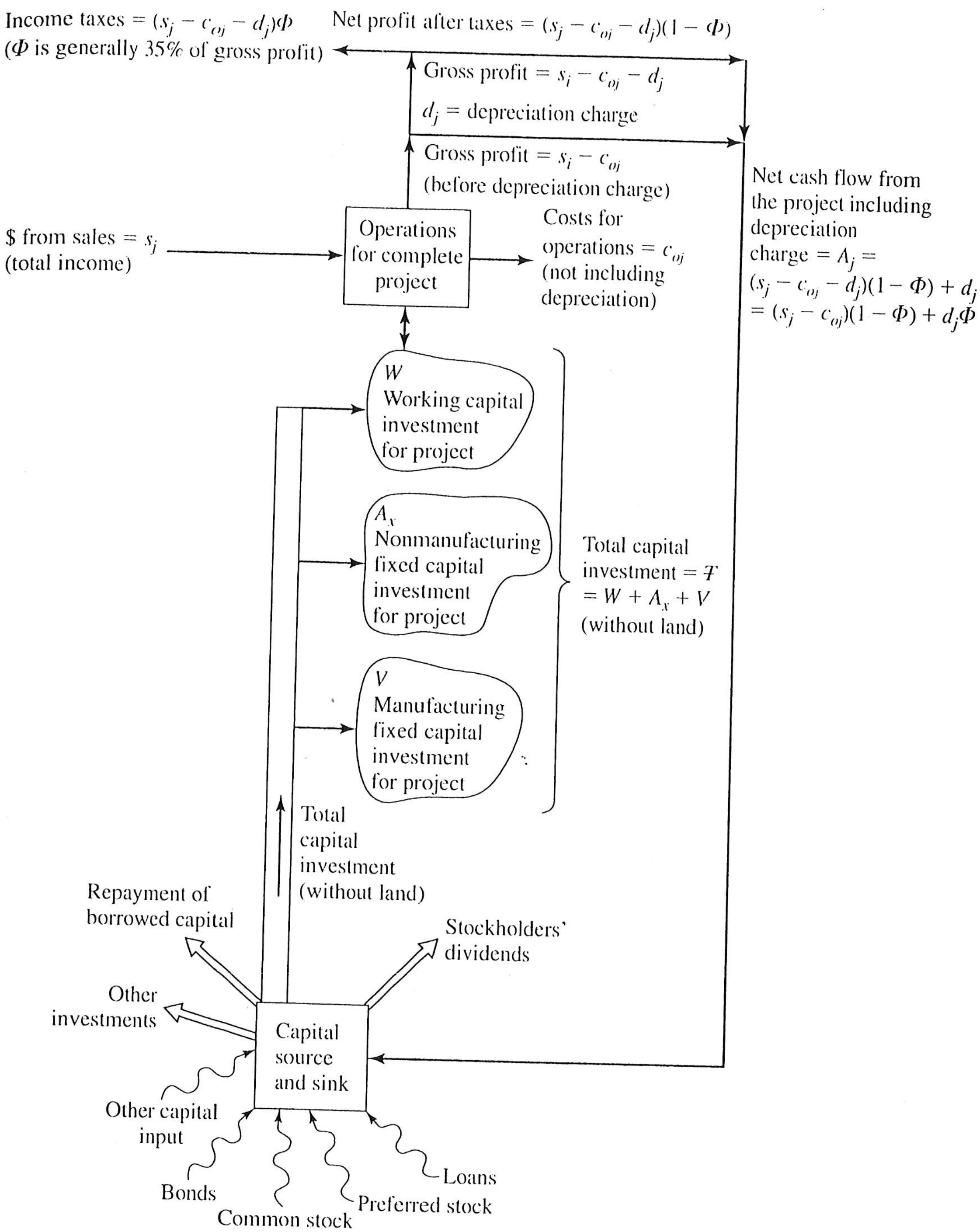

Figure 6-1
Tree diagram showing cash flow for industrial operations

of the completed plant. The flow of cash for the fixed-capital investment is usually spread over the entire construction period. Because income from sales and the costs of operation may occur on an irregular time basis, a reservoir of working capital must be available to meet these requirements.

The rectangular box near the top of Fig. 6-1 represents the operating phase for the complete project with working-capital funds maintained at a level acceptable for

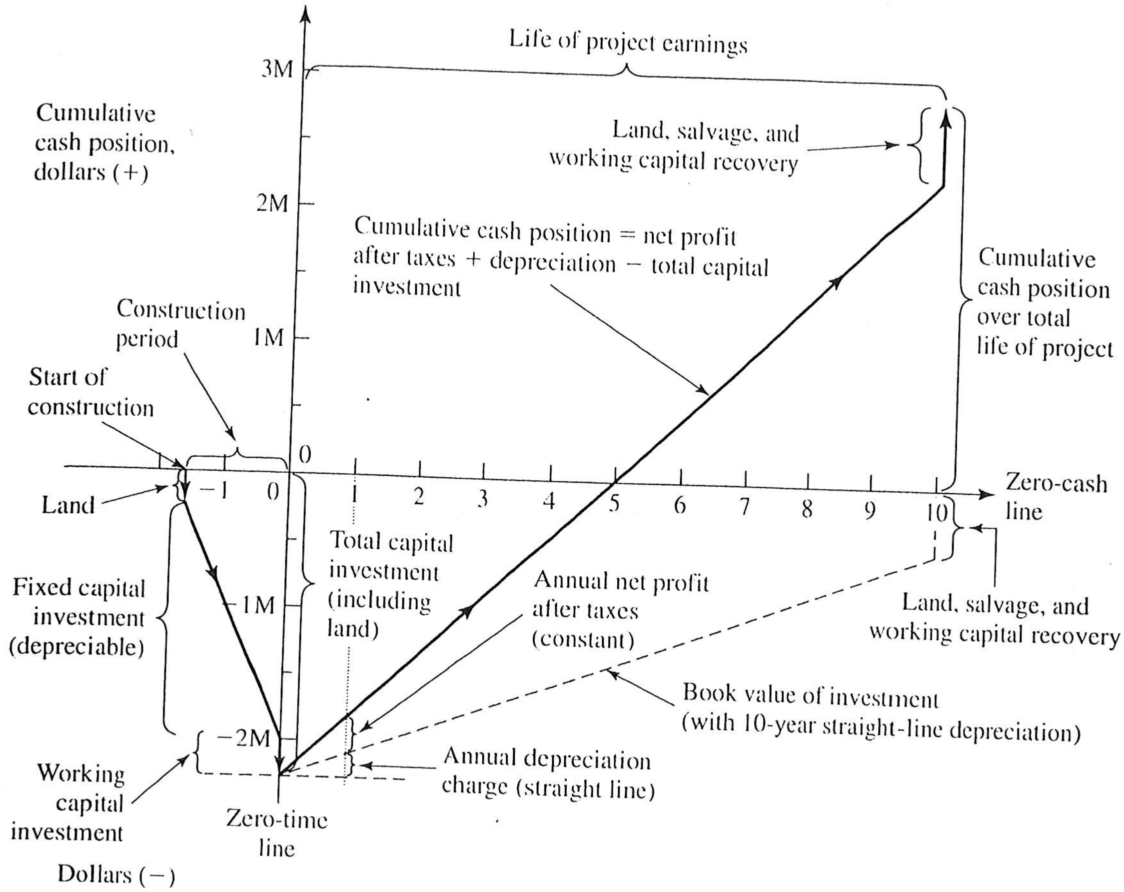

Figure 6-2
Graph of cumulative cash position showing effects of cash flow over the full lif...
for an industrial operation...

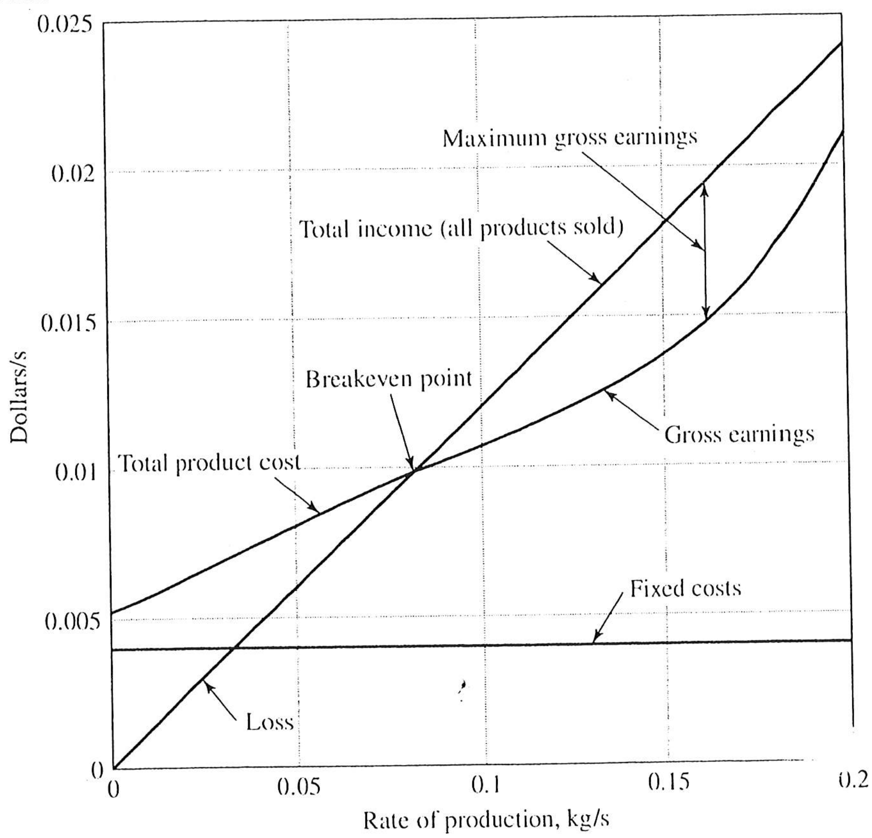

Figure 6-3
Breakeven chart for chemical processing plant

Table 6-1 Breakdown of fixed-capital investment items for a chemical process

Direct costs

1. *Purchased equipment*
   All equipment listed on a complete flowsheet
   Spare parts and noninstalled equipment spares
   Surplus equipment, supplies, and equipment allowance
   Inflation cost allowance
   Freight charges
   Taxes, insurance, duties
   Allowance for modifications during start-up
2. *Purchased-equipment installation*
   Installation of all equipment listed on complete flowsheet
   Structural supports
   Equipment insulation and painting
3. *Instrumentation and controls*
   Purchase, installation, calibration, computer control with supportive software
4. *Piping*
   Process piping utilizing suitable structural materials
   Pipe hangers, fittings, valves
   Insulation
5. *Electrical systems*
   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
9. *Land*
   Surveys and fees
   Property cost

Table 6-1 *Continued*

Indirect costs

1. *Engineering and supervision*
   Engineering costs—administrative, process, design and general engineering, computer graphics, cost engineering, procuring, expediting, reproduction, communications, scale models, consultant fees, travel
   Engineering supervision and inspection
2. *Legal expenses*
   Identification of applicable federal, state, and local regulations
   Preparation and submission of forms required by regulatory agencies
   Acquisition of regulatory approval
   Contract negotiations
3. *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
4. *Contractor's fee*
5. *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 magnitude 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 that 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* or *scope estimate*) based on sufficient data to permit the estimate to be budgeted; probable accuracy of estimate within ±20 percent.
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.

	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 flowsheet	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 arrangement & elevations	●	●			
	Detailed drawings	●				
Utility requirements	Rough quantities (steam, water, electricity, etc.)				●	
	Preliminary heat balance			●		
	Preliminary flowsheets		●	●		
	Engineered heat balance	●	●			
	Engineered flowsheet	●				
	Well-developed drawings	●				
Piping	Preliminary flowsheet & specifications			●	●	
	Engineered flowsheet		●			
	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 & flowsheet	●				
	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	●				
Worker-hours	Engineering & drafting	●	●	●	●	
	Labor by craft	●				
	Supervision	●				
Product scope standard process	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 6-2 Cost indexes as annual averages

Year	Marshall and Swift installed-equipment indexes, 1926 = 100: All industries	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
1987	814	830	4406	956	410	1121.5	324
1988	852	859.3	4519	980	421	1164.5	343
1989	895	905.6	4615	1001	430	1195.9	355
1990	915.1	929.3	4732	1026	441	1225.7	357.6
1991	930.6	949.9	4835	1049	450	1252.9	361.3
1992	943.1	957.9	4985	1081	464	1277.3	358.2
1993	964.2	971.4	5210	1130	485	1310.8	359.2
1994	993.4	992.8	5408	1173	504	1349.7	368.1
1995	1027.5	1029.0	5471	1187	509	1392.1	381.1
1996	1039.1	1048.5	5620	1219	523	1418.9	381.7
1997	1056.8	1063.7	5825	1264	542	1449.2	386.5
1998	1061.9	1077.1	5920	1284	551	1477.6	389.5
1999	1068.3	1081.9	6060	1315	564	1497.2	390.6
2000	1089.0	1097.7	6221	1350	579	1542.7	394.1
2001	1093.9	1106.9	6342	1376	591	1579.7	394.3
2002	1102.5[‡]	1116.9[‡]	6490[‡]	1408[‡]	604[‡]	1599.2[‡]	390.4[†,§]

[†]All costs presented in this text and in the McGraw-Hill website are based on this value for January 2002, obtained from the *Chemical Engineering* index unless otherwise indicated. The website provides the corresponding mathematical cost relationships for all the graphical cost data presented in the text.
[‡]Projected.
[§]Calculated with revised index; see *Chem. Eng.*, **109:** 62 (2002).

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 6-2 presents a list of values for various types of indexes over the past 15 years.

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

[†]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 (1947). See also *Chem. Eng.*, **85**(11): 189 (1978) and **92**(9): 75 (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). A history is presented in the March issue each year; for example, see *Eng. News-Record*, **220**(11): 54 (1988).

[§]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 found in *Chem. Eng.*, **70**(4): 143 (1963) with recapping and updating essentially every 3 years. The index is being revised in 2002 to provide a better relationship between the various cost factors involved in the index; see W. M. Vavatuk, *Chem. Eng.*, **109**(1): 62 (2002) for details.

new equipment, purchase-order prices must be corrected with the appropriate cost index ratio. Limited information on process-equipment costs has also been published in various engineering journals. Costs estimates for a large number of different types and capacities of equipment are presented in Chaps. 12 through 15.

Estimating Equipment Costs by Scaling

It is often necessary to estimate the cost of a piece of equipment when cost data are not available for the particular size or capacity involved. Predictions can be made by using the power 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 b at one capacity is known, the cost of a similar unit a with X times the capacity of the first is $X^{0.6}$ times the cost of the initial unit.

$$\text{Cost of equipment } a = (\text{cost of equipment } b) X^{0.6} \tag{6-2}$$

The preceding equation indicates that a log-log plot of capacity versus 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. The application of the 0.6 rule of thumb for most purchased equipment is, however, an oversimplification, since the actual values of the cost capacity exponent vary from less than 0.3 to greater than 1.0, as shown in Table 6-4. Because of this, the 0.6 power should be used only in

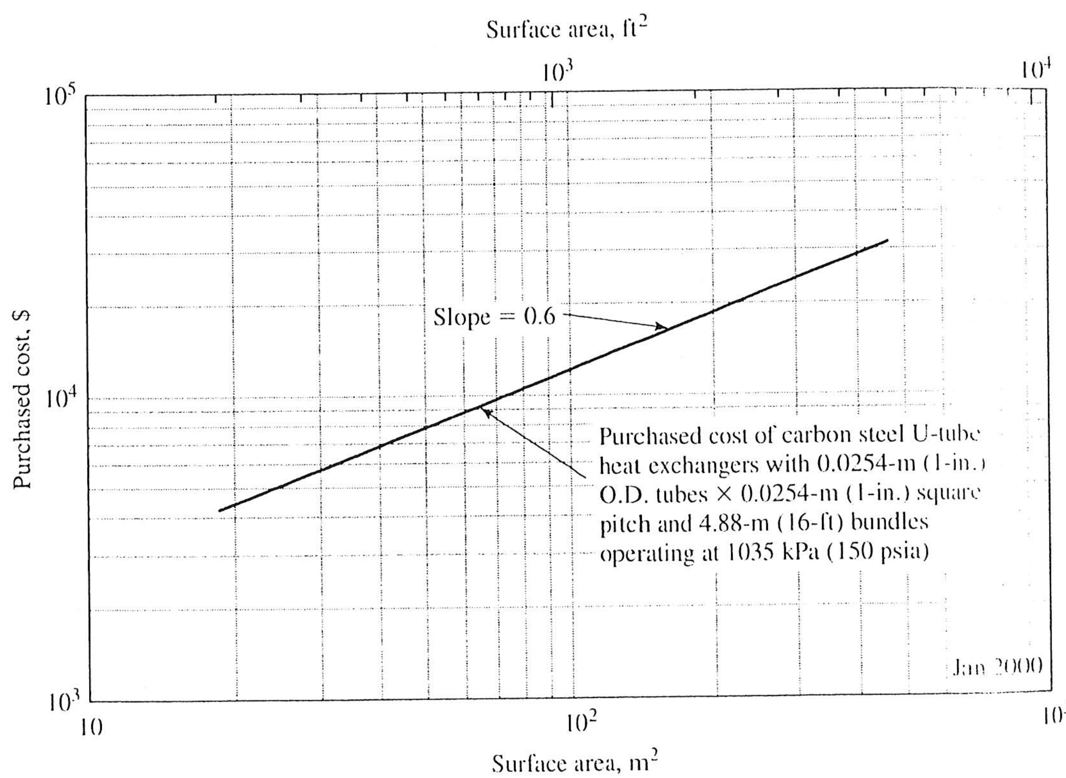

Figure 6-5
Application of "six-tenth factor" rule to costs for U-tube heat exchangers

Table 6-4 Typical exponents for equipment cost as a function of capacity

Equipment	Size range	Exponent
Blender, double cone rotary, carbon steel (c.s.)	1.4–7.1 m^3 (50–250 ft^3)	0.49
Blower, centrifugal	0.5–4.7 m^3/s (10^3–10^4 ft^3/min)	0.59
Centrifuge, solid bowl, c.s.	7.5–75 kW (10–10^2 hp) drive	0.67
Crystallizer, vacuum batch, c.s.	15–200 m^3 (500–7000 ft^3)	0.37
Compressor, reciprocating, air-cooled, two-stage, 1035-kPa discharge	0.005–0.19 m^3 (10–400 ft^3/min)	0.69
Compressor, rotary, single-stage, sliding vane, 1035-kPa discharge	0.05–0.5 m^3/s (10^2–10^3 ft^3/min)	0.79
Dryer, drum, single vacuum	1–10 m^2 (10–10^2 ft^2)	0.76
Dryer, drum, single atmospheric	1–10 m^2 (10–10^2 ft^2)	0.40
Evaporator (installed), horizontal tank	10–1000 m^2 (10^2–10^4 ft^2)	0.54
Fan, centrifugal	0.5–5 m^3/s (10^3–10^4 ft^3/min)	0.44
Fan, centrifugal	10–35 m^3/s (2×10^4–7×10^4 ft^3/min)	1.17
Heat exchanger, shell-and-tube, floating head, c.s.	10–40 m^2 (100–400 ft^2)	0.60
Heat exchanger, shell-and-tube, fixed sheet, c.s.	10–40 m^2 (100–400 ft^2)	0.44
Kettle, cast-iron, jacketed	1–3 m^3 (250–800 gal)	0.27
Kettle, glass-lined, jacketed	0.8–3 m^3 (200–800 gal)	0.31
Motor, squirrel cage, induction, 440-V, explosion-proof	4–15 kW (5–20 hp)	0.69
Motor, squirrel cage, induction, 440-V, explosion-proof	15–150 kW (20–200 hp)	0.99
Pump, reciprocating, horizontal cast-iron (includes motor)	1×10^{-4}–6×10^{-3} m^3/s (2–100 gpm)	0.34
Pump, centrifugal, horizontal, cast steel (includes motor)	4–40 $m^3/s\cdot kPa$ (10^4–10^5 gpm·psi)	0.33
Reactor, glass-lined, jacketed (without drive)	0.2–2.2 m^3 (50–600 gal)	0.54
Reactor, stainless steel, 2070-kPa	0.4–4.0 m^3 (10^2–10^3 gal)	0.56
Separator, centrifugal, c.s.	1.5–7 m^3 (50–250 ft^3)	0.49
Tank, flat head, c.s.	0.4–40 m^3 (10^2–10^4 gal)	0.57
Tank, c.s., glass-lined	0.4–4.0 m^3 (10^2–10^3 gal)	0.49
Tower, c.s.	5×10^2–10^6 kg (10^3–2×10^6 lb)	0.62
Tray, bubble cap, c.s.	1–3 m (3–10 ft) diameter	1.20
Tray, sieve, c.s.	1–3 m (3–10 ft) diameter	0.86

the absence of other information. In general, the cost capacity concept should not be used beyond a 10-fold 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. Nonetheless, this six-tenths rule is widely used in approximations of equipment and even total process costs.

Estimating Cost of Equipment Using Scaling Factors and Cost Index — EXAMPLE 6-2

The purchased cost of a 0.2-m^3, glass-lined, jacketed reactor (without drive) was \$10,000 in 1991. Estimate the purchased cost of a similar 1.2-m^3, glass-lined, jacketed reactor (without drive) in 1996. Use the annual average *Chemical Engineering* plant cost index to update the purchase cost of the reactor.

Table 6-9 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 $100 million.*

	Percent of delivered-equipment cost for		
	Solid processing plant‡	Solid-fluid processing plant‡	Fluid processing plant‡
Direct costs			
Purchased equipment delivered (including fabricated equipment, process machinery, pumps, and compressors)	100	100	100
Purchased-equipment installation	45	39	47
Instrumentation and controls (installed)	18	26	36
Piping (installed)	16	31	68
Electrical systems (installed)	10	10	11
Buildings (including services)	25	29	18
Yard improvements	15	12	10
Service facilities (installed)	40	55	70
Total direct plant cost	269	302	360
Indirect costs			
Engineering and supervision	33	32	33
Construction expenses	39	34	41
Legal expenses	4	4	4
Contractor's fee	17	19	22
Contingency	35	37	44
Total indirect plant cost	128	126	144
Fixed-capital investment	397	428	504
Working capital (15% of total capital investment)	70	75	89
Total capital investment	467	503	593

†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 fixed-capital investment for a new plant located at an undeveloped site may be as much as 100 percent greater than that for an equivalent plant constructed as an addition to the existing plant.

‡See Table 6-6 for descriptions of types of process plants.

Estimation of Fixed-Capital Investment by Percentage of Delivered-Equipment Cost

EXAMPLE 6-3

Prepare a study estimate of the fixed-capital investment for the process plant described in Example 6-1 if the delivered-equipment cost is $100,000.

Solution

Use the ratio factors outlined in Table 6-9 with modifications for instrumentation and outdoor operation. Take instrumentation as 10 percent of fixed-capital investment, that is, 0.1(428/100), or 43 percent, of the purchased equipment delivered. Take buildings as 15 percent of purchased equipment.

Table 6-12 Relative labor rate and productivity indexes in chemical and allied products industries for the United States (1999)†

Geographic 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

Table 6-8 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	0.5–2.0	1.0
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

Table 6-5 Installation cost for process equipment as a percentage of 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

†Modified from K. M. Guthrie, *Process Plant Estimating, Evaluation, and Control*, Craftsman Book Company of America, Solana Beach, CA, 1974.

Table 6-11 Capital cost data for chemical and petroleum processing plants (2000)†

Product or process	Process	Typical plant size	Fixed-capital investment, million $	Power factor x‡ for specified process plant
		10^3 kg/yr (10^3 ton/yr)		
Acetic acid	CH_3OH and CO—catalytic	9×10^3 (10)	8	0.68
Acetone	Propylene-copper chloride catalyst	9×10^4 (100)	33	0.45
Ammonia	Steam reforming	9×10^4 (100)	29	0.53
Ammonium nitrate	Ammonia and nitric acid	9×10^4 (100)	6	0.65
Butanol	Propylene, CO, and H_2O—catalytic	4.5×10^4 (50)	48	0.40
Chlorine	Electrolysis of NaCl	4.5×10^4 (50)	33	0.45
Ethylene	Refinery gases	4.5×10^4 (50)	16	0.83
Ethylene oxide	Ethylene—catalytic	4.5×10^4 (50)	59	0.78
Formaldehyde (37%)	Methanol—catalytic	9×10^3 (10)	19	0.55
Glycol	Ethylene and chlorine	4.5×10^3 (5)	18	0.75
Hydrofluoric acid	Hydrogen fluoride and H_2O	9×10^3 (10)	10	0.68
Methanol	CO_2, natural gas, and steam	5.5×10^4 (60)	15	0.60
Nitric acid (high-strength)	Ammonia—catalytic	9×10^4 (100)	8	0.60
Phosphoric acid	Calcium phosphate and H_2SO_4	4.5×10^3 (5)	4	0.60
Polyethylene (high-density)	Ethylene—catalytic	4.5×10^3 (5)	19	0.65
Propylene	Refinery gases	9×10^3 (10)	4	0.70
Sulfuric acid	Sulfur—contact catalytic	9×10^4 (100)	4	0.65
Urea	Ammonia and CO_2	5.5×10^4 (60)	10	0.70
		10^3 m^3/day (10^3 bbl/day)		
Alkylation (H_2SO_4)	Catalytic	1.6 (10)	23	0.60
Coking (delayed)	Thermal	1.6 (10)	31	0.38
Coking (fluid)	Thermal	1.6 (10)	19	0.42
Cracking (fluid)	Catalytic	1.6 (10)	19	0.70
Cracking	Thermal	1.6 (10)	6	0.70
Distillation (atm.)	65% vaporized	16 (100)	38	0.90
Distillation (vac.)	65% vaporized	16 (100)	23	0.70
Hydrotreating	Catalytic desulfurization	1.6 (10)	3.5	0.65
Reforming	Catalytic	1.6 (10)	34	0.60
Polymerization	Catalytic	1.6 (10)	6	0.58

†Adapted from K. M. Guthrie, *Chem. Eng.*, **77**(13): 140 (1970); and K. M. Guthrie, *Process Plant Estimating, Evaluation, and Control*, Craftsman Book Company of America, Solana Beach, CA, 1974. See also J. E. Haselbarth, *Chem. Eng.*, **74**(25): 214 (1967), and D. E. Drayer, *Petro. Chem. Eng.*, **42**(5): 10 (1970).

‡These power factors apply within roughly a 3-fold ratio extending either way from the plant size as given.

Raw materials
Operating labor
Operating supervision
Utilities
  Electricity
  Fuel
  Refrigeration
  Steam
  Waste treatment and disposal
  Water, process
  Water, cooling
Maintenance and repairs
Operating supplies
Laboratory charges
Royalties (if not on lump-sum basis)
Catalysts and solvents

Subtotal: Variable production costs

Depreciation
Taxes (property)
Financing (interest)
Insurance
Rent

Subtotal: Fixed charges

Medical
Safety and protection
General plant overhead
Payroll overhead
Packaging
Restaurant
Recreation
Salvage
Control laboratories
Plant superintendence
Storage facilities

Subtotal: Plant overhead costs
Total of above = Manufacturing costs

Executive salaries
Clerical wages
Engineering
Legal costs
Office maintenance
Communications

Subtotal: Administrative expenses

Sales offices
Sales personnel expenses
Shipping
Advertising
Technical sales service

Subtotal: Distribution and marketing expenses

Research and development

Total of administrative, distribution and marketing, R&D = General expenses
Total of all above = Total product cost

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

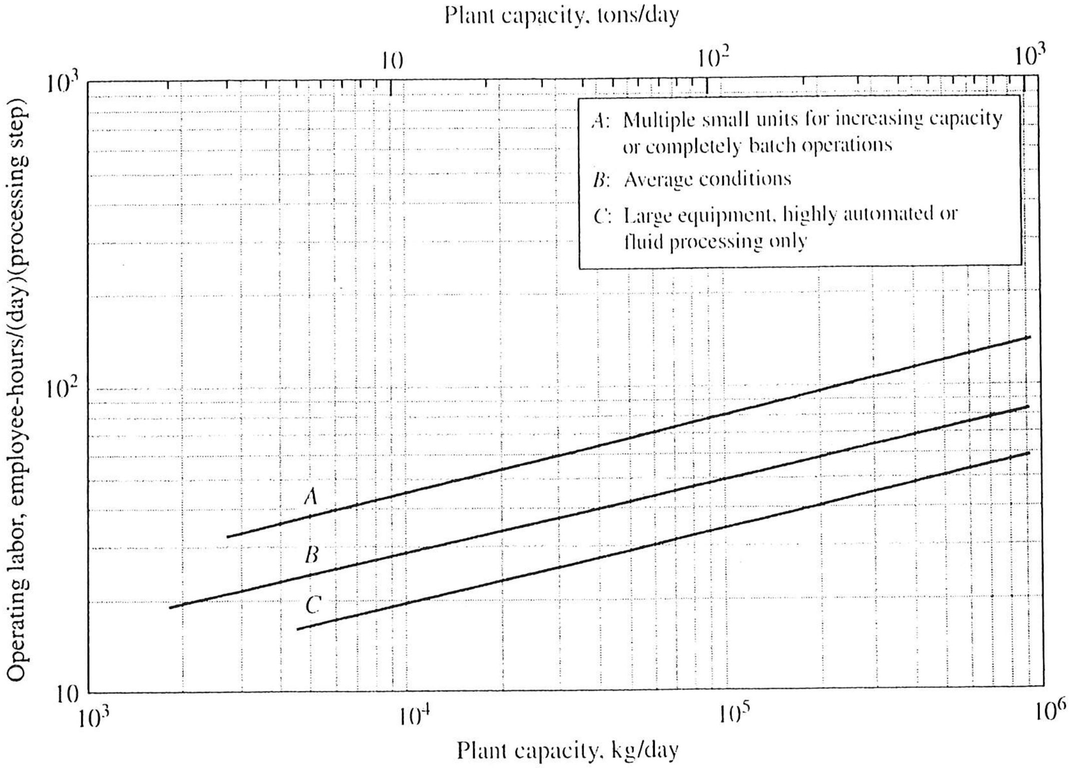

Figure 6-9
Operating labor requirements in the chemical process industry

Table 6-13 Typical labor requirements for process equipment†

Type of equipment	Workers/unit/shift
Blowers and compressors	0.1–0.2
Centrifugal separator	0.25–0.50
Crystallizer, mechanical	0.16
Dryer, rotary	0.5
Dryer, spray	1.0
Dryer, tray	0.5
Evaporator	0.25
Filter, vacuum	0.125–0.25
Filter, plate and frame	1.0
Filter, rotary and belt	0.1
Heat exchangers	0.1
Process vessels, towers (including auxiliary pumps and exchangers)	0.2–0.5
Reactor, batch	1.0
Reactor, continuous	0.5

†For expanded process equipment labor requirements see G. D. Ulrich, *A Guide to Chemical Engineering Process Design and Economics*, J. Wiley, New York, 1984.

labor, complexity of the operation, and product quality standards. The cost for

Table 6-14 Cost tabulation for selected utilities and labor

Utility	Cost
Electricity	0.045 \$/kWh[a]
Fuel	
Coal	0.35 \$/GJ[b]
Petroleum	1.30 \$/GJ[b]
Petroleum coke	0.17 \$/GJ[b]
Gas	1.26 \$/GJ[b]
Refrigeration, to temperature	
5°C	20.0 \$/GJ[c]
−20°C	32.0 \$/GJ[c]
−50°C	60.0 \$/GJ[c]
Steam, saturated	
10^3–10^4 kPa (150–1500 psi)	4.40 \$/1000 kg[c,d]
Wastewater	
Disposal	0.53 \$/1000 kg[e]
Treatment	0.53 \$/1000 kg[e]
Waste	
Hazardous	145.00 \$/1000 kg[c]
Nonhazardous	36.00 \$/1000 kg[c]
Water	
Cooling	0.08 \$/1000 kg[e,f]
Process	0.53 \$/1000 kg[e]
Labor	
Skilled	33.67 \$/h[g]
Common	25.58 \$/h[g]

[a]Based on U.S. Department of Energy, Energy Information Administration form EIA-861, 2001. U.S. average for year 2000.
[b]Based on U.S. Department of Energy, Energy Information Administration form EIA-0348, 2001. U.S. average for year 2000.
[c]R. Turton, R. C. Bailie, W. B. Whiting, and J. A. Shaeiwitz, *Analysis, Synthesis, and Design of Chemical Processes,* Prentice-Hall, Upper Saddle River, NJ, 1998.
[d]U.S. Department of Energy, Office of Industrial Technologies, DOE/GO-102000-1115, December 2000.
[e]U.S. Department of Energy, Office of Industrial Technologies, DOE/GO-10099-953, June 2001.
[f]M. S. Peters and K. D. Timmerhaus, *Plant Design and Economics for Chemical Engineers,* 4th ed., McGraw-Hill, New York, 1991.
[g]*Engineering News-Record* indexes, December 2001.

supervisory and clerical labor averages about 15 percent of the cost for operating labor. For reduced capacities, supervision usually remains fixed at the 100 percent capacity rate.

Utilities The cost for utilities, such as steam, electricity, process and cooling water, compressed air, natural gas, fuel oil, refrigeration, and waste treatment and disposal, varies widely depending on the amount needed, plant location, and source. A detailed list of ranges of rates for various utilities is presented in App. B. Some typical costs for utilities are given in Table 6-14.

The required types of utilities are established by the flowsheet conditions; their amount can sometimes be estimated in preliminary cost analyses from available information about similar operations. More often the utility requirements are determined

Table 6-15 *Engineering News-Record* **labor indexes**†‡

Location	Common labor					Skilled labor				
	1997	1998	1999	2000	2001	1997	1998	1999	2000	2001
Atlanta	6,305	6,305	6,563	7,195	7,326	3,623	3,698	3,850	4,152	4,393
Baltimore	8,442	8,442	8,592	8,745	8,745	4,587	4,671	4,704	4,917	4,917
Birmingham	7,853	7,853	8,432	8,747	9,300	3,589	3,659	3,914	4,084	4,205
Boston	14,605	15,132	15,526	15,526	15,526	6,560	6,820	6,951	7,360	7,360
Chicago	13,974	15,168	15,842	16,553	16,552	6,074	6,553	6,810	7,139	7,235
Cincinnati	11,184	11,316	11,789	12,211	12,211	4,659	4,716	4,839	5,198	5,198
Cleveland	12,771	13,156	13,350	14,232	14,753	5,544	5,701	5,846	6,002	6,201
Dallas	6,637	6,742	6,742	6,742	6,911	3,289	3,383	3,386	3,474	3,819
Denver	7,739	8,255	8,387	8,926	8,926	3,892	4,033	4,189	4,442	4,517
Detroit	13,668	14,216	14,742	15,374	16,032	6,123	6,410	6,631	6,886	7,177
Kansas City	11,621	12,053	12,053	12,834	13,437	4,875	5,015	5,260	5,503	5,653
Los Angeles	14,011	14,458	14,458	15,018	15,574	5,852	5,953	5,953	6,111	6,285
Minneapolis	13,368	13,979	14,532	15,084	15,953	5,429	5,672	5,937	6,222	6,580
New Orleans	6,842	6,842	6,842	6,995	7,274	3,358	3,359	3,587	3,669	3,848
New York	19,284	19,955	20,597	21,368	23,176	9,132	9,416	9,535	9,906	10,634
Philadelphia	14,605	15,211	15,737	16,000	16,974	6,450	6,705	6,978	7,158	7,476
Pittsburgh	11,884	12,234	12,497	12,839	13,195	5,438	5,584	5,733	5,911	6,099
St. Louis	13,726	14,121	14,553	15,000	15,474	5,447	5,696	5,874	6,094	6,252
San Francisco	14,157	14,411	14,411	16,005	16,011	6,477	6,740	6,740	7,057	7,142
Seattle	14,026	14,811	15,300	15,879	15,879	5,425	5,671	5,975	6,173	6,343
Montreal	12,379	12,379	12,742	13,074	13,674	5,381	5,387	5,520	5,685	5,988
Toronto	16,579	16,611	16,913	16,897	16,897	6,320	6,350	6,522	6,651	6,738
National labor index	11,835	12,233	12,547	13,063	14,461	5,294	5,473	5,635	5,873	6,067
Wages, \$/h	22.48	23.24	23.84	24.82	25.58	29.38	30.37	31.27	32.6	33.67

†Published in December issues of *Engineering News-Record* (with permission from *Engineering News Record*, McGraw-Hill, New York).
‡Indexes = 100 in 1913.

from material and energy balances calculated for the process. A utility may be purchased at a predetermined rate from an outside source, or the service may be available within the company. If the company supplies 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, 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.

Electric 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.

The cost for pollution control and waste disposal is best estimated from pollutant quantities calculated from the process material balances. These quantities may require

Table 6-17 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 vary depending on many factors, such as plant location, type of process, and complexity of instrumentation.

I. **Direct costs** = material and labor involved in actual installation of complete facility (65–85% 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 (8–50% 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 purchased-equipment cost)
   - C. Service facilities and yard improvements (40–100% of purchased-equipment cost)
   - D. Land (1–2% of fixed-capital investment or 4–8% of purchased-equipment cost)

II. **Indirect costs** = expenses which are not directly involved with material and labor of actual installation of complete facility (15–35% of fixed-capital investment)
   - A. Engineering and supervision (5–30% of direct costs)
   - B. Legal expenses (1–3% of fixed-capital investment)
   - C. Construction expense and contractor's fee (10–20% of fixed-capital investment)
   - D. Contingency (5–15% of fixed-capital investment)

III. **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

Table 6-18 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 vary depending on many factors, such as plant location, type of process, and company policies.

I. **Manufacturing cost** = direct production costs + fixed charges + plant overhead costs
   - A. Direct production costs (about 66% of total product cost)
     1. Raw materials (10–80% of total product cost)
     2. Operating labor (10–20% of total product cost)
     3. Direct supervisory and clerical labor (10–20% 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 maintenance and repair costs, or 0.5–1% of fixed-capital investment)
     7. Laboratory charges (10–20% 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 method of calculation—see Chap. 7)
     2. Local taxes (1–4% of fixed-capital investment)
     3. Insurance (0.4–1% of fixed-capital investment)

(Continued)

Table 6-18 *Continued*

4. Rent (8–12% of value of rented land and buildings)
5. Financing (interest) (0–10% of total capital investment)

C. Plant overhead costs (50–70% of cost for operating labor, supervision, and maintenance; or 5–15% of total product cost) include 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 (15–25% of the total product cost)

A. Administrative costs (about 20% of costs of operating labor, supervision, and maintenance; or 2–5% of total product cost) include costs for executive salaries, clerical wages, computer support, legal fees, office supplies, and communications

B. Distribution and marketing costs (2–20% of total product cost) include costs for sales offices, salespeople, shipping, and advertising

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

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 15–40% of gross earnings)

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

NOMENCLATURE

A = incremental cost of corrosion-resistant alloy materials, dollars
A_j = annual cash flow in year j, dollars
A_x = nonmanufacturing fixed-capital investment, dollars
c_o = first-year cost of operation, all total product costs except depreciation, at 100% of capacity, dollars
c_{oj} = total product costs except depreciation in year j, dollars
C = original capital investment, dollars
C_n = new capital investment, dollars
d_j = depreciation charge in year j, dollars
d_n = number of drawings and specifications
D = total direct cost of plant, dollars
e = total heat exchanger cost (less incremental cost of alloy), dollars
e_L = labor efficiency index in new location relative to cost of E_L and M'_L
E = purchased-equipment cost (delivered), dollars
E' = purchased-equipment cost on f.o.b. basis, dollars
E_i = installed-equipment cost (delivered and installed), dollars
E_L = purchased-equipment labor cost (base), dollars
f = lumped cost index relative to original installation cost
f_1, f_2, f_3 = multiplying factors for piping, electrical, instrumentation, etc., dimensionless
f_d = unit cost per drawing and specification, dollars per drawing or specification