APPENDIX E

COST DATA

E.1 OPERATING COSTS

Chemicals

The costs of raw materials, products, and by-products can normally be found in the *Chemical Marketing Reporter*. The values listed are the current market prices, which may be significantly different from the price used in a particular company because of long-term contracts. The costs of light gases usually are not listed in the *Chemical Marketing Reporter* because these materials often are sold "over the fence" (a vendor builds a special plant to produce these materials which is located next to the site that will use them) or a long-term contract is negotiated.

Utilities

The best way to estimate the cost of utilities is to relate the costs of any utility to its equivalent fuel value by using thermodynamics and typical efficiencies of power plants, turbines, boilers, etc. Market fluctuations might occur at times which make the value of steam less than that of fuel, but large cost penalties can be encountered

TABLE E.1-1
Utilities costs

Utility	Factor	Price
Fuel (oil or gas)	1.0	$4.00/10^6 Btu
Steam		
600 psig at 750°F	1.30	$5.20/1000 lb
Saturated steam		
600 psig	1.13	$4.52
250 psig	0.93	3.72
150 psig	0.85	3.4
50 psig	0.70	2.8
15 psig	0.57	2.28
Electricity	1.0	$0.04/kwhr
Cooling water	0.75	$0.03/1000 gal

if a design is based on distorted prices and then the costs revert to their normal pattern.

A reasonable set of factors to use is given in Table E.1-1. Once the value of fuel has been specified, the costs of the other utilities can easily be calculated. Note that the values given in Table E.1-1 were not used throughout this text. Similarly, the costs used in different problems are sometimes different. However, the costs used in various problems are identified as the solution is developed.

E.2 SUMMARY OF COST CORRELATIONS

The 1970s have been a period of rapid cost escalation (see Fig. 2.2-11), and so very few cost correlations were published during this period. We use Guthrie's cost correlations in this text, whenever possible, to illustrate costing procedures, but note that these correlations are out of date. We update the correlations from the mid-1968 values* by using a ratio of the M&S indices, but this is not a recommended practice for such a long time span. Instead, if an updated set of company cost correlations is not available, a designer should consult one or more vendors early in the costing procedure to obtain more recent cost data.

For our preliminary process designs, we use a simplified version of Guthrie's correlations. The normal material (the base costs assume carbon steel) and pressure correction factors are used to estimate the purchased cost, but the most conservative base module cost factor is used to estimate the installed costs. This approximation corresponds to a conservative cost estimate. For more accurate estimates, Guthrie's book should be consulted.†

* K. M. Guthrie, "Capital Cost Estimating," *Chem Eng.*, **76**(6): 114 (March 24, 1969).

† K. M. Guthrie, *Process Plant Estimating Evaluation and Control*, Craftsman Book Co., Solana Beach, Calif., 1974.

Process Furnaces

Mid-1968 cost, box or A-frame construction with multiple tube banks, field-erected.

$$\text{Purchased Cost, \$} = \left(\frac{\text{M\&S}}{280}\right)(5.52 \times 10^3)Q^{0.85}F_c$$

where Q = adsorbed duty, 10^6 Btu/hr; $20 < Q < 300$

$$F_c = F_d + F_m + F_p$$

$$\text{Installed Cost, \$} = \left(\frac{\text{M\&S}}{280}\right)(5.52 \times 10^3)Q^{0.85}(1.27 + F_c)$$

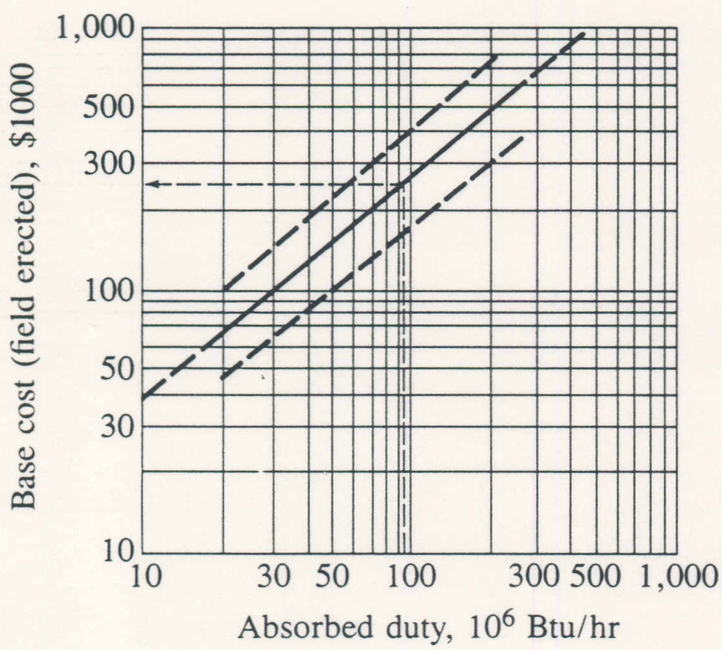

FIGURE E.2-1
Process furnaces. [*K. M. Guthrie, Chem. Eng.*, **76**(6): *114* (*March 24, 1969*).]

TABLE E.2-1
Correction factors F_c for process furnace

Design type	F_d	Radiant tube material	F_m	Design pressure, psi	F_p
Process heater	1.00	Carbon steel	0.0	Up to 500	0.00
Pyrolysis	1.10	Chrome/moly	0.35	1000	0.10
Reformer (no catalyst)	1.35	Stainless	0.75	1500	0.15
				2000	0.25
				2500	0.40
				3000	0.60

Direct-Fired Heaters

Mid-1968 cost, cylindrical construction, field erection.

$$\text{Purchased Cost, \$} = \left(\frac{\text{M\&S}}{280}\right)(5.07 \times 10^3)Q^{0.85}F_c$$

where Q = adsorbed duty, 10^6 Btu/hr; $2 < Q < 30$

$$F_c = F_d + F_m + F_p$$

$$\text{Installed Cost, \$} = \left(\frac{\text{M\&S}}{280}\right)(5.07 \times 10^3)Q^{0.85}(1.23 + F_c)$$

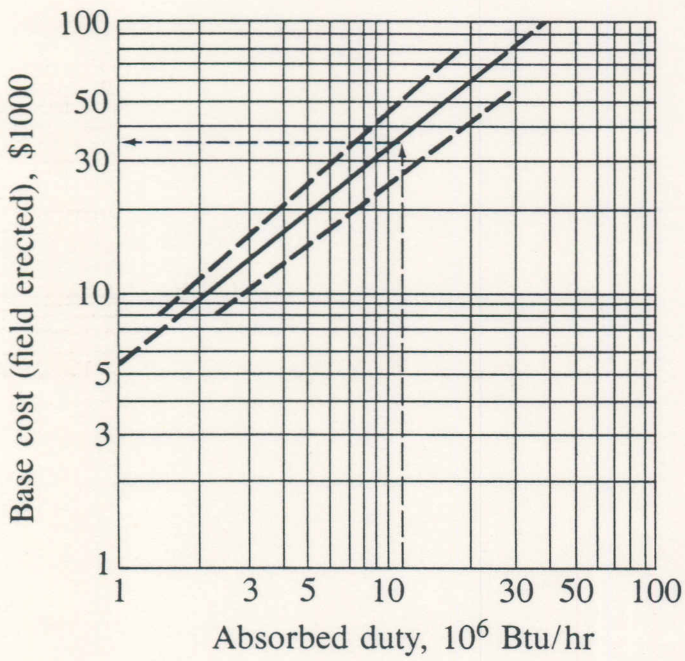

FIGURE E.2-2
Direct-fired heater. [*K. M. Guthrie, Chem. Eng.*, **76**(*6*): *114* (*March 24, 1969*).]

TABLE E.2-2
Correction factors F_c for direct-fired heaters

Design type	F_d	Radiant tube material	F_m	Design pressure, psi	F_p
Cylindrical	1.0	Carbon steel	0.0	Up to 500	0.00
Dowtherm	1.33	Chrome/moly	0.45	1000	0.15
		Stainless	0.50	1500	0.20

Heat Exchangers

Mid-1968 cost, shell and tube, complete fabrication.

$$\text{Purchased Cost, \$} = \left(\frac{\text{M\&S}}{280}\right)(101.3A^{0.65}F_c)$$

where A = area ft^2; $200 < A < 5000$

$$F_c = (F_d + F_p)F_m$$

Shell-and-Tube Material = F_m

Surface area, ft^2	CS/ CS	CS/ Brass	CS/ MO	CS/ SS	SS/ SS	CS/ Monel	Monel/ Monel	CS/ T_i	T_i/ T_i
1000 to 5000	1.00	1.30	2.15	2.81	3.75	3.10	4.25	8.95	13.05

$$\text{Installed Cost, \$} = \left(\frac{\text{M\&S}}{280}\right)101.3A^{0.65}(2.29 + F_c)$$

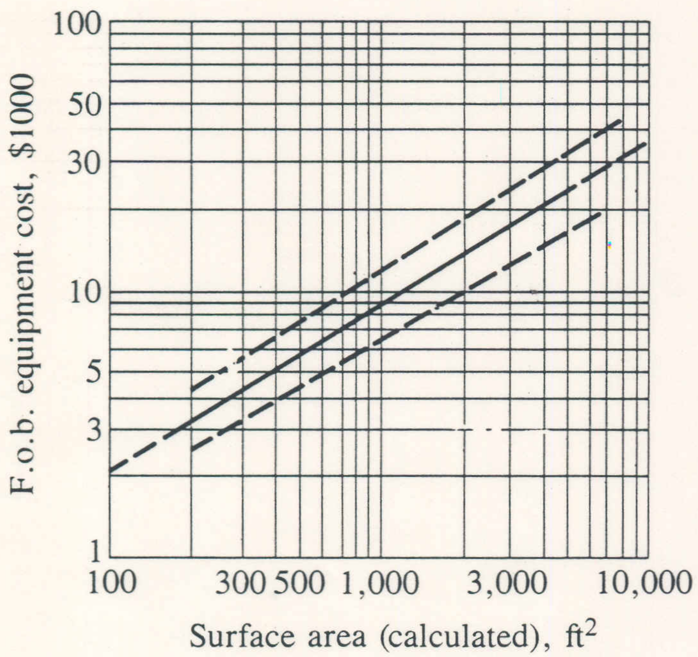

FIGURE E.2-3
Shell-and-tube heat exchangers. [*K. M. Guthrie, Chem. Eng.*, **76**(*6*): *114* (*March 24, 1969*).]

TABLE E.2-3
Correction factors for heat exchangers

Design type	F_d	Design pressure, psi	F_p
Kettle, reboiler	1.35	Up to 150	0.00
Floating head	1.00	300	0.10
U-tube	0.85	400	0.25
Fixed-tube sheet	0.80	800	0.52
		1000	0.55

Gas Compressors

Mid-1968 cost, centrifugal machine, motor drive, base plate and coupling.

$$\text{Purchased Cost, \$} = \left(\frac{\text{M\&S}}{280}\right)(517.5)(\text{bhp})^{0.82}F_c$$

where bhp = brake horsepower; 30 < bhp < 10,000

$$F_c = F_d$$

$$\text{Installed Cost, \$} = \left(\frac{\text{M\&S}}{280}\right)(517.5)(\text{bhp})^{0.82}(2.11 + F_c)$$

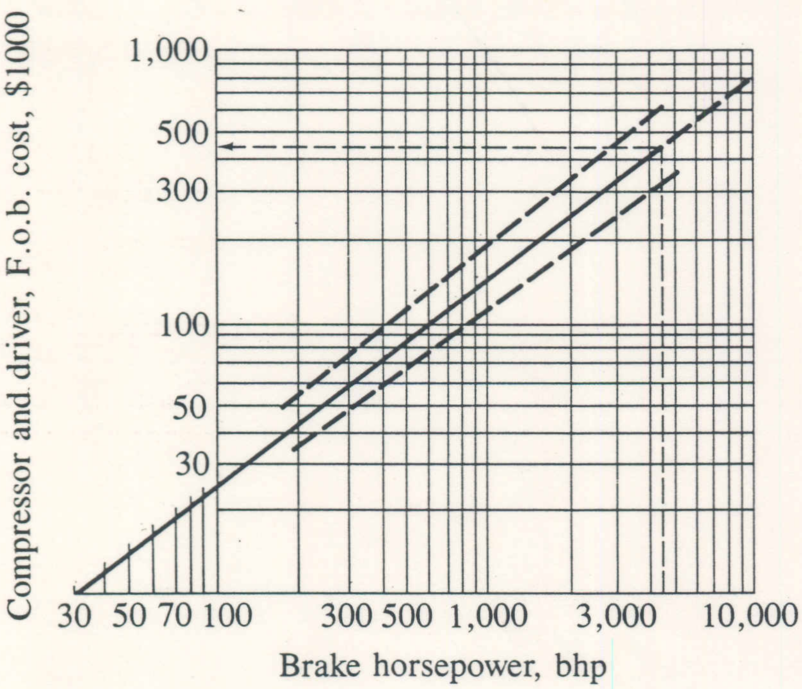

FIGURE E.2-4
Process gas compressors and drives. [*K. M. Guthrie, Chem. Eng.*, **76**(*6*): *114* (*March 24, 1969*).]

TABLE E.2-4
Correction factors for Compressors

Design type F_d	Factor
Centrifugal, motor	1.00
Reciprocating, steam	1.07
Centrifugal, turbine	1.15
Reciprocating, motor	1.29
Reciprocating, gas engine	1.82

Pressure Vessels, Columns, Reactors

$$\text{Purchased Cost, \$} = \left(\frac{\text{M\&S}}{280}\right)(101.9D^{1.066}H^{0.82}F_c)$$

where D = diameter, ft

H = height, ft

$F_c = F_m F_p$

Pressure	Up to 50	100	200	300	400	500	600	700	800	900	1000
F_p	1.00	1.05	1.15	1.20	1.35	1.45	1.60	1.80	1.90	2.30	2.50

$$\text{Installed Cost, \$} = \left(\frac{\text{M\&S}}{280}\right)101.9D^{1.066}H^{0.802}(2.18 + F_c)$$

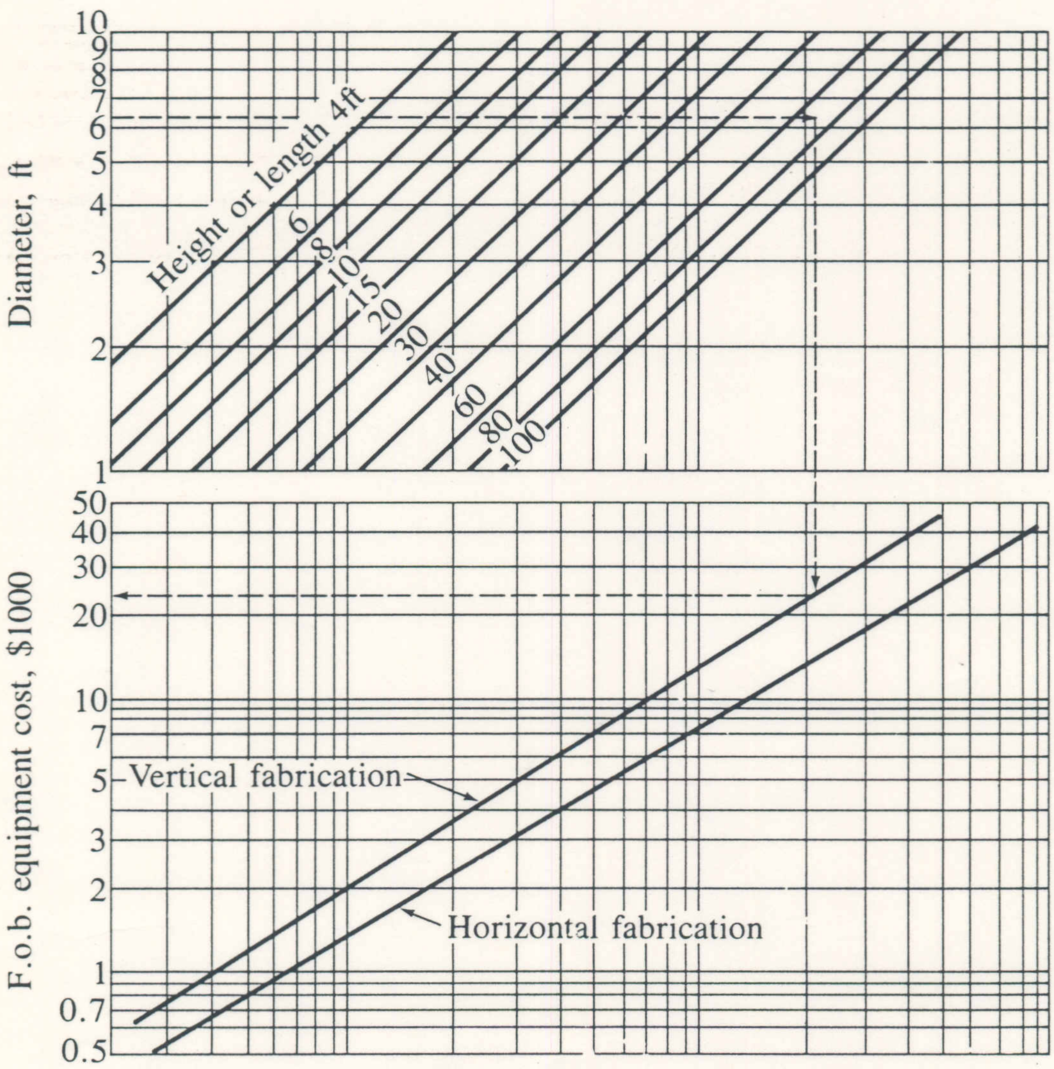

FIGURE E.2-5
Pressure vessels. [*K. M. Guthrie, Chem. Eng.*, **76**(*6*): *114* (*March 24, 1969*).]

TABLE E.2-5
Correction factors for pressure vessels

Shell material	CS	SS	Monel	Titanium
F_m, clad	1.00	2.25	3.89	4.25
F_m, solid	1.00	3.67	6.34	7.89

Distillation Column Trays and Tower Internals

$$\text{Installed Cost, \$} = \left(\frac{\text{M\&S}}{280}\right) 4.7 D^{1.55} H F_c$$

where D = diameter, ft

H = tray stack height, ft (24-in. spacing)

$F_c = F_s + F_t + F_m$

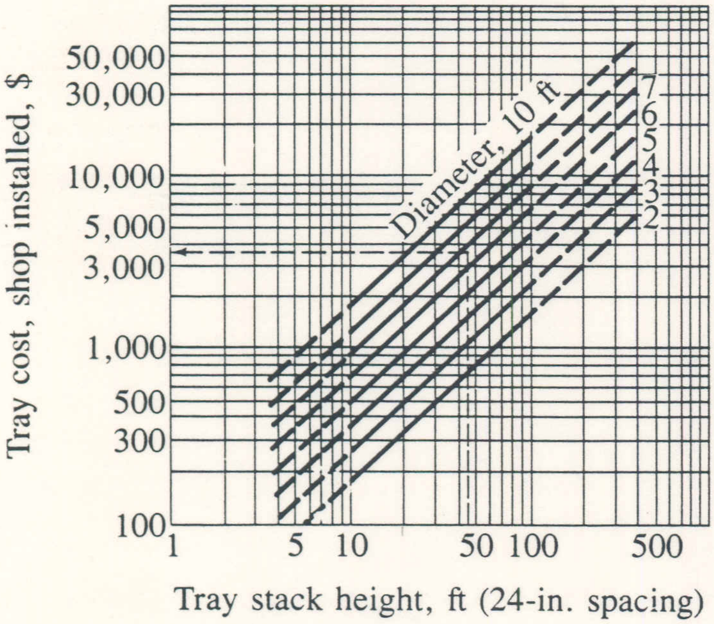

FIGURE E.2-6
Distillation column trays. [*K. M. Guthrie, Chem. Eng.*, **76**(*6*): *114* (*March 24, 1969*).]

TABLE E.2-6
Correction factors for column trays

Tray spacing, in.	24	18	12				
F_s	1.0	1.4	2.2				
Tray type		Grid (no down-comer)	Plate	Sieve	Trough or valve	Bubble cap	Koch Kascade
F_t	0.0		0.0	0.0	0.4	1.8	3.9
Tray material	CS	SS	Monel				
F_m	0.0	1.7	8.9				

TABLE E.2-7
Tower packings

Material	Materials and labor, $/ft^3$
Activated carbon	14.2
Alumina	12.6
Coke	3.5
Crushed limestone	5.8
Silica gel	27.2
1-in. Raschig rings—Stoneware	5.2
Porcelain	7.0
Stainless	70.2
1-in. Berl saddles—Stoneware	14.5
Porcelain	15.9

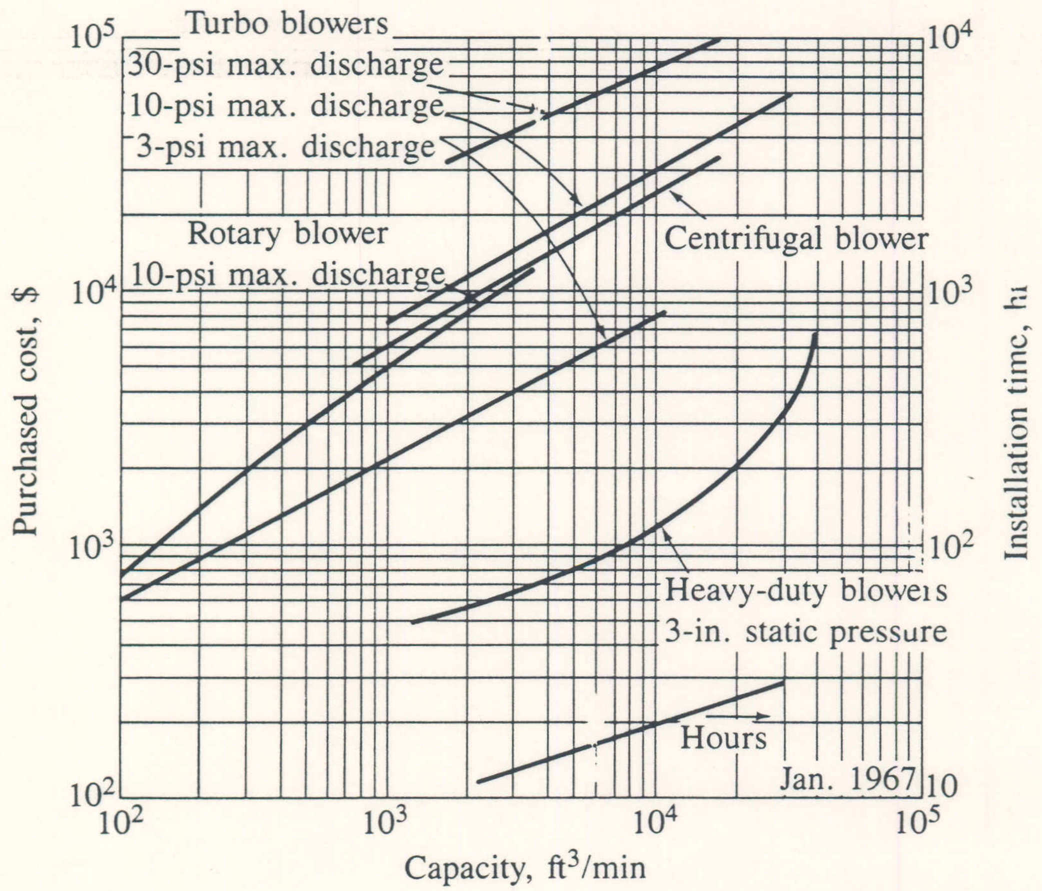

FIGURE E.2-7
Blowers (heavy-duty, industrial type). (*From M. S. Peters and K. D. Timmerhaus, Plant Design and Economics for Chemical Engineers, 3d ed., McGraw-Hill, New York, 1980, p. 562.*)

Turbo Blowers

From Peters and Timmerhaus,* January 1967 cost, see Fig. E.2-7

3-psi maximum discharge:

$$\text{Purchased Cost} = \left(\frac{\text{M\&S}}{260}\right) 39.7 Q^{0.529}$$

where Q = cfm and $100 < Q < 10{,}000$.

10-psi maximum discharge:

$$\text{Purchased Cost} = \left(\frac{\text{M\&S}}{260}\right) 126.5 Q^{0.598}$$

where Q = cfm and $1000 < Q < 30{,}000$.

30-psi maximum discharge:

$$\text{Purchased Cost} = \left(\frac{\text{M\&S}}{260}\right) 838.7 Q^{0.493}$$

where Q = cfm and $2000 < Q < 15{,}000$. Assume installation factor = 4.0.

* M. S. Peters and K. D. Timmerhaus, "Plant Design and Economics for Chemical Engineers," 3d ed., McGraw-Hill, New York, 1980, p. 562.

APPENDIX F

CONVERSION FACTORS

Area

$1\ ft^2 = 0.0929\ m^2$
$= 144\ in.^2$

Density

$1\ lb/ft^3 = 16.018\ kg/m^3$
$= 1/62.4\ g/cm^3$
1 lb mole of an ideal gas, 0°C, 1 atm = 359.0 ft^3
1 lb mole of air, 0°C 1 atm = 0.0807 lb/ft^3

Energy—Also see Work

1 Btu = 252 cal
= 1.055 kJ
= 777.9 ft · lbf
= 3.929×10^{-4} hp · hr
= 2.9307×10^{-4} kwhr

Force

1 lbf = 4.4482 N $(kg \cdot m/s^2)$
= 32.174 $lbm \cdot ft/s^2$
= 4.4482 × 10^5 dyn $(g \cdot cm/s^2)$

Heat Load—Also see Power

1 Btu/hr = 0.29307 w

Heat-Transfer Coefficient

1 $Btu/(hr \cdot ft^2 \cdot °F)$ = 5.6782 $w/(m^2 \cdot °C)$
= 1.3571 × 10^{-4} $cal/(cm^2 \cdot s \cdot °C)$

Length

1 ft = 0.3048 m

Mass

1 lbm = 0.45359 kg
1 ton (short) = 2000 lbm

Pressure

1 atm = 14.7 psi
1 psi = 6894.76 N/m^2 (dyn/cm^2)

Power—Also see Heat Load

1 hp = 550 $ft \cdot lbf/s$
= 0.7457 kw
= 2546.7 Btu/hr

Specific Heat

1 $Btu/(lbm \cdot °F)$ = 4.1869 $kJ/(kg \cdot °C)$

Work—Also see Energy

1 $ft \cdot lbf$ = 1.2851 × 10^{-3} Btu
= 3.7662 × 10^{-7} kwhr

Velocity

1 ft/s = 0.3048 m/s

Viscosity

1 lbm/(ft · s) = 1.4881 kg/(m · s)
1 lbm/(ft · hr) = 4.1338×10^{-3} g/(cm · s)

Volume

1 ft^3 = 0.028317 m^3
= 28.32 L
= 7.481 gal