary to determine the amount of money which must be available at the present time in order to have a certain amount accumulated at some definite time in the future. Because the element of time is involved, interest must be taken into consideration. ***The present worth*** (or ***present value)*** of a future amount is the present principal which must be deposited at a given interest rate to yield the desired amount at some future date.†

In Eq. (5), S represents the amount available after n interest periods if the initial principal is P and the discrete compound-interest rate is i. Therefore, the present worth can be determined by merely rearranging Eq. (5).

$$\text{Present worth} = P = S\frac{1}{(1+i)^n} \qquad (17)$$

The factor $1/(1+i)^n$ is commonly referred to as the *discrete single-payment present-worth factor.*

Similarly, for the case of continuous interest compounding, Eq. (12) gives

$$\text{Present worth} = P = S\frac{1}{e^{rn}} \qquad (18)$$

Some types of capital are in the form of bonds having an indicated value at a future date. In business terminology, the difference between the indicated future value and the present worth (or present value) is known as the *discount.*

Example 4 Determination of present worth and discount. A bond has a maturity value of \$1000 and is paying discrete compound interest at an effective annual rate of 3 percent. Determine the following at a time four years before the bond reaches maturity value:

(*a*) Present worth.
(*b*) Discount.
(*c*) Discrete compound rate of effective interest which will be received by a purchaser if the bond were obtained for \$700.
(*d*) Repeat part (*a*) for the case where the nominal bond interest is 3 percent compounded continuously.

solution

(*a*) By Eq. (17), present worth = $S/(1+i)^n = \$1000/(1+0.03)^4$ = \$888

(*b*) Discount = future value − present worth = \$1000 − \$888 = \$112

(*c*) Principal = \$700 = $S/(1+i)^n = \$1000/(1+i)^4$

$$i = \left(\frac{1000}{700}\right)^{1/4} - 1 = 0.0935 \text{ or } 9.35\%$$

(*d*) By Eq. (18), present worth = $S/e^{rn} = \$1000/e^{(0.03)(4)}$ = \$869

ANNUITIES

An *annuity* is a series of equal payments occurring at equal time intervals. Payments of this type can be used to pay off a debt, accumulate a desired

† In the analyses presented in this chapter, effects of inflation or deflation on future worth are not considered. See Chap. 11 (Optimum Design and Design Strategy) for information on the strategy for dealing with inflation or deflation in design economic evaluations.

amount of capital, or receive a lump sum of capital that is due in periodic installments as in some life-insurance plans. Engineers often encounter annuities in depreciation calculations, where the decrease in value of equipment with time is accounted for by an annuity plan.

The common type of annuity involves payments which occur ***at the end of each interest period.*** This is ***known*** as an ***ordinary annuity.*** Interest is paid on all accumulated amounts, and the interest is compounded each payment period. ***An annuity term*** is the time from the beginning of the first payment period to the end of the last payment period. The ***amount of an annuity*** is the sum of all the payments plus interest if allowed to accumulate at a definite rate of interest from the time of initial payment to the end of the annuity term.

Relation between Amount of Ordinary Annuity and the Periodic Payments

Let R represent the uniform periodic payment made during n discrete periods in an ordinary annuity. The interest rate based on the payment period is i, and S is the amount of the annuity. The first payment of R is made at the end of the first period and will bear interest for $n - 1$ periods. Thus, at the end of the annuity term, this first payment will have accumulated to an amount of $R(1 + i)^{n-1}$. The second payment of R is made at the end of the second period and will bear interest for $n - 2$ periods giving an accumulated amount of $R(1 + i)^{n-2}$. Similarly, each periodic payment will give an additional accumulated amount until the last payment of R is made at the end of the annuity term.

By definition, the amount of the annuity is the sum of all the accumulated amounts from each payment; therefore,

$$S = R(1 + i)^{n-1} + R(1 + i)^{n-2} + R(1 + i)^{n-3} + \cdots + R(1 + i) + R \quad (19)$$

To simplify Eq. (19), multiply each side by $(1 + i)$ and subtract Eq. (19) from the result. This gives

$$Si = R(1 + i)^n - R \quad (20)$$

or

$$S = R\frac{(1 + i)^n - 1}{i} \quad (21)$$

The term $[(1 + i)^n - 1]/i$ is commonly designated as the ***discrete uniform-series compound-amount factor*** or the ***series compound-amount factor.***

Continuous Cash Flow and Interest Compounding

The expression for the case of continuous cash flow and interest compounding, equivalent to Eq. (21) for discrete cash flow and interest compounding, is developed as follows:

As before, let r represent the nominal interest rate with m conversions or interest periods per year so that $i = r/m$ and the total number of interest periods in n years is mn. With m annuity payments per year, let $\bar{R}$ represent the total of all ordinary annuity payments occurring regularly and uniformly throughout the year so that $\bar{R}/m$ is the uniform annuity payment at the end of each period. Under these conditions, Eq. (21) becomes

$$S = \frac{\bar{R}}{m}\,\frac{[1 + (r/m)]^{(m/r)(rn)} - 1}{r/m} \tag{22}$$

For the case of continuous cash flow and interest compounding, m approaches infinity, and Eq. (22), by use of Eq. (11), becomes†

$$S = \bar{R}\left(\frac{e^{rn} - 1}{r}\right) \tag{23}$$

Present Worth of an Annuity

The present worth of an annuity is defined as the principal which would have to be invested at the present time at compound interest rate i to yield a total amount at the end of the annuity term equal to the amount of the annuity. Let P represent the present worth of an ordinary annuity. Combining Eq. (5) with Eq. (21) gives, for the case of discrete interest compounding,

$$P = R\frac{(1 + i)^n - 1}{i(1 + i)^n} \tag{24}$$

The expression $[(1 + i)^n - 1]/[i(1 + i)^n]$ is referred to as the ***discrete uniform-series present-worth factor*** or the ***series present-worth factor,*** while the reciprocal $[i(1 + i)^n]/[(1 + i)^n - 1]$ is often called the ***capital-recovery factor.***

For the case of continuous cash flow and interest compounding, combination of Eqs. (12) and (23) gives the following equation which is analogous to Eq. (24):

$$P = \bar{R}\frac{e^{rn} - 1}{re^{rn}} \tag{25}$$

Example 5 Application of annuities in determining amount of depreciation with discrete interest compounding. A piece of equipment has an initial installed value of \$12,000. It is estimated that its useful life period will be 10 years and its scrap

†The same result is obtained from calculus by noting that the definition of $\bar{R}$ is such that the differential change in S with n is equal to $\bar{R}$, which is the constant gradient during the year, plus the contribution due to interest, or $dS/dn = \bar{R} + rS$. This expression can be integrated as follows to give Eq. (23):

$$\int_0^S \frac{dS}{\bar{R} + rS} = \int_0^n dn$$

$$\ln\frac{\bar{R} + rS}{\bar{R}} = rn \quad \text{or} \quad S = \bar{R}\left(\frac{e^{rn} - 1}{r}\right) \tag{23}$$

value at the end of the useful life will be $2000. The depreciation will be charged as a wst by making equal charges each year, the first payment being made at the end of the first year. The depreciation fund will be accumulated at an annual interest rate of 6 percent. At the end of the life period, enough money must have been accumulated to account for the decrease in equipment value. Determine the yearly **cost** due to depreciation under these conditions.

(NOTE: This method for determining depreciation is based on an ordinary annuity and is known as the sinking-fund method.)

Solution. This problem is a typical case of an ordinary annuity. Over a period of 10 years, equal payments must be made each year at an interest rate of 6 percent. After 10 years, the amount of the annuity must be equal to the total amount of depreciation.

Amount of annuity = S
Total amount of depreciation = \$12,000 − \$2000 = \$10,000 = S
Equal payments per year = R = yearly **cost** due to depreciation
Number of payments = $n = 10$
Annual interest rate = $i = 0.06$.

From Eq. (21),

$$R = S\frac{i}{(1+i)^n - 1} = \$10,000\frac{0.06}{(1.06)^{10} - 1} = \$759/\text{year}$$

Yearly cost due to depreciation = \$759

Example 6 Application of annuities in determining amount of depreciation with continuous cash flow and interest compounding. Repeat Example 5 with continuous cash flow and nominal annual interest of 6 percent compounded **continuously.**

Solution. This problem is solved in exactly the same manner as Example 5, except the appropriate Eq. (23) for the continuous-interest case is used in place of the discrete-interest equation.

Amount of annuity = S
Total amount of depreciation = \$12,000 − \$2000 = S
Equal payments per year based on continuous cash **flow** and interest compounding = $\bar{R}$ = yearly **cost** due to depreciation
Number of years = $n = 10$
Nominal interest rate with continuous compounding = $r = 0.06$

From Eq. (23),

$$\bar{R} = S\frac{r}{e^{rn} - 1} = \$10,000\frac{0.06}{e^{(0.06)(10)} - 1} = \$730/\text{year}$$

Yearly **cost** due to depreciation = \$730

Special Types of Annuities

One special form of an annuity requires that payments be made at the beginning of each period instead of at the end of each period. This is known as an annuity due. An annuity in which the first payment is due after a definite number of years is called a *deferred annuity*. Determination of the periodic payments, amount of annuity, or present value for these two types of annuities can be accomplished by methods analogous to those used in the case of ordinary annuities.

PERPETUITIES AND CAPITALIZED COSTS

A *perpetuity* is an annuity in which the periodic payments continue indefinitely. This type of annuity is of particular interest to engineers, for in some cases they may desire to determine a total cost for a piece of equipment or other asset under conditions which permit the asset to be replaced perpetually without considering inflation or deflation.

Consider the example in which the original cost of a certain piece of equipment is \$12,000. The useful-life period is 10 years, and the scrap value at the end of the useful life is \$2000. The engineer reasons that this piece of equipment, or its replacement, will be in use for an indefinitely long period of time, and it will be necessary to supply \$10,000 every 10 years in order to replace the equipment. He therefore wishes to provide a fund of sufficient size so that it will earn enough interest to pay for the periodic replacement. If the discrete annual interest rate is 6 percent, this fund would need to be \$12,650. At 6 percent interest compounded annually, the fund would amount to $(\$12{,}650)(1 + 0.06)^{10} = \$22{,}650$ after 10 years. Thus, at the end of 10 years, the equipment can be replaced for \$10,000 and \$12,650 will remain in the fund. This cycle could now be repeated indefinitely. If the equipment is to perpetuate itself, the theoretical amount of total capital necessary at the start would be \$12,000 for the equipment plus \$12,650 for the replacement fund. The total capital determined in this manner is called the *capitalized cost*. Engineers use capitalized costs principally for comparing alternative choices.†

In a perpetuity, such as in the preceding example, the amount required for the replacement must be earned as compounded interest over a given length of time. Let P be the amount of present principal (i.e., the present worth) which can accumulate to an amount of S during n interest periods at periodic interest rate i. Then, by Eq. (5),

$$S = P(1 + i)^n \tag{5}$$

†For further discussion of capitalized costs used in engineering, see Chap. 10 and F. C. Jelen and M. S. Cole. Methods for Economic Analysis, Part I, *Hydrocarbon Proc.*, **53**(7):133 (1974); Part II, *Hydrocarbon Proc.*, **53**(9):227 (1974).

If perpetuation is to occur, the amount S accumulated after n periods minus the cost for the replacement must equal the present worth P. Therefore, letting C_R represent the replacement cost,

$$P - S - C_R \tag{26}$$

Combining Eqs. (5) and (26),

$$P = \frac{C_R}{(1+i)^n - 1} \tag{27}$$

The capitalized cost is defined as the original cost of the equipment plus the present value of the renewable perpetuity. Designating K as the capitalized cost and C_V as the original cost of the equipment,†

$$K = C_V + \frac{C_R}{(1+i)^n - 1} \tag{28}$$

Example 7 Determination of capitalized cost. A new piece of completely installed equipment costs $12,000 and will have a scrap value of $2000 at the end of its useful life. If the useful-life period is 10 years and the interest is compounded at 6 percent per year, what is the capitalized cost of the equipment?

Solution. The cost for replacement of the equipment at the end of its useful life (assuming costs unchanged) = $12,000 - $2000 = $10,000.

By Eq. (28)

$$\text{Capitalized cost} = C_V + \frac{C_R}{(1+i)^n - 1}$$

where C_V = $12,000
C_R = $10,000
$i = 0.06$
$n = 10$

$$\text{Capitalized cost} = \$12{,}000 + \frac{\$10{,}000}{(1+0.06)^{10} - 1}$$

$$= \$12{,}000 + \$12{,}650 = \$24{,}650$$

Example 8 Comparison of alternative investments using capitalized costs. A reactor, which will contain corrosive liquids, has been designed. If the reactor is made of mild steel, the initial installed cost will be $5000, and the useful-life period will be 3 years. Since stainless steel is highly resistant to the corrosive action of the liquids, stainless steel, as the material of construction, has been proposed as an alternative to mild steel. The stainless-steel reactor would have an initial installed cost of $15,000. The scrap value at the end of the useful life would be

†For the continuous-interest-compounding expression equivalent to the discrete-interest-compounding case given in Eq. (28), see Prob. 13 at the end of the chapter.

zero for either type of reactor, and both could be replaced at a cost equal to the original price. On the basis of equal capitalized costs for both types of reactors, what should be the useful-life period for the stainless-steel reactor if money is worth 6 percent compounded annually?

Solution. By Eq. (28), the capitalized cost for the mild-steel reactor is

$$K = C_V + \frac{C_R}{(1+i)^n - 1} = \$5000 + \frac{\$5000}{(1+0.06)^3 - 1}$$

$$K = \$5000 + \$26{,}180 = \$31{,}180$$

Therefore, the capitalized cost for the stainless-steel reactor must also be $31,180.

For the stainless-steel reactor,

$$\$31{,}180 = C_V + \frac{C_R}{(1+i)^n - 1} = \$15{,}000 + \frac{\$15{,}000}{(1+0.06)^n - 1}$$

Solving algebraically for n,

$$n = 11.3 \text{ years}$$

Thus, the useful-life period of the stainless-steel reactor should be 11.3 years for the two types of reactors to have equal capitalized costs. If the stainless-steel reactor would have a useful life of more than 11.3 years, it would be the recommended choice, while the mild-steel reactor would be recommended if the useful life using stainless steel were less than 11.3 years.

RELATIONSHIPS FOR CONTINUOUS CASH FLOW AND CONTINUOUS INTEREST OF IMPORTANCE FOR PROFITABILITY ANALYSES

The fundamental relationships dealing with continuous interest compounding can be divided into two general categories: (1) those that involve instantaneous or lump-sum payments, such as a required initial investment or a future payment that must be made at a given time, and (2) those that involve continuous payments or continuous cash flow, such as construction costs distributed evenly over a construction period or regular income that flows constantly into an overall operation. Equation (12) is a typical example of a lump-sum formula, while Eqs. (23) and (25) are typical of continuous-cash-flow formulas.

The symbols S, P, and R represent discrete lump-sum payments as future worth, present principal (or present worth), and end-of-period (or end-of-year) payments, respectively. A bar above the symbol, such as $\bar{S}$, $\bar{P}$, or $\bar{R}$, means that the payments are made *continuously* throughout the time period under consid-