

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, the 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:

$$\log_{10} C_p^o = K_1 + K_2 \log_{10}(A) + K_3 [\log_{10}(A)]^2 \quad (\text{A.1})$$

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 correlations 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.

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.

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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 ²	0.14	3
	Ribbon	4.1366	-0.4928	0.0070	Volume, m ²	0.7	11
	Rotary	4.1366	-0.4928	0.0070	Volume, m ²	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
Crystallizers Drives	Screw	3.6062	-0.7341	0.1982	Area, m ²	0.5	30
	Batch	4.5097	-0.8269	0.1344	Volume, m ³	1.5	30
	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
Dryers	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
	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

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Table A.1 Equipment Cost Data to Be Used with Equation A.1 (Continued)

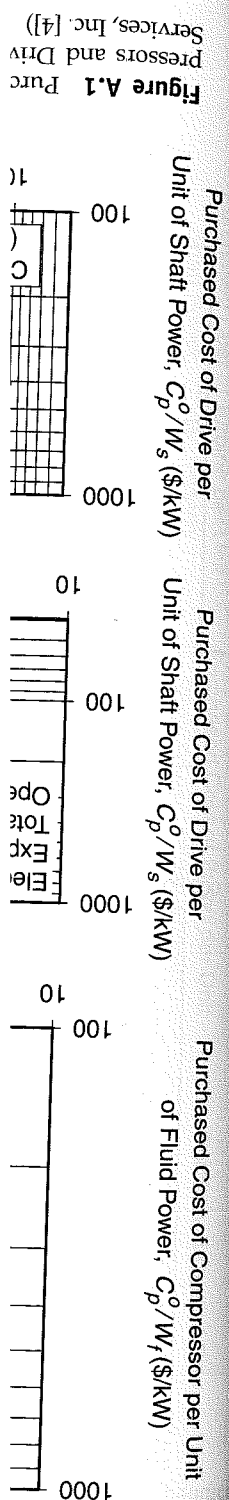
Equipment Type	Equipment Description	K_1	K_2	K_3	Capacity, Units	Min Size	Max Size
Dust Collectors	Baghouse	4.5007	-0.5818	0.0813	Volume, m ³	0.08	350
	Cyclone scrubbers	3.6298	-0.4991	0.0411	Volume, m ³	0.06	200
	Electrostatic precipitator	3.6298	-0.4991	0.0411	Volume, m ³	0.06	200
	Venturi scrubber	3.6298	-0.4991	0.0411	Volume, m ³	0.06	200
	Forced circulation (pumped)	5.0238	0.3475	0.0703	Area, m ²	5	1000
Evaporators	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
	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
Fans	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
	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
Filters	Disc and drum	4.8123	-0.7142	0.0420	Area, m ²	0.9	300
	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
	Par	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	-0.0006	Duty, kW	3000	100,000
	Nonreactive fired heater	7.2488	-1.1666	0.2028	Duty, kW	1000	100,000
Heat exchangers	Scraped wall	3.7803	0.8569	0.0049	Area, m ²	1	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
Heat exchangers	Double pipe	3.3444	0.7745	-0.0477	Area, m ²	1	10

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
Heaters	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
	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
	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)

Table A.1 Equipment Cost Data to Be Used with Equation A.1 (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
	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
Screens	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
	Tray and packed	3.4974	0.4485	0.1074	Volume, m ³	0.3	520
	Tray—fixed roof	4.8509	-0.3973	0.1445	Volume, m ³	90	30000
Tanks	API—floating roof	5.9567	-0.7585	0.1749	Volume, m ³	1000	40000
	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
	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
Vaporizers							



Vaporizers	Internal coils/jackets	Jacketed vessels	4.0000	3.8751	0.1700	0.1901	1	1	100	100
			0.4321	0.3328	Volume, m ³	Volume, m ³				

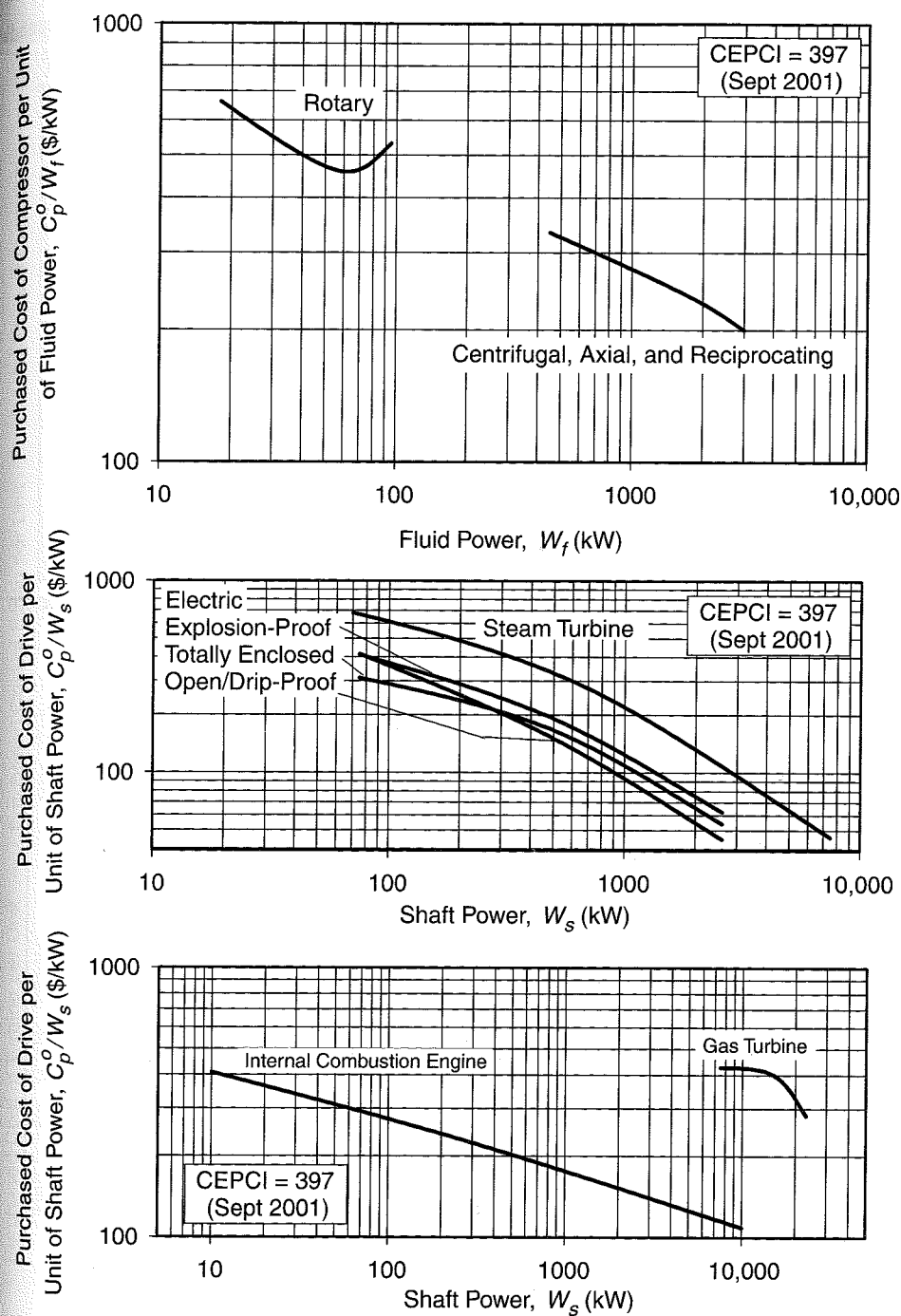


Figure A.1 Purchased Costs for Compressors and Drives (Cost Data for Compressors and Drives Taken from R-Books Software by Richardson Engineering Services, Inc. [4])

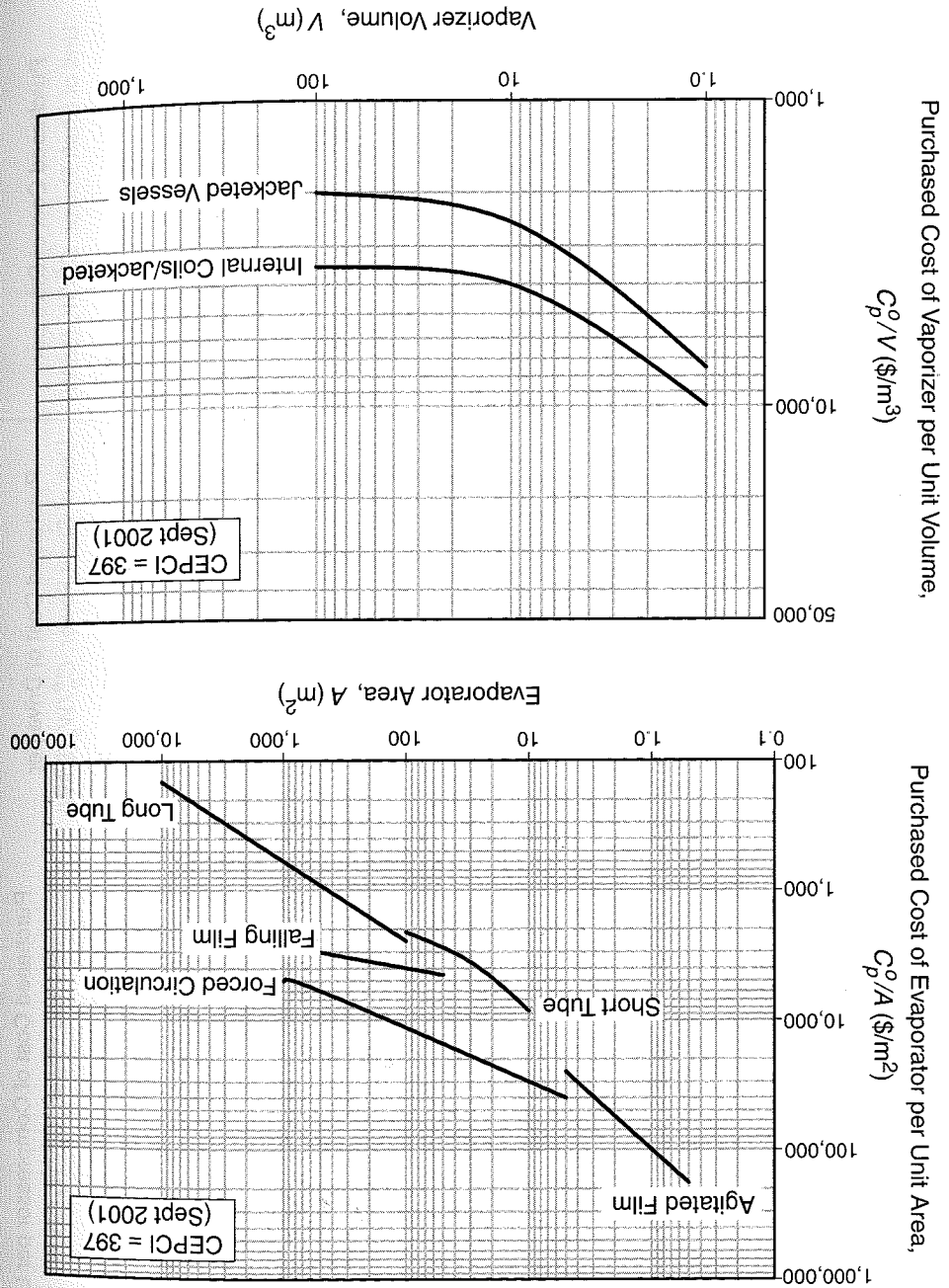


Figure A.2 Purchased Costs for Evaporators and Vaporizers

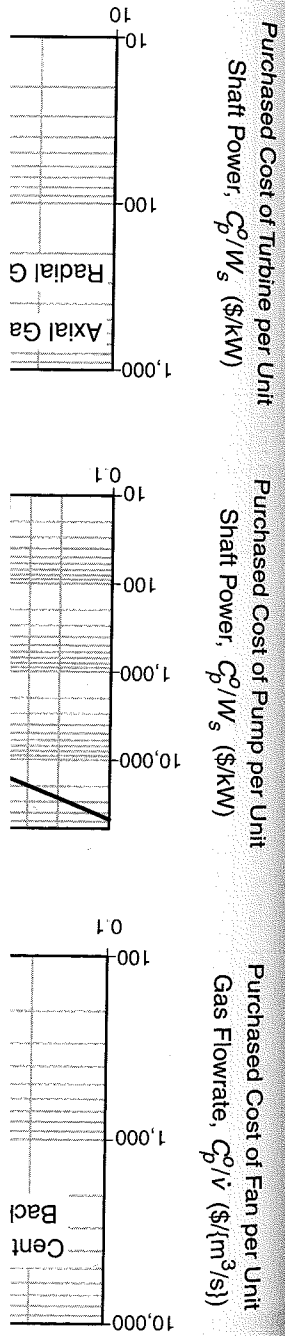
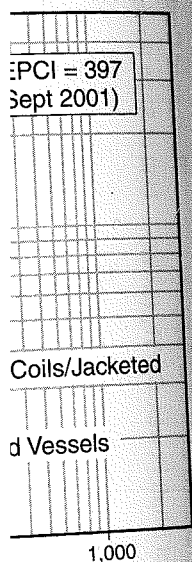
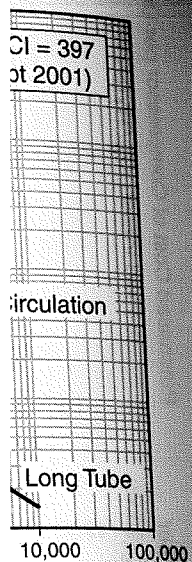


Figure A.3 Purchased Costs for Turbine, Pump, and Fan (Cost Data for Fans services [4])



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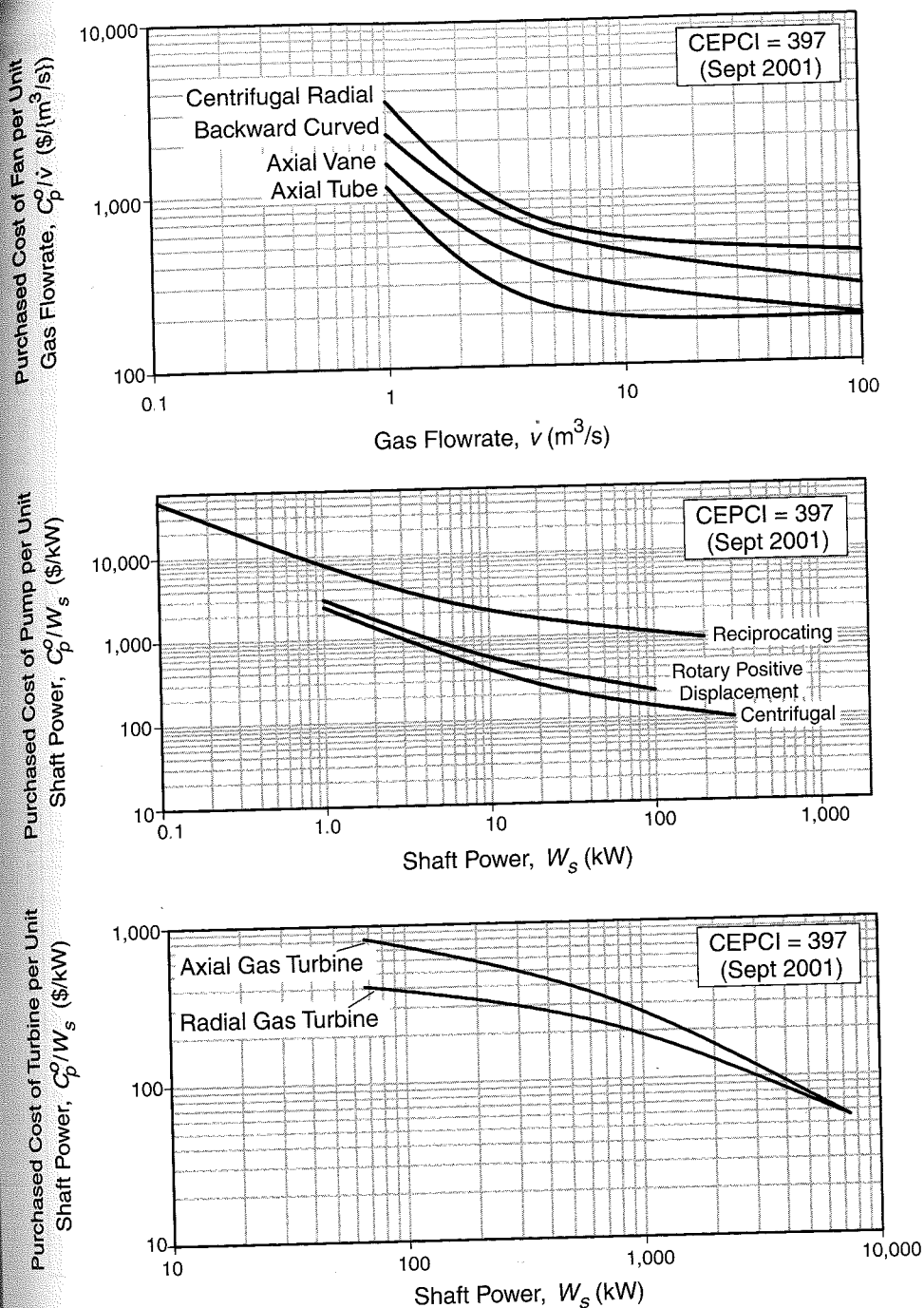
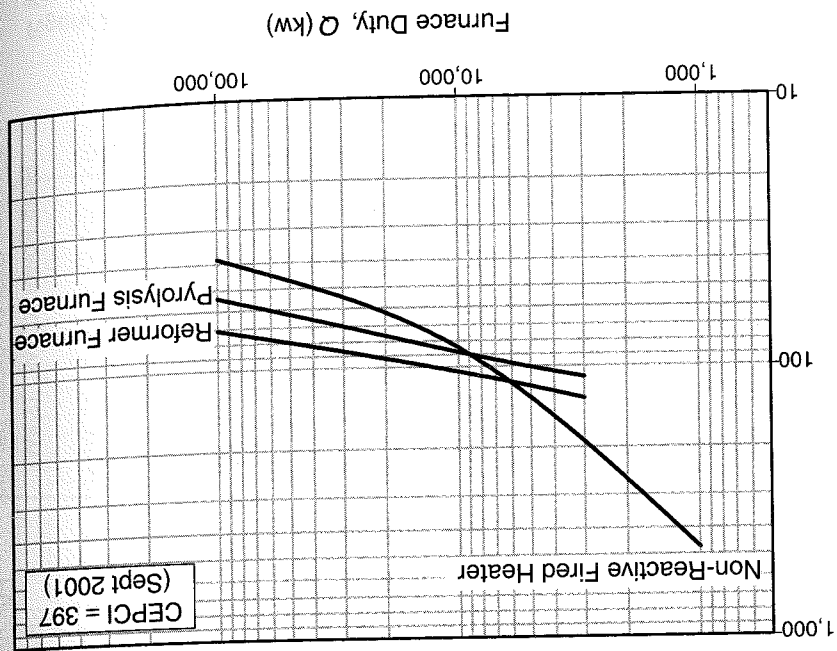


Figure A.3 Purchased Costs for Fans, Pumps, and Power Recovery Equipment (Cost Data for Fans Taken from R-Books Software by Richardson Engineering services [4])

Purchased Cost of Furnace per Unit of
Furnace Duty, C_p^o/Q (\$/kW)



Purchased Cost of Fired Heater per Unit of
Heater Duty, C_p^o/Q (\$/kW)

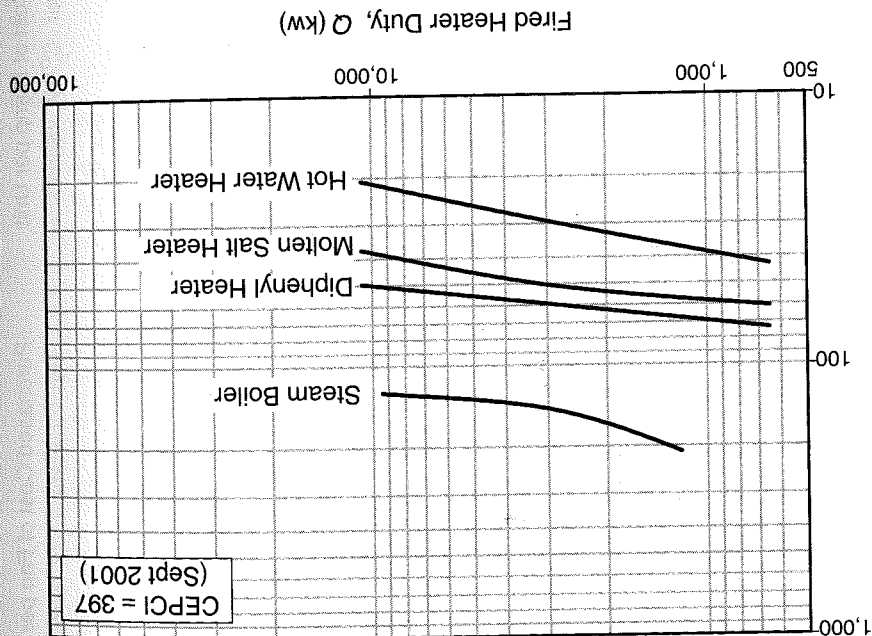
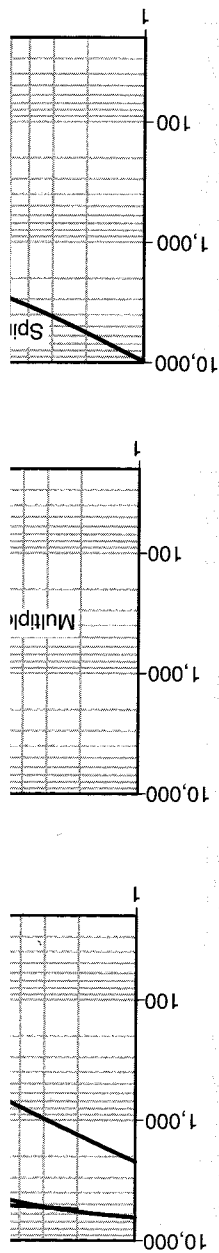
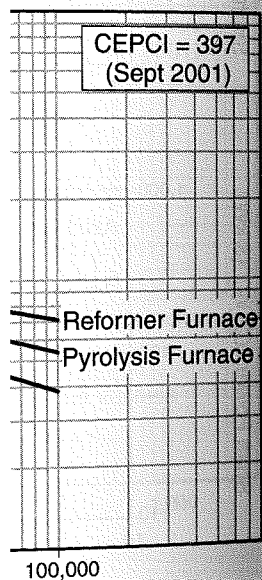
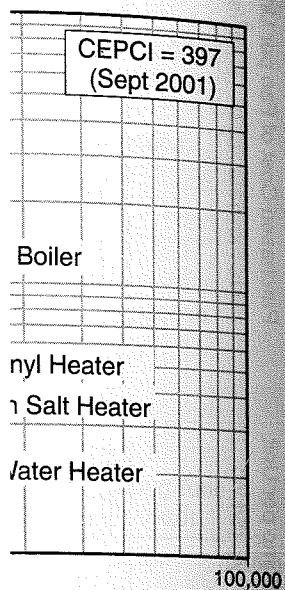


Figure A.4 Purchased Costs for Fired Heaters and Furnaces

Furnace Duty, Q (kW)

Purchased Cost of Heat Exchanger per Unit of Heat Transfer Area, C_p^o/A (\$/m²)





Purchased Cost of Heat Exchanger per Unit of Heat Transfer Area, C_p/A (\$/m²)

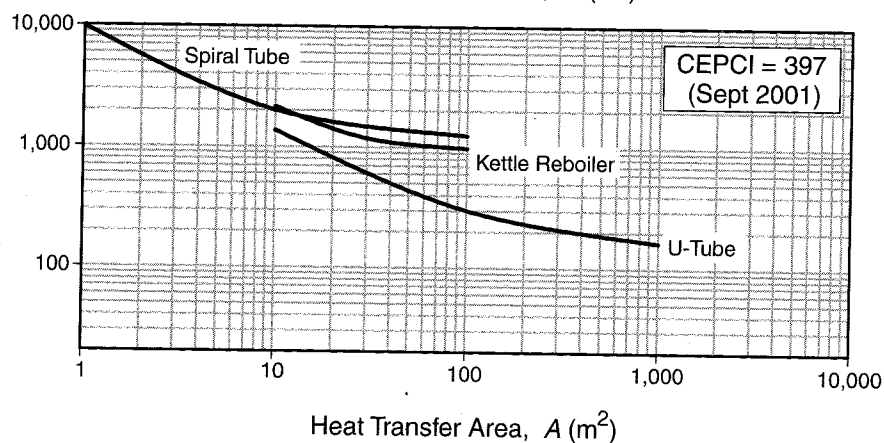
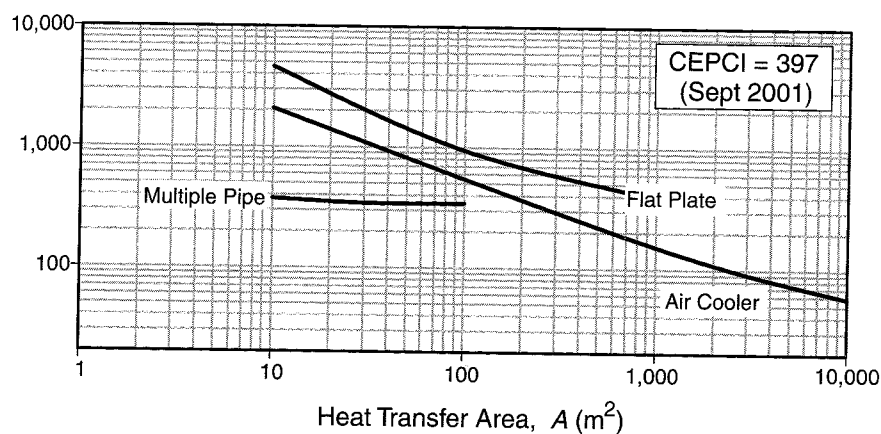
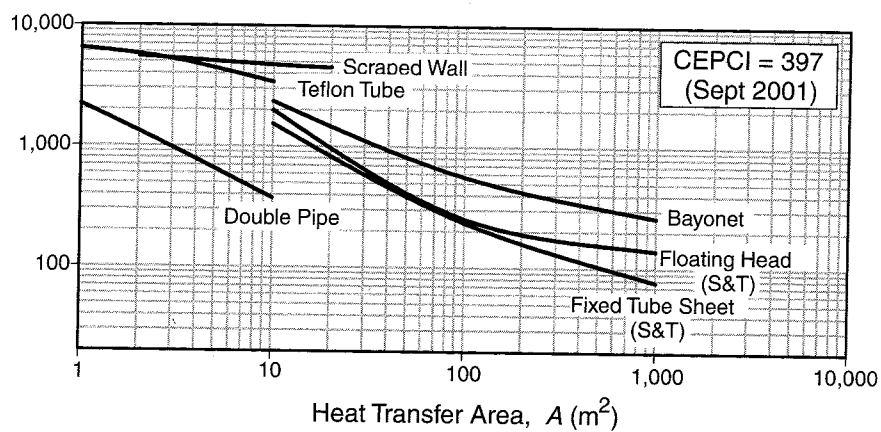
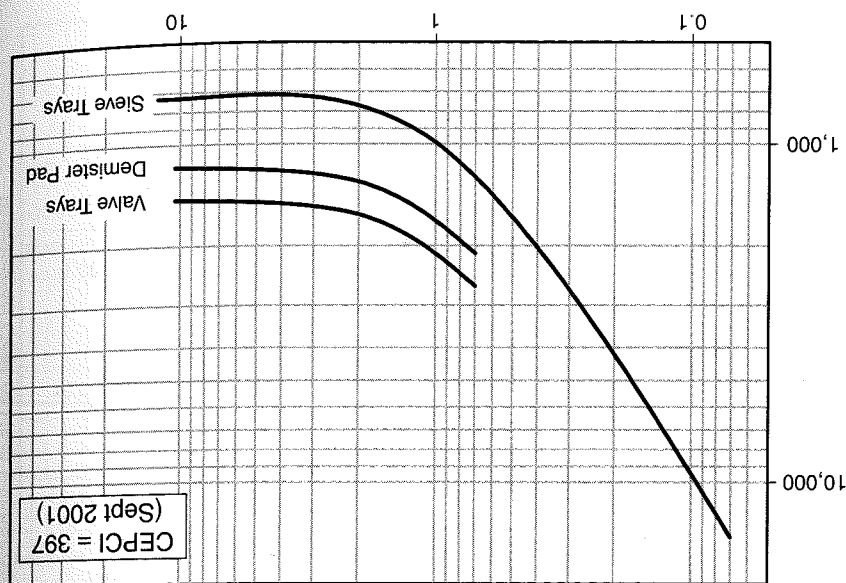


Figure A.5 Purchased Costs for Heat Exchangers

and Furnaces

Purchased Cost of Tray per Unit Area of Tray (Demister), C_p^0/A (\$/m²)



Purchased Cost of Packing per Unit Volume of Packing, C_p^0/V (\$/m³)

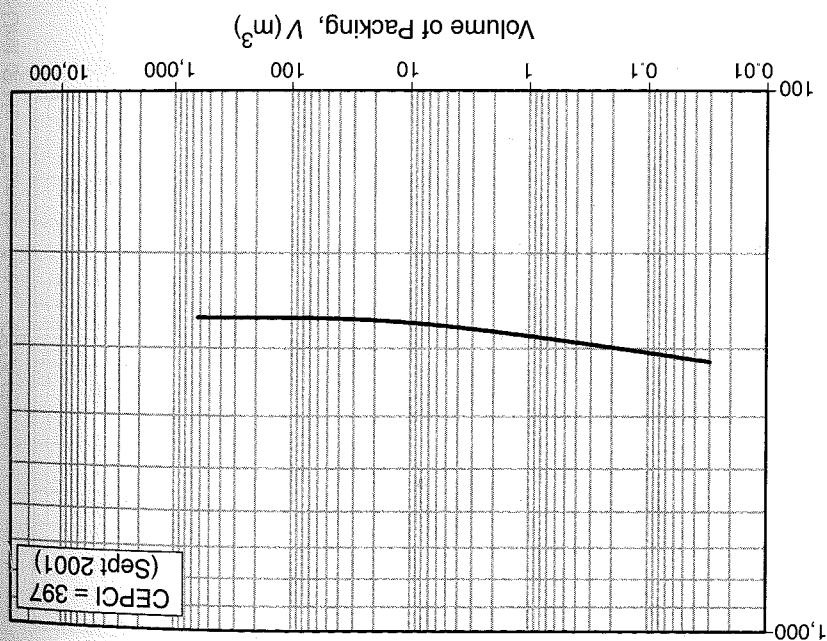
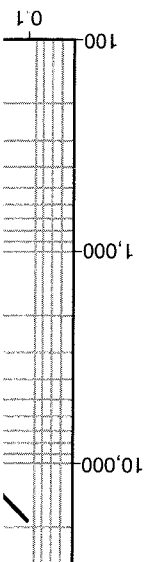
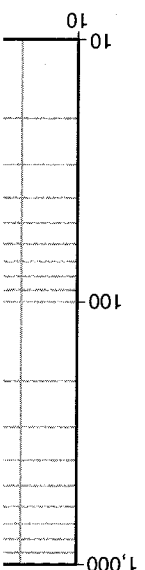


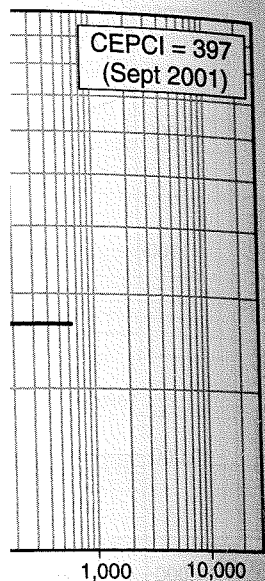
Figure A.6 Purchased Costs for Packing, Trays, and Demisters

Purchased Cost of Vessel per Unit of Vessel Volume, C_p^0/V (\$/m³)

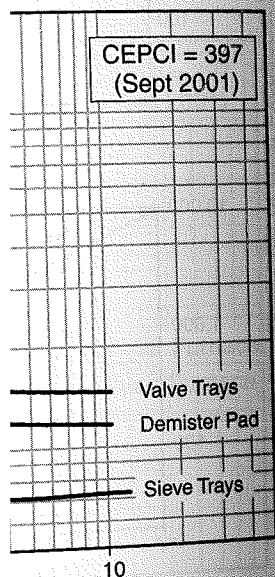


Purchased Cost of Storage Tank per Unit of Tank Volume, C_p^0/V (\$/m³)





m^3



m^2

and Demisters

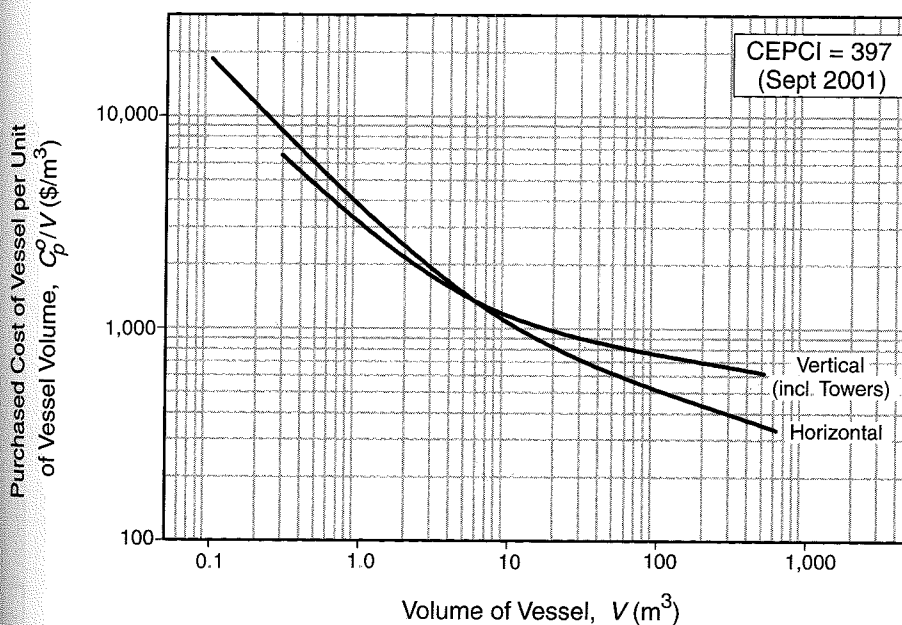
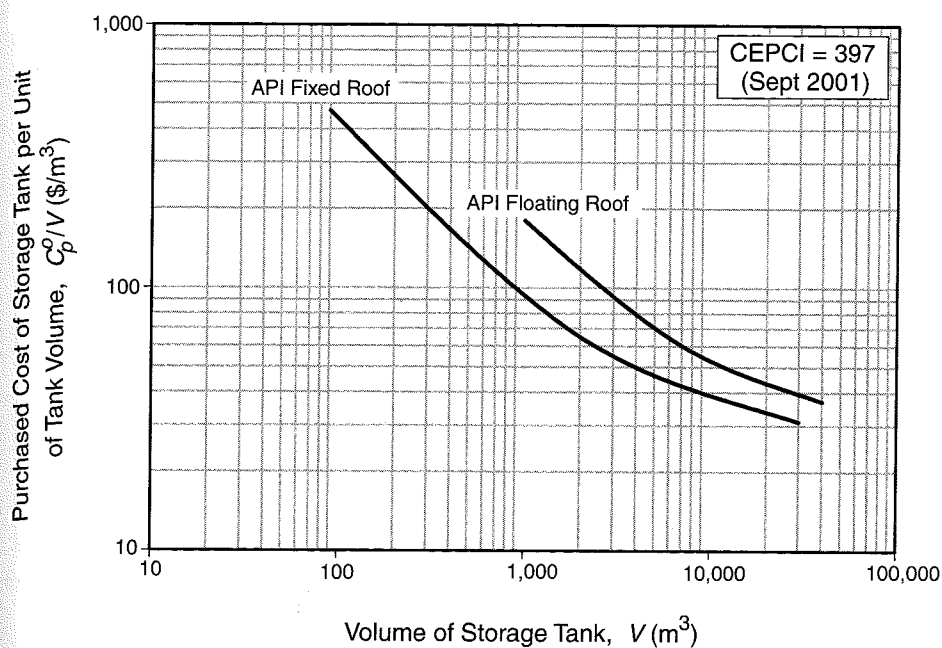


Figure A.7 Purchased Costs of Storage Tank and Process Vessels. (Data for Storage Tanks Taken from R-Books Software by Richardson Engineering Services [4])

Purchased Cost of Blender per Unit
Volume of Blender, C_p^0/V (\$/m³)

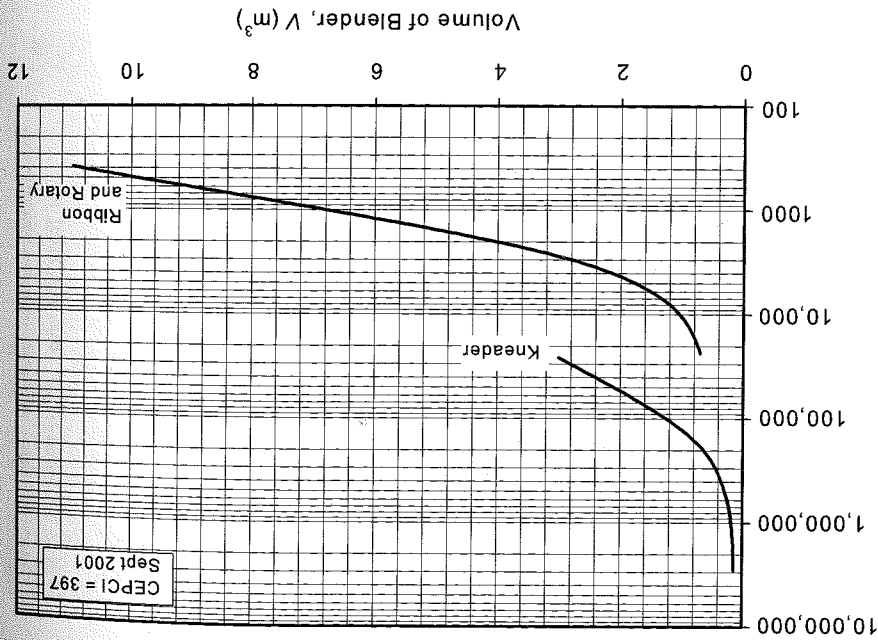


Figure A.8 Purchased Costs for Blenders

Purchased Cost of Centrifuge per Unit
Diameter of Centrifuge, C_p^0/D (\$/m)

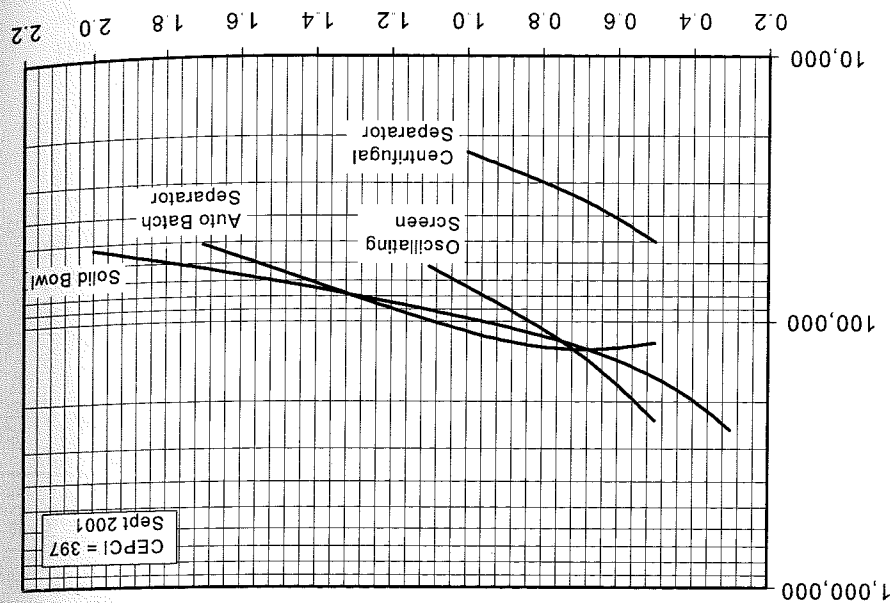
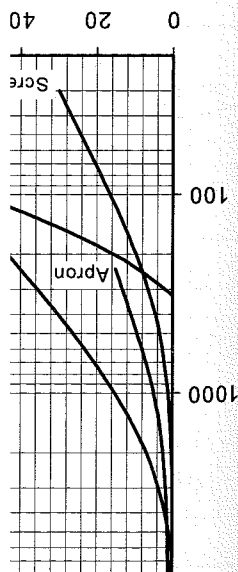
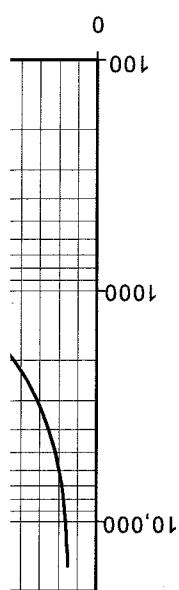


Figure A.9 Purchased Costs of Centrifuges

Purchased Cost of Conveyor per Unit
Area of Conveyor, C_p^0/A (\$/m²)



Purchased Cost of Crystallizer per Unit
Volume of Crystallizer, C_p^0/V (\$/m³)



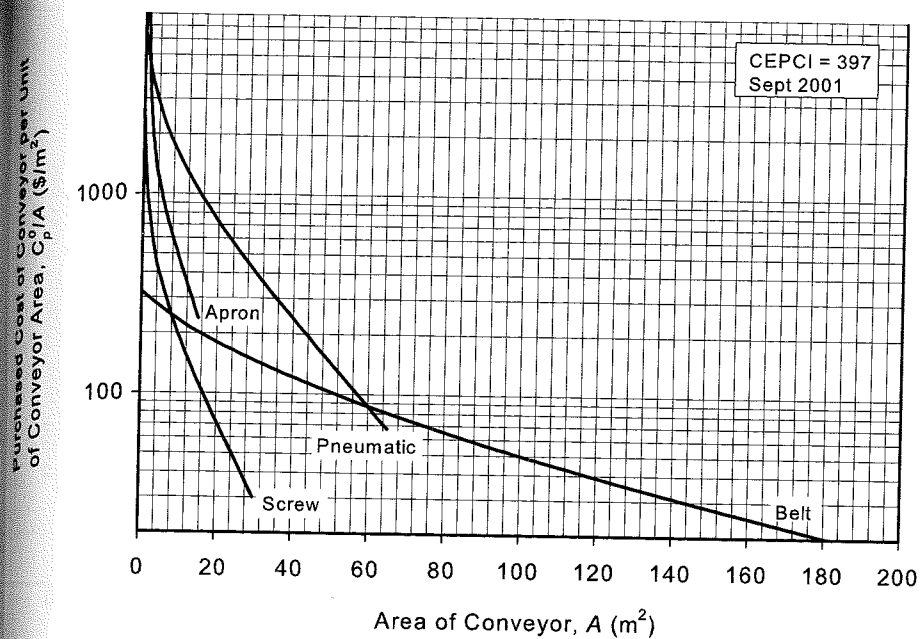
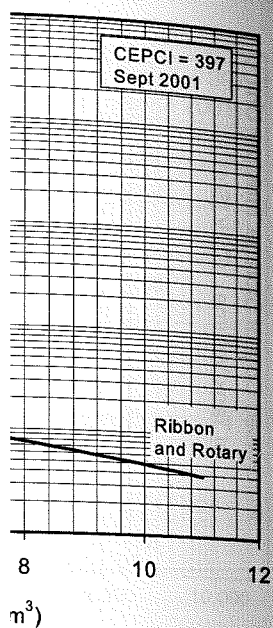


Figure A.10 Purchased Costs for Conveyors

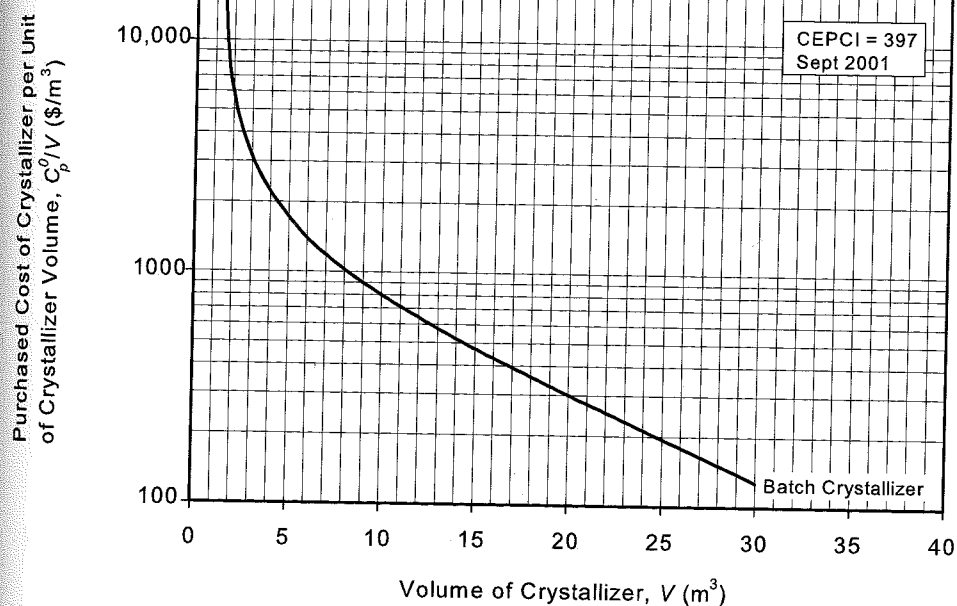
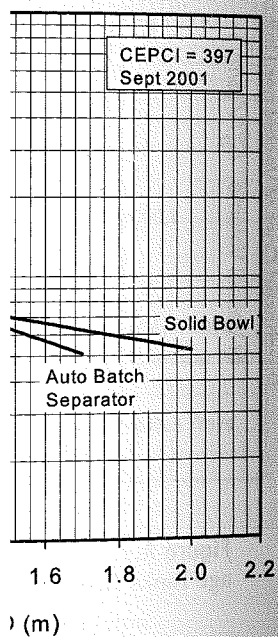


Figure A.11 Purchased Costs for Crystallizers

Purchased Cost of Dust Collector per Unit of Dust Collector Volume, C_p^0/V (\$/m³)

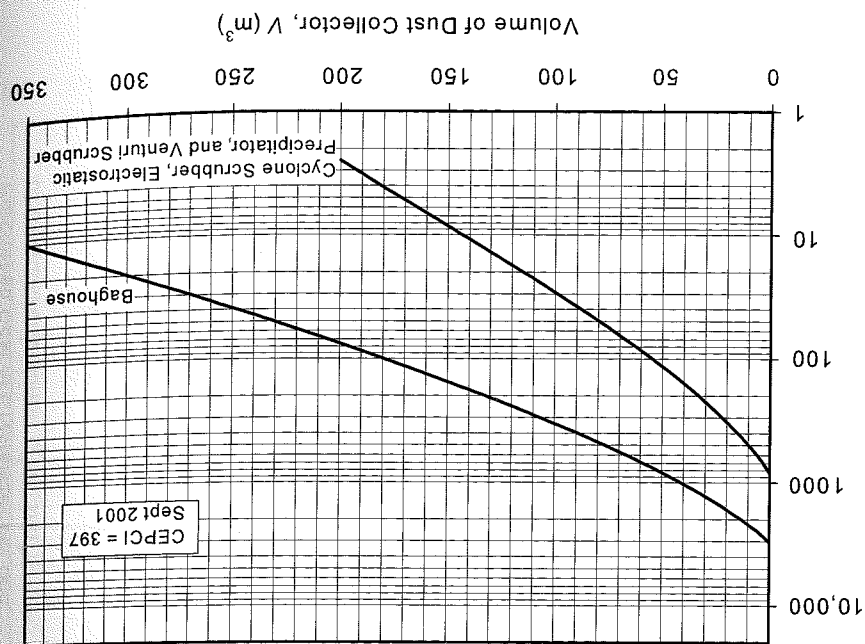


Figure A.13 Purchased Costs of Dust Collectors

Purchased Cost of Dryer per Unit of Dryer Area, C_p^0/A (\$/m²)

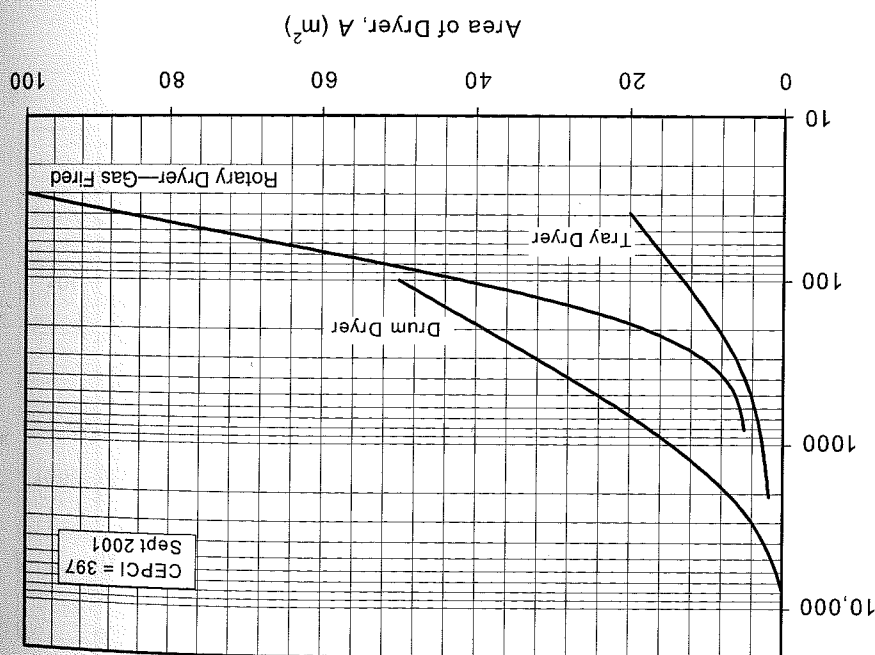
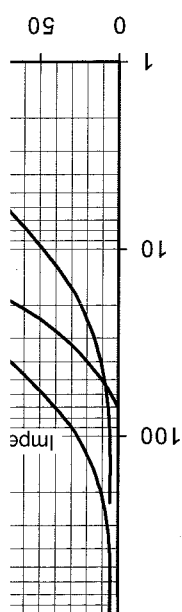
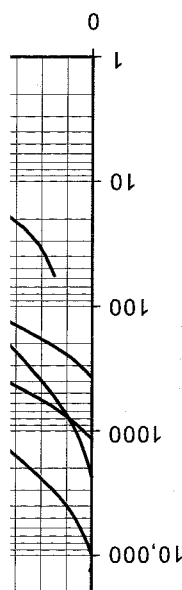


Figure A.12 Purchased Costs for Dryers

Purchased Cost of Mixer per Unit of Mixer Power, C_p^0/P (\$/kW)



Purchased Cost of Filter per Unit of Filter Area, C_p^0/A (\$/m²)



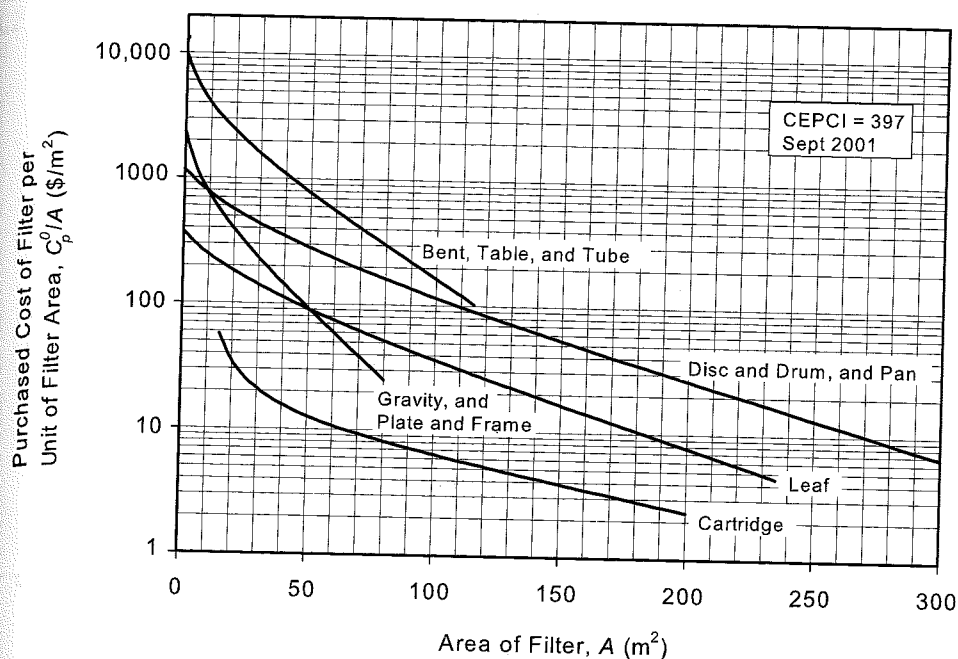
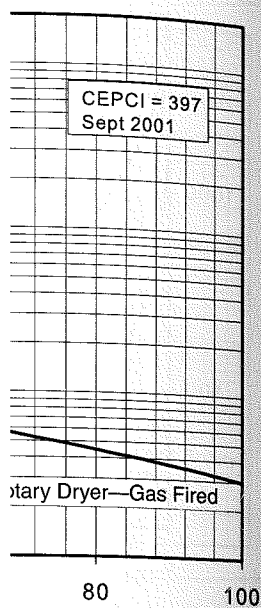


Figure A.14 Purchased Costs of Filters

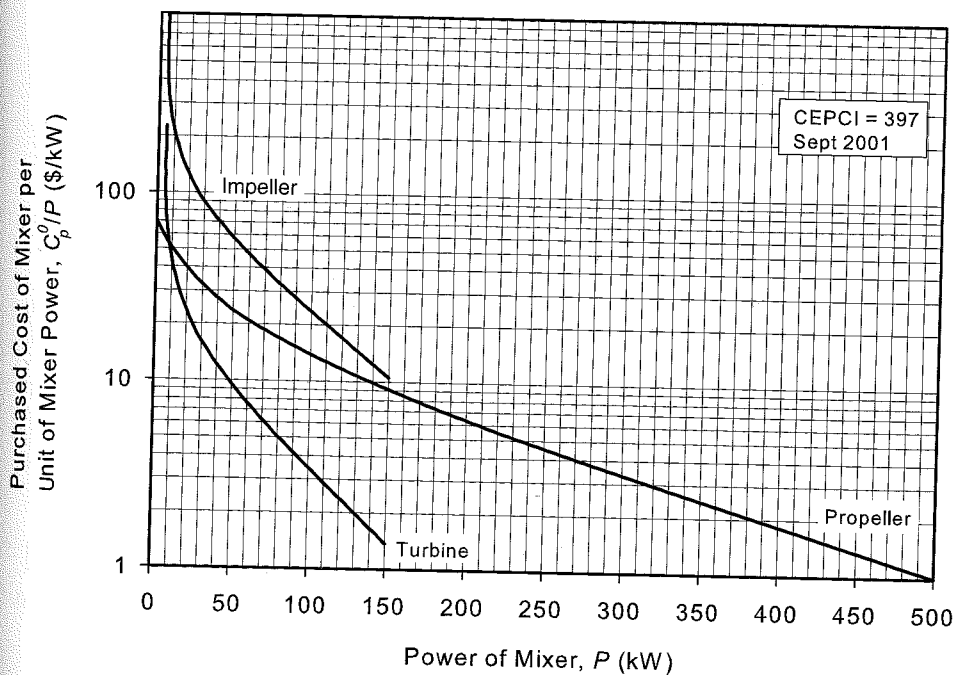
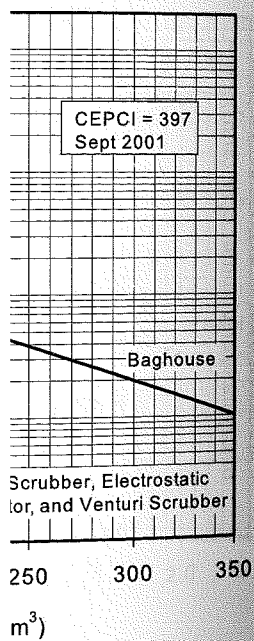


Figure A.15 Purchased Costs of Mixers

Purchased Cost of Reactor per Unit of Reactor Volume, C_p^0/V (\$/m³)

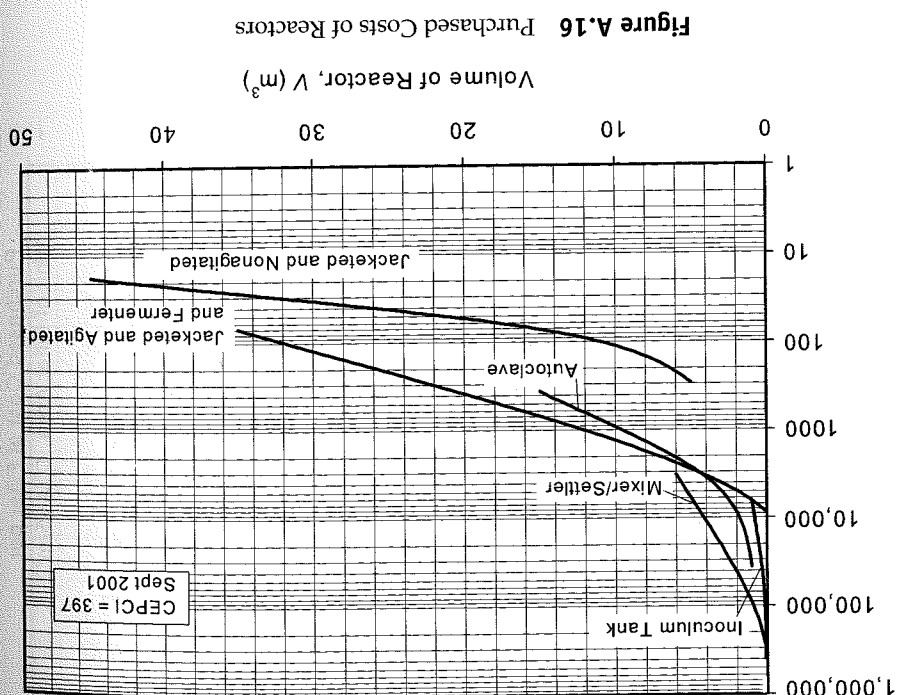


Figure A.16 Purchased Costs of Reactors

Purchased Cost of Screen per Unit of Screen Area, C_p^0/A (\$/m²)

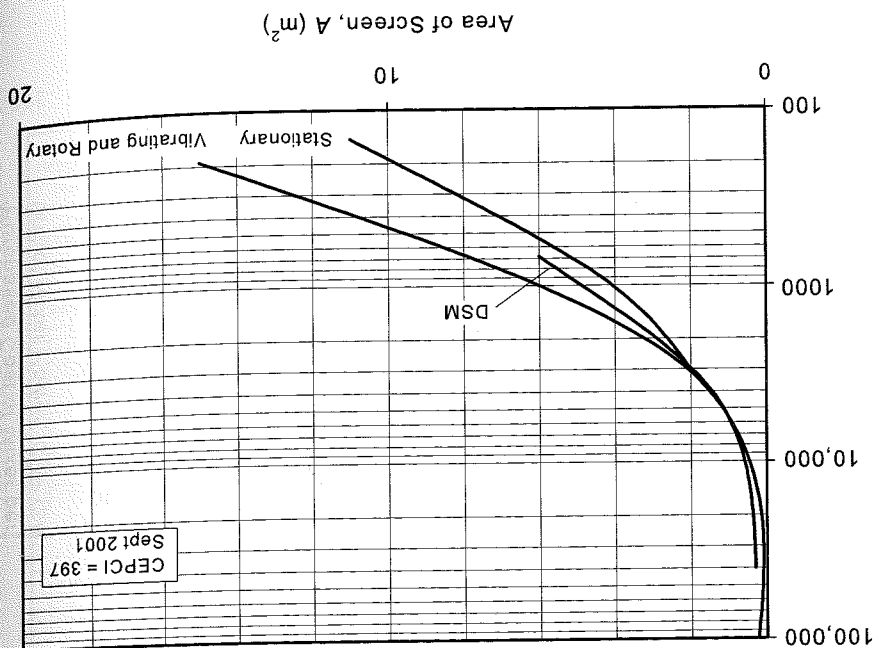


Figure A.17 Purchased Costs of Screens

Purchased Cost of Reactor per Unit of Reactor Volume, C_p^0/V (\$/m³)

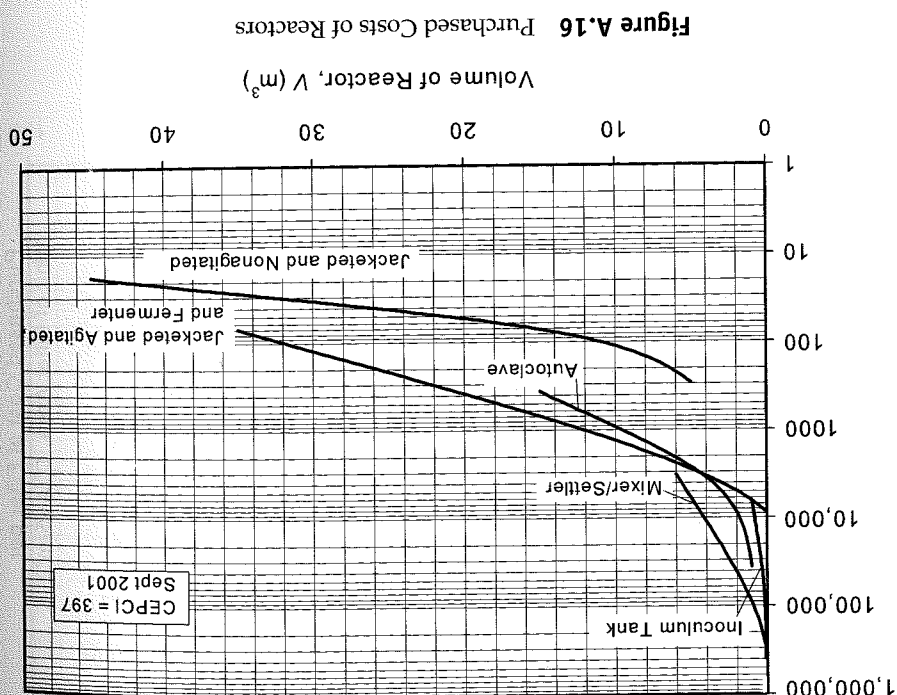


Figure A.16 Purchased Costs of Reactors

Purchased Cost of Screen per Unit of Screen Area, C_p^0/A (\$/m²)

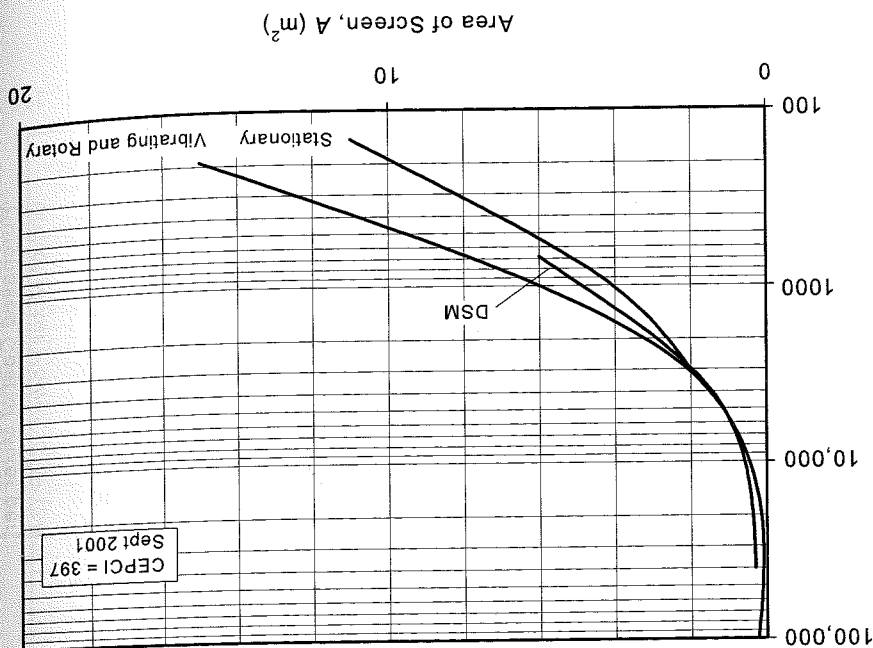


Figure A.17 Purchased Costs of Screens

Purchased Cost of Reactor per Unit of Reactor Volume, C_p^0/V (\$/m³)

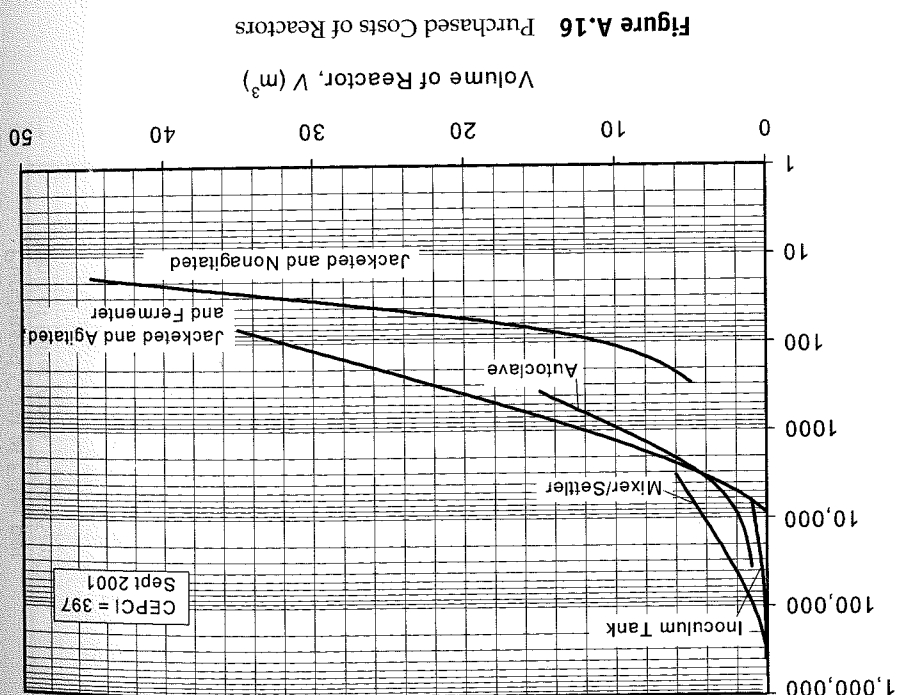


Figure A.16 Purchased Costs of Reactors

Purchased Cost of Screen per Unit of Screen Area, C_p^0/A (\$/m²)

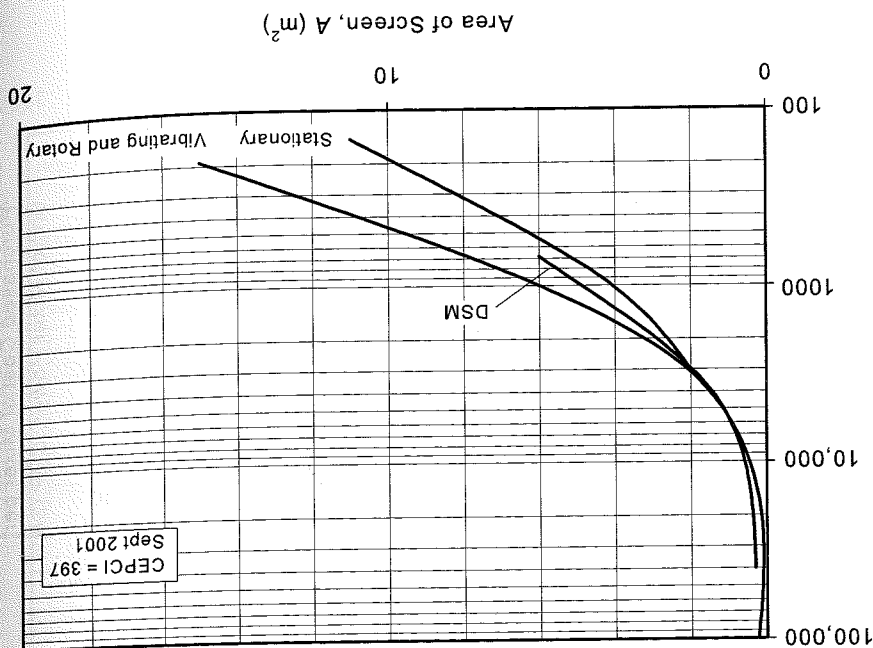


Figure A.17 Purchased Costs of Screens

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:

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

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:

$$\log_{10} F_P = C_1 + C_2 \log_{10} P + C_3 (\log_{10} P)^2 \quad (\text{A.3})$$

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.

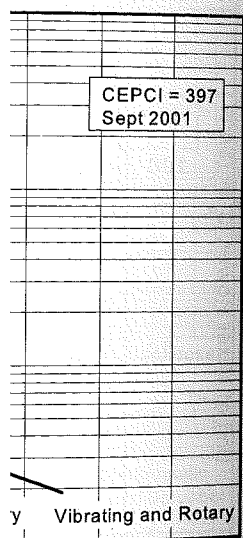
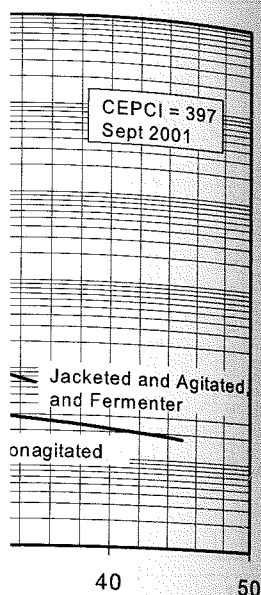


Table A.2 Pressure Factors for Process Equipment (Correlated from Data in Guthrie [1, 2], and Ulrich [3])

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

Table A.2 Pressure Factors for Process Equipment (Correlated from Data in Guthrie [1, 2], and Ulrich [3]) (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	$P < 5$ $5 < P < 140$
	Bayonet, fixed tube sheet, floating head, kettle reboiler, and U-tube (tube only)	0.03881	-0.11272	0.08183	$P < 5$ $5 < P < 140$
	Double pipe and multiple pipe	-0.00164	-0.00627	0.0123	$P < 40$
		0	0	0	$P < 40$

Heat exchangers	Nonreactive fired heater	0.1017	-0.1957	0.09403	10<P<200
		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)

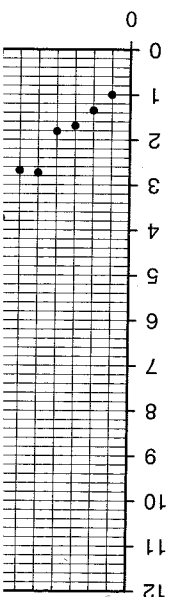
Table A.2 Pressure Factors for Process Equipment (Correlated from Data in Guthrie [1, 2], and Ulrich [3]) (Continued)

Equipment Type	Equipment Description	C ₁	C ₂	C ₃	Pressure Range (barg)
Heaters	Bayonet, fixed tube sheet, floating head, kettle reboiler, and U-tube (both shell and tube)	0	0	0	P<5
	Bayonet, fixed tube sheet, floating head, kettle reboiler, and U-tube (tube only)	0.03881	-0.11272	0.08183	5<P<140
	Double pipe and multiple pipe	0	0	0	P<5
		-0.00164	-0.00627	0.0123	5<P<140
		0	0	0	P<40
		0.6072	-0.9120	0.3327	40<P<100
	Flat plate and spiral plate	13.1467	-12.6574	3.0705	100<P<300
	Air cooler	0	0	0	P<19
		0	0	0	P<10
	Spiral tube (both shell and tube)	-0.1250	0.15361	-0.02861	10<P<100
Heaters	Spiral tube (tube only)	0	0	0	P<150
		-0.4045	0.1859	0	150<P<400
		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
	Steam boiler	-0.01633	0.056875	-0.00876	2<P<200
		0	0	0	P<20
		2.594072	-4.23476	1.722404	20<P<40
		0	0	0	-
				+	
Packing	Loose (for towers)	0	0	0	P<10
Process vessels	Horizontal and vertical	-0.245382	0.259016	-0.01363	10<P<100
	Reciprocating	0	0	0	P<10
	Positive displacement	-0.245382	0.259016	-0.01363	10<P<100
	Centrifugal	0	0	0	P<10
Pumps		-0.3935	0.3957	-0.00226	10<P<100
					(continued)

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

Material Factor, F_M Figure A.18 Material Factor, F_M
 References [1, 2, 3, 6]

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:

$$C_{BM} = C_p^o F_{BM} = C_p^o (B_1 + B_2 F_M F_p) \quad (\text{A.4})$$

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}^o , and the bare module factor for the equipment at these conditions, F_{BM}^o , 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].

(text continues on p. 949)

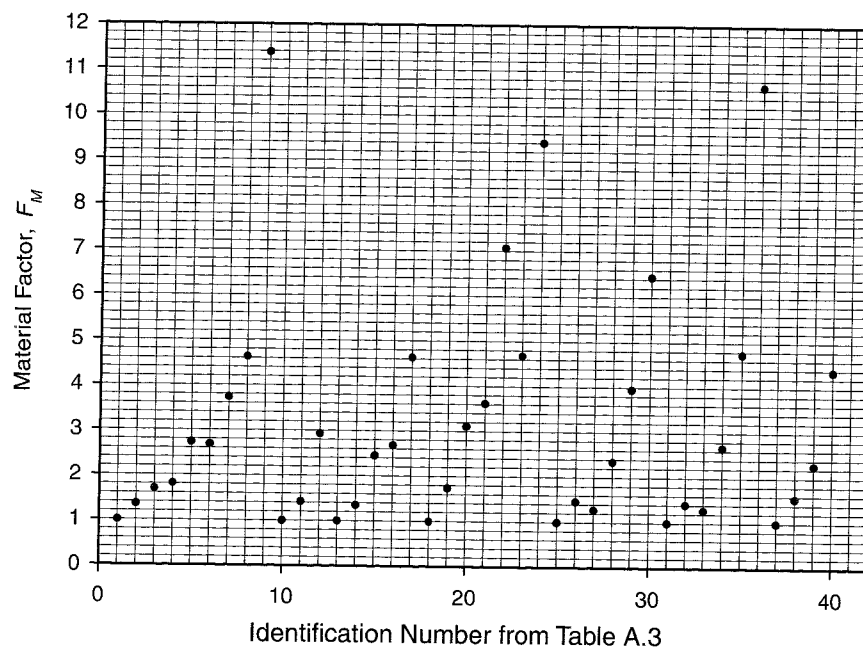


Figure A.18 Material Factors for Equipment in Table A.3 (Averaged Data from References [1, 2, 3, 6, 7, and 8])

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

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	Air cooler		Ti-shell/Ti-tube
10		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	Process vessels	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

(continued)

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

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

17	Process vessels	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

(continued)

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

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	Cast iron
38		Centrifugal	Carbon steel
39		Centrifugal	SS
40		Centrifugal	Ni alloy

Appendices

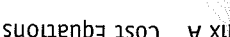
Appendices

App

Appendices

FIX A Cost Equations

FIX A Cost Equations



tion A.4 (Correlated from

	B_1	B_2
spiral tube	1.74	1.55
st, kettle	1.63	1.66
	0.96	1.21
	1.49	1.52
	2.25	1.82
	1.89	1.35
	1.89	1.35
	1.89	1.35

covered by Tables A.3

for Bare Module Cost

$C_{BM} = C_p^o F_{BM}$
 $C_{BM} = C_p^o F_{BM}$
 $C_{BM} = C_p^o F_{BM} F_P$
 $C_{BM} = C_p^o F_{BM} F_P$
 $C_M = C_p^o F_{BM} F_P F_T$
 correction factor for steam
 other heaters and furnaces)

$184\Delta T - 0.00000335(\Delta T)^2$
 amount of superheat in °C.

$C_{BM} = C_p^o F_{BM}$
 $C_M = C_p^o N F_{BM} F_q$
 number of trays and F_q is a
 trays only given by
 $4771 + 0.08516 \log_{10} N -$
 $(\log_{10} N)^2$ for $N < 20$
 $= 1$ for $N \geq 20$

$C_{BM} = C_p^o F_{BM}$

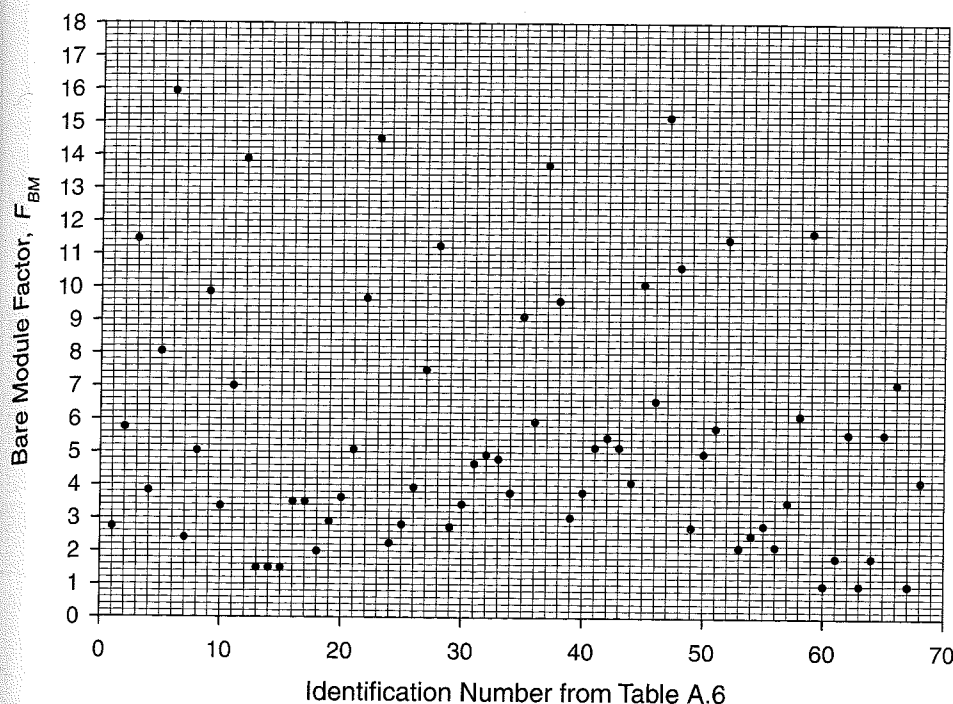


Figure A.19 Bare Module Factors for Equipment in Table A.6 (Average Data from References [1, 2, 3, 6, 7, and 8])

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.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/drip-proof	—
16		Gas turbine	—
17		Steam turbine	—
18		Internal combustion engine	—
19		Evaporator—forced circ, short or long tube	CS
20	Evaporators and vaporizers	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

(continued)

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

Identification Number	Equipment Type	Equipment Description	Material of Construction
25		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			

18	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

(continued)

Table A.6 Identification of Material Factors for Equipment Listed in Table A.5 to Be Used with Figure A.13 (Continued)

Identification Number	Equipment Type	Equipment Description	Material of Construction
25		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

(continued)

17	Steam turbine	—
18	Internal combustion engine	—
19	Evaporators and vaporizers	CS
	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

(continued)

TABLE A-2 Identification of Material Feature for Equipment Listed in Table A-1 to Be Used with Figure A-19 (Continued)

Identification Number	Equipment Type	Equipment Description	Material of Construction
25		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

(continued)

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

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

Screens

Reactors

Mixers

Filters

Dust Collectors

Dryers

Crystallizers

Conveyors

Centrifuges

Blenders

Equipment Type

Figure A.7

Bare Module Factors, Reactors, and Screens

Appendix A

Cost Equations

When possible, bare module factors marked * are estimates

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
	Apron	1.20
Conveyors	Belt	1.25
	Pneumatic	1.25*
	Screw	1.10
	Batch	1.60
Crystallizers	Drum	1.60
Dryers	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*
	Bent	1.65*
Filters	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*
	Propeller	1.38
Mixers	Turbine	1.38
	Autoclave	4.0*
Reactors	Fermenter	4.0*
	Inoculum tank	4.0*
	Jacketed agitated	4.0*
	Jacketed nonagitated	4.0*
	Mixer/settler	4.0*
	DSM	1.34*
	Rotary	1.34*
Screens	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

