

Appendix A Cost Equations and Curves for the CAPCOST Program

The purpose of this appendix is to present the equations and figures that describe the relationships used in the capital equipment-costing program CAPCOST introduced in [Chapter 7](#) and used throughout the text. The program is based on the module factor approach to costing that was originally introduced by Guthrie [1, 2] and modified by Ulrich [3].

A.1 Purchased Equipment Costs

All the data for the purchased cost of equipment for the second edition of this book were obtained from a survey of equipment manufacturers during the period May to September of 2001, so an average value of the CEPCI of 397 over this period should be used when accounting for inflation.

Additional process equipment has been added to the third edition and is listed below:

- Conveyors
- Crystallizers
- Dryers
- Dust Collectors
- Filters
- Mixers
- Reactors
- Screens

The purchased costs for these types of equipment were obtained in 2003 but the costs given here have been normalized to 2001. For this new equipment, bare module factors were not available, nor were pressure factors or materials of construction factors. In general, these units are generally bought as a package, and installation in the plant is not expensive. The bare module factors for these units are taken to be the field installation factors given by Guthrie [1, 2].

Data for the purchased cost of the equipment, at ambient operating pressure and using carbon steel construction, C_p^o , were fitted to the following equation:

(A.1)

$$\log_{10} C_p^o = K_1 + K_2 \log_{10}(A) + K_3 [\log_{10}(A)]^2$$

where A is the capacity or size parameter for the equipment. The data for K_1 , K_2 , and K_3 , along with the maximum and minimum values used in the correlation, are given in [Table A.1](#). These data are also presented in the form of graphs in [Figures A.1–A.17](#). It should be noted that in these figures, the data are plotted as C_p^o/A as a function of size attribute, A . This form of the graph clearly illustrates the decreasing

cost per unit of capacity as the size of the equipment increases.

Table A.1 Equipment Cost Data to Be Used with [Equation A.1](#)

Equipment Type	Equipment Description	K_1	K_2	K_3	Capacity, Units	Min Size	Max Size
Blenders	Kneader	5.0141	-0.4133	0.3224	Volume, m ³	0.14	3
	Ribbon	4.1366	-0.4928	0.0070	Volume, m ³	0.7	11
	Rotary	4.1366	-0.4928	0.0070	Volume, m ³	0.7	11
Centrifuges	Auto batch separator	4.7681	-0.0260	0.0240	Diameter, m	0.5	1.7
	Centrifugal separator	4.3612	-0.1236	-0.0049	Diameter, m	0.5	1
	Oscillating screen	4.8600	-0.6660	0.1063	Diameter, m	0.5	1.1
	Solid bowl w/o motor	4.9697	0.1689	0.0038	Diameter, m	0.3	2
Compressors	Centrifugal, axial, and reciprocating	2.2897	1.3604	-0.1027	Fluid power, kW	450	3000
	Rotary	5.0355	-1.8002	0.8253	Fluid power, kW	18	950
Conveyors	Apron	3.9255	-0.4961	0.1506	Area, m ²	1.0	15
	Belt	4.0637	-0.7416	0.1550	Area, m ²	0.5	325
	Pneumatic	4.6616	-0.6795	0.0638	Area, m ²	0.75	65
	Screw	3.6062	-0.7341	0.1982	Area, m ²	0.5	30
Crystallizers	Batch	4.5097	-0.8269	0.1344	Volume, m ³	1.5	30
Drives	Gas turbine	-21.7702	13.2175	-1.5279	Shaft power, kW	7500	23,000
	Intern comb. engine	2.7635	0.8574	-0.0098	Shaft power, kW	10	10,000
	Steam turbine	2.6259	1.4398	-0.1776	Shaft power, kW	70	7500
	Electric—explosion-proof	2.4604	1.4191	-0.1798	Shaft power, kW	75	2600
	Electric—totally enclosed	1.9560	1.7142	-0.2282	Shaft power, kW	75	2600
	Electric—open/drip-proof	2.9508	1.0688	-0.1315	Shaft power, kW	75	2600
Dryers	Drum	4.5472	-0.7269	0.1340	Area, m ²	0.5	50
	Rotary, gas fired	3.5645	0.1118	-0.0777	Area, m ²	5	100
	Tray	3.6951	-0.4558	-0.1248	Area, m ²	1.8	20

Equipment Type	Equipment Description	K_1	K_2	K_3	Capacity, Units	Min Size	Max Size
Dust Collectors	Baghouse	4.5007	-0.5818	0.0813	Volume, m ³	0.08	350
	Cyclone scrubbers	3.6298	-0.4991	0.0411	Volume, m ³	0.06	200
	Electrostatic precipitator	3.6298	-0.4991	0.0411	Volume, m ³	0.06	200
	Venturi scrubber	3.6298	-0.4991	0.0411	Volume, m ³	0.06	200
Evaporators	Forced circulation (pumped)	5.0238	0.3475	0.0703	Area, m ²	5	1000
	Falling film	3.9119	0.8627	-0.0088	Area, m ²	50	500
	Agitated film (scrapped wall)	5.0000	0.1490	-0.0134	Area, m ²	0.5	5
	Short tube	5.2366	-0.6572	0.3500	Area, m ²	10	100
Fans	Long tube	4.6420	0.3698	0.0025	Area, m ²	100	10,000
	Centrifugal radial	3.5391	-0.3533	0.4477	Gas flowrate, m ³ /s	1	100
	Backward curve	3.3471	-0.0734	0.3090	Gas flowrate, m ³ /s	1	100
	Axial vane	3.1761	-0.1373	0.3414	Gas flowrate, m ³ /s	1	100
Filters	Axial tube	3.0414	-0.3375	0.4722	Gas flowrate, m ³ /s	1	100
	Bent	5.1055	-0.5001	0.0001	Area, m ²	0.9	115
	Cartridge	3.2107	-0.2403	0.0027	Area, m ²	15	200
	Disc and drum	4.8123	-0.7142	0.0420	Area, m ²	0.9	300
Furnaces	Gravity	4.2756	-0.6480	0.0714	Area, m ²	0.5	80
	Leaf	3.8187	-0.3765	0.0176	Area, m ²	0.6	235
	Pan	4.8123	-0.7142	0.0420	Area, m ²	0.9	300
	Plate and frame	4.2756	-0.6480	0.0714	Area, m ²	0.5	80
	Table	5.1055	-0.5001	0.0001	Area, m ²	0.9	115
	Tube	5.1055	-0.5001	0.0001	Area, m ²	0.9	115
	Reformer furnace	3.0680	0.6597	0.0194	Duty, kW	3000	100,000
	Pyrolysis furnace	2.3859	0.9721	-0.0206	Duty, kW	3000	100,000
	Nonreactive fired heater	7.3488	-1.1666	0.2028	Duty, kW	1000	100,000

(continued)

Equipment Type	Equipment Description	K_1	K_2	K_3	Capacity, Units	Min Size	Max Size
Heat exchangers	Scraped wall	3.7803	0.8569	0.0349	Area, m ²	2	20
	Teflon tube	3.8062	0.8924	-0.1671	Area, m ²	1	10
	Bayonet	4.2768	-0.0495	0.1431	Area, m ²	10	1000
	Floating head	4.8306	-0.8509	0.3187	Area, m ²	10	1000
	Fixed tube	4.3247	-0.3030	0.1634	Area, m ²	10	1000
	U-tube	4.1884	-0.2503	0.1974	Area, m ²	10	1000
	Kettle reboiler	4.4646	-0.5277	0.3955	Area, m ²	10	100
	Double pipe	3.3444	0.2745	-0.0472	Area, m ²	1	10
	Multiple pipe	2.7652	0.7282	0.0783	Area, m ²	10	100
	Flat plate	4.6656	-0.1557	0.1547	Area, m ²	10	1000
	Spiral plate	4.6561	-0.2947	0.2207	Area, m ²	1	100
	Air cooler	4.0336	0.2341	0.0497	Area, m ²	10	10000
	Spiral tube	3.9912	0.0668	0.2430	Area, m ²	1	100
Heaters	Diphenyl heater	2.2628	0.8581	0.0003	Duty, kW	650	10750
	Molten salt heater	1.1979	1.4782	-0.0958	Duty, kW	650	10750
	Hot water heater	2.0829	0.9074	-0.0243	Duty, kW	650	10750
	Steam boiler	6.9617	-1.4800	0.3161	Duty, kW	1200	9400
Mixers	Impeller	3.8511	-0.2991	-0.0003	Power, kW	5	150
	Propeller	4.3207	-0.9641	0.1346	Power, kW	5	500
	Turbine	3.4092	-0.5104	0.0030	Power, kW	5	150
Packing	Loose (for towers)	2.4493	0.9744	0.0055	Volume, m ³	0.03	628
Process vessels	Horizontal	3.5565	0.3776	0.0905	Volume, m ³	0.1	628
	Vertical	3.4974	0.4485	0.1074	Volume, m ³	0.3	520
Pumps	Reciprocating	3.8696	0.3161	0.1220	Shaft power, kW	0.1	200
	Positive displacement	3.4771	0.1350	0.1438	Shaft power, kW	1	100
	Centrifugal	3.3892	0.0536	0.1538	Shaft power, kW	1	300

(continued)

Equipment Type	Equipment Description	K_1	K_2	K_3	Capacity, Units	Min Size	Max Size
Reactors	Autoclave	4.5587	-0.7014	0.0020	Volume, m ³	1	15
	Fermenter	4.1052	-0.4680	-0.0005	Volume, m ³	0.1	35
	Inoculum tank	3.7957	-0.5407	0.0160	Volume, m ³	0.07	1
	Jacketed agitated	4.1052	-0.4680	-0.0005	Volume, m ³	0.1	35
	Jacketed nonagitated	3.3496	-0.2765	0.0025	Volume, m ³	5	45
	Mixer/settler	4.7116	-0.5521	0.0004	Volume, m ³	0.04	60
Screens	DSM	3.8050	-0.4144	0.2120	Area, m ²	0.3	6
	Rotary	4.0485	-0.8882	0.3260	Area, m ²	0.3	15
	Stationary	3.8219	0.0368	-0.6050	Area, m ²	2	11
	Vibrating	4.0485	-0.8882	0.3260	Area, m ²	0.3	15
Towers	Tray and packed	3.4974	0.4485	0.1074	Volume, m ³	0.3	520
Tanks	API—fixed roof	4.8509	-0.3973	0.1445	Volume, m ³	90	30000
	API—floating roof	5.9567	-0.7585	0.1749	Volume, m ³	1000	40000
Trays	Sieve	2.9949	0.4465	0.3961	Area, m ²	0.07	12.30
	Valve	3.3322	0.4838	0.3434	Area, m ²	0.70	10.50
	Demisters	3.2353	0.4838	0.3434	Area, m ²	0.70	10.50
Turbines	Axial gas turbines	2.7051	1.4398	-0.1776	Fluid power, kW	100	4000
	Radial gas/liquid expanders	2.2476	1.4965	-0.1618	Fluid power, kW	100	1500
Vaporizers	Internal coils/jackets	4.0000	0.4321	0.1700	Volume, m ³	1	100
	Jacketed vessels	3.8751	0.3328	0.1901	Volume, m ³	1	100

Figure A.1 Purchased Costs for Compressors and Drives (Cost Data for Compressors and Drives Taken from R-Books Software by Richardson Engineering Services, Inc. [4])

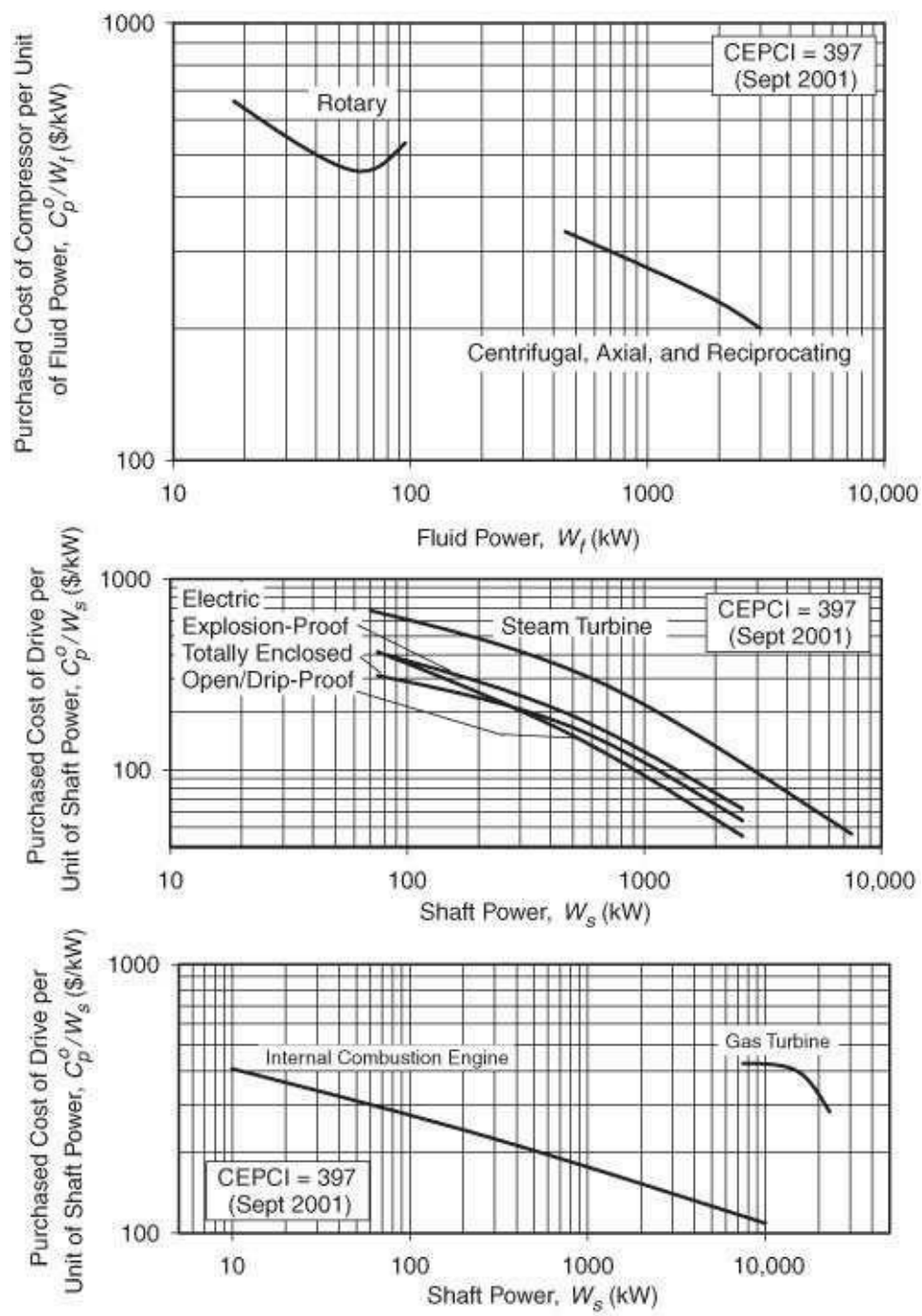


Figure A.2 Purchased Costs for Evaporators and Vaporizers

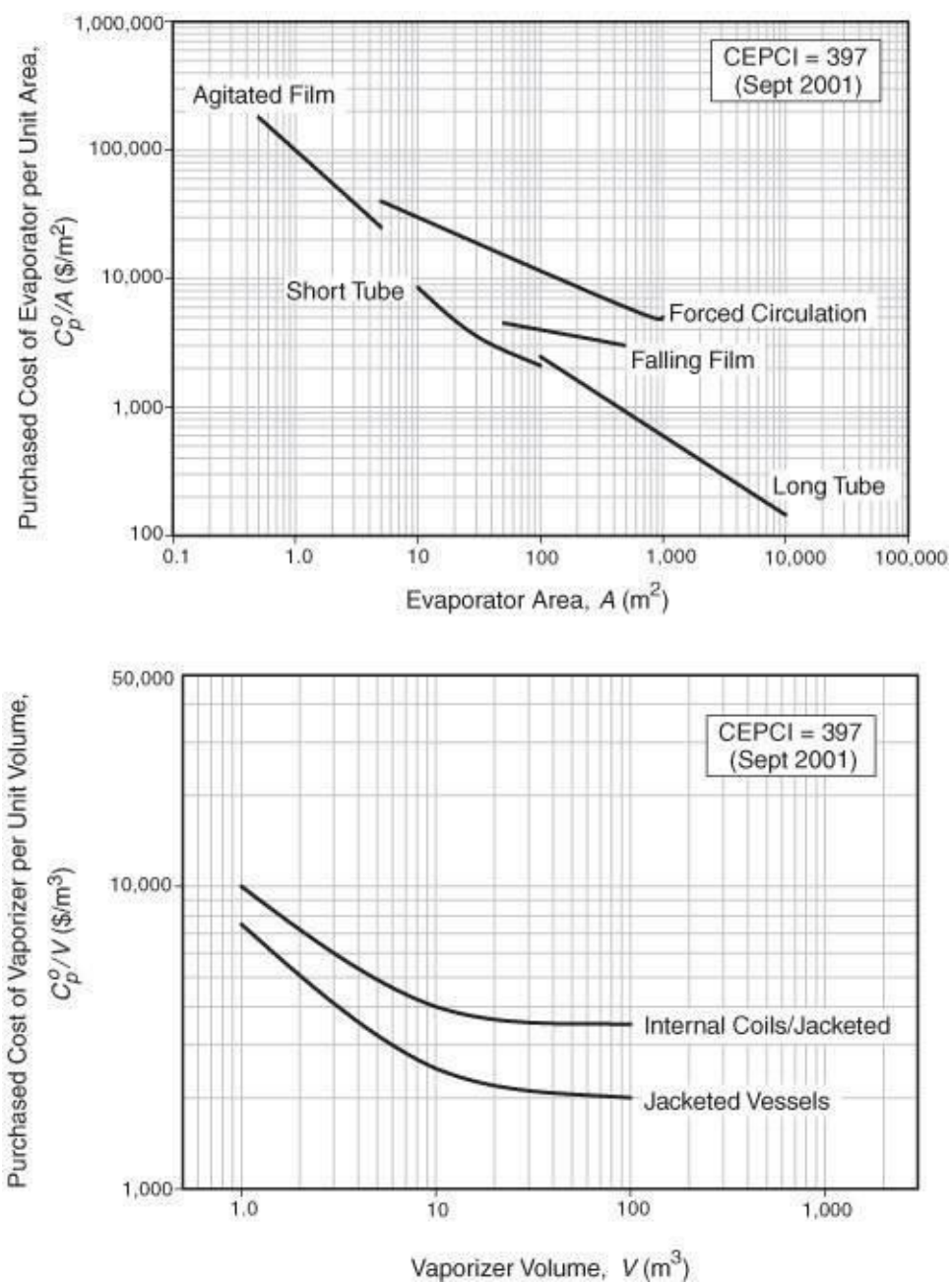


Figure A.3 Purchased Costs for Fans, Pumps, and Power Recovery Equipment (Cost Data for Fans Taken from R-Books Software by Richardson Engineering services [4])

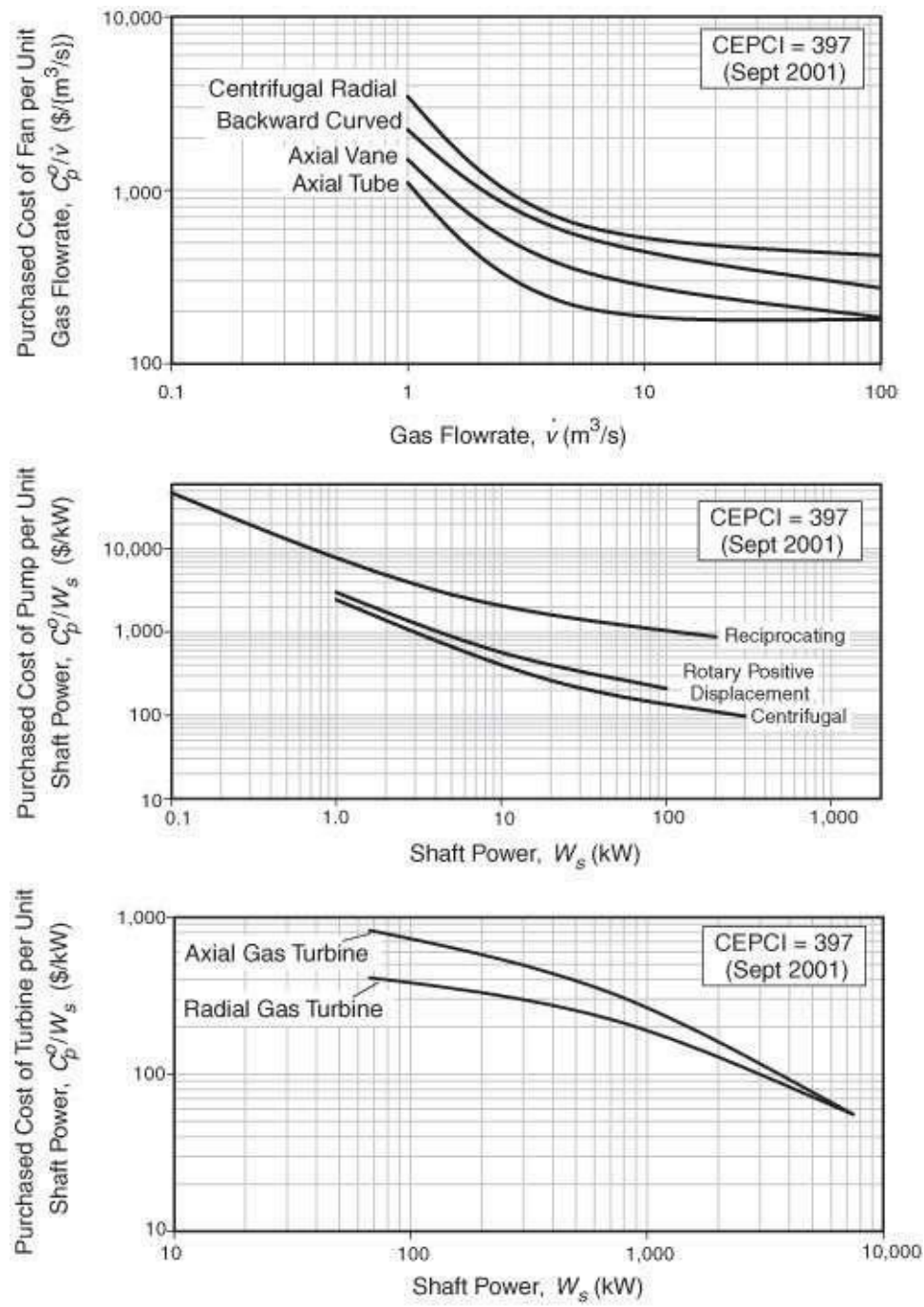


Figure A.4 Purchased Costs for Fired Heaters and Furnaces

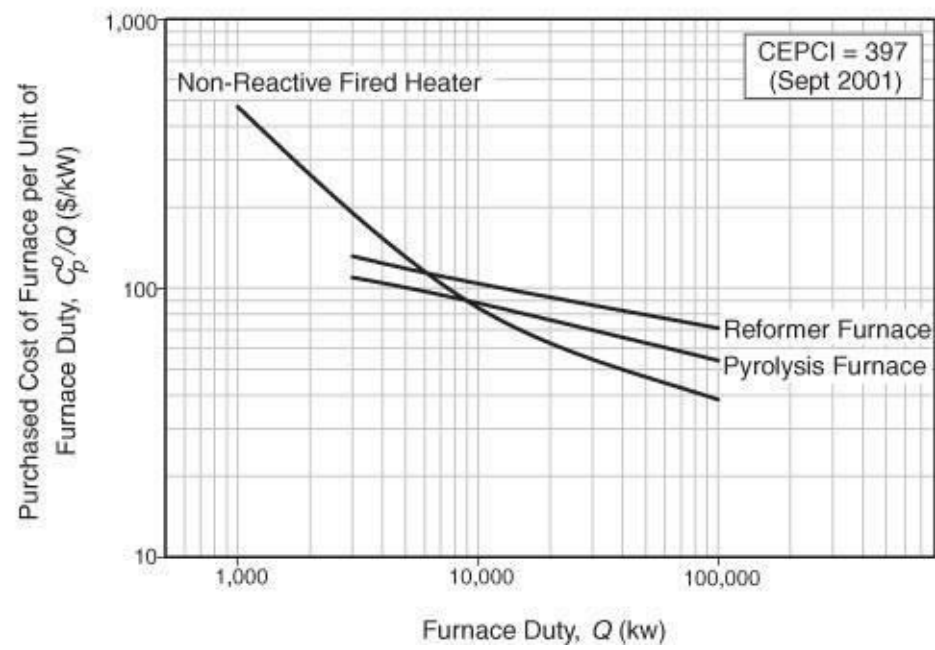
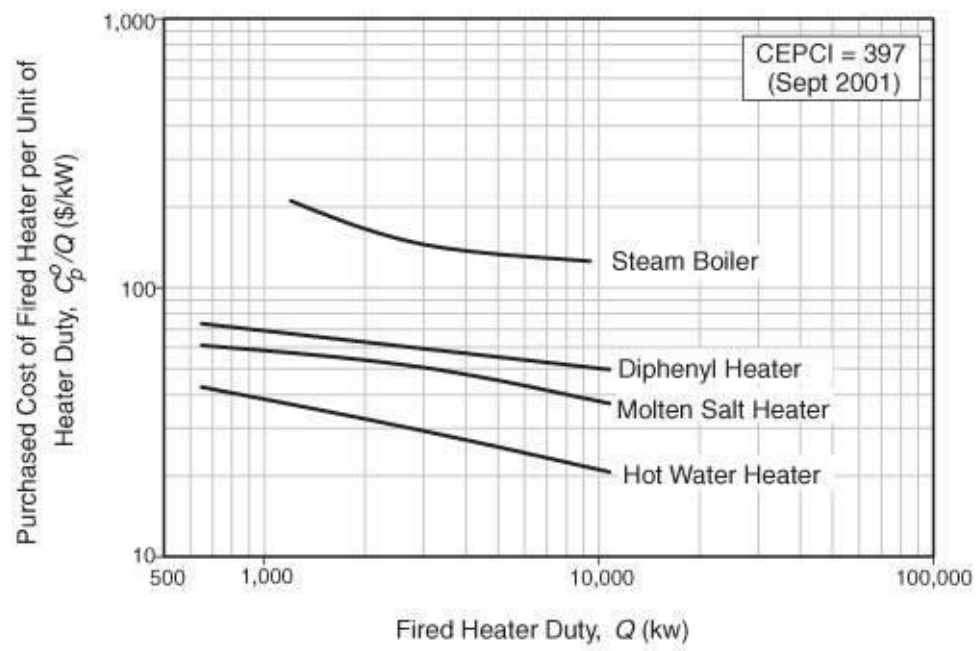


Figure A.5 Purchased Costs for Heat Exchangers

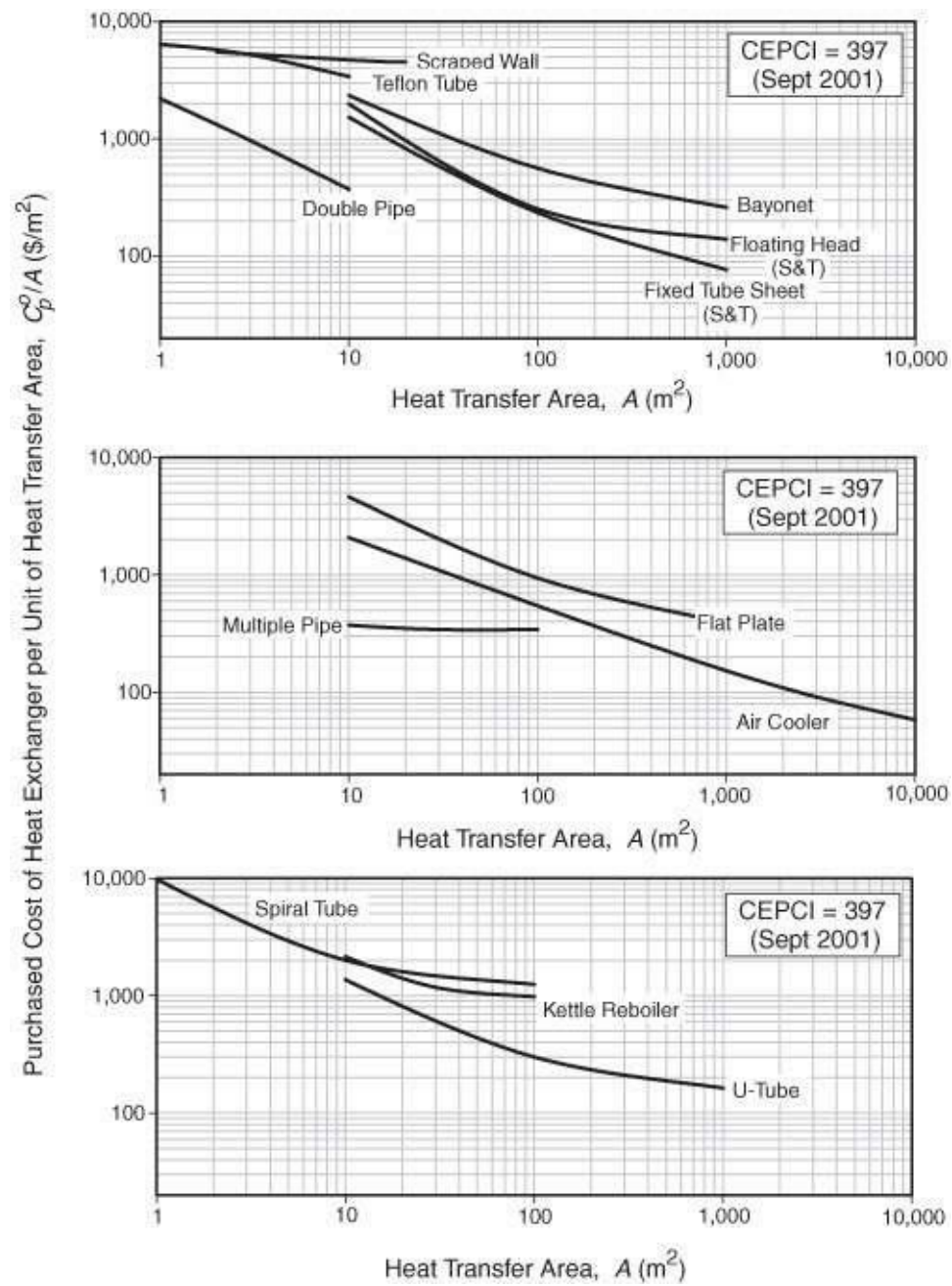


Figure A.6 Purchased Costs for Packing, Trays, and Demisters

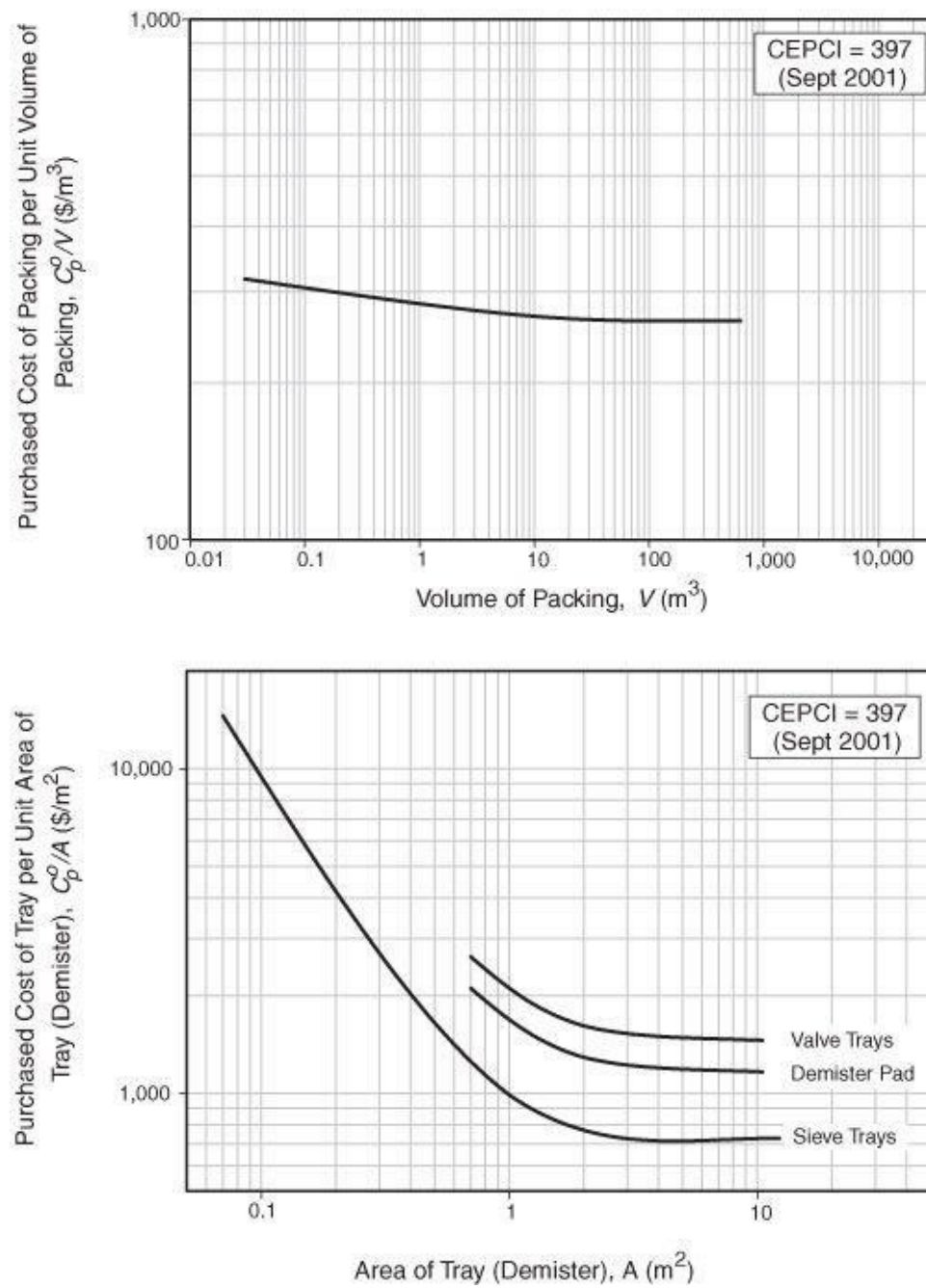


Figure A.7 Purchased Costs of Storage Tank and Process Vessels. (Data for Storage Tanks Taken from R-Books Software by Richardson Engineering Services [4])

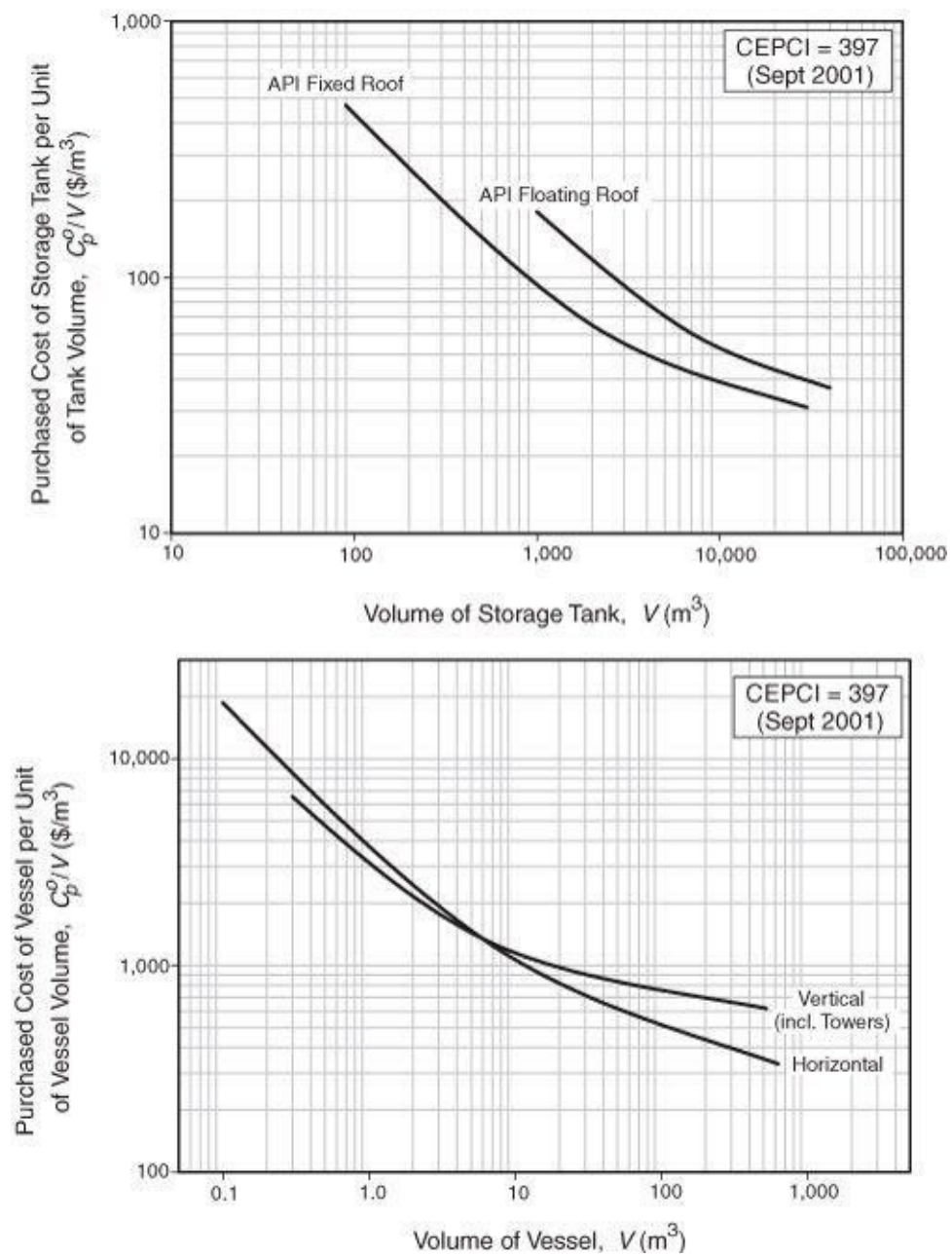
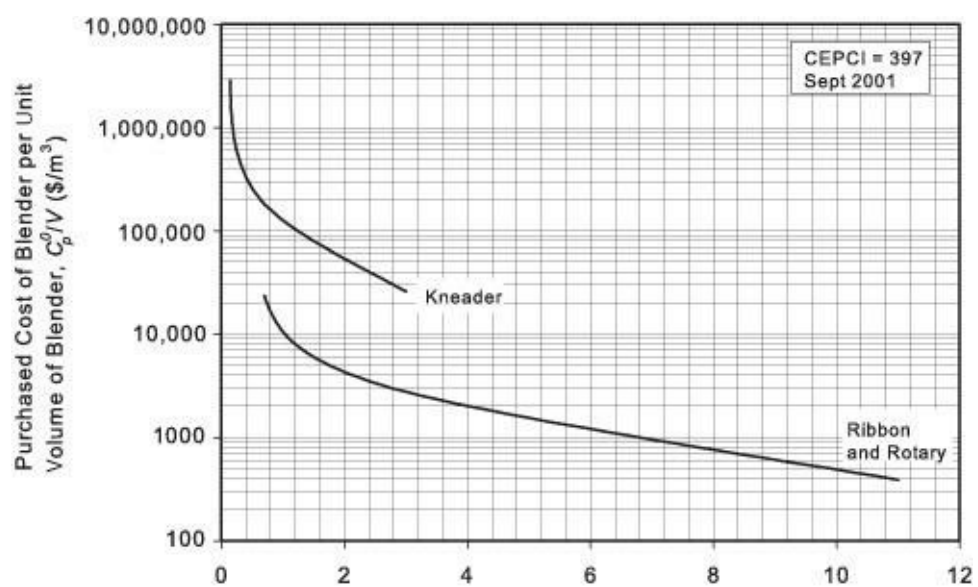


Figure A.8 Purchased Costs for Blenders



Volume of Blender, V (m^3)

Figure A.9 Purchased Costs of Centrifuges

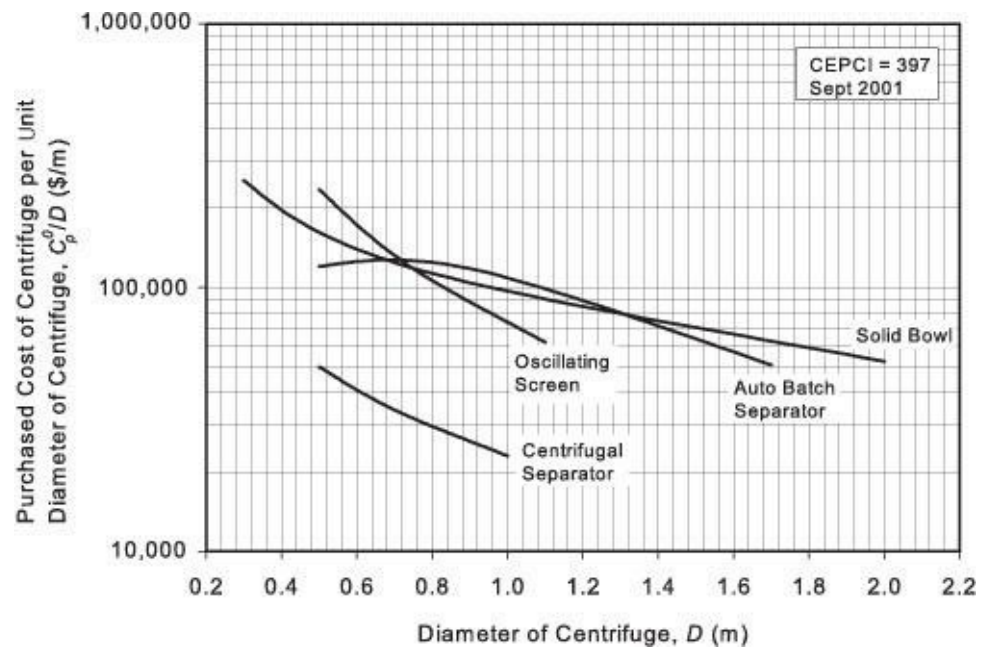


Figure A.10 Purchased Costs for Conveyors

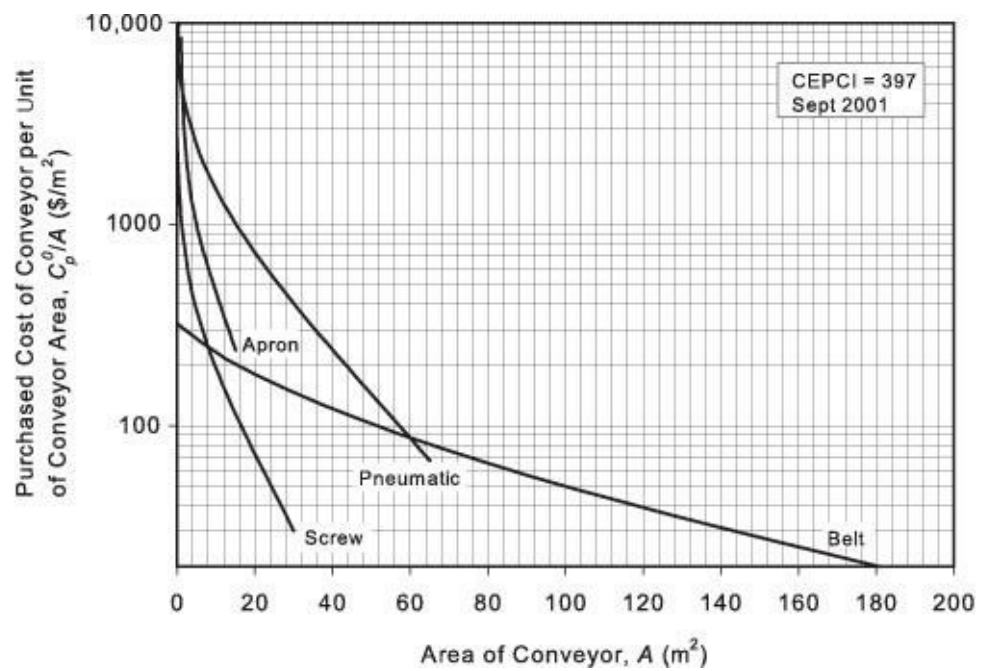


Figure A.11 Purchased Costs for Crystallizers

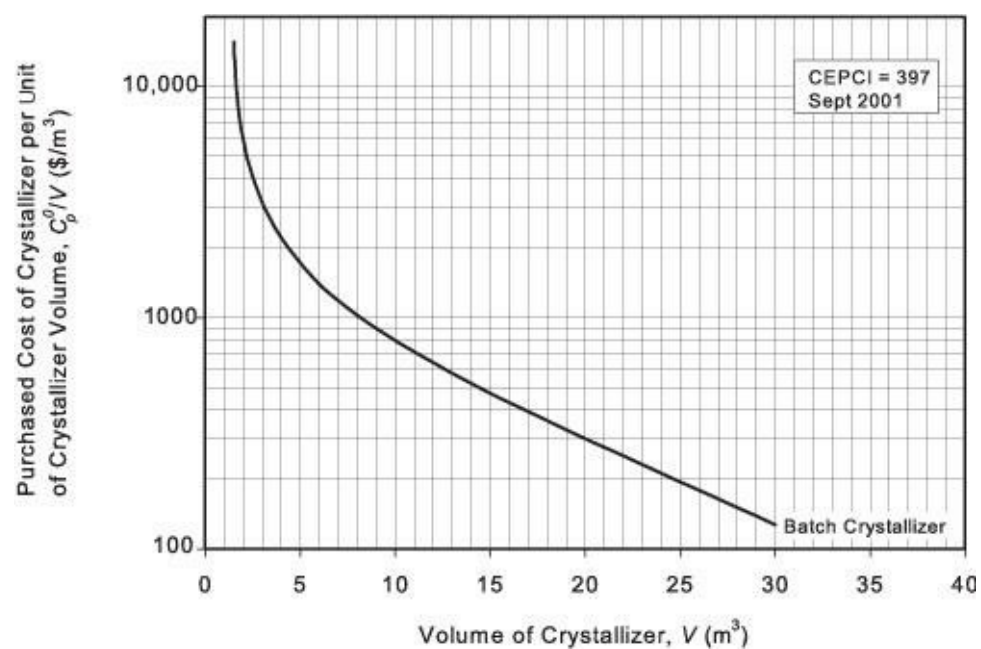


Figure A.12 Purchased Costs for Dryers

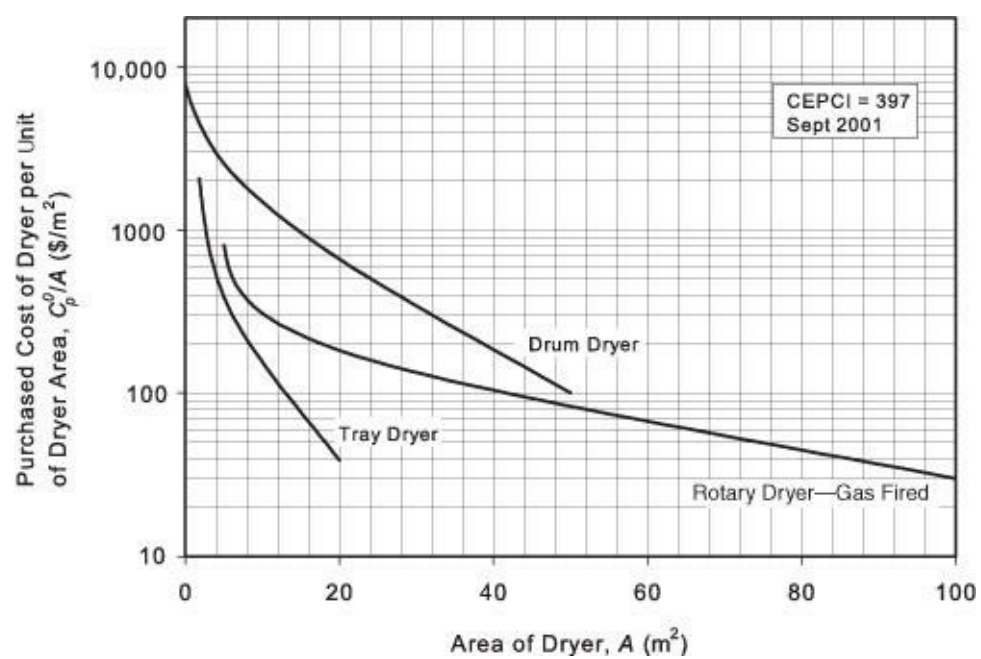


Figure A.13 Purchased Costs of Dust Collectors

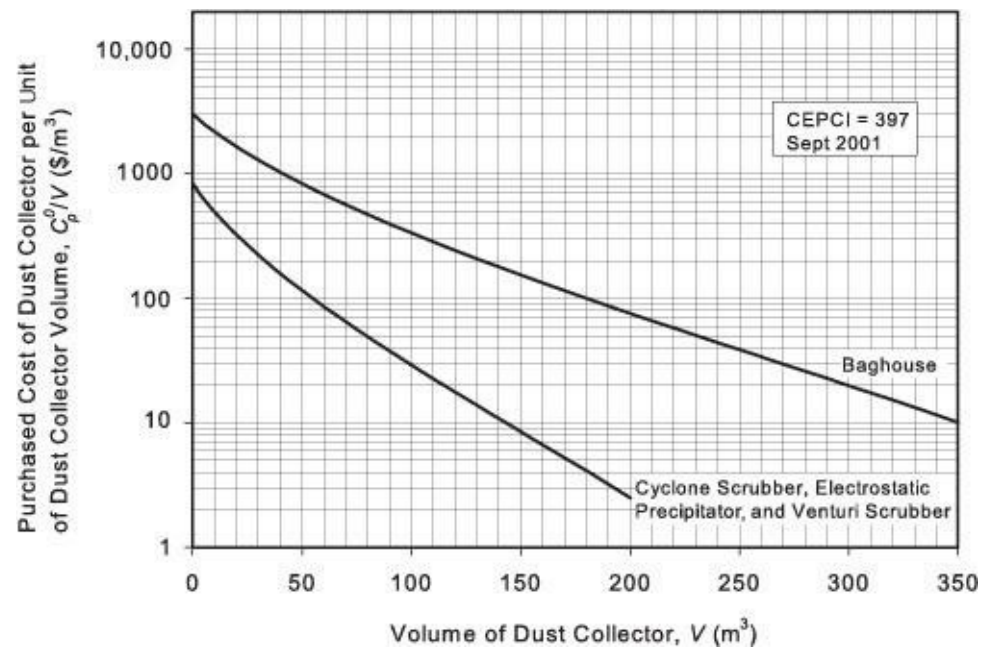


Figure A.14 Purchased Costs of Filters

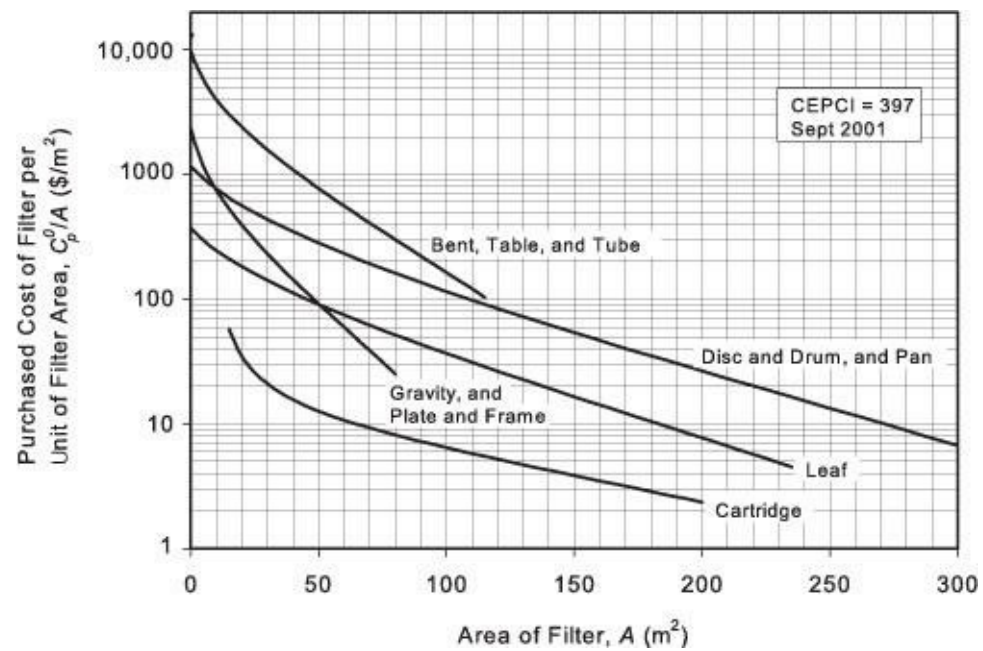


Figure A.15 Purchased Costs of Mixers

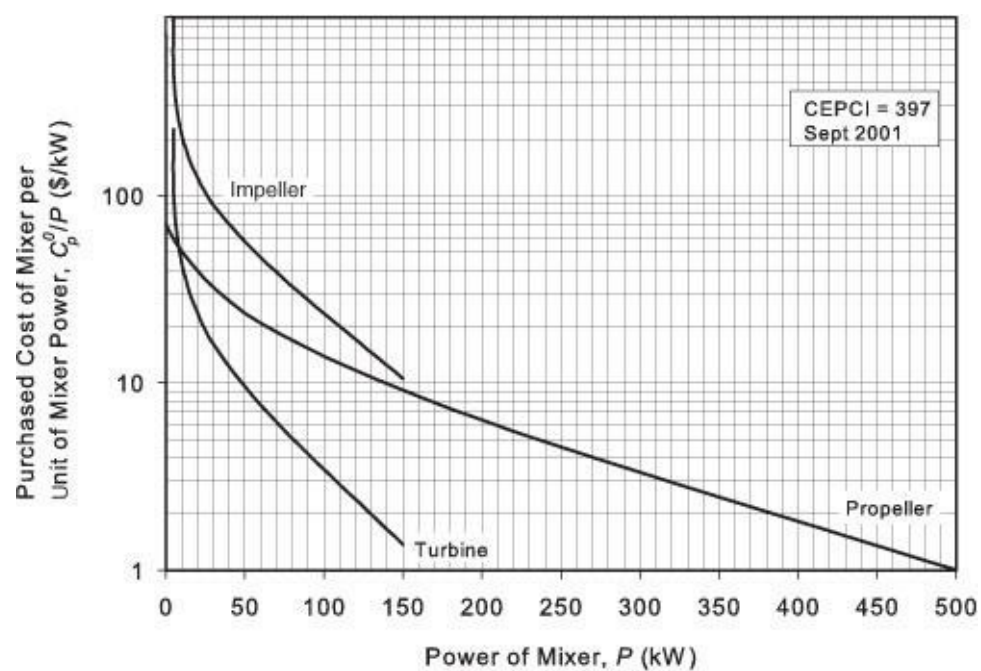


Figure A.16 Purchased Costs of Reactors

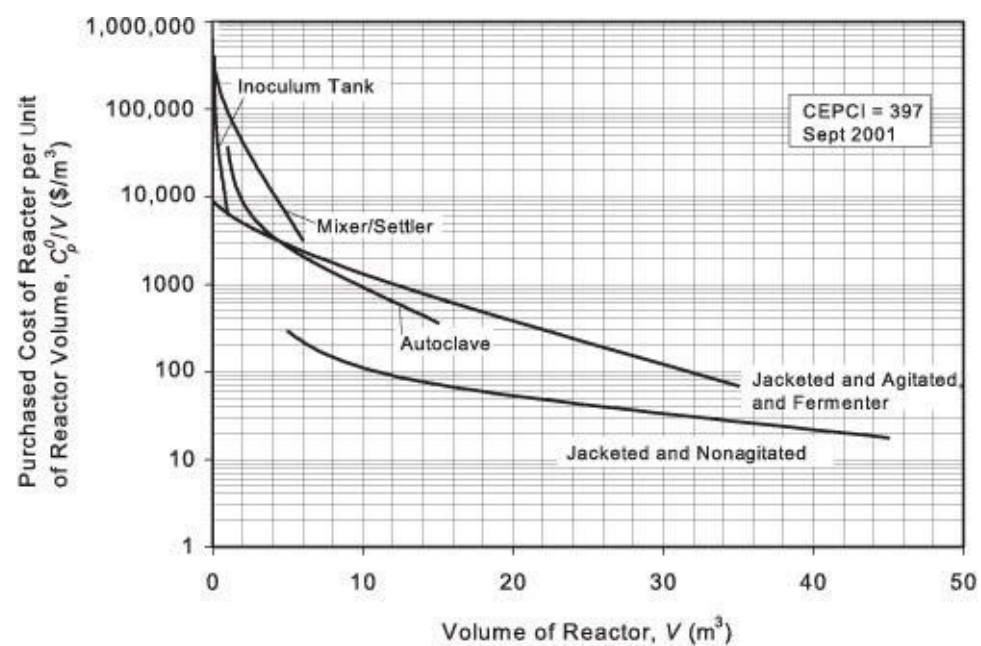
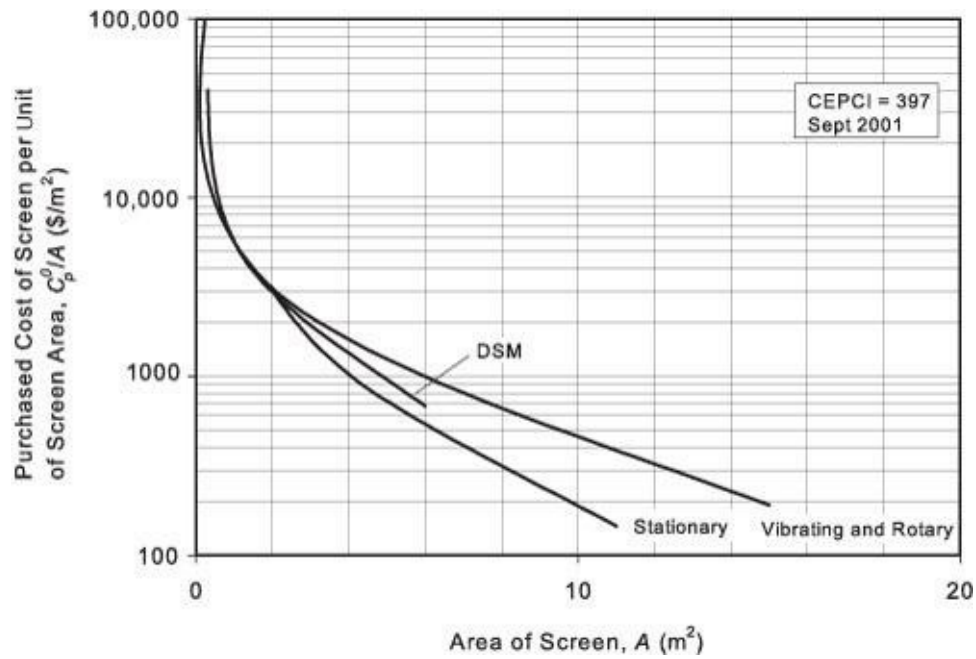


Figure A.17 Purchased Costs of Screens



Data from the R-Books software marketed by Richardson Engineering Services, Inc. [4], were used as a basis for several of the graphs and correlations; acknowledgment is given in the appropriate figures.

A.2 Pressure Factors

As was pointed out in [Chapter 7](#), the costs of equipment increase with increasing operating pressure. In this section, the method of accounting for changes in operating pressure through the use of pressure factors is covered.

A.2.1 Pressure Factors for Process Vessels

The pressure factor for horizontal and vertical process (pressurized) vessels of diameter D meters and operating at a pressure of P barg is based on the ASME code for pressure vessel design [5]. At base material conditions using a maximum allowable stress for carbon steel, S , of 944 bar, a weld efficiency, E , of 0.9, a minimum allowable vessel thickness of 0.0063 m (1/4 inch), and a corrosion allowance, CA , of 0.00315 m (1/8 inch) gives the following expression:

(A.2)

$$F_{P,vessel} = \frac{\frac{(P + 1)D}{2[850 - 0.6(P + 1)]} + 0.00315}{0.0063} \quad \text{for } t_{vessel} > 0.0063 \text{ m}$$

If $F_{P,vessel}$ is less than 1 (corresponding to $t_{vessel} < 0.0063$ m), then $F_{P,vessel} = 1$. For pressures less than –

0.5 barg, $F_{P, vessel} = 1.25$. It should be noted that Equation (A.2) is strictly true for the case when the thickness of the vessel wall is less than $\frac{1}{4} D$; for vessels in the range $D = 0.3$ to 4.0 m, this occurs at pressures of approximately 320 barg.

A.2.2 Pressure Factors for Other Process Equipment

The pressure factors, F_P , for the remaining process equipment are given by the following general form:

(A.3)

$$\log_{10} F_P = C_1 + C_2 \log_{10} P + C_3 (\log_{10} P)^2$$

The units of pressure, P , are bar gauge or barg (1 bar = 0.0 barg) unless stated otherwise. The pressure factors are always greater than unity. The values of constants in Equation (A.3) for different equipment are given in Table A.2, and also shown are the ranges of pressures over which the correlations are valid. The values for the constants given in Table A.2 were regressed from data in Guthrie [1, 2] and Ulrich [3]. Extrapolation outside this range of pressures should be done with extreme caution. Some equipment does not have pressure ratings and therefore has values of C_1 – C_3 equal to zero. If cost estimates are required for these units at high pressures and the equipment cost is affected by pressure, then the correlations should again be used with caution.

Table A.2 Pressure Factors for Process Equipment (Correlated from Data in Guthrie [1, 2], and Ulrich [3])

Equipment Type	Equipment Description	C_1	C_2	C_3	Pressure Range (barg)
Compressors	Centrifugal, axial, rotary, and reciprocating	0	0	0	—
Drives	Gas turbine	0	0	0	—
	Intern. comb. engine	0	0	0	—
	Steam turbine	0	0	0	—
	Electric—explosion-proof	0	0	0	—
	Electric—totally enclosed	0	0	0	—
	Electric—open/drip-proof	0	0	0	—
Evaporators	Forced circulation (pumped), falling film, agitated film (scrapped wall), short tube, and long tube	0	0	0	$P < 10$
		0.1578	−0.2992	0.1413	$10 < P < 150$
Fans*	Centrifugal radial, and centrifugal backward curve	0	0	0	$\Delta P < 1 \text{ kPa}$
		0	0.20899	−0.0328	$1 < \Delta P < 16 \text{ kPa}$
	Axial vane and axial tube	0	0	0	$\Delta P < 1 \text{ kPa}$
		0	0.20899	−0.0328	$1 < \Delta P < 4 \text{ kPa}$
Furnaces	Reformer furnace	0	0	0	$P < 10$
		0.1405	−0.2698	0.1293	$10 < P < 200$
	Pyrolysis furnace	0	0	0	$P < 10$
		0.1017	−0.1957	0.09403	$10 < P < 200$
	Nonreactive fired heater	0	0	0	$P < 10$
		0.1347	−0.2368	0.1021	$10 < P < 200$
Heat exchangers	Scraped wall	0	0	0	$P < 40$
		0.6072	−0.9120	0.3327	$40 < P < 100$
		13.1467	−12.6574	3.0705	$100 < P < 300$
	Teflon tube	0	0	0	$P < 15$

(continued)

Equipment Type	Equipment Description	C_1	C_2	C_3	Pressure Range (barg)
	Bayonet, fixed tube sheet, floating head, kettle reboiler, and U-tube (both shell and tube)	0	0	0	P<5
		0.03881	-0.11272	0.08183	5<P<140
	Bayonet, fixed tube sheet, floating head, kettle reboiler, and U-tube (tube only)	0	0	0	P<5
		-0.00164	-0.00627	0.0123	5<P<140
	Double pipe and multiple pipe	0	0	0	P<40
		0.6072	-0.9120	0.3327	40<P<100
		13.1467	-12.6574	3.0705	100<P<300
	Flat plate and spiral plate	0	0	0	P<19
	Air cooler	0	0	0	P<10
		-0.1250	0.15361	-0.02861	10<P<100
Heaters	Spiral tube (both shell and tube)	0	0	0	P<150
		-0.4045	0.1859	0	150<P<400
	Spiral tube (tube only)	0	0	0	P<150
		-0.2115	0.09717	0	150<P<400
	Diphenyl heater, molten salt heater, and hot water heater	0	0	0	P<2
		-0.01633	0.056875	-0.00876	2<P<200
	Steam boiler	0	0	0	P<20
		2.594072	-4.23476	1.722404	20<P<40
	Packing	0	0	0	-
	Process vessels			†	
Pumps	Reciprocating	0	0	0	P<10
		-0.245382	0.259016	-0.01363	10<P<100
	Positive displacement	0	0	0	P<10
		-0.245382	0.259016	-0.01363	10<P<100
	Centrifugal	0	0	0	P<10
		-0.3935	0.3957	-0.00226	10<P<100

(continued)

Equipment Type	Equipment Description	C_1	C_2	C_3	Pressure Range (barg)
Towers	Tray and packed			†	
Tanks	API—fixed roof	0	0	0	P<0.07
	API—floating roof	0	0	0	P<0.07
Trays	Sieve	0	0	0	-
	Valve	0	0	0	-
	Demisters	0	0	0	-
Turbines	Axial gas turbines	0	0	0	-
	Radial gas/liquid expanders	0	0	0	-
Vaporizers	Internal coils / jackets and jacket vessels	0	0	0	P<5
		-0.16742	0.13428	0.15058	5<P<320

*Pressure factors for fans are written in terms of the pressure rise across the fan, ΔP , where ΔP is measured in kPa.
†See Equation (A.2).

A.3 Material Factors and Bare Module Factors

As was pointed out in [Chapter 7](#), the costs of equipment change with changes in the material of construction. In this section, the method of accounting for different materials of construction is covered.

A.3.1 Bare Module and Material Factors for Heat Exchangers, Process Vessels, and Pumps

The material factors, F_M , for heat exchangers, process vessels, and pumps are given in [Figure A.18](#), with the appropriate identification number listed in [Table A.3](#). The bare module factors for this equipment are given by the following equation:

(A.4)

$$C_{BM} = C_p^o F_{BM} = C_p^o (B_1 + B_2 F_M F_P)$$

Figure A.18 Material Factors for Equipment in [Table A.3](#) (Averaged Data from References [[1](#), [2](#), [3](#), [6](#), [7](#), and [8](#)])

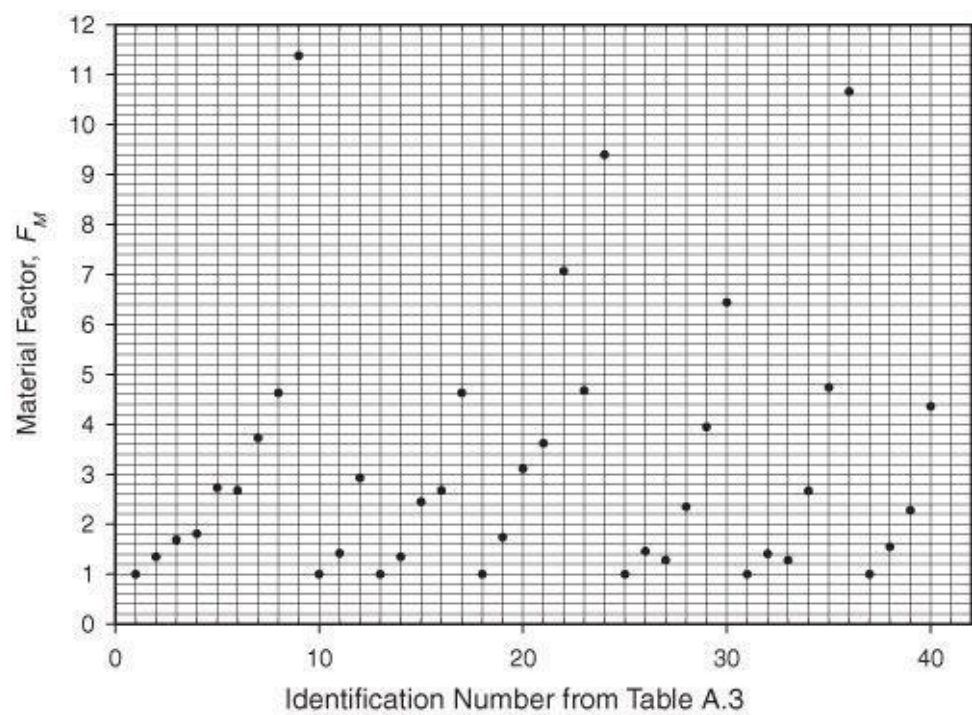


Table A.3 Identification Numbers for Material Factors for Heat Exchangers, Process Vessels, and Pumps to Be Used with [Figure A.18](#)

Identification Number	Equipment Type	Equipment Description	Material of Construction
1	Heat exchanger	Double pipe, multiple pipe,	CS-shell/CS-tube
2		fixed tube sheet, floating head,	CS-shell/Cu-tube
3		U-tube, bayonet, kettle reboiler, scraped	Cu-shell/Cu-tube
4		wall, and spiral tube	CS-shell/SS-tube
5			SS-shell/SS-tube
6			CS-shell/Ni alloy tube
7			Ni alloy, shell/Ni alloy-tube
8			CS-shell/Ti-tube
9			Ti-shell/Ti-tube
10	Process vessels	Air cooler	CS tube
11		Air cooler	Al tube
12		Air cooler	SS tube
13		Flat plate and spiral plate	CS (in contact with fluid)
14		Flat plate and spiral plate	Cu (in contact with fluid)
15		Flat plate and spiral plate	SS (in contact with fluid)
16		Flat plate and spiral plate	Ni alloy (in contact with fluid)
17		Flat plate and spiral plate	Ti (in contact with fluid)
18		Horizontal, vertical (including towers)	CS
19		Horizontal, vertical (including towers)	SS clad
20		Horizontal, vertical (including towers)	SS
21		Horizontal, vertical (including towers)	Ni alloy clad
22		Horizontal, vertical (including towers)	Ni alloy
23		Horizontal, vertical (including towers)	Ti clad
24		Horizontal, vertical (including towers)	Ti

Identification Number	Equipment Type	Equipment Description	Material of Construction
25	Pumps	Reciprocating	Cast iron
26		Reciprocating	Carbon steel
27		Reciprocating	Cu alloy
28		Reciprocating	SS
29		Reciprocating	Ni alloy
30		Reciprocating	Ti
31		Positive displacement	Cast iron
32		Positive displacement	Carbon steel
33		Positive displacement	Cu alloy
34		Positive displacement	SS
35		Positive displacement	Ni alloy
36		Positive displacement	Ti
37	Centrifugal	Centrifugal	Cast iron
38		Centrifugal	Carbon steel
39		Centrifugal	SS
40		Centrifugal	Ni alloy

The values of the constants B_1 and B_2 are given in [Table A.4](#). The bare module cost for ambient pressure and carbon steel construction, C_{BM}° , and the bare module factor for the equipment at these conditions, F_{BM}° , are found by setting F_M and F_P equal to unity. The data given in [Tables A.3](#) and [A.4](#) and [Figure A.18](#) are average values from the following references: Guthrie [[1](#), [2](#)], Ulrich [[3](#)], Navarrete [[6](#)], Perry et al. [[7](#)], and Peters and Timmerhaus [[8](#)].

Table A.4 Constants for Bare Module Factor to Be Used in [Equation A.4](#) (Correlated from Data in Guthrie [[1](#), [2](#)] and Ulrich [[3](#)])

Equipment Type	Equipment Description	B_1	B_2
Heat exchangers	Double pipe, multiple pipe, scraped wall, and spiral tube	1.74	1.55
	Fixed tube sheet, floating head, U-tube, bayonet, kettle reboiler, and Teflon tube	1.63	1.66
	Air cooler, spiral plate, and flat plate	0.96	1.21
Process vessels	Horizontal	1.49	1.52
	Vertical (including towers)	2.25	1.82
Pumps	Reciprocating	1.89	1.35
	Positive displacement	1.89	1.35
	Centrifugal	1.89	1.35

A.3.2 Bare Module and Material Factors for the Remaining Process Equipment

For the remaining equipment, the bare module costs are related to the material and pressure factors by equations different from [Equation \(A.4\)](#). The form of these equations is given in [Table A.5](#). The bare module factors that correspond to the equations in [Table A.5](#) are given in [Figure A.19](#) using the identification numbers listed in [Table A.6](#). Again, the data used to construct [Figure A.19](#) are compiled from average values taken from Guthrie [[1](#), [2](#)], Ulrich [[3](#)], Navarrete [[6](#)], Perry et al. [[7](#)], and Peters and Timmerhaus [[8](#)]. In addition, bare module factors for the equipment added to the third edition of the book (conveyors, crystallizers, dryers, dust collectors, filters, mixers, reactors, and screens) are given separately in [Table A.7](#).

Table A.5 Equations for Bare Module Cost for Equipment Not Covered by [Tables A.3](#) and [A.4](#)

Equipment Type	Equation for Bare Module Cost
Compressors and blowers without drives	$C_{BM} = C_p F_{BM}$
Drives for compressors and blowers	$C_{BM} = C_p F_{BM}$
Evaporators and vaporizers	$C_{BM} = C_p F_{BM} F_p$
Fans with electric drives	$C_{BM} = C_p F_{BM} F_p$
Fired heaters and furnaces	$C_{BM} = C_p F_{BM} F_p F_T$
	F_T is the superheat correction factor for steam boilers ($F_T = 1$ for other heaters and furnaces) and is given by $F_T = 1 + 0.00184\Delta T - 0.00000335(\Delta T)^2$ where ΔT is the amount of superheat in °C.
Power recovery equipment	$C_{BM} = C_p F_{BM}$
Sieve trays, valve trays, and demister pads	$C_{BM} = C_p N F_{BM} F_q$ Where N is the number of trays and F_q is a quantity factor for trays only given by $\log_{10} F_q = 0.4771 + 0.08516 \log_{10} N - 0.3473 (\log_{10} N)^2 \text{ for } N < 20$ $F_q = 1 \text{ for } N \geq 20$
Tower packing	$C_{BM} = C_p F_{BM}$

Figure A.19 Bare Module Factors for Equipment in [Table A.6](#) (Average Data from References [1, 2, 3, 6, 7, and 8])

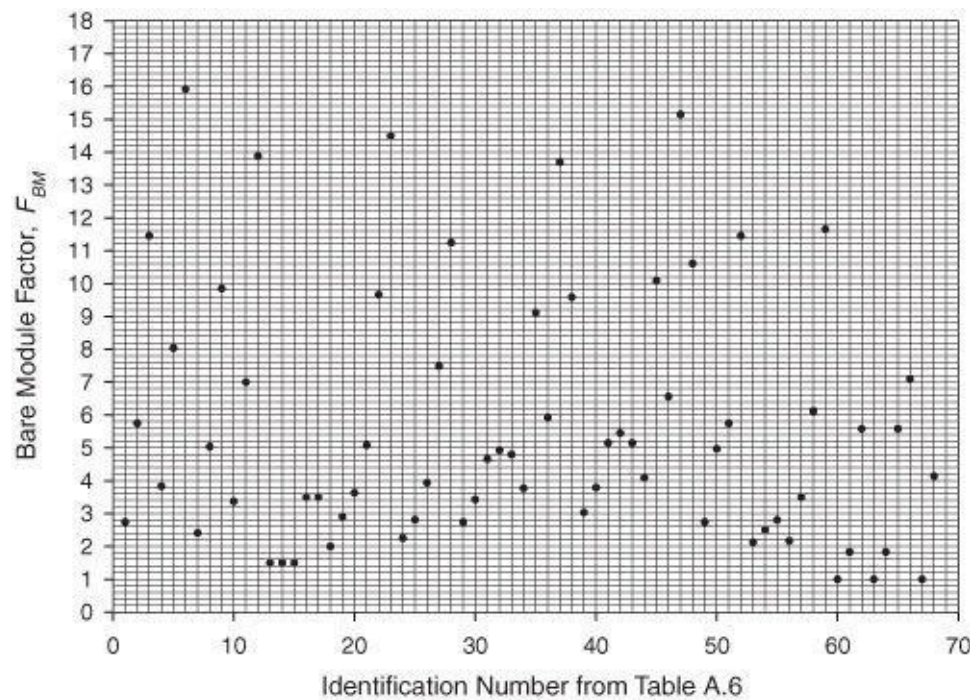


Table A.6 Identification of Material Factors for Equipment Listed in [Table A.5](#) to Be Used with [Figure A.19](#)

Identification Number	Equipment Type	Equipment Description	Material of Construction
1	Compressors/blowers	Centrifugal compressor or blower	CS
2		Centrifugal compressor or blower	SS
3		Centrifugal compressor or blower	Ni alloy
4		Axial compressor or blower	CS
5		Axial compressor or blower	SS
6		Axial compressor or blower	Ni alloy
7		Rotary compressor or blower	CS
8		Rotary compressor or blower	SS
9		Rotary compressor or blower	Ni alloy
10		Reciprocating compressor or blower	CS
11		Reciprocating compressor or blower	SS
12		Reciprocating compressor or blower	Ni alloy
13	Drives for compressors and blowers	Electric—explosionproof	—
14		Electric—totally enclosed	—
15		Electric—open/dripproof	—
16		Gas turbine	—
17		Steam turbine	—
18	Evaporators and vaporizers	Internal combustion engine	—
19		Evaporator—forced circ, short or long tube	CS
20		Evaporator—forced circ, short or long tube	Cu alloy
21		Evaporator—forced circ, short or long tube	SS
22		Evaporator—forced circ, short or long tube	Ni alloy
23		Evaporator—forced circ, short or long tube	Ti
24		Evaporator—falling film, scraped-wall	CS

Identification Number	Equipment Type	Equipment Description	Material of Construction
25	Evaporators and vaporizers	Evaporator—falling film, scraped-wall	Cu alloy
26		Evaporator—falling film, scraped-wall	SS
27		Evaporator—falling film, scraped-wall	Ni alloy
28		Evaporator—falling film, scraped-wall	Ti
29		Vaporizer—jacketed vessel	CS
30		Vaporizer—jacketed vessel	Cu
31		Vaporizer—jacketed vessel	Glass lined/SS coils
32		Vaporizer—jacketed vessel	Glass lined/Ni coils
33		Vaporizer—jacketed vessel	SS
34		Vaporizer—jacketed vessel	SS clad
35		Vaporizer—jacketed vessel	Ni alloy
36		Vaporizer—jacketed vessel	Ni alloy clad
37		Vaporizer—jacketed vessel	Ti
38		Vaporizer—jacketed vessel	Ti clad
39		Vaporizer—jacketed vessel + internal coil	CS
40		Vaporizer—jacketed vessel + internal coil	Cu
41		Vaporizer—jacketed vessel + internal coil	Glass lined/SS coils
42		Vaporizer—jacketed vessel + internal coil	Glass lined/Ni coils
43		Vaporizer—jacketed vessel + internal coil	SS
44		Vaporizer—jacketed vessel + internal coil	SS clad
45		Vaporizer—jacketed vessel + internal coil	Ni alloy
46		Vaporizer—jacketed vessel + internal coil	Ni alloy clad
47		Vaporizer—jacketed vessel + internal coil	Ti
48		Vaporizer—jacketed vessel + internal coil	Ti clad
49	Fans	Fan with electric drive	CS

Identification Number	Equipment Type	Equipment Description	Material of Construction
50	Fired heaters and furnaces	Fan with electric drive	Fiberglass
51		Fan with electric drive	SS
52		Fan with electric drive	Ni alloy
53		Tube for furnaces and nonreactive process heater	CS
54		Tube for furnaces and nonreactive process heater	Alloy steel
55		Tube for furnaces and nonreactive process heater	SS
56	Power recovery equipment	Thermal fluid heater—hot water, molten salt, or diphenyl-based oil	—
57		Turbines	CS
58		Turbines	SS
59	Trays and demister pads	Turbines	Ni alloy
60		Sieve and valve trays	CS
61		Sieve and valve trays	SS
62		Sieve and valve trays	Ni alloy
63	Tower packing	Demister pad	SS
64		Demister pad	Fluorocarbon
65		Demister pad	Ni alloy
66		Packing	Metal (304SS)
67		Packing	Polyethylene
68		Packing	Ceramic

Figure A.7 Bare Module Factors for Conveyors, Crystallizers, Dryers, Dust Collectors, Filters, Mixers, Reactors, and Screens

Equipment Type	Equipment Description	Bare Module Factor, FBM
Blenders	Kneader	1.12*
	Ribbon	1.12*
	Rotary	1.12
Centrifuges	Auto batch separator	1.57*
	Centrifugal separator	1.57
	Oscillating screen	1.57*
	Solid bowl w/o motor	1.27
Conveyors	Apron	1.20
	Belt	1.25
	Pneumatic	1.25*
	Screw	1.10
Crystallizers	Batch	1.60
Dryers	Drum	1.60
	Rotary, gas fired	1.25
	Tray	1.25
Dust Collectors	Baghouse	2.86*
	Cyclone scrubbers	2.86*
	Electrostatic precipitator	2.86*
	Venturi scrubber	2.86*
Filters	Bent	1.65*
	Cartridge	1.65*
	Disc and drum	1.65*
	Gravity	1.65*
	Leaf	1.65
	Pan	1.65*
	Plate and frame	1.80
	Table	1.65*
	Tube	1.65*
	Impeller	1.38*
Mixers	Propeller	1.38
	Turbine	1.38
Reactors	Autoclave	4.0*
	Fermenter	4.0*
	Inoculum tank	4.0*
	Jacketed agitated	4.0*
	Jacketed nonagitated	4.0*
	Mixer/settler	4.0*
Screens	DSM	1.34*
	Rotary	1.34*
	Stationary	1.34*
	Vibrating	1.34

When possible, bare module factors are taken to be equal to the Field Installation Factors from Guthrie [2].
Items marked * are estimates.

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