SECTION 5. Dust Collectors, Flares; Typical Operating Costs

	Electrostatic					*Flares*	
	High Voltage	*Low Voltage*	*Liquid Scrubbing*	*Filter, Fabric*	*Centri-fugal*	*Direct After-burner*	*Catalytic After-burner*
Assume:							
Fan efficiency, 60%;							
Pump efficiency, 50%							
Operating power, HP/actual cfm							
Low efficiency	0.00019	0.000015	0.0013				
Med. efficiency	0.00026	0.000030	0.0035				
High efficiency	0.00034	0.000040	0.015				
Maintenance cost, $/actual cfm							
Low	0.01	0.005	0.02	0.02	0.005	0.03	0.07
Typical	0.02	0.014	0.04	0.05	0.015	0.06	0.20
High	0.03	0.02	0.06	0.08	0.025	0.10	0.35
Liquid consumption, $/(1,000 gal) (hr)							
Low			0.35				
Typical			0.50				
High			1.00				
Pressure drop, in. H_2O							
Low	0.1	0.1		2.0	0.5	0.5	0.5
Typical	0.5	0.5		5.0	3.0	1.0	1.0
High	1.0	1.0		8.0	4.0	2.0	2.0
Fuel costs, $/(actual cfm) (hr)							
(50% excess air)							
With heat exchanger						0.00023	0.00014
Without heat exchanger						0.00057	0.00028

Source: Alonso 1970. Excerpted by permission of *Chemical Engineering*. Copyright 1971, McGraw-Hill, NY.

REFERENCES

1. Guthrie, Kenneth M. 1974. *Process Plant Estimating, Evaluation, and Control.* Craftsman Book Co., Solano Beach, CA.

Hydrycarbon Process. 1967. 46 (11):135.

Jenckes, L. C. 1970. How to estimate operating costs and depreciation. *Chemical Engineering* (Dec.).

2. Chemical Engineering, ed. and comp. 1973–1974. *Sources and Production Economics of Chemical Products.* McGraw-Hill, New York; 121–180.
3. Kharbanda, O. P. 1979. *Process Plant and Equipment Cost Estimation.* Craftsman Book Co., Solano Beach, CA.

Ohsol, E. O. 1971. Estimating marketing costs. *Chemical Engineering* (May).

Smith and DiGregorio 1970. *Chemical Engineering.*

APPENDIX 4

SAMPLE QUESTIONS AND ANSWERS FOR EACH CHAPTER

CHAPTER 1. INTRODUCTION

1-1. What are the principal reasons for an engineer to study economics?
Answer:
   a. Many engineering decisions require an economic input to be the most practical and effective.
   b. In the course of most engineers' careers they will need to consider some, or even frequent, economic matters.
   c. Businesses are economic entities. Consequently, staff promotions are favored for those not only with ability, but also with an economic understanding.
   d. In one's personal life some skill with economics will greatly assist in budgeting, financial management, retirement security, etc.

1-2. Why not have one's supervisor or the company's engineering or financial departments handle all of the economic problems?
Answer: There are too many small or very preliminary economic problems where you need guidance. The expense, time, and authorization trouble would be too great for others to handle them. If such economic information is needed, you generally must obtain it yourself.

1-3. Do some branches of chemical engineering use economics much more frequently than others (i.e., might it not be needed in some areas of work)?
Answer: Basically, no. Perhaps in academic, governmental, or some other fields the economic *demand* will be less, but to do the best job possible, and to advance into management, all chemical engineering fields need a knowledge and practice of economics.

1-4. Does an engineer need to have an MBA (Master of Business Administration) degree to advance into management, or handle economic assignments?
Answer: Decidely no. It is generally true that management appreciates the MBA training, but usually less so than outstanding performance and a general economic knowledge (such as should be obtained from this text). With this background almost all companies will then send promising employees to economic and managerial courses for further training.

CHAPTER 2. EQUIPMENT COST ESTIMATING

2-1. You are a production engineer in a chemical plant, and your boss asks you for a quick answer on how much a new rotary dryer of a certain size would cost. What do you tell him?
Answer:
a. If there is time you call a vendor and ask for an immediate, over-the-phone rough estimate.
b. If there is not time, or you cannot get a vendor quotation, look up the information in Appendix 1. Then be sure to tell your boss that it is a very rough estimate.
c. Be sure to include the cost of transportation and/or installation (or even auxiliaries) if that is what your boss really wants.

2-2. You are a plant technical service engineer and feel that a certain high-maintenance centrifugal pump should be replaced with one of a different design or material of construction. You call the local representative of a well-known pump manufacturer for prices, knowing only the required flow rate (gpm) and pressure (feet of head). However, he won't tell you anything without being informed of the required NPSH, the pump speed, and the type of seal. What should you do?
Answer:
a. You might immediately call several more vendors. At least one or two will probably discuss the problem with you and give you advice and price quotations without this extra information.
b. For your own education you probably should look up or inquire as to the importance of the requested information. NPSH is net positive suction head (i.e., is the pump suction "flooded" from an adjacent tank, have to lift from a sump, under vacuum, etc.?). The impellor speed helps determine cost, output head, abrasion wear, etc. The type of seal is quite critical in determining leakage, shaft wear, etc. Each of these factors can be important in determining the pump performance, and so should be considered. When you have quantified each point you can then recontact that vendor.

2-3. a. What is the cost of a 200-gpm, 80-ft (of water) head, cast iron centrifugal pump (with motor, coupling, and baseplate)? The CE Index is 350.
b. What is its installed cost?
c. Module cost?
d. What is the purchase cost if it were 316 stainless steel?
e. What if the SS pump operated at 400-psi suction pressure?
f. What is the size exponent in this range?
Answer:
a. 80 ft of water is 80 ft head/2.307 ft water per psi (Appendix 5) = 34.68 psi. Therefore, 34.68 psi × 200 gpm = 6,935. Reading from the (Conventional, AVS) chart, \$2,420 × 350/320 (CE Index) = \$2,647 or rounded-off to \$2,600.
b. Installation factor = 1.3, so 1.3 × 2,647 = 3,440, or rounded-off to \$3,400.
c. Module factor = 3.5, so 3.5 × 2,647 = 9,264, or rounded-off, \$9,300.

d. Stainless steel factor = 2.0, so 2,647 × 2.0 = 5,294, or rounded-off to \$5,300.
e. The 150–500 psi pressure factor is 1.62, so 5,294 × 1.62 = 8,576, or \$8,600.
f. Obtain the curve's slope from slightly smaller and larger pumps, psi × gpm 5,000 = \$2,140; psi × gpm 10,000 = \$2,800;

$$\frac{\log 2800 - \log 2{,}140}{\log 10 - \log 5} = \frac{3.4472 - 3.3304}{1.0000 - .6990} = \frac{0.1168}{0.301} = 0.39$$

2-4. a. What would be the cost of a mild steel rotary dryer, 6 ft diameter by 40 feet long? The CE Index is 350.
b. Using the size exponent, what would be the cost of a 4 ft diameter by 30 ft long dryer?
c. What would be the installed cost of the larger dryer?
d. The module cost?
e. What if it were a stainless roto-louver dryer?
Answer:
a. Peripheral area: $\pi 6 \times 40 = 754$ ft.^{2} From the chart, \$46,200. Correcting for a CE Index of 350:

$$46{,}200 \times \frac{350}{320} = \$50{,}531, \text{ or rounded-off to } \$50{,}500$$

b. Area = $\pi 4 \times 30 = 377$. The size exponent is 0.45 so

$$\$50{,}531\left(\frac{377}{754}\right)^{0.45} = 36{,}991, \text{ or } \$37{,}000$$

c. Installation factor (average) = 1.64: 50,531 × 1.64 = 82,869 or \$82,900.
d. Module factor 2.3, so 50,531 × 2.3 = 116,221, or \$116,000.
e. Roto-louvre factor 1.25; stainless factor 2.2, so 50,531 × 1.25 × 2.2 = \$138,960 or \$139,000.

CHAPTER 3. PLANT COST ESTIMATES

3-1. You are an R & D engineer who has conceived of a "brilliant" new process idea. After making a very preliminary cost estimate for the concept, what accuracy do you tell your boss the estimate has?
Answer: Use your best judgment of your knowledge and confidence factor over the range ±40–100%. Often it will be in the 50–70% range.

3-2. After an initial budget estimate by a contractor for a very large project, the contractor estimates a ±25% capital cost accuracy. What comment do you give your boss?
Answer: The contractor's claimed accuracy may be true for a very well-defined and studied project, but it is probably low. Remind your boss of the recent

average 31% overrun for projects up to $500 million, and 82% overrun for larger projects. Then discuss with him the environmental impact report, community relations, etc. checklist if these factors may be involved.

3-3. You work for the production department of an electronics firm and have been asked to design and estimate the capital (plant cost and total capital requirement) of a plant to treat an acidic and metal containing wastewater. Laboratory tests have shown that reaction with soda ash (Na_2CO_3) is the most effective treatment, producing a water capable of being recycled and a reasonably small amount of sludge that can be hauled to a hazardous waste dump.

You have drawn a flow sheet, made heat (not a factor) and material balances, and sized the equipment. The purchase price (from vendors) of all of the equipment, other than the 40 ft diameter, mild steel thickener and the 1 t/hr, 50 ft^2 rotary vacuum filter and its auxilliaries is $90,000. A building is available to house the bags of soda ash, along with a forklift to transport it. There is adequate utility serviced land available to locate the plant. The CE Index is 350. Show your detailed capital estimates.

Answer: First estimate the total purchase price of the plant equipment from Appendix I.

Vendor price quotations	$90,000
Thickener, 40 ft: chart $88,000 (for a concrete tank); 0.7 factor for steel; 0.7 × 350/320 = $67,375	67,000
Filter, rotary vacuum, 50 ft^2 chart = $40,000 × 350/320 = 43,750	44,000
Filter auxilliaries (vacuum pump, liquid receivers, etc.), 50%	22,000
Total purchased cost	$223,000

Next determine the appropriate multipling factors from Table 3-4.

Total equipment = $223,000	1.00
Piping	0.40
Electrical	0.15
Instrumentation	0.30
Utilities	0.30
Foundations, structure	0.07
Insulation	0
Painting, safety	0.10
Yard Improvements	0.10
Environmental	0
Buildings	0
Land	0
Subtotal	2.42
Construction, engineering	0.40 (16.5% of subtotal)
Contractors fee	0.25 (10% of subtotal)
Contingency	0.25 (10% of subtotal)
Total plant cost	3.32[a] × 223,000 = $740,000
Off-site facilities	0
Plant start-up	10
Working capital	10
Total capital required	1.20 × 740,000 = $888,000, or round off to $900,000

a. This total factor is low for a mixed processing plant, but it is appropriate for a rather small addition to an existing facility.

3-4. In plant cost estimating when do you use installation factors, module factors, and direct equipment values from the charts?

Answer: Use installation factors when dealing with equipment replacement installations, or when one or a limited number of pieces of simple equipment is involved. Module factors may be needed with plant additions or modifications when a major piece (or small groups) of equipment and all of its support equipment are required. Purchased equipment cost directly from the charts is used alone in all other cases.

3-5. In plant cost estimating do you ever make subtotals of some of the cost? If so, why?

Answer: Yes. It is easier to visualize and estimate the contractors' charges and the contingency based upon the total plant cost before these charges. For rapid estimating work no such subtotal should be taken, but to more accurately analyze (and estimate) the contractor charges and contingency on many projects a subtotal plant cost is highly desirable.

3-6. When do you use a "Lang" or overall multiplier for plant cost estimating?

Answer: Only for the simplest and most rapid and preliminary estimates. A detailed factor breakdown is almost always warranted. However, in *all* cases, your total factor should be checked against the normal overall (a Lang-type) factor.

3-7. When do you use complete plant estimating charts?

Answer: Whenever the desired estimate is the same or similar to the chemical production shown on one of the plant charts. Even though not too accurate, they are probably closer than you could estimate from any but the most knowledgeable and detailed flow diagram.

3-8. Do "cost per ton of product" or "capital ratio" estimates have much value in plant cost estimating?

Answer: Generally no, but with certain types of plants the factors are in surprisingly common use. Power plants are usually quoted as $/installed kW, some paper mills as $/ton of pulp, etc. When close in size to a known plant the numbers may be useful, but since most plant costs increase as some power of plant size (such as 0.64), these numbers are only of value over a limited size range.

3-9. Are the "other components," or auxilliary costs of capital estimates always involved?

Answer: In many cases of single equipment replacement or additions, and in simple plant modifications, no. However, on new facilities or modifications of

any appreciable size, start-up costs and working capital must be considered. Off-site facilities, distribution facilities, R & D, etc. are generally very specific to any project. Sometimes there is no cost involvement, but just as often it can be modest to extensive.

CHAPTER 4. MANUFACTURING COST

4-1. If a plant normally produces 100 t/d of product, and the on-stream efficiency (OSE) or operating rate is 90%, how many tons are produced per year?
Answer: 100 t/d × 365 d/yr × 90% OSE = 32,850 t/yr (or in more correct round numbers, 33,000 t/yr)

4-2. If your plant in Los Angeles wishes to purchase sulfuric acid, and the *Chemical Marketing Reporter* correctly states that 93% H_2SO_4 costs $20/ton, 100% basis, FOB Arizona, tank car lots, what is the price delivered to your plant?
Answer: You must first determine the "commodity" freight rate (a special, low freight rate that the railroad can establish for any commodity moved in large tonnages) for sulfuric acid. Either the smelter company or the railroad can tell you this rate. Let's say that it is $30/ton from the smelter to your plant. This makes the price:

$$\$20 \text{ (purchase price)} + \frac{30}{0.93} \text{ (freight)} = \$52.26/\text{ton}$$

of 100% H_2SO_4 or 20 × 0.93 + 30 = $48.60/ton of actual 93% H_2SO_4, delivered by rail (in 100-ton capacity cars) to your plant.

4-3. What would be the yearly electricity cost for a plant that had a total of 2,000 HP of installed motors? Assume as a first approximation that they are always running and drawing their full load amperage (this is usually a considerable exaggeration on both counts). Also assume that electricity costs $0.07/kW hr, and that there is a 90% OSE, with all motors off during the downtime (also an exaggeration).
Answer: 2,000 HP × 365 d/yr × 24 h/d × 0.07 $/kW hr × 0.746 kW hr/HP (Appendix 5) × 0.90 OSE = $823,405/yr (or rounded-off to $823,000).

4-4. What would be the annual operating labor cost for a continuously operating plant that needed six operators per shift, and the average labor cost was $12.00/hr?
Answer:
a. If 5 shifts were employed, and each man were paid for 40 hr/wk: 6 men × 5 shifts × $12.00/hr × 40 hr/wk × 52 wk/yr = $748,800/yr (or rounded-off to $749,000/yr).
b. If 4 shifts were employed, and as above it was assumed that they were paid (and working) during the plant downtime: 6 men × 4 shifts × 12.00/hr × 40 hr/wk × 52 wks = $599,040 for their normal hours. However, they need to work 365 × 24 = 4 shifts (52 weeks − 29 days normally off) hr/wk; average hr/wk = 45.76, or 5.76 hr/wk overtime at time and one-half pay: 6 men × 4 shifts × $12.00/hr × 1.5 overtime premium × 5.76 hr/wk OT × 52 = $129,393. The total pay is thus 599,040 + 129,393 = $728,433/yr (or rounded-off to $728,000/yr). Either answer (a). or (b). would be acceptable, just so that the basis was stated.

4-5. For the wastewater treating plant of Problem 3-3 estimate the manufacturing cost. There is a nearby facility to provide worker safety, and the supervisor and service staff can be shared. Your equipment sizing is based upon an anticipated 3 shift/day, 365 d/yr operation with a 90% on-stream efficiency (equivalent to 330 d/yr). There is adequate water storage capacity for the anticipated downtime. Your flow sheet shows a total of 80 HP motors (electricity costs $0.09/kW hr), and the skip loader will consume 1,000 gal/yr of diesel fuel, costing $0.80/gal (the diesel tank is all ready available). Tests indicate a coagulant consumption of 5 ppm of fluid in the thickener, and the coagulant will cost $8/lb. Assume that the equivalent sales value of the "product" is that of a capital or turnover ratio of 1.0. Bagged soda ash cost $131.00/ton (CMR 2-22-88), and freight is $19/ton. It will be mixed on a batch basis to form a 25% Na_2CO_3 solution weighing 10 lb/gal and used at 3 gpm. Operating labor costs average $12.00/hr. The wastewater enters at a rate of 100 gpm.
Answer: First calculate the raw materials, utilities, and operating labor required.

Raw materials: (7920 hrs/yr)

a. Soda ash: $\frac{3 \text{ gpm} \times 10 \times 0.25}{2000} \times 330 \times 24 \times 60 = 1{,}782$ t/yr; $150/ton = $267,300/yr

b. Coagulant: $(100 \times 8.34 \times 60 \times \frac{7920 \times 5}{10^6} = 1{,}982$ lb @ $8/lb = $15,853/yr

Sub/total $283,200

Utilities:

a. Electricity: 80 × 0.746 × 7,920 × 0.09 = 42,500
b. Diesel: 1,000 × 0.80 = 800

Sub/total $43,300

Labor: Assume 2 men, 5 shifts
2 × 5 × 52 × 40 × 12 = $249,600

Next calculate the factored manufacturing costs from Table 4-4

Labor related costs:

Payroll overhead	40%	
Supervisory, miscellaneous	10	
Laboratory charges	10	
Sub-total	60% =	$149,800

Capital related costs; ($740,000 plant cost + 74,000 start up = 814,000 capital cost)

Maintenance	6%	
Operating supplies	1.5	
Environmental	1.5	
Depreciation	10	
Local taxes, insurance	4	
Plant overhead	3	
Sub-total	26.0% =	$211,800

Sales related costs: (Assume capital ratio = 1)		
Patents, royalties	0	
Packaging	0	
Distribution and sales	0	
Administration	10	
R & D	0.5	
Sub-total	10.5 =	$86,200
Total Manufacturing Cost		$1,023,900/yr

Total gal treated = $100 \times 8.34 \times 7920 \times 60 = 3.963 \cdot 10^8$ gal or $2.58/1,000 gal treated

CHAPTER 5. INTEREST CALCULATIONS; PRELIMINARY PROJECT EVALUATION

5-1. Using the capitalized cost procedure compare the merits of replacing an existing pump that costs $2,000, needs replacement every 5 years, and requires $300/yr in maintenance expense with a new one that costs $4,000 but would have a 10-year life and only need $100/yr in maintenance. Assume a 10% simple, annual interest rate basis.

Answer: Let's calculate this problem in two parts: (1) the capitalized cost based upon the purchase price alone, and then add (2) the present value of the maintenance cost calculated as an annuity.

Present pump capitalized cost:

$$\$2{,}000\left(\frac{1+1}{(1+0.1)^5-1}\right) = \$2{,}000\left(\frac{1+1}{1.6105-1}\right)$$

$$= \$2{,}000(1+1.638) = \$5{,}276$$

Present pump maintenance (present worth of annuity)

$$\$300\,\frac{(1+0.1)^5-1}{0.1\,(1+0.1)^5} = \$300\left(\frac{1.6105-1}{0.1\times 1.6105}\right) = \$1{,}137$$

Old pump total capitalize cost:

$$\$5{,}276 + \$1{,}137 = \$6{,}413$$

New pump capitalized cost

$$\$4{,}000\left(\frac{1+1}{(1+0.1)^{10}-1}\right) = \$4{,}000\left(\frac{1+1}{2.5937-1}\right)$$

$$= \$4{,}000(1+0.6275) = \$6{,}510$$

New pump maintenance

$$\$100\,\frac{(1+0.1)^{10}-1}{0.1\,(1+0.1)^{10}} = \$100\,\frac{1.5937}{0.25937} = \$614$$

New pump total capitalized cost:

$$\$6{,}510 + \$614 = \$7{,}124$$

The present pump is thus seen to be the most economical. However, at a lower interest rate they become more nearly equal, and if the value of leakage and downtime (if this is a factor) are considered, then the more expensive pump may actually be the better choice.

5-2. You work for a company which is considering building a new plant which would cost $10,000,000, including off-site installations and start-up expense. The working capital would be $1,000,000 and the depreciation $1,000,000/yr. Assume no salvage value. What would be the:

a. ROI (return on investment)?

b. Payback period?

Answer:

a. $$\text{ROI} = \frac{\text{1,000,000 after-tax profit}}{\text{10,000,000 plant cost + 1,000,000 working capital}}$$

$$\text{ROI} = \frac{1}{11} = 9.09\%$$

b. $$\text{Payback period} = \frac{\text{10,000,000 plant cost}}{\text{1,000,000 after-tax profit + 1,000,000 depreciation}}$$

$$= 5 \text{ years}$$

CHAPTER 6. PROFITABILITY ANALYSIS; DISCOUNTED CASH FLOW

6-1. *DCF Calculation (with charts).* The same plant noted in Problem 5-2 is now expected to make $500,000 after-tax profit the first year, $600,000 the second, $800,000 the third, $900,000 the fourth, and $1,000,000/yr thereafter for its 10-year life. It should have a $500,000 salvage value. As a simplification still assume a $1,000,000/gr depreciation rate. Calculate its DCF by the charts.

Answer:

First prepare a calculation table, list the yearly cash flows, guess at an initial interest rate, and look up the discount factors. Then make trials until the present value of all cash flows is zero.

			Assume 11% Interest		*Assume 12% Interest*	
Year	*Cash Flow*	*Table*	*Discount Factor*	*Present Value*	*Discount Factor*	*Present Value*
0	−11.0 MM	—	1	−11 MM	1	−11 MM
0–1	1.5	6-2	0.9470	1.421	0.9423	1.414
1–2	1.6	6-2	0.8483	1.357	0.8358	1.337
2–3	1.8	6-2	0.7600	1.368	0.7413	1.334
3–4	1.9	6-2	0.6808	1.294	0.6574	1.249
4–10	2.0 × 6	6-1 and	0.664 × 0.7320 = 0.4714 × 12	5.657	0.6188 × 0.7128	5.293

Year	Cash Flow	Table	Assume 11% Interest: Discount Factor	Assume 11% Interest: Present Value	Assume 12% Interest: Discount Factor	Assume 12% Interest: Present Value
		6-4			= 0.4411[a] × 12	
10	1.5	6-1	0.3329	0.499	0.3012	0.452
Total present value				0.596		0.079

Extrapolate: PV Δ 11–12% 0.596 − 0.079 = 0.517
0.079/0.517 = 0.15; DCF = 12.15

a. If solved year-by-year (Table 6-2)
4–5 0.5831
5–6 0.5172
6–7 0.4588
7–8 0.4069
8–9 0.3609
9–10 0.3201
avg. = 0.4412

6-2. If the estimated total capital (including $1,000,000 working capital) for a project was $10,000,000, the after-tax profit constant at $500,000/yr, and the project life 10 years, what would be the DCF? use both Figure 6-1 and annuity-type calculations.

Answer:

a. Figure 6-1. The depreciation rate is $900,000, thus the cash flow is $1,400,000/yr. C_0/C_n = 10/1.4 = 7.14. Reading Figure 6-1, the DCF is about 6.5%.

b. By annuity calculations the following equation must balance:
Equation 5-13 P/C, or Figure 6-1 Co/Cn:

$$\frac{10}{1.4} = \frac{(1 + i)^n - 1}{i(1 + i)^n}$$

First assume i = 6%.

$$\frac{(1 + 0.06)^{10} - 1}{0.06\,(1 + 0.06)^{10}} = \frac{1.7908 - 1}{0.06 \times 1.7908} = \frac{0.7908}{0.10745} = 7.36$$

Next assume i = 7%.

$$\frac{(1.07)^{10} - 1}{0.07 \times (1.07)^{10}} = \frac{1.9672 - 1}{0.13770} = 7.02:$$

Extrapolate between these two answers: Actual C_0/C_n = 10/1.4 = 7.14, so 7.36 − 7.02 = 0.34; 7.14 − 7.02 = 0.12; 0.12/0.34 = 0.35 or DCF = 6.65%.

6-3. If the above problem were recalculated, but now also including the return of working capital at the end of year 10 (the realistic case), what would be the DCF value (use equations only)?

Answer: The working capital's present value would be calculated as an instantaneous cash flow by means of Equation (6-2). Thus $C_{wc} = 1{,}000{,}000/(1 + i)^{10}$. Assume i = 7%, 1,000,000/$(1.07)^{10}$ = $508,337; If i = 8%, C_{wc} = $463,200. The sum of the cash flows @ 7% (calculated in 6-2) was 0.9672/0.1377 × 1,400,000 = $9,833,600, making the total 508,300 + 9,833,600 = $10,341,900. This is more than the original $10,000,000 investment. Recalculating the yearly cash flows at 8% gives

$$\frac{(1 + 0.08)^{10} - 1}{0.08\,(1 + 0.08)^{10}} = \frac{1.08^{10} - 1}{0.08 \times 1.08^{10}} = \frac{1.1589}{0.08 \times 2.1589} = 6.71$$

6.71 × $1,400,000 = $9,394,000; plus $463,200 = $9,857,200

Extrapolating between these two interest rates: 10,341,900 − 9,857,200 = 484,700, or 341,900/484,700 = 0.71, so DCF = 7.71%.

6-4. *Sensitivity analysis.* You are studying a potential new process where the plant cost (including off-site equipment and start-up) is estimated to be $50 MM. The yearly manufacturing cost calculates to be: raw materials, $12 MM; utilities, $5 MM; operating labor and related costs, $5 MM; capital related costs, $13 MM (including depreciation); and sales related costs, $12 MM. Sales are hoped to be $60 MM/yr. Assume a 10-year project life and depreciation period; working capital at 20% of the manufacturing cost; 40% taxes, and no salvage value.

a. Calculate the DCF.

b. Determine the DCF at ½ and 2 times the plant (production) size. Assume that all of the product can be sold, labor costs stay constant, all other costs change proportionally with plant capacity, and the capital size exponent is 0.6.

c. Determine the DCF at 10% higher and 10% lower sales price (than case a).

d. Determine the break-even production rate (for case a) and the rate at zero cash flow. Assume that only raw material and utility costs vary in proportion to the amount of sales.

Answer:

a. Manufacturing Cost		Period	Cash Flow, $ MM
Raw materials	$12 MM		− $50 plant cost
Utilities	5		− 9.4 working capital (20% of
Labor related costs	5	0	−59.4 $47MM)
Capital related costs	13 (26 of capital)		
Sales related costs	12 (20% of sales)	0–9	12.8 cash flow
Total mfg. cost	$47 MM	10	22.2 (12.8 + 9.4) C.F.
Gross profit: 60–47	$13 MM		DCF = 17.96% by a hand-held calculator
Tax (40%)	5.2		(annual compound interest)

a. *Manufacturing Cost*

	Period	*Cash Flow,$ MM*
Net after-tax profit	7.8	
Cash flow	12.8 MM	

b. $2^{0.6} = 1.516$;

	Plant size ×2	*×1/2*	*Plant size ×2*		*×1/2*
Plant cost	$75.79 or	32.98 MM	Gross profit $120 − 82.71 = 37.29 MM		$30 − 28.07 = 1.93MM
Raw materials	24	6.	After-tax profit	22.37	1.16
Utilities	10	2.5	Depreciation	7.58	3.30
Labor related costs	5	5	Cash flow	29.95	4.46
Capital related costs	19.71	8.57	Working capital	16.54	5.61
Sales related costs	24	6	10th year C.F.	46.49	10.07
Total mfg. cost	82.71	28.07	Total Capital	92.33	38.59
			DCF	30.57%	4.65%

c. *Sales Change*

	−10%	*+10%*
Sales	$54 MM	$66 MM
Nonsales related operating cost	35	35
Sales related	10.8	13.2
Total mfg. cost	45.8	48.2
Gross profit	8.2	17.8
After-tax profit	4.92	10.68
Cash flow	9.92	15.68
Working capital	9.16	9.64
10th year C.F.	19.08	25.32
Total capital	59.16	59.64
DCF	11.94%	23.59%

d. Let X = % of normal production

(1) Break even (zero profit)

Raw Matl.	*Util.*	*Sales Related*	*Labor*	*Capital Related*	*Sales Value*
(12	+ 5	+ 12)X	+ 5	+ 13	= 60X

31X = 18; X = 0.58, or break even = 58% of rated capacity

(2) Zero cash flow (i.e. no depreciation or profit)

29 X + 13 = 60X;
31X = 13; X = 0.42, or

zero cash flow occurs at 42% of rated capacity.

CHAPTER 7. ECONOMY OF THE CHEMICAL INDUSTRY

7-1. Based upon Table 7-4, in 1986 for the 18 listed chemical companies what was the:
- a. Percent that the average chemical plant was depreciated?
- b. Average debt-to-equity ratio?
- c. Average fraction of income spent on stock dividends?
- d. Average fraction of income spent on new capital additions?

Answer:
- a. 50.0%.
- b. 33.2/66.8 = 49.7%.
- c. 44.6%.
- d. 7.6/5.5 = 138%.

7-2. Based upon Figures 7-3, 7-4, and 7-6, what was the 1976–1986 average chemical industry:
- a. Return on equity?
- b. Return on sales?
- c. Operating rate (1983–1987)?

Answer:
- a. About 12%.
- b. About 5.5%.
- c. About 78%.

7-3. What were some of the major factors resulting in declining profitability for the U. S. chemical industry over the past 20 years?

Answer:
- a. Increasing foreign competition.
- b. Overcapacity caused by oil companies (and others) entering the market with large plants.
- c. Higher energy prices.
- d. Nonprogressive and high overhead management.
- e. Greatly reduced acceptance of new innovations.

7-4. What are some of the factors that the U. S. chemical industry is pursuing in an attempt to increase profitability?

Answer:
- a. Cost cutting with layoffs, lower overhead, and decentralization.
- b. Divestitures, acquisitions, and mergers.
- c. Strengthening existing production.
- d. Moving to higher value-added products.
- e. Increasing foreign trade and diversification.

7-5. What are some of the worrisome aspects of current CPI activities?

Answer:
- a. With many companies there is much more attention to mergers, acquisitions, and divestitures than there is to strengthening their basic production.
- b. Foreign competitors and financial groups are acquiring a large segment of the U. S. CPI.
- c. There is an overemphasis on value-added products and not enough capital spending on more economical basic commodities, new R & D developments and plant improvements.

CHAPTER 8. ACCOUNTING AND BUDGETS

8-1. What is the difference between cash and accrual accounting?

Answer: In cash accounting entries are only considered for income tax purposes when bills are actually paid and the funds from sales are received. When using the accrual basis debt is considered to have occurred (for tax purposes) when the obligation is incurred (the purchase made, etc.), and sales are credited when the shipment is made.

8-2. What is cost accounting?

Answer: This is the name given to the accounting procedures that establish manufacturing or production costs. It usually implies their breakdown into a larger number of subaccounts, and the allocation of costs between various divisions, processes, and products.

8-3. On many operating statements costs such as sales, legal, accounting, R&D, etc. are shown as fixed (and not controllable) expenses. Why is this?

Answer: For large companies the above items, and many more, are part of the corporate budget, and are distributed to the operating units as fixed costs for each year. The production plants may also have some of these charges on their budgets for their own specific use (such as R & D for that plant alone, in addition to its fixed share of the corporate R & D), and these then become controllable charges. For more decentralized divisions or small plants these same costs become entirely under the plant's jurisdiction, and thus are more discretionary. The tendancy for efficient management is to have more locally controllable costs, and a reduced corporate fixed "G&A" (general and administrative) charge.

8-4. Why is accurate cost allocation to individual products so important?
Answer: Most plants produce a multiplicity of products, and there are numerous shared costs between them. When competition is severe (as it usually is), only with accurate cost allocation can the management know exactly where they stand on the profitability and pricing of each product.

8-5. What are some of the computer-assisted plant management tools that are currently available?
Answer: The PMS, CIM, MRPII, etc., programs to assist with scheduling, inventory control, production efficiency, etc. in plant management.

8-6. What effect might the "just-in-time" inventory management system have in the CPI?
Answer: For most chemical production it is difficult to operate with the minimum raw material inventory, and to depend upon prompt deliveries. When it can be done, however, it would assist profitability by decreasing inventory and working capital. In most cases, however, some customers use the "just-in-time" method, and this requires more CPI inventory to meet their needs.

CHAPTER 9. CORPORATE ANNUAL REPORTS

9-1. On the balance sheet of Table 9-1 what is meant by:
a. Other current assets?
b. Other assets?
c. Other current liabilities?
Answer:
a. Other current assets are usually investments of capital reserves that can be fairly quickly converted into cash, such as stock or bonds.
b. Other assets include investments and intangibles, such as investments in land, real estate, other ventures, etc. that cannot be quickly sold.
c. Other current liabilities covers all of the otherwise unlisted liabilities, such as monies owed to pension funds, bonuses, profit sharing, prefered stock, dividends, etc. It is usually a large number.

9-2. On the hypothetical income statement of Table 9-2, what was the 1986:
a. Sales and G & A expense (as % of sales)?
b. R & D expense (as % of sales)?
c. Income tax percentage of income before taxes?
d. By CPI standards is this a well-run company?
Answer:

a. 120,000/800,000 = 15%
b. 10,000/800,000 = 1.25%
c. 20,000/81,500 = 24.5%
d. No. The G & A is high, R & D low, and the income tax payment relatively high for such a small company.

9-3. In examining the "Cash Flow" section of Table 9-1, and the "debt ratios," what conclusions can be reached concerning acquisitions and divestitures?
Answer: The "other internal sources" figures for the source of funds, and "other applications" spending indicate an unusually high amount of selling company operations (source of funds) and purchasing others (application). At the same time the debt-to-equity ratio increased from about 0.5 to 0.6 over the period of this table. It again indicates acquisitions, since the capital expenditures were modest compared to cash flow and dividends.

CHAPTER 10. PROJECT MANAGEMENT

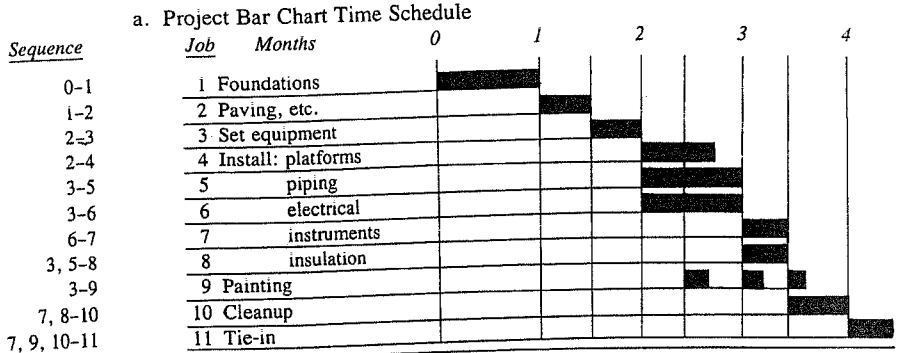
10-1. Why is defining the scope of work on a project so important?
Answer: The scope of work first of all provides official management approval for the project and its detailed execution. It provides the basis for coordinating the activities of all of the company and outside staffs working on the project, and allows detailed instructions and schedules to be made for all of the work each group will perform. If adequately discussed, and formulated with each group's input and approval it provides the basis for a cooperative and successful project.

10-2. You are an engineer at a gas purification plant, and have been asked to be the project manager for the installation of a foam separator-sulfur melter at its Stredford sulfur-removal operation. A contractor has done all of the engineering, design, permitting, and procurement, but your company will do the installation with your own staff.
a. Prepare a simple bar chart schedule for the installation, making your best guess of manpower, activity duration, and costs. Perform the job as rapidly as possible, allowing 2 weeks for tie-ins. The site is at present adequately prepared, and there is room for the new equipment.
b. Prepare a budgeted expenditure curve based upon the information established in (a) above (do not include the contractor's cost, i.e., equipment, permits, engineering, etc.).
c. Prepare a critical path bar chart *and* flow sheet layout for the project. What is the critical path?
d. State how (c) above can be "crashed" to reduce the elapsed time by 20%. Estimate the extra cost to do this. Did it change the critical path?
e. Chart the labor requirement for (c) above, and then perform the maximum manpower leveling that will not raise costs or delay the project.
Answer: First break the project into as many subdivision tasks as appears to be appropriate. (A limited number will be used in this book's answer to simplify the discussion.) Then estimate the sequence, time, manpower, and cost:

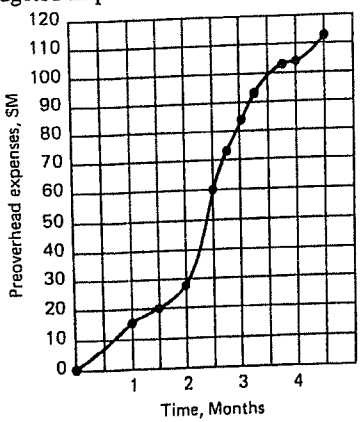
a. Project Sub-Tasks

Job	Required Time	Manpower	Cost: Labor	Cost: Other	Cost: Total	Job Sequence
1. Site preperation, foundations	1 mo	4 men	$12 M	$13 M	$15 M	0-1
2. Yard paving, sumps, underground facilities	2 wk	2 men	3	2	5	1-2
3. Set the equipment	2 wk	4 men	6	3	9	2-3
4. Platforms	3 wk	2 men	4.5	1.5	6	3-4
5. Install piping	1 mo	8 men	24	6	30	3-5
6. Install electrical	1 mo	4 men	12	4	16	3-6
7. Install instruments	2 wk	2 men	3	1	4	6-7
8. Install insulation	2 wk	2 men	3	2	5	5-8
9. Painting	3 wk	2 men	4.5	4.5	9	3-9
10. Cleanup, lables, etc.	2 wk	2 men	3	1	4	7, 8-10
11. Testing, tie-in	2 wk	6 men	9	3	12	7, 9, 10-11
				Total	$115,000	
				Plus overhead 100%:	$230,000	

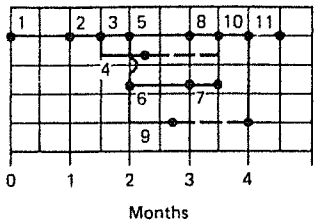
a. Project Bar Chart Time Schedule



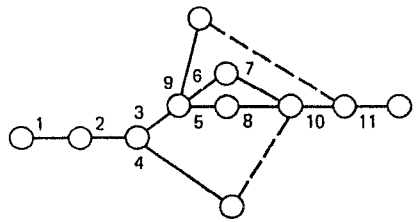
b. Budgeted Expenditure Curve



c. Critical Path (Bar) Chart



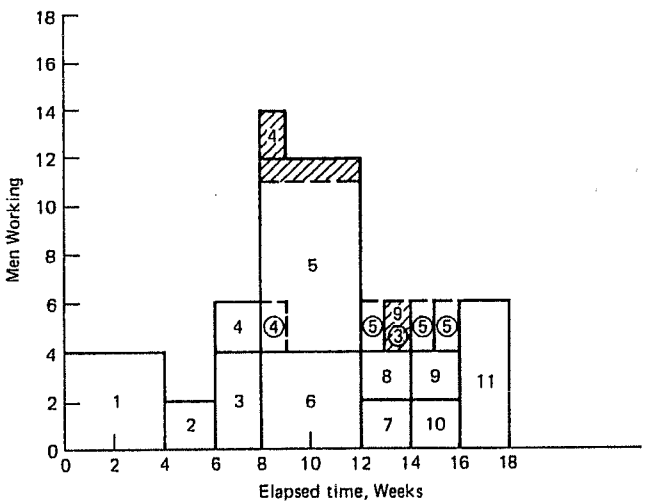
Critical Path (Flow Sheet) Chart



Critical path 1, 2, 3, 5, 8, 10, 11 4½ mo = 18 wks

d. 20% of 18 wk = 3.6 wk. Reduce job 1 by 2 wks, Estimated cost increase: about $1.5 M. Reduce jobs 2 and 10 by 0.3 weeks: Estimated cost $1.0M Reduce jobs 5 and 6 by 1 week; cost: 3.0 M; Total est. cost increase $5.5M (could be much more)
No change in critical path

e. Manpower Leveling



Numbers = jobs; circled numbers = jobs moved to new times; shaded periods = men no longer working (moved to new times); dotted lines = new job periods

10-3. What is a:
a. PERT program?
b. Decision tree analysis?
Answer:
a. A critical path program with statistical probabilities considered for the likelihood of each job duration.
b. A form of sensitivity analysis in which all of the possible occurrences are charted to their ultimate conclusion, with present value or DCF calculations made on all of the possible possible variations.

CHAPTER 11. PERSONAL INVESTING

11-1. You are a process engineer in a small but prosperous firm that is planning a new $10 million expansion to start one year from now, and take one year to complete. Present retained earnings plus the cash flow generated during this period will be adequate for the total financing. Your boss has asked you to outline a general investment strategy for your present funds and future cash flow to safely attempt to earn the maximum possible income until the money is needed. Please note the types of investments you recommend, and your reasons for these choices.
Answer: Suggested investment strategy:
a. Must have reasonable diversification, safety, and liquidity.
b. One possible group of investments might be:
(1) Maintain some cash (i.e., about $1 MM). This could be a money market account, but preferably short-term (30–90 day) commercial paper or CDs in a strong, sound bank.
(2) If interest rates appear to be stable or declining, the majority of funds (i.e., about $7 MM) should be placed in a high yielding, no-load, utility stock market mutual fund with switching privileges. Interest rates must be watched carefully, and if they appear to have a possibility of rising, quickly switch to a money market fund.
(3) Place the remaining funds in a high yielding, no-load, municipal (tax-free) bond fund, again with switching privileges so that it may be sold at any firm indication of a rise in interest rates.
(4) Alternately to the above, with uncertain interest rates, and depending upon the economy, some investments may be placed in any or all of stocks, precious metals, overseas funds, etc. Your own company's stock might be a good investment.

11-2. a. You are single and earn $28,000/yr. How much of an IRA contribution may you deduct from your income taxes?
b. You are married and your combined income is $49,500. How much may each person deduct from taxes for their IRA contribution?
Answer:
a. The single taxpayer may deduct $2,000/yr from his taxes if his income is less than $25,000, and zero if over $35,000. Thus, with $28,000 income the deduction may be 2,000 × (7,000/10,000) = $1,400. Of course, the remaining $600 may be put into the IRA account with no (actually, deferred) taxes on earnings, but not deducted from that year's income for tax purposes.
b. Married couples can each deduct $2,000 in IRA payments from their taxable income if their combined earnings do not exceed $40,000, and zero if over $50,000. The minimum deduction for married and single taxpayers is $200. Therefore, with $49,500 combined earnings, the calculation would indicate: $2,000 (500/10,000) = $100 deduction. However, the minimum deduction is $200, so this is the amount they may each utilize.

11-3. For a long-term investment in a utility stock paying originally 8% dividends, and with a dividend reinvestment program, does the stockholder have a poor investment when interest rates rise to 15%
Answer: No. The utility stock at that time will probably only be worth about $^{8}/_{15}$ of its original value, but the number of dollars earned each quarter is fixed (actually growing through the quarterly dividend compounding), so with dividend reinvestment one receives more shares ($^{15}/_{8}$) for each dividend. If the stockholder can wait until the stock value is back to its original price (or higher) before selling, he will have essentially received the always-current interest rate over the holding period, plus any increase in the dividend (many utilities increase it every year), and of course, the appreciation from compounding.

CHAPTER 12. EMPLOYMENT CONSIDERATIONS

12-1. How does the AIChE job referral service work?
Answer: It is an electronic data base that attempts to match participating members' eduction and experience with the requirements of jobs that AIChE knows are or may become open. If job and applicant match up the member will be given the name of the appropriate contact at each company. The employer will also be given the applicant's name and address if he or she wishes.

12-2. Is a multipage, elaborate resume worthwhile?
Answer: Generally no. If the resume is too pretentious it is usually a mark against the applicant. Perhaps an exception would be when applying for a managerial job, where more detail is generally needed. At that level; or with sales or other contact positions, the videotape resume is also becoming increasingly popular. It may well become commonplace for all professional positions in the coming years.

12-3. When applying for a position at an electronics (or other non-CPI) firm, what skills and areas of expertise might you list?
Answer: Many industries, such as electronics, do some (or considerable) chemical handling and processing (electroplating, etching, cleaning, semiconductors, etc.) and miscellaneous fluid flow (piping systems, clean-rooms, etc.), heat transfer (cogeneration, heating, cooling, etc.), mass transfer (scrubbers, purification, etc.), computer process control, environmental control, and other chemical engineering operations. They may not recognize each of the areas as being within the ChE training area, but they have been increasingly hiring chemical engineers to help with their problems.

12-4. Are interoffice memos really of much importance to an engineer's career?
Answer: Yes, they are one of the means by which management several layers above your boss, or in other divisions, on occasion review your work. Good memos definitely stand out, and their authors are remembered. Often you will read older memos in the file to study a problem and develop a real appreciation and respect for certain authors. They may by then be in higher positions with your firm, or with other companies, and their old memos can make a very interesting bond between you when you meet.

APPENDIX 5

CONVERSION FACTORS

Multiply	By	To Obtain
Atmospheres	76.0	Cms. of mercury
Atmospheres	29.92	Inches of mercury
Atmospheres	33.90	Feet of water
Atmospheres	1.0333	Kgs. / sq. cm.
Atmospheres	14.70	Lbs. / sq. inch
Atmospheres	1.058	Tons / sq. ft.
Barrels—Oil	42	Gallons-Oil
British Thermal Units	0.2520	Kilogram-calories
British Thermal Units	777.5	Foot-lbs.
British Thermal Units	3.927×10^{-4}	Horse-power-hrs
British Thermal Units	107.5	Kilogram-meters
British Thermal Units	2.928×10^{-4}	Kilowatt hrs
B.T.U./min.	12.96	Foot-lbs./sec
B.T.U./min.	0.02356	Horse-power
B.T.U./min	0.01757	Kilowatts
B.T.U./min	17.57	Watts
Centares (Centiares)	1	Square meters
Centigrams	0.01	Grams
Centiliters	0.01	Liters
Centimeters	0.3937	Inches
Centimeters	0.01	Meters
Centimeters	10	Millimeters
Centimtrs. of Mercury	0.01316	Atmospheres
Centimtrs. of mercury	0.4461	Feet of water
Centimtrs. of mercury	136.0	Kgs./sq. meter
Centimtrs. of mercury	27.85	Lbs. / sq. ft.
Centimtrs. of mercury	0.1934	Lbs. / sq. inch
Centimeters/second	1.969	Feet/min.
Centimeters/second	0.03281	Feet/sec.
Centimeters/second	0.036	Kilometers/hr.
Centimeters/second	0.6	Meters/min.
Centimeters/second	0.02237	Miles/hr.
Centimeters/second	3.728×10^{-4}	Miles/min.
Cms./sec./sec.	0.03281	Feet/sec./sec.
Cubic centimeters	3.531×10^{-5}	Cubic feet
Cubic centimeters	6.102×10^{-2}	Cubic inches
Cubic centimeters	10^{-6}	Cubic meters
Cubic centimeters	1.308×10^{-6}	Cubic yards
Cubic centimeters	2.642×10^{-4}	Gallons
Cubic centimeters	10^{-3}	Liters
Cubic centimeters	2.113×10^{-3}	Pints (liq.)
Cubic centimeters	1.057×10^{-3}	Quarts (liq.)

Multiply	By	To Obtain
Fathoms	6	Feet
Feet	30.48	Centimeters
Feet	12	Inches
Feet	0.3048	Meters
Feet	1/3	Yards
Feet of water	0.02950	Atmospheres
Feet of water	0.8826	Inches of mercury
Feet of water	0.03048	Kgs./sq. cm.
Feet of water	62.43	Lbs. / sq. ft.
Feet of water	0.4335	Lbs. / sq. inch
Feet, min.	0.5080	Centimeters/sec.
Feet/min.	0.01667	Feet/sec.
Feet/min.	0.01829	Kilometers/hr.
Feet/min.	0.3048	Meters/min.
Feet/min.	0.01136	Miles/hr.
Feet/sec./sec.	30.48	Cms./sec./sec.
Feet/sec./sec.	0.3048	Meters/sec./sec.
Foot-pounds	1.286×10^{-3}	British Thermal Units
Foot-pounds	5.050×10^{-7}	Horse-power-hrs.
Foot-pounds	3.241×10^{-4}	Kilogram-calories
Foot-pounds	0.1383	Kilogram-meters
Foot-pounds	3.766×10^{-7}	Kilowatt-hrs
Foot-pounds/min.	1.286×10^{-3}	B. T. Units/min.
Foot-pounds/min.	0.01667	Foot-pounds/sec.
Foot-pounds/min.	3.030×10^{-5}	Horse-power
Foot-pounds/min.	3.241×10^{-4}	Kg.-calories/min.
Foot-pounds/min.	2.260×10^{-5}	Kilowatts
Foot-pounds/sec.	7.717×10^{-2}	B. T. Units/min.
Foot-pounds/sec.	1.818×10^{-3}	Horse-power
Foot-pounds/sec.	1.945×10^{-2}	Kg.-calories/min.
Foot-pounds/sec.	1.356×10^{-3}	Kilowatts
Gallons	3785	Cubic centimeters
Gallons	0.1337	Cubic feet
Gallons	231	Cubic inches
Gallons	3.785×10^{-3}	Cubic meters
Gallons	4.95×10^{-3}	Cubic yards
Gallons	3.785	Liters
Gallons	8	Pints (liq.)
Gallons	4	Quarts (liq.)
Gallons, Imperial	1.20095	U. S. Gallons
Gallons, U.S.	0.83267	Imperial gallons

Multiply	By	To Obtain
Inches of water	0.07355	Inches of mercury
Inches of water	0.002540	Kgs./sq. cm.
Inches of water	0.5781	Ounces/sq. inch
Inches of water	5.202	Lbs./sq. foot
Inches of water	0.03613	Lbs. / sq. inch
Kilograms	980.665	Dynes
Kilograms	2.205	Lbs.
Kilograms	1.102×10^{-3}	Tons (short)
Kilograms	10^{3}	Grams
Kgs./meter	0.6720	Lbs. / foot
Kgs./sq. cm.	0.9678	Atmospheres
Kgs./sq. cm.	32.81	Feet of water
Kgs./sq. cm.	28.96	Inches of mercury
Kgs./sq. cm.	2048	Lbs. / sq. foot
Kgs./sq. cm.	14.22	Lbs. / sq. inch
Kgs./sq. millimeter	10^{6}	Kgs./sq. meter
Kiloliters	10^{3}	Liters
Kilometers	10^{5}	Centimeters
Kilometers	3281	Feet
Kilometers	10^{3}	Meters
Kilometers	0.6214	Miles
Kilometers	1094	Yards
Kilometers/hr.	27.78	Centimeters/sec.
Kilometers/hr.	54.68	Feet/min.
Kilometers/hr.	0.9113	Feet/sec.
Kilometers/hr.	0.5396	Knots
Kilometers/hr.	16.67	Meters/min.
Kilometers/hr.	0.6214	Miles/hr.
Kms./hr./sec.	27.78	Cms./sec./sec.
Kms./hr./sec.	0.9113	Ft./sec./sec.
Kms./hr./sec.	0.2778	Meters/sec./sec.
Kilowatts	56.92	B. T. Units/min.
Kilowatts	4.425×10^{4}	Foot-lbs./min.
Kilowatts	737.6	Foot-lbs./sec.
Kilowatts	1.341	Horse-power
Kilowatts	14.34	Kg.-calories/min.
Kilowatts	10^{3}	Watts
Kilowatt-hours	3415	British Thermal Units
Kilowatt-hours	2.655×10^{6}	Foot-lbs.
Kilowatt-hours	1.341	Horse-power-hrs.
Kilowatt-hours	860.5	Kilogram-calories
Kilowatt-hours	3.671×10^{5}	Kilogram-meters

Multiply	By	To Obtain
Ounces	16	Drams
Ounces	437.5	Grains
Ounces	0.0625	Pounds
Ounces	28.349527	Grams
Ounces	0.9115	Ounces (troy)
Ounces	2.790×10^{-5}	Tons (long)
Ounces	2.835×10^{-5}	Tons (metric)
Ounces, troy	480	Grains
Ounces, troy	20	Pennyweights (troy)
Ounces, troy	0.08333	Pounds (troy)
Ounces, troy	31.103481	Grams
Ounces, troy	1.09714	Ounces (avoir.)
Ounces (fluid)	1.805	Cubic inches
Ounces (fluid)	0.02957	Liters
Ounces sq. inch	0.0625	Lbs. / sq. inch
Parts / million	0.0584	Grains / U. S. gal.
Parts / million	0.07016	Grains / Imp. gal.
Parts / million	8.345	Lbs. / million gal.
Pennyweights (troy)	24	Grains
Pennyweights (troy)	1.55517	Grams
Pennyweights (troy)	0.05	Ounces (troy)
Pennyweights (troy)	4.1667×10^{-3}	Pounds (troy)
Pounds	16	Ounces
Pounds	256	Drams
Pounds	7000	Grains
Pounds	0.0005	Tons (short)
Pounds	453.5924	Grams
Pounds	1.21528	Pounds (troy)
Pounds	14.5833	Ounces (troy)
Pounds (troy)	5760	Grains
Pounds (troy)	240	Pennyweights (troy)
Pounds (troy)	12	Ounces (troy)
Pounds (troy)	373.24177	Grams
Pounds (troy)	0.822857	Pounds (avoir.)
Pounds (troy)	13.1657	Ounces (avoir.)
Pounds (troy)	3.6735×10^{-4}	Tons (long)
Pounds (troy)	4.1143×10^{-4}	Tons (short)
Pounds (troy)	3.7324×10^{-4}	Tons (metric)
Pounds of water	0.01602	Cubic feet
Pounds of water	27.68	Cubic inches
Pounds of water	0.1198	Gallons
Pounds of water/min.	2.670×10^{-4}	Cubic ft./sec.

Multiply	By	To Obtain
Cubic feet	2.832×10^{4}	Cubic cms.
Cubic feet	1728	Cubic inches
Cubic feet	0.02832	Cubic meters
Cubic feet	0.03704	Cubic yards
Cubic feet	7.48052	Gallons
Cubic feet	28.32	Liters
Cubic feet	59.84	Pints (liq.)
Cubic feet	29.92	Quarts (liq.)
Cubic feet/minute	472.0	Cubic cms./sec.
Cubic feet/minute	0.1247	Gallons/sec.
Cubic feet/minute	0.4720	Liters/sec.
Cubic feet/minute	62.43	Lbs. of water/min
Cubic feet/second	0.646317	Million gals./day
Cubic feet/second	448.831	Gallons/min
Cubic inches	16.39	Cubic centimeters
Cubic inches	5.787×10^{-4}	Cubic feet
Cubic inches	1.639×10^{-5}	Cubic meters
Cubic inches	2.143×10^{-5}	Cubic yards
Cubic inches	4.329×10^{-3}	Gallons
Cubic inches	1.639×10^{-2}	Liters
Cubic inches	0.03463	Pints (liq.)
Cubic inches	0.01732	Quarts (liq.)
Cubic meters	10^{6}	Cubic centimeters
Cubic meters	35.31	Cubic feet
Cubic meters	61,023	Cubic inches
Cubic meters	1.308	Cubic yards
Cubic meters	264.2	Gallons
Cubic meters	10^{3}	Liters
Cubic meters	2113	Pints (liq.)
Cubic meters	1057	Quarts (liq.)
Cubic yards	7.646×10^{5}	Cubic centimeters
Cubic yards	27	Cubic feet
Cubic yards	46,656	Cubic inches
Cubic yards	0.7646	Cubic meters
Cubic yards	202.0	Gallons
Cubic yards	764.6	Liters
Cubic yards	1616	Pints (liq.)
Cubic yards	807.9	Quarts (liq.)
Cubic yards/min.	0.45	Cubic feet/sec.
Cubic yards/min.	3.367	Gallons/sec.
Cubic yards/min.	12.74	Liters/sec.
Decigrams	0.1	Grams
Deciliters	0.1	Liters
Decimeters	0.1	Meters
Degrees (angle)	60	Minutes
Degrees (angle)	0.01745	Radians
Degrees (angle)	3600	Seconds
Degrees/sec.	0.01745	Radians/sec.
Degrees/sec.	0.1667	Revolutions/min.
Degrees/sec.	0.002778	Revolutions/sec.
Dekagrams	10	Grams
Dekaliters	10	Liters
Dekameters	10	Meters
Drams	27.34375	Grains
Drams	0.0625	Ounces
Drams	1.771845	Grams

Multiply	By	To Obtain
Gallons water	8.3453	Pounds of water
Gallons/min.	2.228×10^{-2}	Cubic feet/sec.
Gallons/min.	0.06308	Liters/sec.
Gallons/min.	8.0208	Cu. ft./hr.
Gallons water/min.	6.0086	Tons water/24 hrs.
Grains (troy)	1	Grains (avoir.)
Grains (troy)	0.06480	Grams
Grains (troy)	0.04167	Pennyweights (troy)
Grains (troy)	2.0833×10^{-3}	Ounces (troy)
Grains/U.S. gal.	17.118	Parts / million
Grains/U.S. gal.	142.86	Lbs. / million gal.
Grains/imp. gal.	14.286	Parts / million
Grams	980.7	Dynes
Grams	15.43	Grains
Grams	10^{-3}	Kilograms
Grams	10^{3}	Milligrams
Grams	0.03527	Ounces
Grams	0.03215	Ounces (troy)
Grams	2.205×10^{-3}	Pounds
Grams/cm.	5.600×10^{-3}	Pounds/inch
Grams/cu. cm.	62.43	Pounds/cubic foot
Grams/cu. cm.	0.03613	Pounds/cubic inch
Grams/liter	58.417	Grains/gal.
Grams/liter	8.345	Pounds/1000 gals.
Grams/liter	0.062427	Pounds/cubic foot
Grams/liter	1000	Parts/million
Hectograms	100	Grams
Hectoliters	100	Liters
Hectometers	100	Meters
Hectowatts	100	Watts
Horse-power	42.44	B. T. Units/min
Horse-power	33,000	Foot-lbs./min
Horse-power	550	Foot-lbs./sec.
Horse-power	1.014	Horse-pwr. (Metric)
Horse-power	10.70	Kg.-calories/min.
Horse-power	0.7457	Kilowatts
Horse-power	745.7	Watts
Horse-power (boiler)	33,479	B. T. U./hr.
Horse-power (boiler)	9.803	Kilowatts
Horse-power-hours	2547	British Thermal Units
Horse-power-hours	1.98×10^{6}	Foot-lbs.
Horse-power-hours	641.7	Kilogram-calories
Horse-power-hours	2.737×10^{5}	Kilogram-meters
Horse-power-hours	0.7457	Kilowatt-hours
Inches	2.540	Centimeters
Inches of mercury	0.03342	Atmospheres
Inches of mercury	1.133	Feet of water
Inches of mercury	0.03453	Kgs./sq. cm.
Inches of mercury	70.73	Lbs./sq. ft.
Inches of mercury	0.4912	Lbs. / sq. inch
Inches of water	0.002458	Atmospheres

Multiply	By	To Obtain
Liters	10^{3}	Cubic centimeters
Liters	0.03531	Cubic feet
Liters	61.02	Cubic inches
Liters	10^{-3}	Cubic meters
Liters	1.308×10^{-3}	Cubic yards
Liters	0.2642	Gallons
Liters	2.113	Pints (liq.)
Liters	1.057	Quarts (liq.)
Liters/min.	5.886×10^{-4}	Cubic ft./sec.
Liters/min.	4.403×10^{-3}	Gals./sec.
Lumber Width (in.) x Thickness (in.) / 12	Length (ft.)	Board Feet
Meters	100	Centimeters
Meters	3.281	Feet
Meters	39.37	Inches
Meters	10^{-3}	Kilometers
Meters	10^{3}	Millimeters
Meters	1.094	Yards
Meters/min.	1.667	Centimeters/sec.
Meters/min.	3.281	Feet/min.
Meters/min.	0.05468	Feet/sec.
Meters/min.	0.06	Kilometers/hr.
Meters/min.	0.03728	Miles/hr.
Meters/sec.	196.8	Feet/min.
Meters/sec.	3.281	Feet/sec.
Meters/sec.	3.6	Kilometers/hr.
Meters/sec.	0.06	Kilometers/min.
Meters/sec.	2.237	Miles/hr.
Meters/sec.	0.03728	Miles/min.
Microns	10^{-6}	Meters
Miles	1.609×10^{5}	Centimeters
Miles	5280	Feet
Miles	1.609	Kilometers
Miles	1760	Yards
Miles/hr.	44.70	Centimeters/sec.
Miles/hr.	88	Feet/min.
Miles/hr.	1.467	Feet/sec.
Miles/hr.	1.609	Kilometers/hr.
Miles/hr.	0.8684	Knots
Miles/hr.	26.82	Meters/min.
Miles/min.	2682	Centimeters/sec.
Miles/min.	88	Feet/sec.
Miles/min.	1.609	Kilometers/min.
Miles/min.	60	Miles/hr.
Milliers	10^{3}	Kilograms
Milligrams	10^{-3}	Grams
Milliliters	10^{-3}	Liters
Millimeters	0.1	Centimeters
Millimeters	0.03937	Inches
Milligrams/liter	1	Parts / million
Million gals./day	1.54723	Cubic ft./sec.
Miner's inches	1.5	Cubic ft./min.
Minutes (angle)	2.909×10^{-4}	Radians

Multiply	By	To Obtain
Pounds, cubic foot	0.01602	Grams/cubic cm.
Pounds/cubic foot	16.02	Kgs. / cubic meter
Pounds/cubic foot	5.787×10^{-4}	Lbs. / cubic inch
Pounds, cubic inch	27.68	Grams/cubic cm.
Pounds/cubic inch	2.768×10^{4}	Kgs. / cubic meter
Pounds/cubic inch	1728	Lbs. / cubic foot
Pounds/foot	1.488	Kgs. / meter
Pounds/inch	178.6	Grams/cm.
Pounds/sq. foot	0.01602	Feet of water
Pounds/sq. foot	4.883×10^{-4}	Kgs. / sq. cm.
Pounds/sq. foot	6.945×10^{-3}	Pounds/sq. inch
Pounds/sq. inch	0.06804	Atmospheres
Pounds/sq. inch	2.307	Feet of water
Pounds/sq. inch	2.036	Inches of mercury
Pounds/sq. inch	0.07031	Kgs. / sq. cm.
Quarts (dry)	67.20	Cubic inches
Quarts (liq.)	57.75	Cubic inches
Quintal, Argentine	101.28	Pounds
Quintal, Brazil	129.54	Pounds
Quintal, Castile, Peru	101.43	Pounds
Quintal, Chile	101.41	Pounds
Quintal, Mexico	101.47	Pounds
Quintal, Metric	220.46	Pounds
1 / Sq. ft./gal./min.	8.0208	Overflow rate (ft./hr.)
Temp. (°C.) + 273	1	Abs. temp. (°C.)
Temp. (°C.) + 17.78	1.8	Temp. (°F.)
Temp. (°F.) + 460	1	Abs. temp. (°F.)
Temp. (°F.) - 32	5/9	Temp. (°C.)
Tons (long)	1016	Kilograms
Tons (long)	2240	Pounds
Tons (long)	1.12000	Tons (short)
Tons (metric)	10^{3}	Kilograms
Tons (metric)	2205	Pounds
Tons (short)	2000	Pounds
Tons (short)	32000	Ounces
Tons (short)	907.18486	Kilograms
Tons (short)	2430.56	Pounds (troy)
Tons (short)	0.89287	Tons (long)
Tons (short)	29166.66	Ounces (troy)
Tons (short)	0.90718	Tons (metric)
Tons of water/24 hrs.	83.333	Pounds water/hour
Tons of water/24 hrs.	0.16643	Gallons/min.
Tons of water/24 hrs.	1.3349	Cu. ft./hr.
Watts	0.05692	B. T. Units/min.
Watts	44.26	Foot-pounds/min.
Watts	0.7376	Foot-pounds/sec.
Watts	1.341×10^{-3}	Horse-power
Watts	0.01434	Kg.-calories/min.
Watts	10^{-3}	Kilowatts
Watt-hours	3.415	British Thermal Units
Watt-hours	2655	Foot-pounds
Watt-hours	1.341×10^{-3}	Horse-power-hours
Watt-hours	0.8605	Kilogram-calories
Watt-hours	367.1	Kilogram-meters
Watt-hours	10^{-3}	Kilowatt-hours

Units of Area

Units	Square Inches	Square Feet	Square Yards	Square Miles	Square Centimeters	Square Meters
1 square inch	1	0.00694444	0.000771605	0.0000000002491	6.451626	0.0006451626
1 square foot	144	1	0.111111	0.0000000358701	929.0341	0.09290341
1 square yard	1,296	9	1	0.000000322831	8361.307	0.8361307
1 square mile	4,014,489,600	27,878,400	3,097,600	1	25,899,964,703	2,589,998
1 square centimeter	0.1549969	0.001076387	0.0001195985	0.00000000003861006	1	0.0001
1 square meter	1549.9969	10.76387	1.195985	0.0000003861006	10,000	1

Units of Length

Units	Inches	Feet	Yards	Miles	Centimeters	Meters
1 inch	1	0.0833333	0.0277778	0.0000157828	2.540005	0.02540005
1 foot	12	1	0.333333	0.000189393 9	30.48006	0.3048006
1 yard	36	3	1	0.000568182	91.44018	0.9144018
1 mile	63,360	5280	1760	1	160,934.72	1609.3472
1 centimeter	0.3937	0.03280833	0.0109361 1	0.000006213699	1	0.01
1 meter	39.37	3.280833	1.0936111	0.0006213699	100	1

Units of Liquid Measure

Units	Fluid ounces	Liquid pints	Liquid Quarts	Gallons	Milliliters	Liters	Cubic Inches
1 fluid ounce	1	0.0625	0.03125	0.0078125	29.5729	0.0295729	1.80469
1 liquid pint	16	1	0.5	0.125	473.167	0.473167	28.875
1 liquid quart	32	2	1	0.25	946.333	0.946333	57.75
1 gallon	128	8	4	1	3785.332	3.785332	231
1 milliliter	0.0338147	0.00211342	0.00105671	0.000264178	1	0.001	0.0610250
1 liter	33.8147	2.11342	1.05671	0.264178	1000	1	61.0250
1 cubic inch	0.554113	0.0346320	0.0173160	0.00432900	16.3867	0.0163867	1

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