# 20

# COSTS OF INDIVIDUAL EQUIPMENT

The choice of appropriate equipment often is influenced by considerations of price. A lower efficiency or a shorter life may be compensated for by a lower price. Funds may be low at the time of purchase and expected to be more abundant later, or the economic life of the process is expected to be limited. Alternate kinds of equipment for the same service may need to be considered: water-cooled exchangers vs. air coolers, concrete cooling towers vs. redwood, filters vs. centrifuges, pneumatic conveyors vs. screw or bucket elevators, and so on.

In this chapter, the prices of classes of the most frequently used equipment are collected in the form of correlating equations. The prices are given in terms of appropriate key characteristics of the equipment, such as sqft, gpm, lb/hr, etc. Factors for materials of construction and performance characteristics other than the basic ones also are provided. Although graphs are easily read and can bring out clearly desirable comparisons between related types of equipment, algebraic representation has been adopted here. Equations are .capable of consistent reading, particularly in comparison with interpolation on logarithmic scales, and are amenable to incorporation in computer programs.

Unless otherwise indicated, the unit price is $1000, $K. Except where indicated, notably for fired heaters, refrigeration systems, and cooling towers (which are installed prices), the prices are purchase prices, FOB, with delivery charges extra. In the United States delivery charges are of the order of 5% of the purchase price, but, of course, dependent on the unit value, as cost per lb or per

**EXAMPLE 20.1**
**Installed Cost of a Distillation Tower**

Shell and trays are made of AISI 304 stainless steel. Dimensional data are:

$D = 4$ ft,
$L = 120$ ft,
$N = 58$ sieve trays,
wall thickness $t_p = 0.50$ in. for pressure,
$t_b = 0.75$ in. at the bottom,
flanged and dished heads weigh 325 lb each,

$$\text{weight } W = (\pi/4)(16)(120(0.5/12)(501) + 2(325) = 32{,}129 \text{ lb}$$

$$C_b = \exp[7.123 + 0.1478(10.38) + 0.02488(10.38)^2 + 0.0158(120/4)\ln(0.75/0.50)] = 101{,}726$$

$$f_1 = 1.7,$$
$$f_2 = 1.189 + 0.0577(4) = 1.420,$$
$$f_3 = 0.85,$$
$$f_4 = 1,$$
$$C_t = 375.8\exp[0.1739(4)] = 753.4,$$
$$C_{p1} = 204.9(4)^{0.6332}(120)^{0.8016} = 22{,}879,$$
$$\text{purchase price } C = 1.7(101{,}726) + 58(1.42)(0.85)(753.4) + 22{,}879 = \$248{,}646$$

From Table 20.1, the installation factor is 2.1 so that the installed price is

$$C_{\text{installed}} = 2.1(248{,}646) = \$522{,}156$$

A tower packed with 2 in. pall rings instead of trays:

$$\text{packing volume } V_p = (\pi/4)(4)^2(120) = 1508 \text{ cuft},$$
$$C_{\text{installed}} = 2.1[1.7(101{,}726) + 1508(23.0) + 22{,}879)] = \$484{,}044$$

**EXAMPLE 20.2**
**Purchased and Installed Prices of Some Equipment**

**a.** A box type fired heater with CrMo tubes for pyrolysis at 1500 psig with a duty of 40 million Btu/hr. From Item No. 10 (Table 20.1), the installed price is

$$C_{\text{installed}} = 33.8(1.0 + 0.10 + 0.15)(40)^{0.86} = 1008.32 \text{ K\$}, \$1{,}008{,}320.$$

**b.** A 225 HP-reciprocating compressor with motor drive and belt drive coupling. Items Nos. 2 and 13 (Table 20.1). The installation factor is 1.3.

$$\text{compressor } C = 5960(225)^{0.61} = 162{,}210,$$
$$\text{motor, 1800 rpm, TEFC, } C = 1.2 \times \exp[4.5347 + 0.57065(5.42) + 0.04069(5.42)^2] = \$8113,$$
$$\text{belt drive coupling, } C = 1.2\exp[3.689 + 0.8917(5.42)] = \$6008,$$
$$\text{total installed cost, } C_{\text{total}} = 1.3(162{,}210 + 8113 + 6008) = \$229{,}230.$$

**c.** A two-stage steam ejector with one surface condenser to handle 200 lb/hr of air at 25 Torr, in carbon steel construction. From Table 20.3 the installation factor is 1.7.

$$X = 200/25 = 8,$$
$$f_1 = 1.6, \quad f_2 = 1.8, \quad f_3 = 1.0$$
$$\text{purchase } C = 11(1.6)(1.8(1.0)(8))^{0.41} = 74.31 \text{ K\$}, \$74{,}310,$$
$$\text{installed } C = 1.7C_p = \$126{,}330.$$

cuft. Multipliers have been developed whereby the installed cost of various kinds of equipment may be found. Such multipliers range from 1.2 to 3.0, but details are shown in Table 20.3.

Data are taken from a number of published sources and are updated to the beginning of 1985 with the cost indexes of *Chemical Engineering Magazine,* a selection of which is in Table 20.2. The main sources and the dates of their prices are Hall et al. (1981), Institut Francais du Petrole (1975), and Evans et al. (1979). References also are made to price data of some equipment not covered here. Many data as of mid-1982 have been collected by Ulrich (1984). Perry's *Chemical Engineers Handbook* (1984) has many data scattered throughout; the page numbers having such data are listed in the reference (Green, 1984).

Material of construction is a major factor in the price of equipment so that multipliers for prices relative to carbon steel or other standard materials are given for many of the items covered here. Usually only the parts in contact with process substances need be of special construction, so that, in general, the multipliers are not always as great as they are for vessels that are made entirely of special materials. Thus, when the tube side of an exchanger is special and the shell is carbon steel, the multiplier will vary with the amount of tube surface, as shown in that section.

As with most collections of data, the price data correlated here exhibit a certain amount of scatter. This is due in part to the incomplete characterizations in terms of which the correlations are made, but also to variations among manufacturers, qualities of construction, design differences, market situations, and other factors. Accordingly, the accuracy of the correlations cannot be claimed to be better than ±25% or so.

**TABLE 20.1. Index of Equipment**

1. Agitators
2. Compressors, turbines, fans
   - Centrifugal compressors
   - Reciprocating compressors
   - Screw compressors
   - Turbines
     - Pressure discharge
     - Vacuum discharge
   - Fans
3. Conveyors
   - Troughed belt
   - Flat belt
   - Screw, steel
   - Screw, stainless
   - Bucket elevator
   - Pneumatic
4. Cooling towers
   - Concrete
   - Wooden
5. Crushers and grinders
   - Cone crusher
   - Gyratory crusher
   - Jaw crusher
   - Hammer mill
   - Ball mill
   - Pulverizer
6. Crystallizers
   - External forced circulation
   - Internal draft tube
   - Batch vacuum
7. Distillation and absorption towers
   - Distillation tray towers
   - Absorption tray towers
   - Packed towers
8. Dryers
   - Rotary, combustion gas heated
   - Rotary, hot air heated
   - Rotary, steam tube heated
   - Cabinet dryers
   - Spray dryers
   - Multiple hearth furnace
9. Evaporators
   - Forced circulation
   - Long tube
   - Falling film
10. Fired heaters
    - Box types
    - Cylindrical types
11. Heat exchangers
    - Shell-and-tube
    - Double pipe
    - Air coolers
12. Mechanical separators
    - Centrifuges
    - Cyclone separators
      - Heavy duty
      - Standard duty
      - Multiclone
    - Disk separators
    - Filters
      - Rotary vacuum belt discharge
      - Rotary vacuum scraper discharge
      - Rotary vacuum disk
      - Horizontal vacuum belt
      - Pressure leaf
      - Plate-and-frame
    - Vibrating screens
13. Motors and couplings
    - Motors
    - Belt drive coupling
    - Chain drive coupling
    - Variable speed drive coupling
14. Pumps
    - Centrifugal
    - Vertical mixed flow
    - Vertical axial flow
    - Gear pumps
    - Reciprocating pumps
15. Refrigeration
16. Steam ejectors and vacuum pumps
    - Ejectors
    - Vacuum pumps
17. Vessels
    - Horizontal pressure vessels
    - Vertical pressure vessels
    - Storage tanks, shop fabricated
    - Storage tanks, field erected

**TABLE 20.2. Purchase Prices of Process Equipment (Basic: CE Plant Cost Index = 325, Middle 1985)**

**1. Agitators**
[Meyers and Kime, *Chem. Eng.*, 109–112 (27 Sep. 1976)]

$$C = \exp[a + b \ln \text{HP} + c(\ln \text{HP})^2] \quad \$, \quad 1 < \text{HP} < 400$$

| | | Single Impeller | | | Dual Impeller | | |
|---|---|---|---|---|---|---|---|
| | | Speed 1 | 2 | 3 | 1 | 2 | 3 |
| Carbon steel | a | 8.57 | 8.43 | 8.31 | 8.80 | 8.50 | 8.43 |
| | b | 0.1195 | −0.0880 | −0.1368 | 0.1603 | 0.0257 | −0.1981 |
| | c | 0.0819 | 0.1123 | 0.1015 | 0.0659 | 0.0878 | 0.1239 |
| Type 316 | a | 8.82 | 8.55 | 8.52 | 9.25 | 8.82 | 8.72 |
| | b | 0.2474 | 0.0308 | −0.1802 | 0.2801 | 0.1235 | −0.1225 |
| | c | 0.0654 | 0.0943 | 0.1158 | 0.0542 | 0.0818 | 0.1075 |

Speeds 1: 30, 37, and 45 rpm
2: 56, 68, 84, and 100 rpm
3: 125, 155, 190, and 230 rpm

**2. Compressors, turbines, and fans (K$)**

Centrifugal compressors, without drivers (IFP, 1981):

$$C = 6.49(\text{HP})^{0.62} \quad \text{K\$}, \quad 200 < \text{HP} < 30{,}000$$

Reciprocating compressors without drivers (IFP):

$$C = 5.96(\text{HP})^{0.61} \quad \text{K\$}, \quad 100 < \text{HP} < 20{,}000$$

Screw compressors with drivers (IFP):

$$C = 1.49(\text{HP})^{0.71} \quad \text{K\$}, \quad 10 < \text{HP} < 800$$

Turbines (IFP):

Pressure discharge, $C = 0.31(\text{HP})^{0.81}$ K$, $20 < \text{HP} < 5000$
vacuum discharge, $C = 0.69(\text{HP})^{0.81}$ K$, $200 < \text{HP} < 8000$

Fans with motors (Ulrich)

$$C = f_m f_p \exp[a + b \ln Q + c(\ln Q)^2] \text{ installed cost, K\$}, \quad Q \text{ in KSCFM}$$

| | *a* | *b* | *c* | *Q* |
|---|---|---|---|---|
| Radial blades | 0.4692 | 0.1203 | 0.0931 | 2–500 |
| Backward curved | 0.0400 | 0.1821 | 0.0786 | 2–900 |
| Propeller | −0.4456 | 0.2211 | 0.0820 | 2–300 |
| Propeller, with guide vanes | −1.0181 | 0.3332 | 0.0647 | 2–500 |

materials factor, $f_m$

| | |
|---|---|
| Carbon steel | 2.2 |
| Fiberglass | 4.0 |
| Stainless steel | 5.5 |
| Nickel alloy | 11.0 |

Pressure Factors, $F_p$

| | Centrifugal | | Axial | |
|---|---|---|---|---|
| Pressure (kPa[gage]) | Radial | Backward Curved | Prop. | Vane |
| 1 | 1.0 | 1.0 | 1.0 | 1.00 |
| 2 | 1.15 | 1.15 | — | 1.15 |
| 4 | 1.30 | 1.30 | — | 1.30 |
| 8 | 1.45 | 1.45 | — | — |
| 16 | 1.60 | — | — | — |

**3. Conveyors (IFP) K$**

Troughed belt: $C = 1.40L^{0.66}$, $10 < L < 1300$ ft
Flat belt: $C = 0.90L^{0.66}$, $10 < L < 1300$ ft
Screw (steel): $C = 0.40L^{0.78}$, $7 < L < 100$ ft
Screw (stainless steel): $C = 0.70L^{0.78}$, $7 < L < 100$ ft
Bucket elevator: $C = 4.22L^{0.63}$, $10 < L < 100$ ft
Pneumatic conveyor (*Chemical Engineers' Handbook,* McGraw-Hill, New York, 1984), 600 ft length

$$C = \exp[3.5612 - 0.0048 \ln W + 0.0913(\ln W)^2], \quad 10 < W < 100 \text{ klb/hr}$$

**4. Cooling towers, installed K$**

Concrete (IFP) $C = 135fQ^{0.61}$, $1 < Q < 60$ K gal/min:

| $\Delta t$ (°C) | 10 | 12 | 15 |
|---|---|---|---|
| $f$ | 1.0 | 1.5 | 2.0 |

Redwood, without basin (Hall): $C = 33.9Q^{0.85}$, $1.5 < Q < 20$ K gal/min

**5. Crushers and grinders (IFP) K$**

Cone crusher: $C = 1.55W^{1.05}$, $20 < W < 300$ tons/hr
Gyratory crusher: $C = 8.0W^{0.60}$, $25 < W < 200$ tons/hr
Jaw crusher: $C = 6.3W^{0.57}$, $10 < W < 200$ tons/hr
Hammer mill: $C = 2.44W^{0.78}$, $2 < W < 200$ tons/hr
Ball mill: $C = 50.0W^{0.69}$, $1 < W < 30$ tons/hr
Pulverizer: $C = 22.6W^{0.39}$, $1 < W < 5$ tons/hr

**6. Crystallizers** (IFP, *Chemical Engineers' Handbook,* p. 19.40)

External forced circulation:

$$C = f \exp[4.868 + 0.3092 \ln W + 0.0548(\ln W)^2],$$
$$10 < W < 100 \text{ klb/hr of crystals}$$

Internal draft tube: $C = 178fW^{0.58}$, $15 < W < 100$ klb/hr of crystals
Batch vacuum: $C = 8.16fV^{0.47}$,. $50 < V < 1000$ cuft of vessel

| Type | Material | *f* |
|---|---|---|
| Forced circulation | Mild steel | 1.0 |
| | Stainless type 304 | 2.5 |
| Vacuum batch | Mild steel | 1.0 |
| | Rubber-lined | 1.3 |
| | Stainless type 304 | 2.0 |

**7. Distillation and absorption towers, tray and packed (Evans et al., 1984) prices in $**

*Tray towers:*

$$C_t = f_1 C_b + N f_2 f_3 f_4 C_t + C_{p1}$$

*Distillation:*

$$C_b = \exp[7.123 + 0.1478(\ln W) + 0.02488(\ln W)^2 + 0.01580(L/D)\ln(T_b/T_p)],$$

$9020 < W < 2{,}470{,}000$ lbs of shell exclusive of nozzles and skirt

$C_t = 375.8\exp(0.1739D)$, $2 < D < 16$ ft tray diameter

$N$ = number of trays

$C_{p1} = 204.9D^{0.6332}L^{0.8016}$, $2 < D < 24$, $57 < L < 170$ ft (platforms and ladders)

| Material | $f_1$ | $f_2$ |
|---|---|---|
| Stainless steel, 304 | 1.7 | 1.189 + 0.0577*D* |
| Stainless steel, 316 | 2.1 | 1.401 + 0.0724*D* |
| Carpenter 20CB-3 | 3.2 | 1.525 + 0.0788*D* |
| Nickel-200 | 5.4 | |
| Monel-400 | 3.6 | 2.306 + 0.1120*D* |
| Inconel-600 | 3.9 | |
| Incoloy-825 | 3.7 | |
| Titanium | 7.7 | |

(*continued*)

**TABLE 20.2**—*(continued)*

| Tray Types | $f_3$ |
|---|---|
| Valve | 1.00 |
| Grid | 0.80 |
| Bubble cap | 1.59 |
| Sieve (with downcomer) | 0.85 |

$f_4 = 2.25/(1.0414)^N$, when the number of trays $N$ is less than 20

$T_b$ is the thickness of the shell at the bottom, $T_p$ is thickness required for the operating pressure, $D$ is the diameter of the shell and tray, $L$ is tangent-to-tangent length of the shell

*Absorption:*

$$C_b = \exp[6.629 + 0.1826(\ln W) + 0.02297(\ln W)^2],$$

$4250 < W < 980{,}000$ lb shell

$$C_{p1} = 246.4D^{0.7396}L^{0.7068}, \quad 3 < D < 21,$$

$27 < L < 40$ ft (platforms and ladders),

$f_1$, $f_2$, $f_3$, and $f_4$ as for distillation

Packed towers:

$$C = f_1 C_b + V_p C_p + C_{p1}$$

$V_p$ is volume of packing, $C_p$ is cost of packing \$/cuft

| Packing Type | $C_p$ (\$/cuft) |
|---|---|
| Ceramic Raschig rings, 1 in. | 19.6 |
| Metal Raschig rings, 1 in. | 32.3 |
| Intalox saddles, 1 in. | 19.6 |
| Ceramic Raschig rings, 2 in. | 13.6 |
| Metal Raschig rings, 2 in. | 23.0 |
| Metal Pall rings, 1 in. | 32.3 |
| Intalox saddles, 2 in. | 13.6 |
| Metal Pall rings, 2 in. | 23.0 |

**8. Dryers (IFP)**

Rotary combustion gas heated: $C = (1 + f_g + f_m)\exp[4.9504 - 0.5827(\ln A) + 0.0925(\ln A)^2]$, $200 < A < 30{,}000$ sqft lateral surface

Rotary hot air heated: $C = 2.38(1 + f_g + f_m)A^{0.63}$, $200 < A < 4000$ sqft lateral surface

Rotary steam tube: $C = 1.83FA_t^{0.60}$, $500 < A_t < 18{,}000$ sqft tube surface, $F = 1$ for carbon steel, $F = 1.75$ for 304 stainless

Cabinet dryer: $C = 1.15 f_p A^{0.77}$, $10 < A < 50$ sqft tray surface

| Pressure | $f_p$ |
|---|---|
| Atmospheric pressure | 1.0 |
| Vacuum | 2.0 |

| Material | $f_m$ |
|---|---|
| Mild steel | 1.0 |
| Stainless type 304 | 1.4 |

| Drying Gas | $f_g$ |
|---|---|
| Hot air | 0.00 |
| Combustion gas (direct contact) | 0.12 |
| Combustion gas (indirect contact) | 0.35 |

| Materials | $f_m$ |
|---|---|
| Mild steel | 0.00 |
| Lined with stainless 304–20% | 0.25 |
| Lined with stainless 316–20% | 0.50 |

Spray dryers:

$$C = F\exp(0.8403 + 0.8526(\ln x) - 0.0229(\ln x)^2,$$

$30 < x < 3000$ lb/hr evaporation

| Material | F |
|---|---|
| Carbon steel | 0.33 |
| 304, 321 | 1.00 |
| 316 | 1.13 |
| Monel | 3.0 |
| Inconel | 3.67 |

Multiple hearth furnaces (Hall et al., 1984)

$C = \exp(a + 0.88N)$, $4 < N < 14$ number of hearths

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Diameter (ft) | 6.0 | 10.0 | 14.25 | 16.75 | 18.75 | 22.25 | 26.75 |
| Sqft/hearth, approx | 12 | 36 | 89 | 119 | 172 | 244 | 342 |
| $a$ | 5.071 | 5.295 | 5.521 | 5.719 | 5.853 | 6.014 | 6.094 |

**9. Evaporators (IFP; also Chemical Engineers Handbook, p. 11.42)**

Forced circulation: $C = f_m \exp[5.9785 - 0.6056(\ln A) + 0.08514(\ln A)^2]$, $150 < A < 8000$ sqft heat transfer surface

Long tube: $C = 0.36 f_m A^{0.85}$, $300 < A < 20{,}000$ sqft

Falling film (316 internals, carbon steel shell)

$$C = \exp[3.2362 - 0.0126(\ln A) + 0.0244(\ln A)^2], \quad 150 < A < 4000 \text{ sqft}$$

**Forced-Circulation Evaporators**

| Construction Material: Shell/Tube | $f_m$ |
|---|---|
| Steel/copper | 1.00 |
| Monel/cupronickel | 1.35 |
| Nickel/nickel | 1.80 |

**Long-Tube Evaporators**

| Construction Material: Shell/Tube | $f_m$ |
|---|---|
| Steel/copper | 1.0 |
| Steel/steel | 0.6 |
| Steel/aluminum | 0.7 |
| Nickel/nickel | 3.3 |

**10. Fired heaters, installed (Hall) K\$**

Box type: $C = k(1 + f_d + f_p)Q^{0.86}$, $20 < Q < 200$ M Btu/hr

| Tube Material | $k$ |
|---|---|
| Carbon steel | 25.5 |
| CrMo steel | 33.8 |
| Stainless | 45.0 |

| Design Type | $f_d$ |
|---|---|
| Process heater | 0 |
| Pyrolysis | 0.10 |
| Reformer (without catalyst) | 0.35 |

| Design Pressure, (psi) | $f_p$ |
|---|---|
| Up to 500 | 0 |
| 1,000 | 0.10 |
| 1,500 | 0.15 |
| 2,000 | 0.25 |
| 2,500 | 0.40 |
| 3,000 | 0.60 |

Cylindrical type: $C = k(1 + f_d + f_p)Q^{0.82}$, $2 < Q < 30$ M Btu/hr

| Tube Material | $k$ |
|---|---|
| Carbon steel | 27.3 |
| CrMo steel | 40.2 |
| Stainless | 42.0 |

*(continued)*

| Design Type | $f_d$ |
|---|---|
| Cylindrical | 0 |
| Dowtherm | 0.33 |

| Design Pressure (psi) | $f_p$ |
|---|---|
| Up to 500 | 0 |
| 1,000 | 0.15 |
| 1,500 | 0.20 |

**11. Heat exchangers**

Shell-and-tube (Evans): $C = f_d f_m f_p C_b$, price in \$

$$C_b = \exp[8.821 - 0.30863(\ln A) + 0.0681(\ln A)^2],\quad 150 < A < 12{,}000 \text{ sqft}$$

| Type | $f_d$ |
|---|---|
| Fixed-head | $\exp[-1.1156 + 0.0906(\ln A)]$ |
| Kettle reboiler | 1.35 |
| U-tube | $\exp[-0.9816 + 0.0830(\ln A)]$ |

| Pressure Range (psig) | $f_p$ |
|---|---|
| 100–300 | $0.7771 + 0.04981(\ln A)$ |
| 300–600 | $1.0305 + 0.07140(\ln A)$ |
| 600–900 | $1.1400 + 0.12088(\ln A)$ |

| | $f_m = g_1 + g_2(\ln A)$ | |
|---|---|---|
| Material | $g_1$ | $g_2$ |
| Stainless steel 316 | 0.8603 | 0.23296 |
| Stainless steel 304 | 0.8193 | 0.15984 |
| Stainless steel 347 | 0.6116 | 0.22186 |
| Nickel 200 | 1.5092 | 0.60859 |
| Monel 400 | 1.2989 | 0.43377 |
| Inconel 600 | 1.2040 | 0.50764 |
| Incoloy 825 | 1.1854 | 0.49706 |
| Titanium | 1.5420 | 0.42913 |
| Hastelloy | 0.1549 | 0.51774 |

Double pipe (IFP): $C = 900 f_m f_p A^{0.18}$, $2 < A < 60$ sqft, price in \$

| Material: Shell/Tube | $f_m$ |
|---|---|
| cs/cs | 1.0 |
| cs/304L stainless | 1.9 |
| cs/316 stainless | 2.2 |

| Pressure (bar) | $f_p$ |
|---|---|
| ≤4 | 1.00 |
| 4–6 | 1.10 |
| 6–7 | 1.25 |

Air coolers (Hall): $C = 24.6A^{0.40}$, $0.05 < A < 200$ K sqft, price in K\$

**12. Mechanical separators**

Centrifuges: solid bowl, screen bowl or pusher types

$C = a + bW$, K\$

| | Inorganic Process | | Organic Process | |
|---|---|---|---|---|
| Material | $a$ | $b$ | $a$ | $b$ |
| Carbon steel | 42 | 1.63 | — | — |
| 316 | 65 | 3.50 | 98 | 5.06 |
| Monel | 70 | 5.50 | 114 | 7.14 |
| Nickel | 84.4 | 6.56 | 143 | 9.43 |
| Hastelloy | — | — | 300 | 10.0 |
| | $10 < W < 90$ | | $5 < W < 40$ tons/hr | |

Disk separators, 316 stainless (IFP):

$C = 8.0Q^{0.52}$, $15 < Q < 150$ gpm, K\$

Cyclone separators (IFP): K\$

heavy duty: $C = 1.39Q^{0.98}$, $2 < Q < 40$ K SCFM

standard duty: $C = 0.65Q^{0.91}$, $2 < Q < 40$ K SCFM

multiclone: $C = 1.56Q^{0.68}$, $9 < Q < 180$ K SCFM

Filters (Hall), prices in \$/sqft:

rotary vacuum belt discharge: $C = \exp[11.20 - 1.2252(\ln A) + 0.0587(\ln A)^2]$, $10 < A < 800$ sqft

rotary vacuum drum scraper discharge: $C = \exp[11.27 - 1.3408(\ln A) + 0.0709(\ln A)^2]$ \$/sqft, $10 < A < 1500$ sqft

rotary vacuum disk: $C = \exp[10.50 - 1.008(\ln A) + 0.0344(\ln A)^2]$ \$/sqft, $100 < A < 4000$ sqft

horizontal vacuum belt: $C = 28300/A^{0.5}$ \$/sqft, $10 < A < 1200$ sqft

pressure leaf: $C = 695/A^{0.29}$ \$/sqft, $30 < A < 2500$ sqft

plate-and-frame: (*Chemical Engineers' Handbook*):

$C = 460/A^{0.45}$ \$/sqft, $10 < A < 1000$ sqft

vibrating screen (IFP): $C = 3.1A^{0.59}$ K\$, $0.5 < A < 35$ sqft

**13. Motors and couplings, prices in \$**

Motors: $C = 1.2\exp[a_1 + a_2(\ln \text{HP}) + a_3(\ln \text{HP})^2]$

Belt drive coupling: $C = 1.2\exp[3.689 + 0.8917(\ln \text{HP})]$

Chain drive coupling: $C = 1.2\exp[5.329 + 0.5048(\ln \text{HP})]$

Variable speed drive coupling:

$C = 12{,}000/(1.562 + 7.877/\text{HP})$, HP < 75

| | Coefficients | | | |
|---|---|---|---|---|
| Type | $a_1$ | $a_2$ | $a_3$ | HP limit |
| Open, drip-proof | | | | |
| 3600 rpm | 4.8314 | 0.09666 | 0.10960 | 1–7.5 |
| | 4.1514 | 0.53470 | 0.05252 | 7.5–250 |
| | 4.2432 | 1.03251 | −0.03595 | 250–700 |
| 1800 rpm | 4.7075 | −0.01511 | 0.22888 | 1–7.5 |
| | 4.5212 | 0.47242 | 0.04820 | 7.5–250 |
| | 7.4044 | −0.06464 | 0.05448 | 250–600 |
| 1200 rpm | 4.9298 | 0.30118 | 0.12630 | 1–7.5 |
| | 5.0999 | 0.35861 | 0.06052 | 7.5–250 |
| | 4.6163 | 0.88531 | −0.02188 | 250–500 |
| Totally enclosed, fan-cooled | | | | |
| 3600 rpm | 5.1058 | 0.03316 | 0.15374 | 1–7.5 |
| | 3.8544 | 0.83311 | 0.02399 | 7.5–250 |
| | 5.3182 | 1.08470 | −0.05695 | 250–400 |
| 1800 rpm | 4.9687 | −0.00930 | 0.22616 | 7.5–250 |
| | 4.5347 | 0.57065 | 0.04609 | 250–400 |
| 1200 rpm | 5.1532 | 0.28931 | 0.14357 | 1–7.5 |
| | 5.3858 | 0.31004 | 0.07406 | 7.5–350 |
| Explosion-proof | | | | |
| 3600 rpm | 5.3934 | −0.00333 | 0.15475 | 1–7.5 |
| | 4.4442 | 0.60820 | 0.05202 | 7.5–200 |
| 1800 rpm | 5.2851 | 0.00048 | 0.19949 | 1–7.5 |
| | 4.8178 | 0.51086 | 0.05293 | 7.5–250 |
| 1200 rpm | 5.4166 | 0.31216 | 0.10573 | 1–7.5 |
| | 5.5655 | 0.31284 | 0.07212 | 7.5–200 |

**14. Pumps**

Centrifugal (Evans) prices in \$: $C = F_M F_T C_b$, base cast-iron, 3550 rpm VSC

$$C_b = 1.55\exp[8.833 - 0.6019(\ln Q\sqrt{H}) + 0.0519(\ln Q\sqrt{H})^2],\quad Q \text{ in gpm},\quad H \text{ in ft head}$$

| Material | Cost Factor $F_M$ |
|---|---|
| Cast steel | 1.35 |
| 304 or 316 fittings | 1.15 |
| Stainless steel, 304 or 316 | 2.00 |
| Cast Gould's alloy no. 20 | 2.00 |
| Nickel | 3.50 |
| Monel | 3.30 |
| ISO B | 4.95 |
| ISO C | 4.60 |
| Titanium | 9.70 |
| Hastelloy C | 2.95 |
| Ductile iron | 1.15 |
| Bronze | 1.90 |

$$F_T = \exp[b_1 + b_2(\ln Q\sqrt{H}) + b_3(\ln Q\sqrt{H})^2]$$

*(continued)*

**TABLE 20.2—(continued)**

| Type | $b_1$ | $b_2$ | $b_3$ |
|---|---|---|---|
| One-stage, 1750 rpm, VSC | 5.1029 | −1.2217 | 0.0771 |
| One-stage, 3550 rpm, HSC | 0.0632 | 0.2744 | −0.0253 |
| One-stage, 1750 rpm, HSC | 2.0290 | −0.2371 | 0.0102 |
| Two-stage, 3550 rpm, HSC | 13.7321 | −2.8304 | 0.1542 |
| Multistage, 3550 rpm, HSC | 9.8849 | −1.6164 | 0.0834 |

| Type | Flow Range (gpm) | Head Range (ft) | HP (max) |
|---|---|---|---|
| One-stage, 3550 rpm, VSC | 50–900 | 50–400 | 75 |
| One-stage, 1750 rpm, VSC | 50–3500 | 50–200 | 200 |
| One-stage. 3550 rpm, HSC | 100–1500 | 100–450 | 150 |
| One-stage, 1750 rpm, HSC | 250–5000 | 50–500 | 250 |
| Two-stage, 3550 rpm, HSC | 50–1100 | 300–1100 | 250 |
| Two-stage, 3550 rpm, HSC | 100–1500 | 650–3200 | 1450 |

Vertical mixed flow (IFP): $C = 0.036(\text{gpm})^{0.82}$ K\$, $500 < \text{gpm} < 130{,}000$

Vertical axial flow (IFP): $C = 0.020(\text{gpm})^{0.78}$ K\$, $1000 < \text{gpm} < 130{,}000$

Gear pumps (IFP): $C = \exp[-0.0881 + 0.1986(\ln Q) + 0.0291(\ln Q)^2]$ K\$, $10 < Q < 900$ gpm

Reciprocating (Pikulik and Diaz, 1979), without motor,

Cast iron: $C = 40.0Q^{0.81}$ K\$, $15 < Q < 400$ gpm

Others: $C = 410FQ^{0.52}$ K\$, $1 < Q < 400$ gpm

| | |
|---|---|
| 316 stainless | $F = 1.00$ |
| Al bronze | 1.40 |
| Nickel | 1.86 |
| Monel | 2.20 |

**15. Refrigeration (IFP):** $C = 146FQ^{0.65}$ K\$, $0.5 < Q < 400$ M Btu/hr, installed prices

| Temperature Level (°C) | $F$ |
|---|---|
| 0 | 1.00 |
| −10 | 1.55 |
| −20 | 2.10 |
| −30 | 2.65 |
| −40 | 3.20 |
| −50 | 4.00 |

**16. Steam ejectors and vacuum pumps (Pikulik and Diaz, 1979):**

Ejectors: $C = 11.0f_1f_2f_3X^{0.41}$ K\$, $0.1 < X < 100$

$X$ = (lb air/hr)/(suction pressure in Torr)

| Type | $f_1$ | No. Stages | $f_2$ | Material | $f_3$ |
|---|---|---|---|---|---|
| No condenser | 1.0 | 1 | 1.0 | carbon steel | 1.0 |
| 1 surface condenser | 1.6 | 2 | 1.8 | stainless steel | 2.0 |
| 1 barometric condenser | 1.7 | 3 | 2.1 | hastelloy | 3.0 |
| 2 surface condensers | 2.3 | 4 | 2.6 | | |
| 2 barometric condensers | 1.9 | 5 | 4.0 | | |

Vacuum pumps: $C = 8.15X^{1.03}$ K\$,

$0.3 < X < 15$ (lbs air/hr)/(suction Torr).

**17. Vessels (Evans) prices in \$**

Horizontal pressure vessels: $C = F_MC_b + C_a$

$C_b = \exp[8.571 - 0.2330(\ln W) + 0.04333(\ln W)^2]$,

$800 < W < 914{,}000$ lb shell weight

$C_a = 1370D^{0.2029}$, $3 < D < 12$ ft diameter (platforms and ladders)

Vertical vessels: $C = F_MC_b + C_a$

$C_b = \exp[9.100 - 0.2889(\ln W) + 0.04576(\ln W)^2]$,

$5000 < W < 226{,}000$ lb

$C_a = 246D^{0.7396}L^{0.7068}$, $6 < D < 10$,

$12 < L < 20$ ft tangent-to-tangent

| Material | Cost Factor $F_M$ |
|---|---|
| Stainless steel, 304 | 1.7 |
| Stainless steel, 316 | 2.1 |
| Carpenter 20CB-3 | 3.2 |
| Nickel-200 | 5.4 |
| Monel-400 | 3.6 |
| Inconel-600 | 3.9 |
| Incoloy-825 | 3.7 |
| Titanium | 7.7 |

Storage tanks, shop fabricated: $C = F_M \exp[2.631 + 1.3673(\ln V) - 0.06309(\ln V)^2]$, $1300 < V < 21{,}000$ gal

Storage tanks, field erected: $C = F_M \exp[11.662 - 0.6104(\ln V) + 0.04536(\ln V)^2]$, $21{,}000 < V < 11{,}000{,}000$ gal

| Material of Construction | Cost Factor $F_M$ |
|---|---|
| Stainless steel 316 | 2.7 |
| Stainless steel 304 | 2.4 |
| Stainless steel 347 | 3.0 |
| Nickel | 3.5 |
| Monel | 3.3 |
| Inconel | 3.8 |
| Zirconium | 11.0 |
| Titanium | 11.0 |
| Brick-and-rubber-or brick-and-polyester-lined steel | 2.75 |
| Rubber- or lead-lined steel | 1.9 |
| Polyester, fiberglass-reinforced | 0.32 |
| Aluminum | 2.7 |
| Copper | 2.3 |
| Concrete | 0.55 |

**TABLE 20.3. Multipliers for Installed Costs of Process Equipment[a]**

| Equipment | Multiplier | Equipment | Multiplier |
|---|---|---|---|
| Agitators, carbon steel | 1.3 | Chimneys and stacks | 1.2 |
| stainless steel | 1.2 | Columns, distillation, carbon steel | 3.0 |
| Air heaters, all types | 1.5 | distillation, stainless steel | 2.1 |
| Beaters | 1.4 | Compressors, motor driven | 1.3 |
| Blenders | 1.3 | steam on gas driven | 1.5 |
| Blowers | 1.4 | Conveyors and elevators | 1.4 |
| Boilers | 1.5 | Cooling tower, concrete | 1.2 |
| Centrifuges, carbon steel | 1.3 | Crushers, classifiers and mills | 1.3 |
| stainless steel | 1.2 | Crystallizers | 1.9 |

(continued)

**TABLE 20.3**—(*continued*)

| Equipment | Multiplier | Equipment | Multiplier |
|---|---|---|---|
| Cyclones | 1.4 | Pumps, centrifugal, carbon steel | 2.8 |
| Dryers, spray and air | 1.6 | centrifugal, stainless steel | 2.0 |
| other | 1.4 | centrifugal, Hastelloy trim | 1.4 |
| Ejectors | 1.7 | centrifugal, nickel trim | 1.7 |
| Evaporators, calandria | 1.5 | centrifugal, Monel trim | 1.7 |
| thin film, carbon steel | 2.5 | centrifugal, titanium trim | 1.4 |
| thin film, stainless steel | 1.9 | all others, stainless steel | 1.4 |
| Extruders, compounding | 1.5 | all others, carbon steel | 1.6 |
| Fans | 1.4 | Reactor kettles, carbon steel | 1.9 |
| Filters, all types | 1.4 | kettles, glass lined | 2.1 |
| Furnaces, direct fired | 1.3 | kettles, carbon steel | 1.9 |
| Gas holders | 1.3 | Reactors, multitubular, stainless steel | 1.6 |
| Granulators for plastic | 1.5 | multitubular, copper | 1.8 |
| Heat exchangers, air cooled, carbon steel | 2.5 | multitubular, carbon steel | 2.2 |
| coil in shell, stainless steel | 1.7 | Refrigeration plant | 1.5 |
| glass | 2.2 | Steam drums | 2.0 |
| graphite | 2.0 | Sum of equipment costs, stainless steel | 1.8 |
| plate, stainless steel | 1.5 | Sum of equipment costs, carbon steel | 2.0 |
| plate, carbon steel | 1.7 | Tanks, process, stainless steel | 1.8 |
| shell and tube, stainless/stainless steel | 1.9 | Tanks, process, copper | 1.9 |
| shell and tube, carbon/stainless steel | 2.1 | process, aluminum | 2.0 |
| Heat exchangers, shell and tube, carbon steel/aluminum | 2.2 | storage, stainless steel | 1.5 |
| shell and tube, carbon steel/copper | 2.0 | storage, aluminum | 1.7 |
| shell and tube, carbon steel /Monel | 1.8 | storage, carbon steel | 2.3 |
| shell and tube, Monel/Monel | 1.6 | field erected, stainless steel | 1.2 |
| shell and tube, carbon steel/Hastelloy | 1.4 | field erected, carbon steel | 1.4 |
| Instruments, all types | 2.5 | Turbines | 1.5 |
| Miscellaneous, carbon steel | 2.0 | Vessels, pressure, stainless steel | 1.7 |
| stainless steel | 1.5 | pressure, carbon steel | 2.8 |

[a] [J. Gran, *Chem. Eng.*, (6 Apr. 1981)].
Installed Cost = (purchase price)(multiplier).

**TABLE 20.4. Chemical Engineering Magazine Cost Indexes**

| Year | 1970 | 1975 | 1980 | Oct. 1985 |
|---|---|---|---|---|
| CE Plant Cost Index | 125.7 | 182.4 | 261.2 | 325.8 |
| Equipment costs | 123.8 | 194.7 | | 347.5 |
| Fabricated equipment | 122.7 | 192.2 | | 335.5 |
| Process machinery | 122.9 | 184.7 | | 333.3 |
| Piping, valves, and fittings | 132.0 | 217.0 | | 385.3 |
| Process instruments and controls | 132.1 | 181.4 | | 323.9 |
| Pumps and compressors | 125.6 | 208.3 | | 421.1 |
| Electrical equipment | 99.8 | 142.1 | | 251.9 |

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