APPENDIX C

Equipment Cost-Capacity Algorithms[1]

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. Alternative 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

[1]The cost-capacity algorithms were obtained from Stanley M. Walas' book, Chemical Process Equipment: Selection and Design (Woburn, MA: Butterworth, 1988). Permission was obtained to reproduce the material. Butterworth is now part of Elsevier Science and Technical Publications.

Example 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,

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

$$C_b = 1.218 \exp[7.123 + 0.1478(10.38) + 0.02488(10.38)^2 + 0.158(120/4) \ln(0.75/0.50)] = 697{,}532,$$

$f_1 = 1.7$,

$f_2 = 1.189 + 0.0577(4) = 1.420$,

$f_3 = 0.85$,

$f_4 = 1$,

$C_t = 457.7 \exp[0.1739(4)] = 917.6$,

$C_{p1} = 249.1(4)^{0.6332}(120)^{0.8016} = 27{,}867$,

$$\text{purchase price } C = 1.7(697{,}532) + 58(1.42)(0.85)(917.6) + 27{,}867 = \$1{,}266{,}414$$

From Table 3, the installation factor is 2.1 so that the installed price is

$$C_{\text{installed}} = 2.1(1{,}266{,}414) = \$2{,}659{,}467.$$

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

packing volume $V_p = (\pi/4)(4)^2(120) = 1508$ cuft,

$$C_{\text{installed}} = 2.1[1.7(697{,}532) + 1508(28.0) + 27{,}867] = \$2{,}637{,}380.$$

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

Example 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 1), the installed price is

$$C_{installed} = (6218)\ 33.8(1.0 + 0.10 + 0.15)(40)^{0.86} = 1{,}228{,}134$$

b. A 225 HP reciprocating compressor with motor drive and belt drive coupling. Items Nos. 2 and 13 (Table 1). The installation factor is 1.3.

$$\text{Compressor } C = 7190(225)^{0.61} = 197{,}572,$$

$$\text{motor, 1800 rpm, TEFC, } C = 1.46 \times \exp[4.5347 + 0.57065(5.42) + 0.04069(5.42)^2] = \$11{,}858$$

$$\text{belt drive coupling, } C = 1.46 \exp[3.689 + 0.8917(5.42)] = \$8{,}772,$$

$$\text{total installed cost, } C_{total} = 1.3(197{,}572 + 11{,}858 + 8772) = \$283{,}663.$$

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 3 the installation factor is 1.7.

$$X = 200/25 = 8,$$

$$f_1 = 1.6,\ f_2 = 1.8,\ f_3 = 1.0$$

$$\text{purchase } C_p = 13.3(1.6)(1.8(1.0)(8))^{0.41} = \$90{,}510,$$

$$\text{installed } C = 1.7C_p = \$153{,}866.$$

(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 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 1.

Data are taken from Walas and were updated to the end of fourth quarter 2002, a selection of which is in Table 2. The equipment prices have been spot checked with vendors.

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   - Reciprocating compressors
   - Screw compressors
   - Turbines
     - Pressure discharge
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   - Fans
3. Conveyors
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   - Bucket elevator
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5. Crushers and grinders
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   - Hammer mill
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   - Pulverizer
6. Crystallizers
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Table 2 Purchase Prices of Process Equipment Costs 1st Q 2003

1. Agitators

$C = 1.218 \exp[a + b \ln HP + c(\ln HP)^2]$ K$, $1 < HP < 400$

		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

$$C = 7.90(HP)^{0.62} \quad K\$, \quad 200 < HP < 30{,}000$$

Reciprocating compressors without drivers

$$C = 7.19(HP)^{0.61} \quad K\$, \quad 100 < HP < 20{,}000$$

Screw compressors with drivers

$$C = 1.81(HP)^{0.71} \quad K\$, \quad 10 < HP < 800$$

Turbines:

Pressure discharge, $C = 0.378(HP)^{0.81}$ K$, $20 < HP < 5000$
vacuum discharge, $C = 1.10(HP)^{0.81}$ K$, $200 < HP < 8000$

Fans with motors

$$C = 1.218\, f_m f_p \exp[a + b \ln Q + c(\ln Q)^2] \text{ installed cost, K\$}, \quad Q \text{ in KSCFM}$$

(*continued*)

TABLE 2 (*continued*)

	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

Installation 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 K$

Troughed belt: $C = 1.71L^{0.66}$, $10 < L < 1300$ ft

Flat belt: $C = 1.10L^{0.66}$, $10 < L < 1300$ ft

Screw (steel): $C = 0.49L^{0.78}$, $7 < L < 100$ ft

Screw (stainless steel): $C = 0.85L^{0.78}$, $7 < L < 100$ ft

Bucket elevator: $C = 5.14L^{0.63}$, $10 < L < 100$ ft

Pneumatic conveyor 600 ft length

$$C = 1.218 \exp[3.5612 - 0.0048 \ln W + 0.0913(\ln W)^2], 10 < W < 100 \text{ klb/hr}$$

4. Cooling towers, installed K$

Concrete $C = 164fQ^{0.61}$, $1 < Q < 60$ K gal/min:

Δt(°C)	10	12	15
f	1.0	1.5	2.0

Redwood, without basin: $C = 44.3Q^{0.85}$, $1.5 < Q < 20$ K gal/min

Table 2 *(continued)*

5. Crushers and grinders K$

Cone crusher: $C = 1.89W^{1.05}$, $20 < W < 300$ tons/hr
Gyratory crusher: $C = 9.7W^{0.60}$, $25 < W < 200$ tons/hr
Jaw crusher: $C = 7.7W^{0.57}$, $10 < W < 200$ tons/hr
Hammer mill: $C = 2.97W^{0.78}$, $2 < W < 200$ tons/hr
Ball mill: $C = 61.0W^{0.69}$, $1 < W < 30$ tons/hr
Pulverizer: $C = 27.5W^{0.39}$, $1 < W < 5$ tons/hr

6. Crystallizers

External forced circulation:

$$C = 1.218\, f \exp\{4.868 + 0.3092 \ln W + 0.0548(\ln W)^2\},$$
$10 < W < 100$ klb/hr of crystals

Internal draft tube: $C = 217fW^{0.58}$, $15 < W < 100$ klb/hr of crystals
Batch vacuum: $C = 9.94fV^{0.47}$, $50 < V < 1000$ 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 prices in $

Tray towers:

$$C_t = 1.218\,[f_1 C_b + N f_2 f_3 f_4 C_t + C_{pl}]$$

Distillation:

$$C_b = 1.218 \exp[7.123 + 0.1478 (\ln W) + 0.02488(\ln W)^2 + 0.01580(L/D) \ln (T_b/T_p)],$$
$9020 < W < 2{,}470{,}000$ lbs of shell exclusive of nozzles and skirt

$C_t = 457.7 \exp(0.1739D)$, $2 < D < 16$ ft tray diameter
N = number of trays
$C_{p1} = 249.6D^{0.6332}L^{0.8016}$, $2 < D < 24$, $57 < L < 170$ ft (platforms and ladders)

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

TABLE 2 (*continued*)

Tray Types	f_3
Valve	1.00
Grid	0.80
Bubble cap	1.59
Sieve (with downcorner)	0.95

$f_4 = 2.25/(1.0414)^N$, 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:

$C_b = 1.218\exp[6.629 + 0.1826(\ln W) + 0.02297(\ln W)^2]$,
$4250 < W < 980{,}000$ lb shell
$C_{p1} = 300D^{0.7396}L^{0.7068}$, $3 < D < 21$,
$27 < L < 40$ ft (platforms and ladders),

f_1, f_2, f_3, and f_4 as for distillation

Packed towers:

$C = 1.218\,[f_1C_b + V_pC_p + C_{p1}]$

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

Packing Type	C_p (\$/cuft)
Ceramic Raschig rings, 1 in.	23.9
Metal Raschig rings, 1 in.	39.3
Intalox saddles, 1 in.	23.9
Ceramic Raschig rings, 2 in.	76.6
Metal Raschig rings, 2 in.	28.0
Metal Pall rings, 1 in.	39.3
Intalox saddles, 2 in.	17.4
Metal Pall rings, 2 in.	28.0

8. Dryers

Rotary combustion gas heated: $C = 1.218(1 + f_g + f_m)\exp[4.9504 - 0.5827(\ln A) + 0.0925(\ln A)^2]$, $200 < A < 30{,}000$ sqft lateral surface

Table 2 *(continued)*

Rotary hot air heated: $C = 2.90(1 + f_g + f_m)A^{0.63}$, $200 < A < 4000$ sqft lateral surface

Rotary steam tube: $C = 2.23FA_t^{0.60}$, $500 < A_t < 18{,}000$ sqft tube surface, $F = 1$ for carbon steel, $F = 1.75$ for 304 stainless

Cabinet dryer: $C = 1.40 f_p A^{0.77}$, $10 < A < 50$ 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:

$$C = 1.218\ F\exp(0.8403 + 0.8526(\ln x) - 0.0229(\ln x)^2,$$

$30 < x < 3000$ 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, 1984)

$$C = 1.218\exp(a + 0.88N), \quad 4 < N < 14 \text{ number of hearths}$$

TABLE 2 (*continued*)

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)

Forced circulation: $C = 1.218\, f_m \exp[5.9785 - 0.6056(\ln A) + 0.08514(\ln A)^2]$, $150 < A < 8000$ sqft heat transfer surface

Long tube: $C = 0.44 f_m A^{0.85}$, $300 < A < 20{,}000$ sqft

Falling film (316 internals, carbon steel shell)

$$C = 1.218 \exp[3.2362 - 0.0126(\ln A) + 0.0244(\ln A)^2], \quad 150 < A < 4000 \text{ sqft}$$

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

Box type: $C = 1.218\, k(1 + f_d + f_p)Q^{0.86}$, $20 < Q < 200$ 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

TABLE 2 (*continued*)

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: $C = 1.218k(1 + f_d + f_p)Q^{0.82}$, $2 < Q < 30$ M Btu/hr

Tube Material	k
Carbon steel	27.3
CrMo steel	40.2
Stainless	42.0

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: $C = 1.218\, f_d f_m f_p C_b$, price in \$

$C_b = \exp[8.821 - 0.30863(\ln A) + 0.0681(\ln A)^2]$, $150 < A < 12{,}000$ 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	$1.1400 + 0.12088(\ln A)$

$f_m = g_1 + g_2(\ln A)$

TABLE 2 *(continued)*

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: $C = 1096\, f_m f_p A^{0.18}$, $2 < A < 60$ 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: $C = 30.0A^{0.40}$, $0.05 < A < 200$ K sqft, price in K$

12. Mechanical separators

Centrifuges: solid bowl, screen bowl or pusher types

$C = 1.218\,[a + bW]$, 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	

TABLE 2 *(continued)*

Disk separators, 316 stainless:

$C = 9.74\ Q^{0.52}$, $15 < Q < 150$ gpm, K$

Cyclone separators: K$

Heavy duty: $C = 1.69Q^{0.98}$, $2 < Q < 40$ K SCFM

Standard duty: $C = 0.79Q^{0.91}$, $2 < Q < 40$ K SCFM

Multiclone: $C = 1.90Q^{0.68}$, $9 < Q < 180$ K SCFM

Filters, prices in $/sqft:

rotary vacuum belt discharge: $C = 1.218\exp[11.20 - 1.2252(\ln A) + 0.0587(\ln A)^2]$, $10 < A < 800$ sqft

rotary vacuum drum scraper discharge: $C = 1.218\exp[11.27 - 1.3408(\ln A) + 0.0709(\ln A)^2]$ $/sqft, $10 < A < 1500$ sqft

rotary vacuum disk: $C = 1.218\exp[10.50 - 1.008(\ln A) + 0.0344(\ln A)^2]$ $/sqft, $100 < A < 4000$ sqft

horizontal vacuum belt: $C = 34469/A^{0.5}$ $/sqft, $10 < A < 1200$ sqft

pressure leaf: $C = 847/A^{0.29}$ $/sqft, $30 < A < 2500$ sqft

plate-and-frame: $C = 560/A^{0.45}$ $/sqft, $10 < A < 1000$ sqft

vibrating screen: $C = 3.8A^{0.59}$ K$, $0.5 < A < 35$ sqft

13. Motors and couplings, prices in $

Motors: $C = 1.46\exp[a_1 + a_2(\ln \mathrm{HP}) + a_3(\ln \mathrm{HP})^2]$

Belt drive coupling: $C = 1.46\exp[3.689 + 0.8917(\ln \mathrm{HP})]$

Chain drive coupling: $C = 1.46\exp[5.329 + 0.5048(\ln \mathrm{HP})]$

Variable speed drive coupling: $C = 14616/(1.562 + 7.877/\mathrm{HP})$, $\mathrm{HP} < 75$

	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

Table 2 (*continued*)

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 prices in \$: $C = F_M F_T C_b$, base cast-iron, 3550 rpm

VSC

$$C_b = 1.39 \exp[8.833 - 0.6019(\ln Q\sqrt{H}) + 0.0519(\ln Q\sqrt{H})^2],\ Q \text{ in gpm, } H \text{ in ft head}$$

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

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

Table 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: $C = 0.044(\text{gpm})^{0.82}\text{K\$}, \; 500 < \text{gpm} < 130{,}000$

Vertical axial flow: $C = 0.024(\text{gpm})^{0.78}\text{K\$}, \; 1000 < \text{gpm} < 130{,}000$

Gear pumps: $C = 1.218 \exp[-0.0881 + 0.1986(\ln Q) + 0.0291(\ln Q)^2]\text{K\$}, \; 10 < Q < 900 \text{ gpm}$

Reciprocating:

Cast iron: $C = 76.9Q^{0.81}\text{K\$}, \; 15 < Q < 400 \text{ gpm}$

Others: $C = 795FQ^{0.52}\text{K\$}, \; 1 < Q < 400 \text{ gpm}$

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

15. Refrigeration: $C = 178FQ^{0.65}\text{K\$}$, $0.5 < Q < 400$ 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

Table 2 (*continued*)

16. Steam ejectors and vacuum pumps

Ejectors: $C = 13.3 f_1 f_2 f_3 X^{0.41}$ K\$, $0.1 < X < 100$

X = (fb 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	astelloy	3.0
2 surface condensers	2.3	4	2.6		
2 barometric condensers	1.9	5	4.0		

Vacuum pumps: $C = 9.93 X^{1.03}$ K\$,

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

17. Vessels prices in \$

Horizontal pressure vessels: $C = F_M C_b + C_a$

$C_b = 1.218 \exp[8.571 - 0.2330(\ln W) + 0.04333(\ln W)^2]$,
$800 < W < 914{,}000$ lb shell weight
$C_a = 1669 D^{0.2029}$, $3 < D < 12$ ft diameter (platforms and ladders)

Vertical vessels: $C = F_M C_b + C_a$

$C_b = 1.218 \exp[9.100 - 0.2889(\ln W) + 0.04576(\ln W)^2]$,

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

$C_a = 300 D^{0.7396} L^{0.7068}$, $6 < D < 10$,

$12 < L < 20$ 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

Table 2 (*continued*)

Storage tanks, shop fabricated: $C = 1.218F_M \exp[2.631 + 1.3673(\ln V) - 0.06309(\ln V)^2]$, $1300 < V < 21{,}000$ gal

Storage tanks, field erected: $C = 1.218F_M \exp[11.662 - 0.6104(\ln V) + 0.04536(\ln V)^2]$, $21{,}000 < V < 11{,}000{,}000$ 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
Polyster, fiberglass-reinforced	0.32
Aluminium	2.7
Copper	2.3
Concrete	0.55

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 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. For multipliers see Table 3.

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 $\pm 25\%$ or so.

TABLE 3 Multipliers for Installed Costs of Process Equipment[a]

Equipment	Multiplier	Equipment	Multiplier
Agitators, carbon steel	1.3	Evaporators, calandria	1.5
stainless steel	1.2	thin film, carbon steel	2.5
Air heaters, all types	1.5	thin film, stainless steel	1.9
Beaters	1.4	Extruders, compounding	1.5
Blenders	1.3	Fans	1.4
Blowers	1.4	Filters, all types	1.4
Boilers	1.5	Furnaces, direct fired	1.3
Centrifuges, carbon steel	1.3	Gas holders	1.3
stainless steel	1.2	Granulators for plastic	1.5
Chimneys and stacks	1.2	Heat exchangers, air cooled, carbon steel	2.5
Columns, distillation, carbon steel	3.0	coil in shell, stainless steel	1.7
distillation, stainless steel	2.1	Glass	2.2
Compressors, motor driven	1.3	Graphite	2.0
steam on gas driven	1.5	plate, stainless steel	1.5
Conveyors and elevators	1.4	plate, carbon steel	1.7
Cooling tower, concrete	1.2	shell and tube, stainless/stainless steel	1.9
Crushers, classifiers and mills	1.3	shell and tube, carbon/stainless steel	2.1
Crystallizers	1.9	Heat exchangers, shell and tube, carbon/steel/aluminum	2.2
Cyclones	1.4	shell and tube, carbon steel/copper	2.0
Dryers, spray and air	1.6	shell and tube, carbon steel/Monal	1.8
other	1.4	shell and tube, Monel/Monel	1.6
Ejectors	1.7	shell and tube, carbon steel/Hastelloy	1.4

Instruments, all types	2.5	multitubular, carbon steel	2.2
Miscellaneous, carbon steel	2.0	Refrigeration plant	1.5
stainless steel	1.5	Steam drums	2.0
Pumps, centrifugal, carbon steel	2.8	Sum of equipment costs, stainless steel	1.8
centrifugal, stainless steel	2.0	Sum of equipment costs, carbon steel	2.0
centrifugal, Hastelloy trim	1.4	Tanks, process, stainless steel	1.8
centrifugal, nickel trim	1.7	Tanks, process, copper	1.9
centrifugal, Monel trim	1.7	process, aluminum	2.0
centrifugal, titanium trim	1.4	storage, stainless steel	1.5
all others, stainless steel	1.4	storage, aluminum	1.7
all others, carbon steel	1.6	storage, carbon steel	2.3
Reactor kettles, carbon steel	1.9	field erected, stainless steel	1.2
kettles, glass lined	2.1	field erected, carbon steel	1.4
kettles, carbon steel	1.9	Turbines	1.5
Reactors, multitubular, stainless steel	1.6	Vessels, pressure, stainless steel	1.7
multitubular, copper	1.8	pressure, carbon steel	2.8

[a] [J. Gran, *Chem. Eng.*, (6 Apr. 1981)].
Installed Cost = (purchase price)(multiplier).
Note: The multipliers have remained essentially the same through late 2002.

REFERENCE

1. SM Walas. Chemical Process Equipment: Selection and Design. Woburn, MA: Butterworth, 1988.