DOE/NETL-2002/1169

Process Equipment Cost Estimation

Final Report

Prepared for:
National Energy Technology Center
P.O. Box 10940, 626 Cochrans Mill Road
Pittsburgh, PA 15236-0940
and
P.O. Box 880, 3610 Collins Ferry Road
Morgantown, WV 26507-0880

Prepared by:
H. P. Loh
National Energy Technology Center
P.O. Box 10940, 626 Cochrans Mill Road
Pittsburgh, PA 15236-0940

Jennifer Lyons
Charles W. White, III
EG&G Technical Services, Inc.
3604 Collins Ferry Road Suite 200
Morgantown, West Virginia 26505

January, 2002

DISCLAIMER

Table of Contents

List of Tables

Abstract

This report presents generic cost curves for several equipment types generated using ICARUS Process Evaluator. The curves give Purchased Equipment Cost as a function of a capacity variable. This work was performed to assist NETL engineers and scientists in performing rapid, order of magnitude level cost estimates or as an aid in evaluating the reasonableness of cost estimates submitted with proposed systems studies or proposals for new processes. The specific equipment types contained in this report were selected to represent a relatively comprehensive set of conventional chemical process equipment types.

Background

As part of its mission to identify and develop practical and viable processes for power production, chemicals processing, fuel processing, CO_2 capture and sequestration, and other environmental management applications, NETL engineers and scientists need to both perform order of magnitude cost estimates and evaluate and assess cost estimates contained in proposals for novel processes. In these applications where process and technological specifics are lacking, detailed cost estimates are not justified. Rather, rough estimates that can be obtained relatively quickly are more suitable. There are a number of tools available to NETL engineers to assist in the performance and evaluation of chemical process equipment cost estimates.

One such tool is ICARUS Process Evaluator (IPE). IPE is a sophisticated and industry-accepted software tool for generating cost estimates, process facility designs, and engineering and construction schedules. The IPE equipment library contains over 320 process equipment types. Sizing is performed using common engineering methodologies from intrinsic sizing algorithms. IPE utilizes self-contained equipment, piping, instrumentation, electrical, civil, steel, insulation, and paint sizing and design algorithms for a preliminary equipment model that is properly integrated and evaluated for many safety and operability issues.

When used with appropriate values for the adjustable design and construction parameters, IPE provides a highly detailed and accurate cost estimate. However, the program is very complex and both expensive and time consuming to learn and use. Furthermore, IPE requires well-defined process configuration and process parameters that typical proposals do not provide. In general, it is not practical or cost-effective to use IPE for the assessment of cost estimates contained in proposals for novel processes or in generating rough cost estimates from laboratory scale data. Instead, the factored estimation methodology, a cost-effective methodology widely used in industry, is more suitable for that application. To leverage the cost information contained within IPE, a series of cost curves for different equipment types were generated. The cost curves and other

information contained in this report can then be used to develop the overall process plant capital cost using the factored estimation methodology.

Results and Usage

For this activity, a general file was created in ICARUS Process Evaluator version 5.0 that contained several pieces of stand-alone equipment. The specific equipment types were selected by NETL and intended to represent a relatively comprehensive set of conventional chemical process equipment types that might be encountered in processes relevant to CO_2 capture and sequestration. Each piece of equipment was then varied in size to generate costs for a spectrum of sizes. The cost versus sizing capacity was plotted for each equipment type. The data was then regressed to provide smoothed cost curves.

The cost curves for the 31 different types of equipment examined in this report are shown on pages 6 - 40. In addition to the graphs, the applicable design specifications and equipment descriptions are provided as appropriate.

All graphs portray purchased equipment cost data. This total material cost includes:

- Internals, shells, nozzles, manholes, covers, etc as noted for each piece equipment.
- Vendor engineering, shop drawings shop testing, certification.
- Shop fabrication labor (and field labor if field-fabricated).
- Typical manuals, small tools, accessories.
- Packaging for shipment by land.
- FOB Vendor.

The total material cost does not include:

- Owner/contractor indirects (engineering, shop inspection, start-up/commissioning).
- Packaging for overseas/air shipment, modularization.
- Freight, insurance, taxes/duties
- Field setting costs (off-loading, storage, transportation, setting, testing)
- Installation bulks

The total capital cost of each piece of equipment includes material and labor charges. The material charges include the delivered equipment costs and installation bulk material costs. The labor charges include labor for handling and placing bare equipment and labor for installation of bulk materials.

Installation bulks consist of foundations, structural steel, buildings, insulation, instruments, electrical, piping, painting and miscellaneous. Tables 2 - 5 list distributive percentage factors that can be used to estimate installation bulk labor and materials for different plant types. [1] The factors vary depending on the type of process and the

[1] AACE Recommended Practices and Standards – "Conducting Technical and Economic Evaluations in the Process and Utility Industries," adopted November 1990.

temperature and pressure of the system. The bare equipment cost is used as the base to apply the percentage factor for the installation material cost. This installation material cost is then used as the base to apply the percentage factor for determining the associated labor cost involved.

Handling and placing equipment involves unloading, uncrating, mechanical connection, alignment, storage, inspection, and other factors. The costs vary by type and size of equipment. The setting costs can be estimated by using historical work hours or by applying factors for labor cost as a percentage of delivered equipment cost. Table 6 shows approximate factors for setting various types of equipment.[1]

The total cost for installing a piece of equipment would be the bare equipment cost plus the setting labor cost plus the installation bulks material and labor costs as determined from the distributive labor percentages. See Appendix A for a detailed example.

Appendix B shows the ICARUS generated purchased/ installed costs of the equipment used in each chart. All costs in this document are reported in first quarter 1998 dollars.

Assessment

The charts can be used for preliminary purchased equipment cost estimates (i.e. order of magnitude estimates with accuracy of +50%/-30% and budget estimates with accuracy of +30%/-15%). Clearly, the charts are most accurate when used for the operating conditions listed as defaults for each equipment type. Nevertheless, they should provide reasonable cost estimates for conditions that contain small or moderate deviations from the assumed design conditions. Correlations to correct for deviations in some design variables, particularly pressure, are available in the literature. Peters and Timmerhaus "Plant Design and Economics for Chemical Engineers" is one such source for correction factor data. Without appropriate correction, estimates generated for conditions that deviate markedly from those used in this study should be used with caution.

Another limitation is that most of the charts give estimates for equipment manufactured from carbon steel. Conversion factors for converting the carbon steel costs to equivalent alloy costs for a few items of equipment are shown in Table 7.[2]

As mentioned previously, setting costs can be estimated by using historical data or by applying factors. It should be noted that the factors do not work well for very large pieces of equipment. If available, historical work hours provide more accurate costs.

[2] Perry, Robert H. , and Don W. Green, "Perry's Chemical Engineers' Handbook," The McGraw-Hill Companies, Inc., 1999.

Conclusions/Recommendations

This report contains cost curves for various equipment types at specific operating temperatures and pressures. These conditions and other design parameters are listed for each equipment type. When used within the expected design conditions, the cost estimates derived from the cost curves contained in this report will provide accurate estimates. The data can also be used to provide reasonableness estimates when the actual design conditions are outside the expected values but the level of accuracy cannot be quantified.

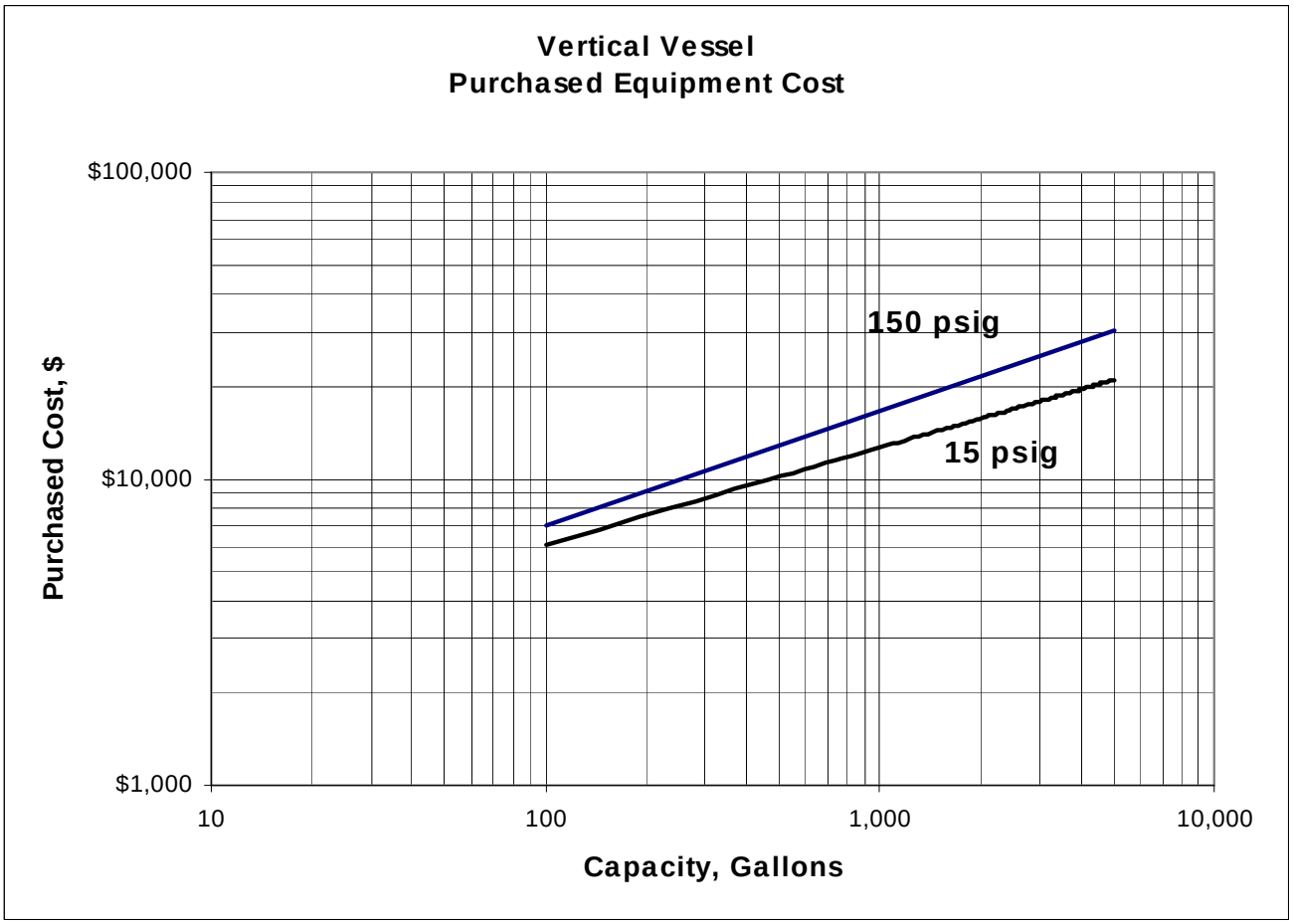
To help quantify the error induced by large deviations in the design conditions, it is recommended that a first-order sensitivity analysis of the cost curves be performed. Another activity that could improve the range of accuracy of the charts would be to run cases with various materials of construction to show how the price is affected. If requested, additional support can be provided to expand the set of equipment types beyond those examined in this report. For example, cost data for slurry pumps and solids conveying equipment would be useful for many of the technologies at NETL.

Cost Curves

Vertical Vessel

Description: The vertical process vessel is erected in the vertical position. They are cylindrical in shape with each end capped by a domed cover called a head. The length to diameter ratio of a vertical vessel is typically 3 to 1. Vertical tanks include: process, storage applications liquid, gas, solid processing and storage; pressure/vacuum code design for process and certain storage vessel types; includes heads, single wall, saddles, lugs, nozzles, manholes, legs or skirt, base ring, davits where applicable.

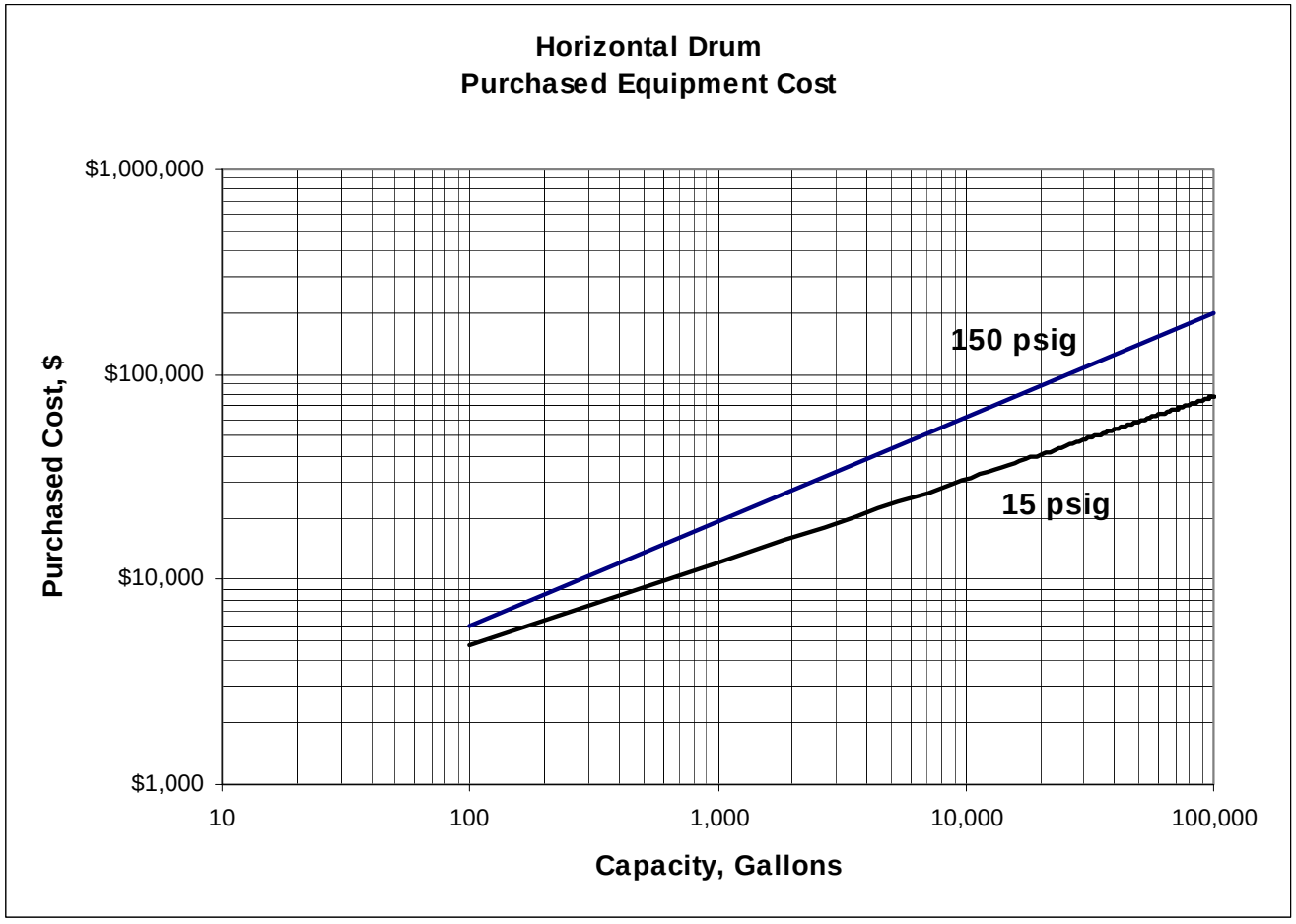
Design Basis:
1st Quarter 1998 Dollars
Shell Material: A515
(Carbon Steel Plates for pressure vessels for intermediate and higher temperature service)
Design Temperature: 650 °F
Design Pressure: 15 psig and 150 psig
Diameter: 2.5 – 8 feet
Length: 2.7 – 13.3 feet
Total Weight: 1,000 –7,100 pounds



Horizontal Vessel

Description: The horizontal vessel is a pressure vessel fabricated according to the rules of the specified code and erected in the horizontal position. Although the horizontal vessel may be supported by lugs in an open steel structure, the more usual arrangement is for the vessel to be erected at grade and supported by a pair of saddles. Cylindrical, pressure/vacuum, code design and construction, includes head, single wall (base material, clad/lined), saddles/lugs, nozzles and manholes.

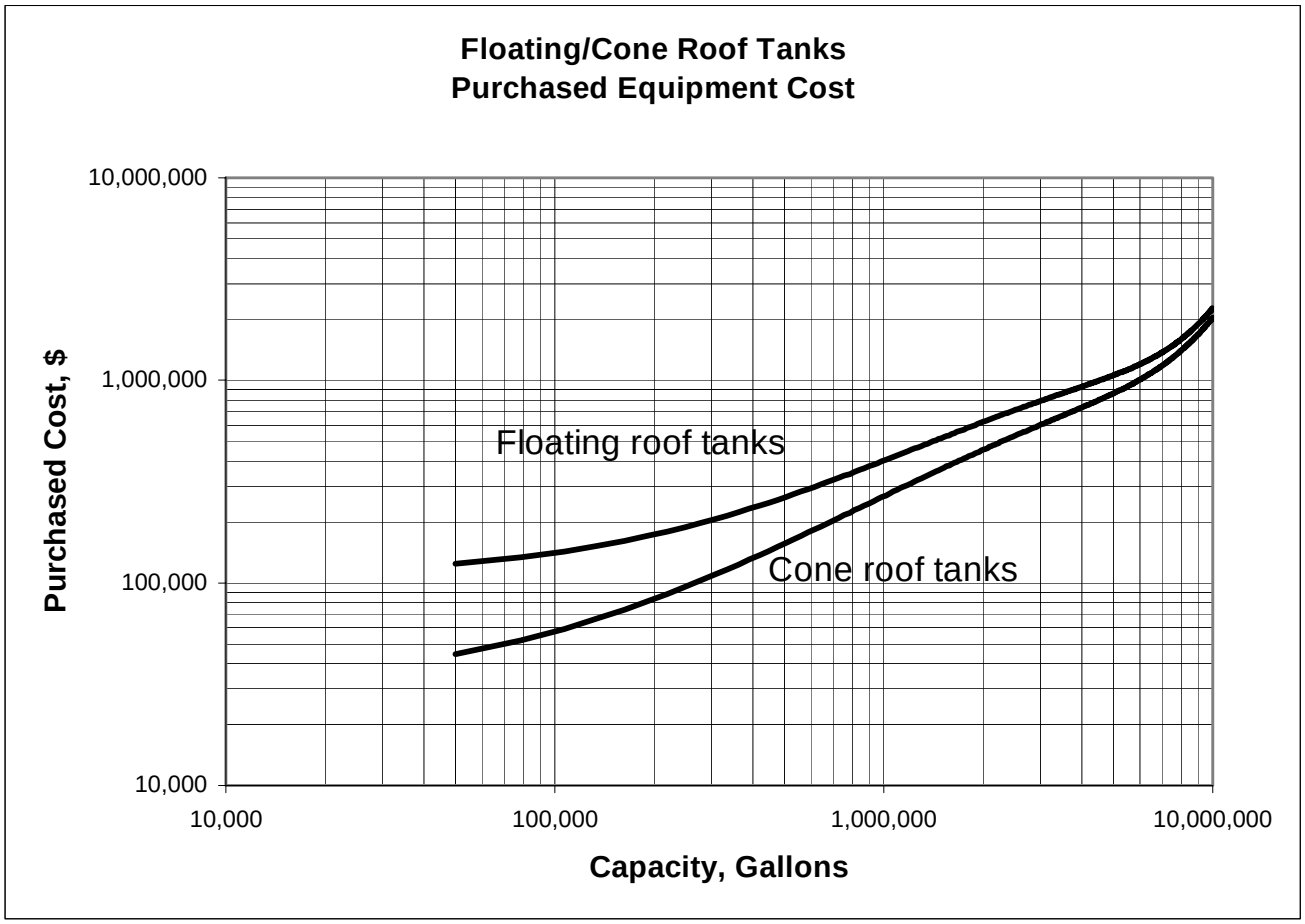
Design Basis:
1st Quarter 1998 Dollars
Shell Material: A515
(Carbon Steel Plates for pressure vessels for intermediate and higher temperature service)
Design Temperature: 650 °F
Design Pressure: 15 psig
Diameter: 2 – 14 feet
Length: 4.3 – 81 feet
Total Weight: 1100 –59,400 pounds



Storage Tanks

Description:
Floating Roof: Typically constructed from polyurethane foam blocks or nylon cloth impregnated with rubber or plastic, floating roofs are designed to completely contact the surface of the storage products and thereby eliminate the vapor space between the product level and the fixed roof. Floating roof tanks are suitable for storage of products having vapor pressure from 2 to 15 psia.
Cone Roof: Typically field fabricated out of carbon steel. They are used for storage of low vapor pressure (less than 2 psia) products, typically ranging from 50,000 – 1,000,000 gallons.

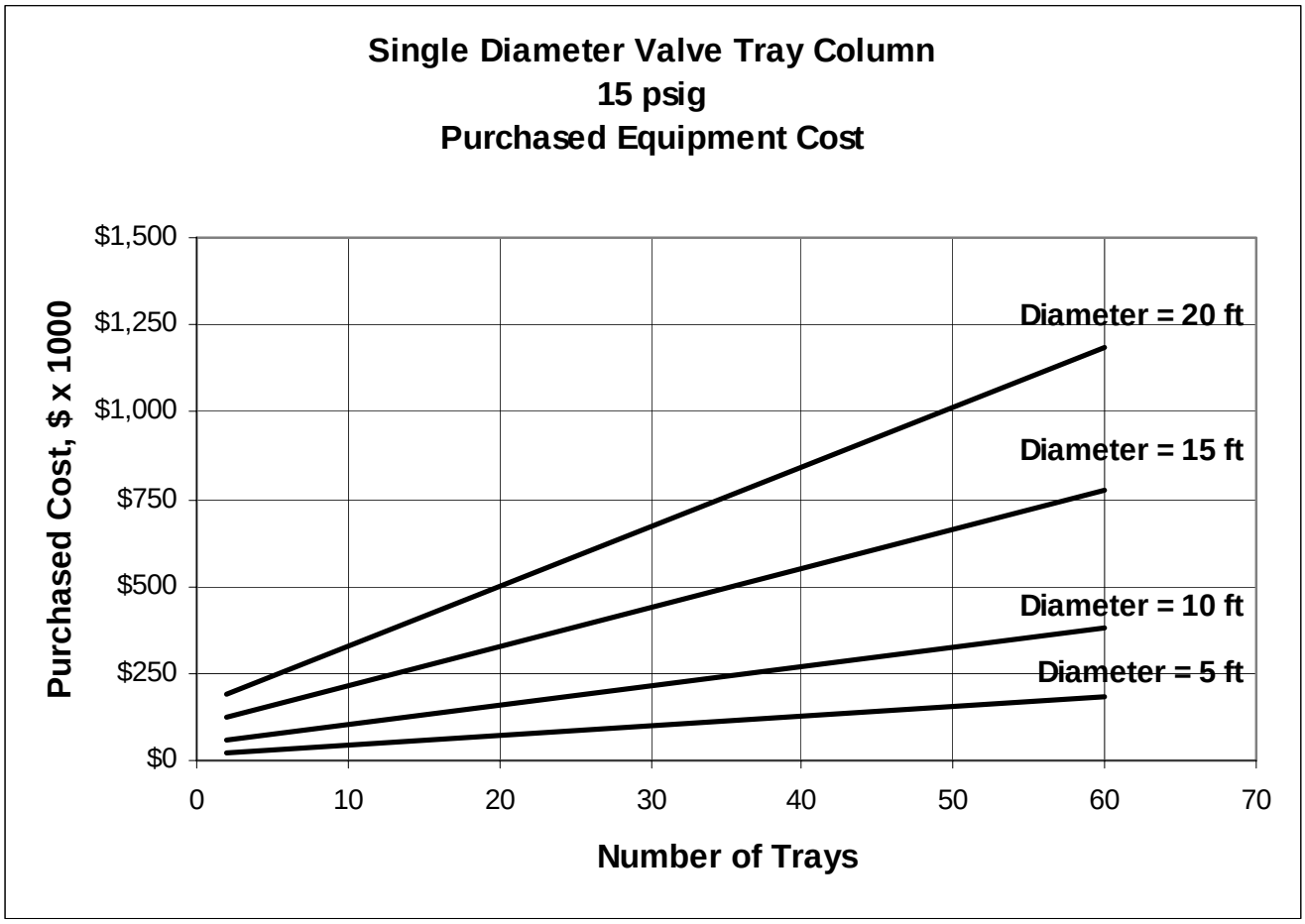
Design Basis:
1st Quarter 1998 Dollars
Shell Material: A515
(Carbon Steel Plates for pressure vessels for intermediate and higher temperature service)
Design Temperature: 650 °F
Design Pressure: 15 psig
Diameter: 2 – 14 feet
Length: 4.3 – 81 feet
Total Weight: 1100 –59,400 pounds



Valve Tray Column – 15 psig

Description: Pressure/vacuum column includes vessel shell, heads, single base material (lined or clad, nozzles, manholes (one manhole below and above tray stack or packed section and one manhole every tenth tray or 25 feet of packed height), jacket and nozzles for heating or cooling medium, base ring, lugs, skirt or legs; tray clips, tray supports (if designated), distributor piping, plates.

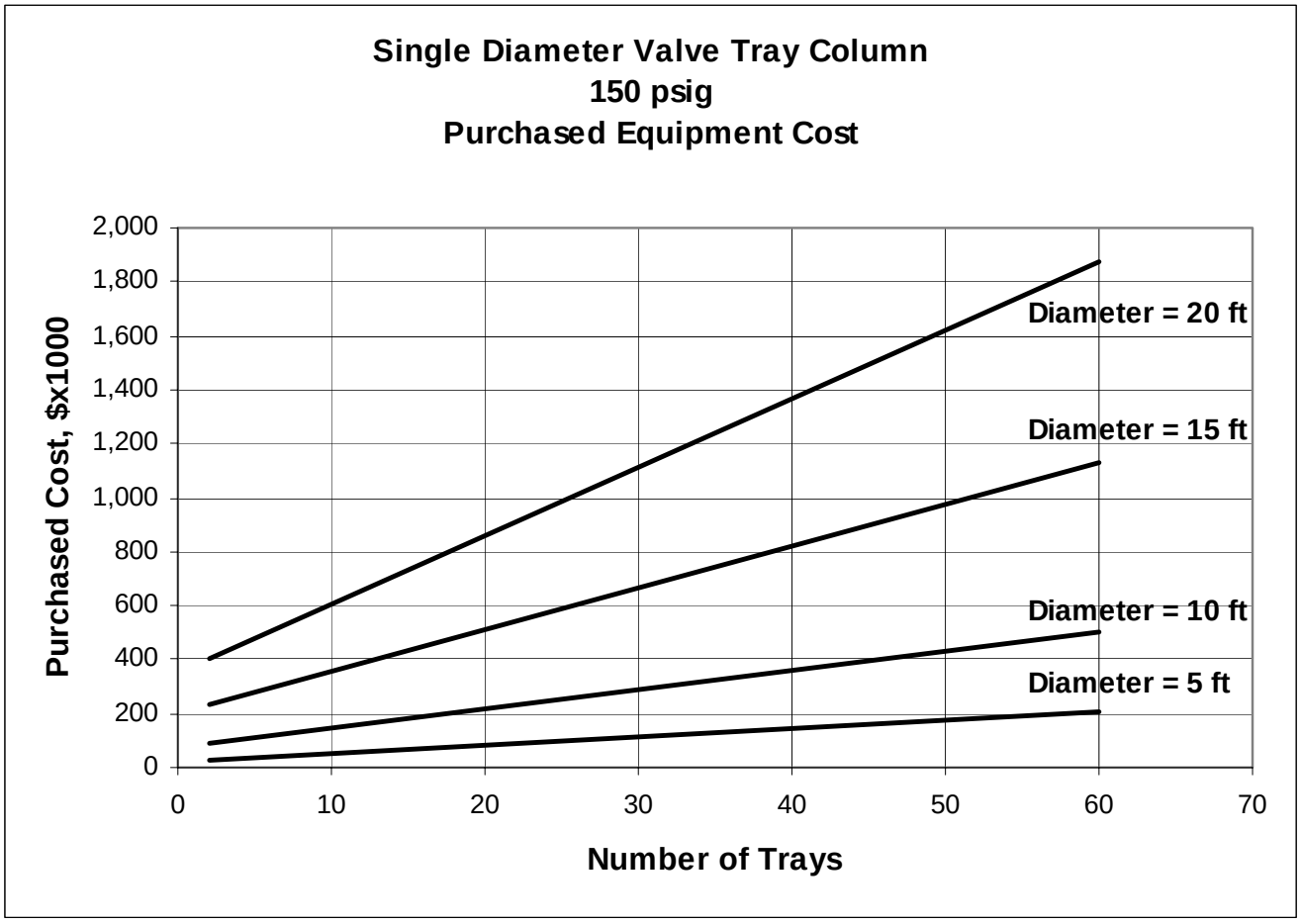
Design Basis:
1st Quarter 1998 Dollars
Shell Material: A515
(Carbon Steel Plates for pressure vessels for intermediate and higher temperature service)
Design Temperature: 650 °F
Design Pressure: 15 psig
Height: 17 - 133 feet
Application: Distillation
Tray Type: Valve
Tray Spacing: 24 Inches
Tray Material: A285C
(Low and intermediate strength carbon steel plates for pressure vessels.)
Tray Thickness: 0.19 Inches



Valve Tray Column – 150 psig

Description: Pressure/vacuum column includes vessel shell, heads, single base material (lined or clad, nozzles, manholes (one manhole below and above tray stack or packed section and one manhole every tenth tray or 25 feet of packed height), jacket and nozzles for heating or cooling medium, base ring, lugs, skirt or legs; tray clips, tray supports (if designated), distributor piping, plates.

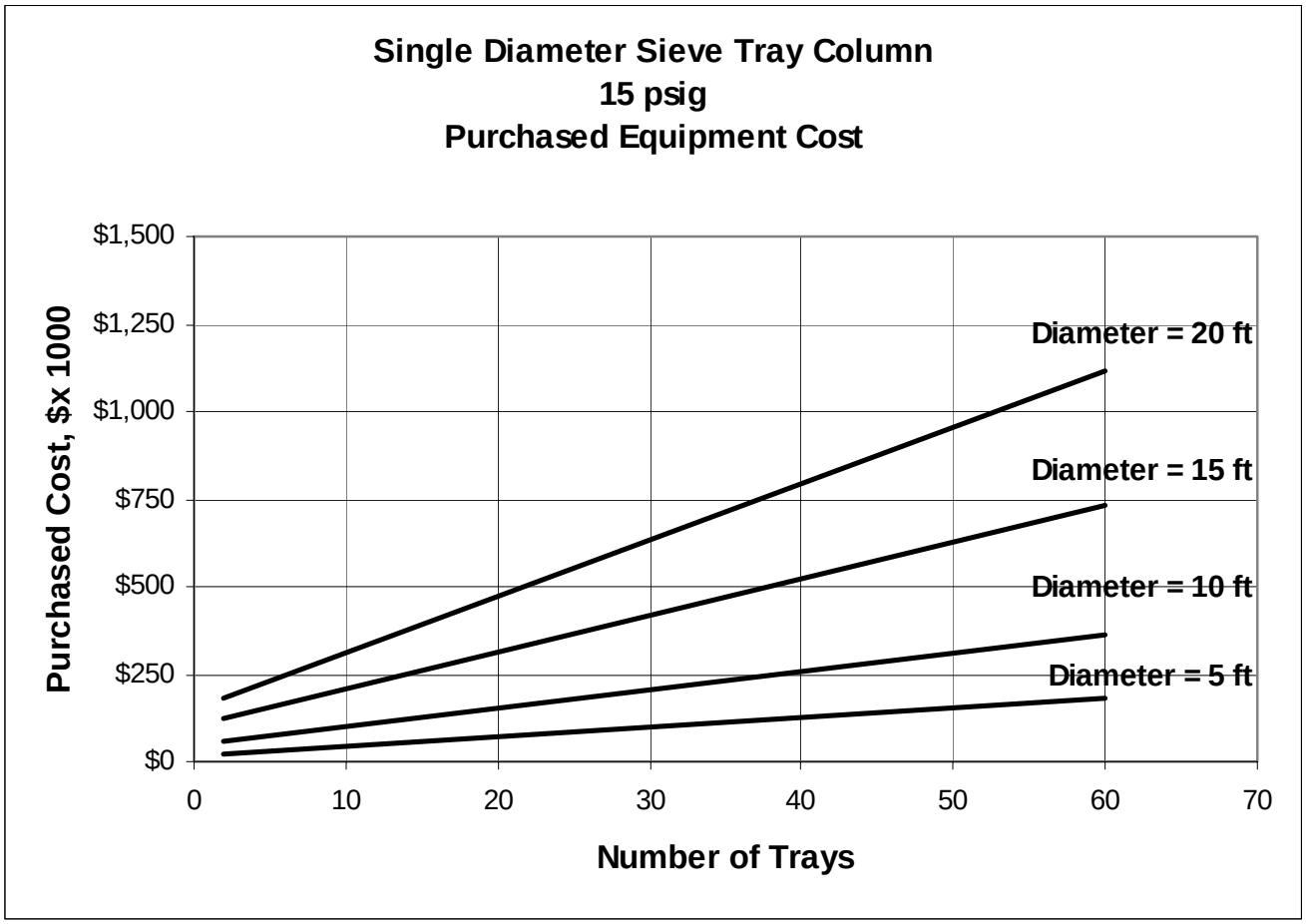
Design Basis:
1st Quarter 1998 Dollars
Shell Material: A515
(Carbon Steel Plates for pressure vessels for intermediate and higher temperature service)
Design Temperature: 650 °F
Design Pressure: 150 psig
Height: 17 - 133 feet
Application: Distillation
Tray Type: Valve
Tray Spacing: 24 Inches
Tray Material: A285C
(Low and intermediate strength carbon steel plates for pressure vessels.)
Tray Thickness: 0.19 Inches



Sieve Tray Column – 15 psig

Description: Pressure/vacuum column includes vessel shell, heads, single base material (lined or clad, nozzles, manholes (one manhole below and above tray stack or packed section and one manhole every tenth tray or 25 feet of packed height), jacket and nozzles for heating or cooling medium, base ring, lugs, skirt or legs; tray clips, tray supports (if designated), distributor piping, plates.

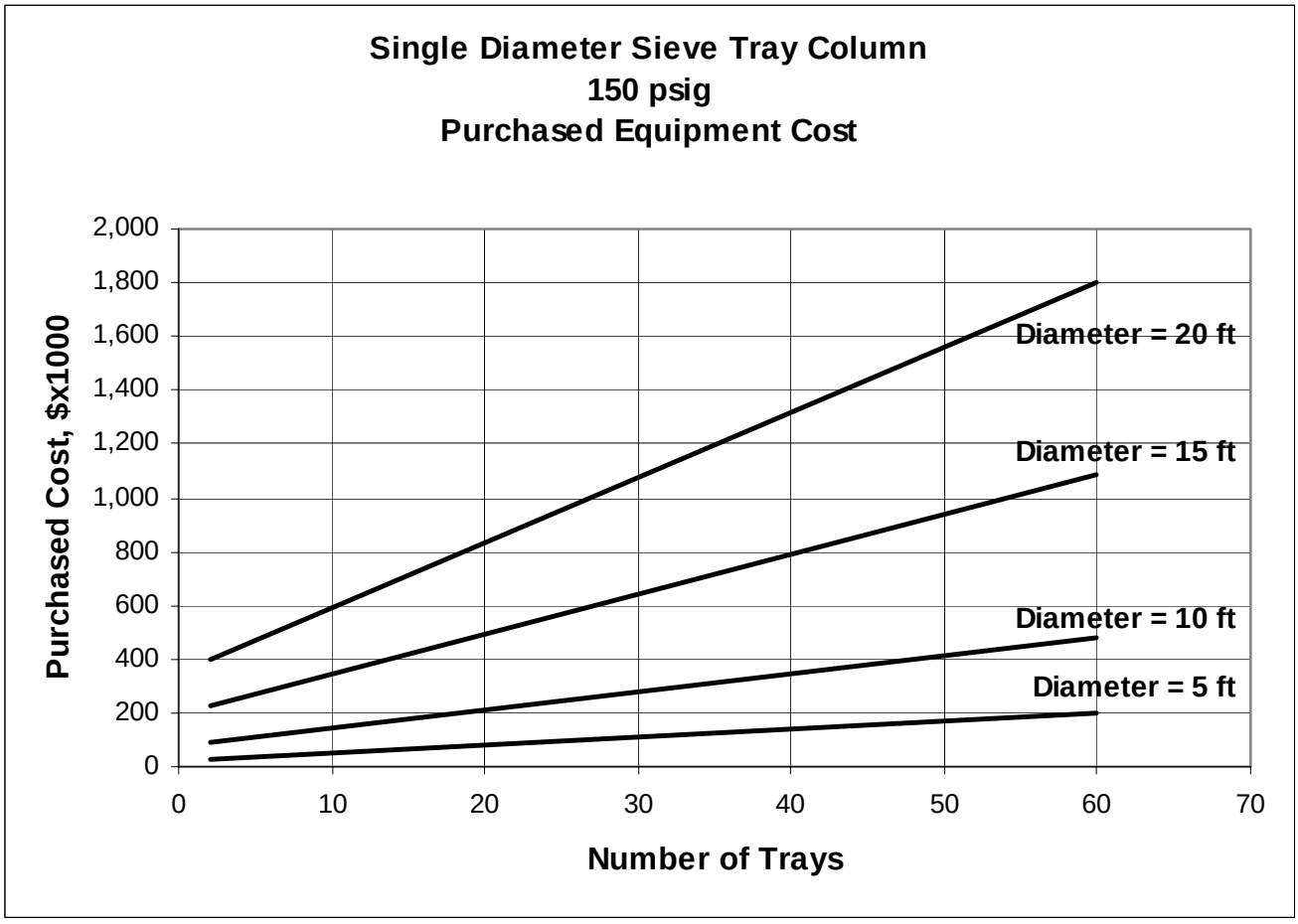
Design Basis:
1st Quarter 1998 Dollars
Shell Material: A515
(Carbon Steel Plates for pressure vessels for intermediate and higher temperature service)
Design Temperature: 650 °F
Design Pressure: 15 psig
Height: 17 - 133 feet
Application: Distillation
Tray Type: Sieve
Tray Spacing: 24 Inches
Tray Material: A285C
(Low and intermediate strength carbon steel plates for pressure vessels.)
Tray Thickness: 0.19 Inches



Sieve Tray Column – 150 psig

Description: Pressure/vacuum column includes vessel shell, heads, single base material (lined or clad, nozzles, manholes (one manhole below and above tray stack or packed section and one manhole every tenth tray or 25 feet of packed height), jacket and nozzles for heating or cooling medium, base ring, lugs, skirt or legs; tray clips, tray supports (if designated), distributor piping, plates.

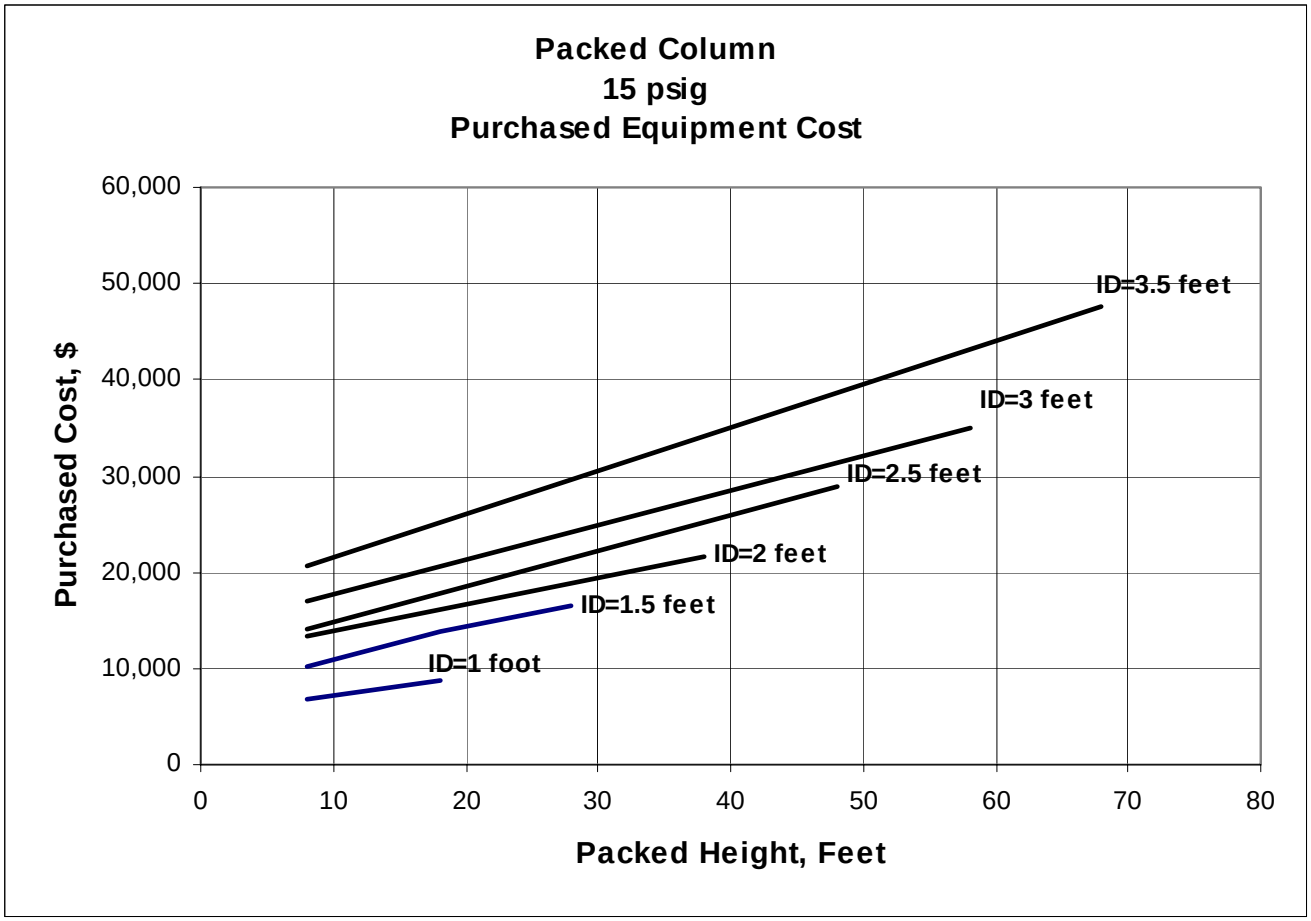
Design Basis:
1st Quarter 1998 Dollars
Shell Material: A515
(Carbon Steel Plates for pressure vessels for intermediate and higher temperature service)
Design Temperature: 650 °F
Design Pressure: 150 psig
Height: 17 - 133 feet
Application: Distillation
Tray Type: Sieve
Tray Spacing: 24 Inches
Tray Material: A285C
(Low and intermediate strength carbon steel plates for pressure vessels.)
Tray Thickness: 0.19 Inches



Packed Column – 15 psig

Description: Pressure/vacuum column includes vessel shell, heads, single base material (lined or clad, nozzles, manholes (one manhole below and above tray stack or packed section and one manhole every tenth tray or 25 feet of packed height), jacket and nozzles for heating or cooling medium, base ring, lugs, skirt or legs; tray clips, tray supports (if designated), distributor piping, plates, packing not included (see Table 1).

Design Basis:
1st Quarter 1998 Dollars
Shell Material: A515
(Carbon Steel Plates for pressure vessels for intermediate and higher temperature service)
Design Temperature: 650 °F
Design Pressure: 15 psig
Application: Absorption



Packed Column – 150 psig

Description: Pressure/vacuum column includes vessel shell, heads, single base material (lined or clad, nozzles, manholes (one manhole below and above tray stack or packed section and one manhole every tenth tray or 25 feet of packed height), jacket and nozzles for heating or cooling medium, base ring, lugs, skirt or legs; tray clips, tray supports (if designated), distributor piping, plates, packing not included (see Table 1).

Design Basis:
1st Quarter 1998 Dollars
Shell Material: A515
(Carbon Steel Plates for pressure vessels for intermediate and higher temperature service)
Design Temperature: 650 °F
Design Pressure: 150 psig
Application: Absorption

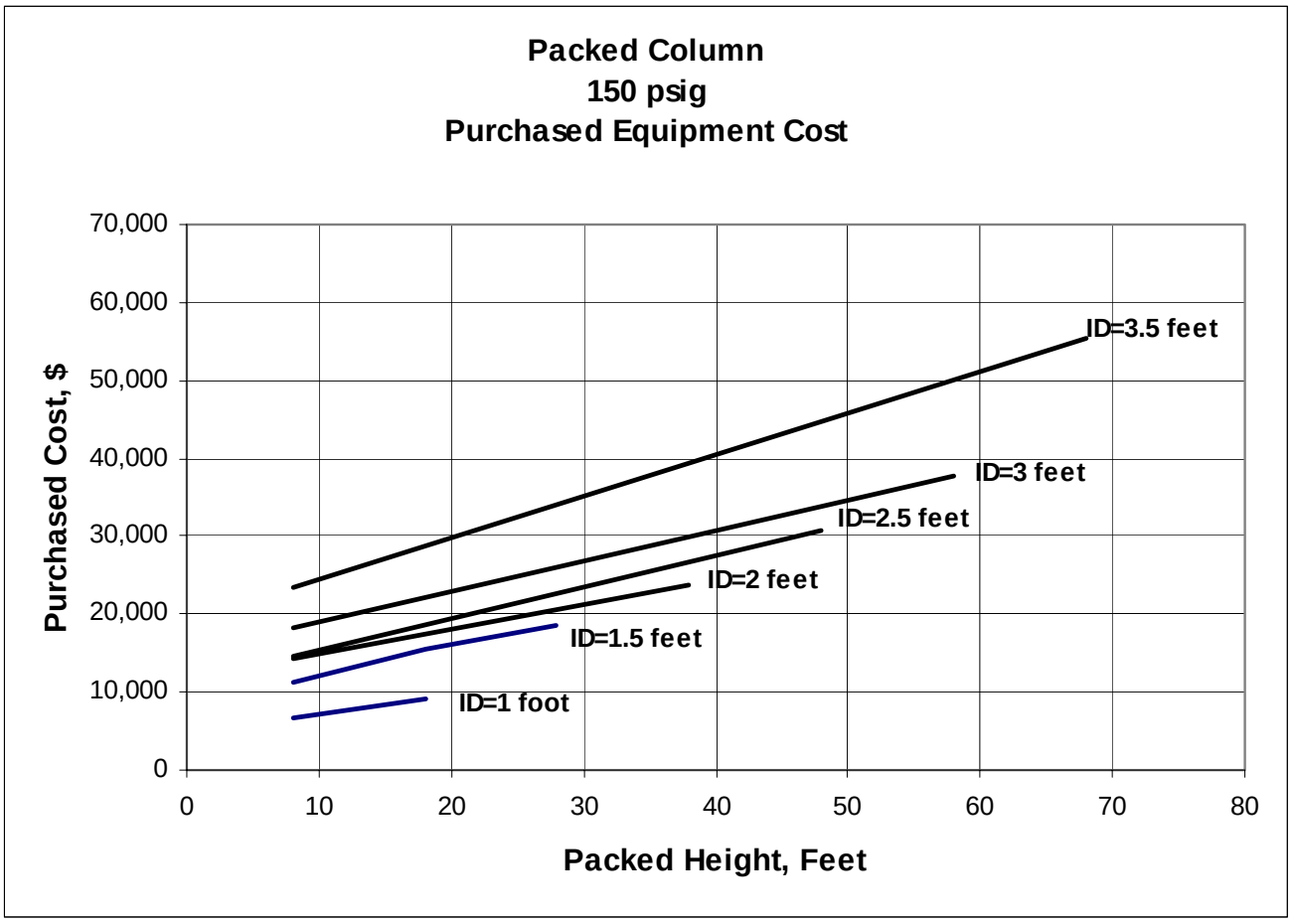


Table 1

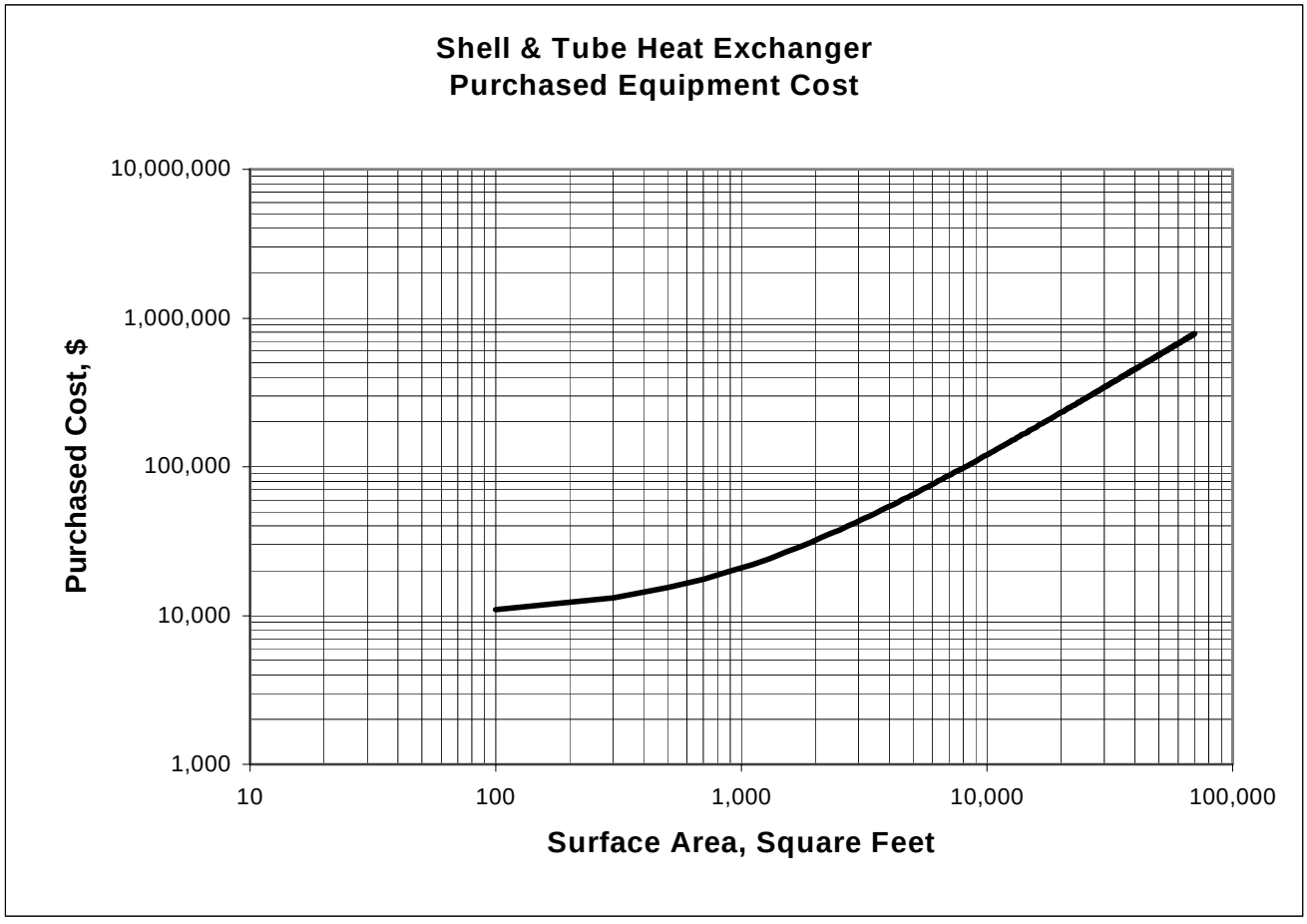
Packing Costs
Uninstalled cost, dollar per cubic feet
1st Quarter 1998 Dollars

Diameter (Inches)	0.5	1.0	1.5	2.0	3.0
Pall Rings					
Polypropylene	33	29	21	8	-
Stainless Steel	130	118	92	76	-
INTALOX Saddles					
Ceramic	31	28	23	21	-
Porcelain	32	29	24	21	-
Raschig Rings					
Ceramic	119	14	12	12	11
Porcelain	-	17	15	12	11
Stainless Steel	-	111	94	59	54
Carbon Steel	-	37	31	20	18
Activated Carbon	25				
13X Molecular Sieve	61				
Silica Gel	94				
Calcium Chloride	11				

Shell and Tube Heat Exchanger

Description: Shell and tube heat exchanger consists of a bundle of tubes held in a cylindrical shape by plates at either end called tube sheets. The tube bundle placed inside a cylindrical shell. The size of the exchanger is defined as the total outside surface area of the tube bundle. Maximum shell size is 48 Inches.

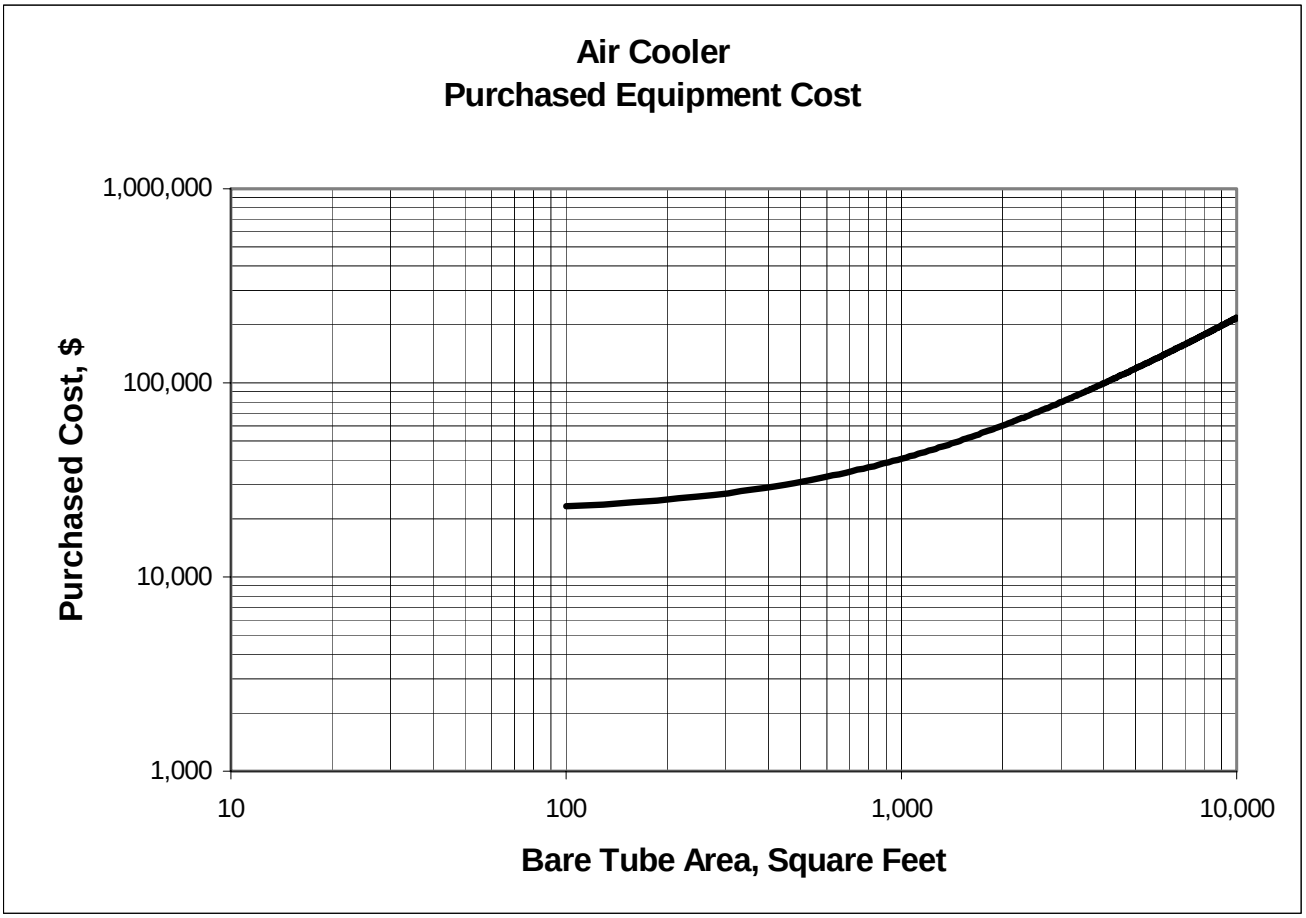
Design Basis:
1st Quarter 1998 Dollars
Type: Floating Head (BES)/ Fixed Head (BEM)
Shell Material: A285C
(Low and intermediate strength carbon steel plates for pressure vessels.)
Shell Temperature: 650 °F
Shell Pressure: 150 psig
Tube Material: A214
(Electric-resistance-welded carbon steel heat exchanger and condenser tubes)
Tube Temperature: 650 °F
Tube Pressure: 150 psig
Tube Length: 10– 20 Feet
Tube Diameter: 1 Inch



Air Cooler

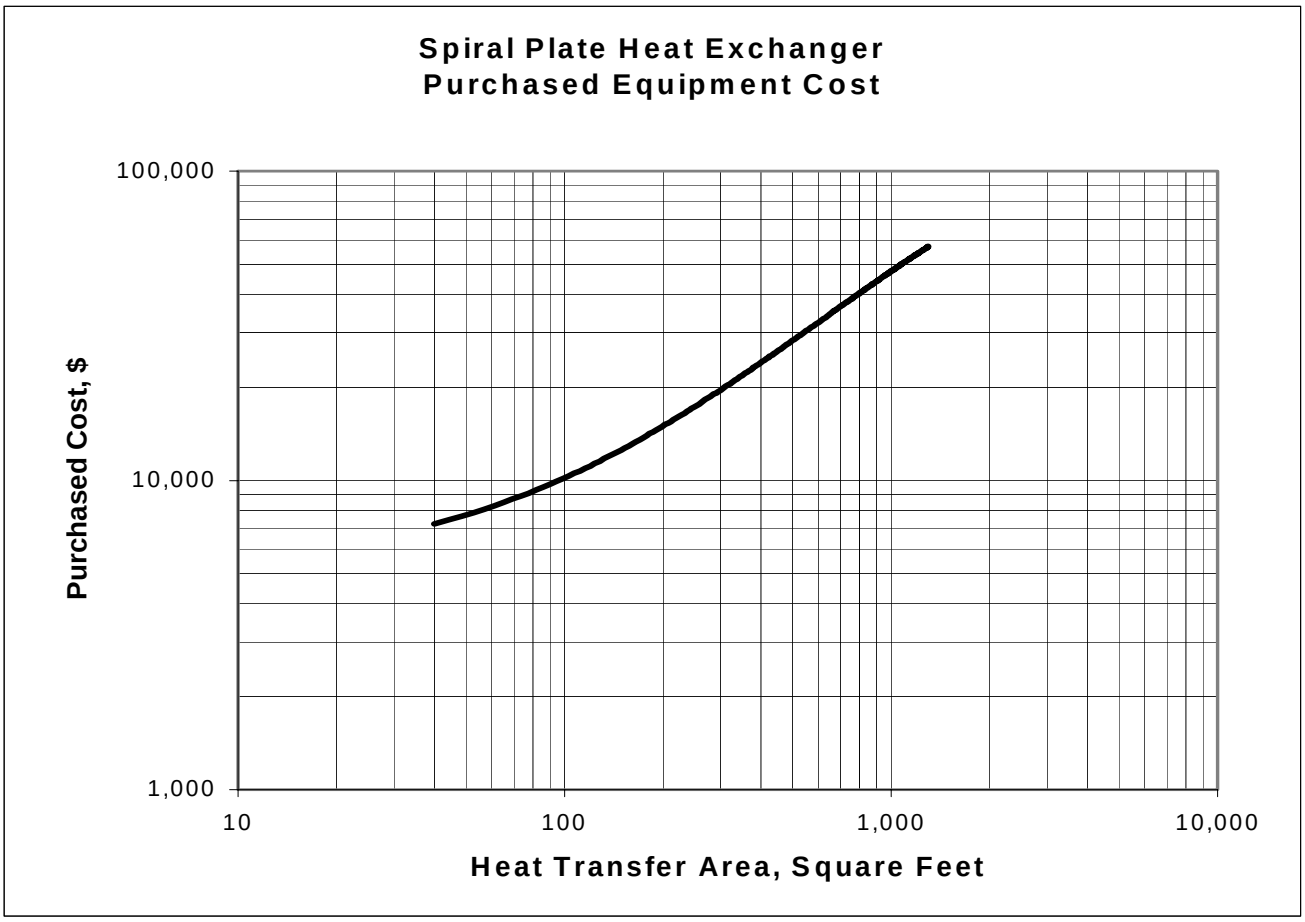
Description: Variety of plenum chambers, louver arrangements, fin types (or bare tubes), sizes, materials, free-standing or rack mounted, multiple bays and multiple services within a single bay.

Design Basis:
1st Quarter 1998 Dollars
Tube Material: A214
(Electric-resistance-welded carbon steel heat exchanger and condenser tubes)
Tube Length: 6 – 60 Feet
Number of Bays: 1 – 3
Power/ Fan: 2 – 25 Horsepower
Bay Width: 4 – 12 Feet
Design Pressure: 150 psig
Inlet Temperature: 300 °F
Tube Diameter: 1 Inch
Plenum Type: Transition shaped
Louver Type: Face louvers only
Fin Type: L-footed tension wound Aluminum



Spiral Plate Heat Exchanger

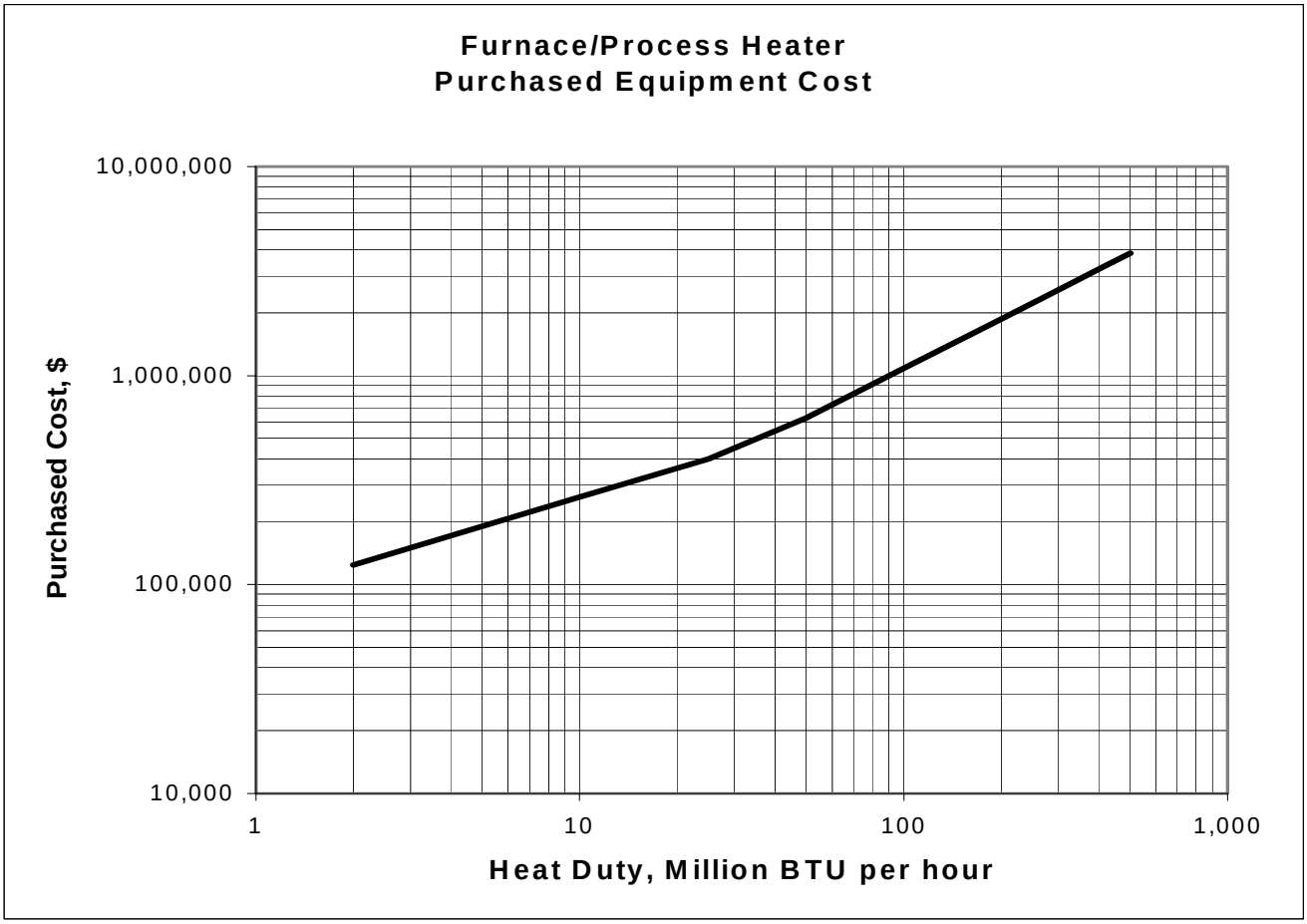
Design Basis:
1st Quarter 1998 Dollars
Material: SS304
(High Alloy Steel - Chromium-Nickel stainless steel plate, sheet and strip for fusion-welded unfired pressure vessels)
Tube Pressure: 150 psig



Furnace

Description: Gas or Oil fired vertical cylindrical type for low heat duty range moderate temperature with long contact time. Walls of the furnace are refractory lined.

Design Basis:
1st Quarter 1998 Dollars
Tube Material: A214
(Electric-resistance-welded carbon steel heat exchanger and condenser tubes)
Design Pressure: 500 psig
Design Temperature: 750 °F

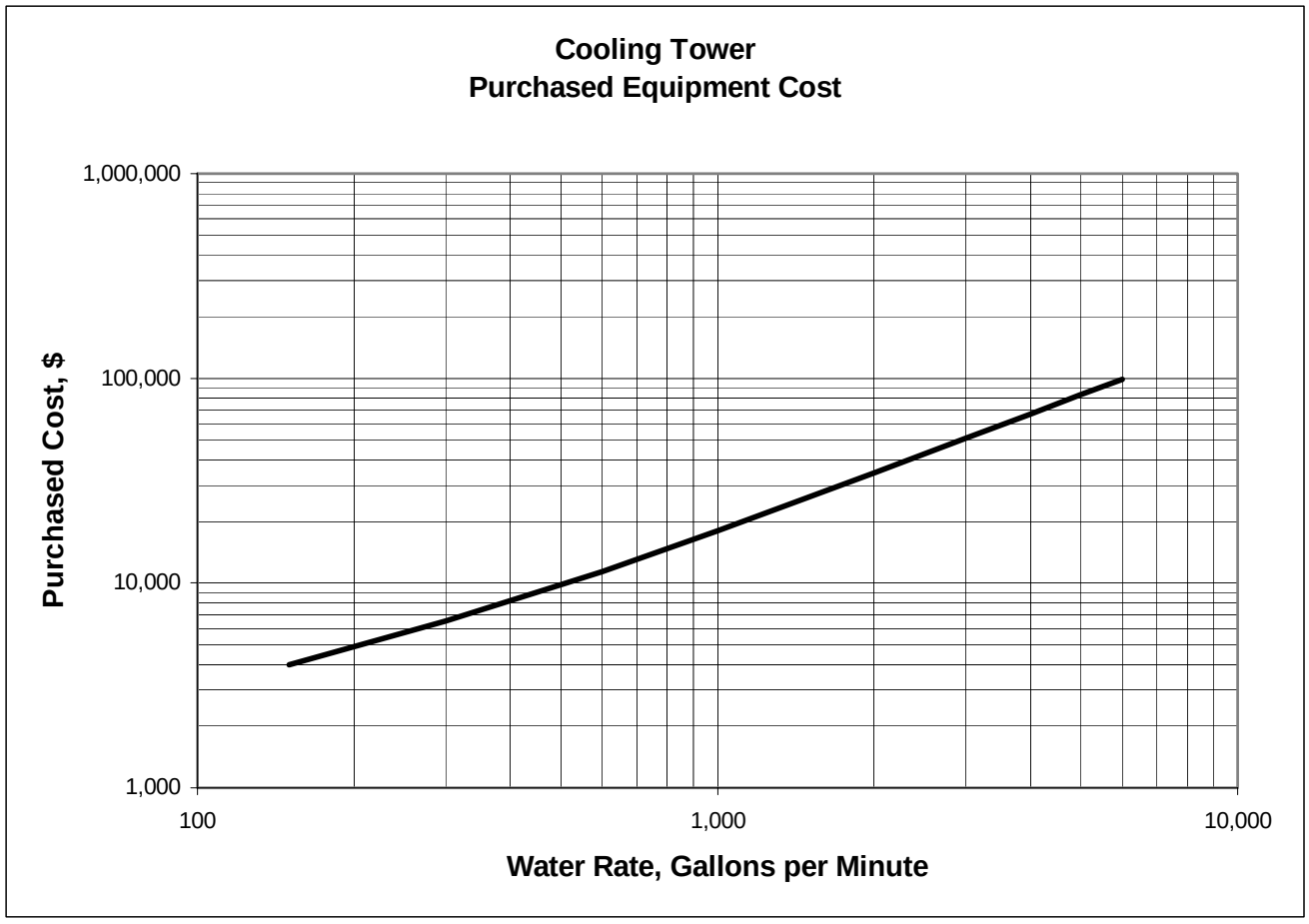


Cooling Tower

Description: Factory Assembled cooling tower includes fans, drivers and basins

Design Basis:
1st Quarter 1998 Dollars

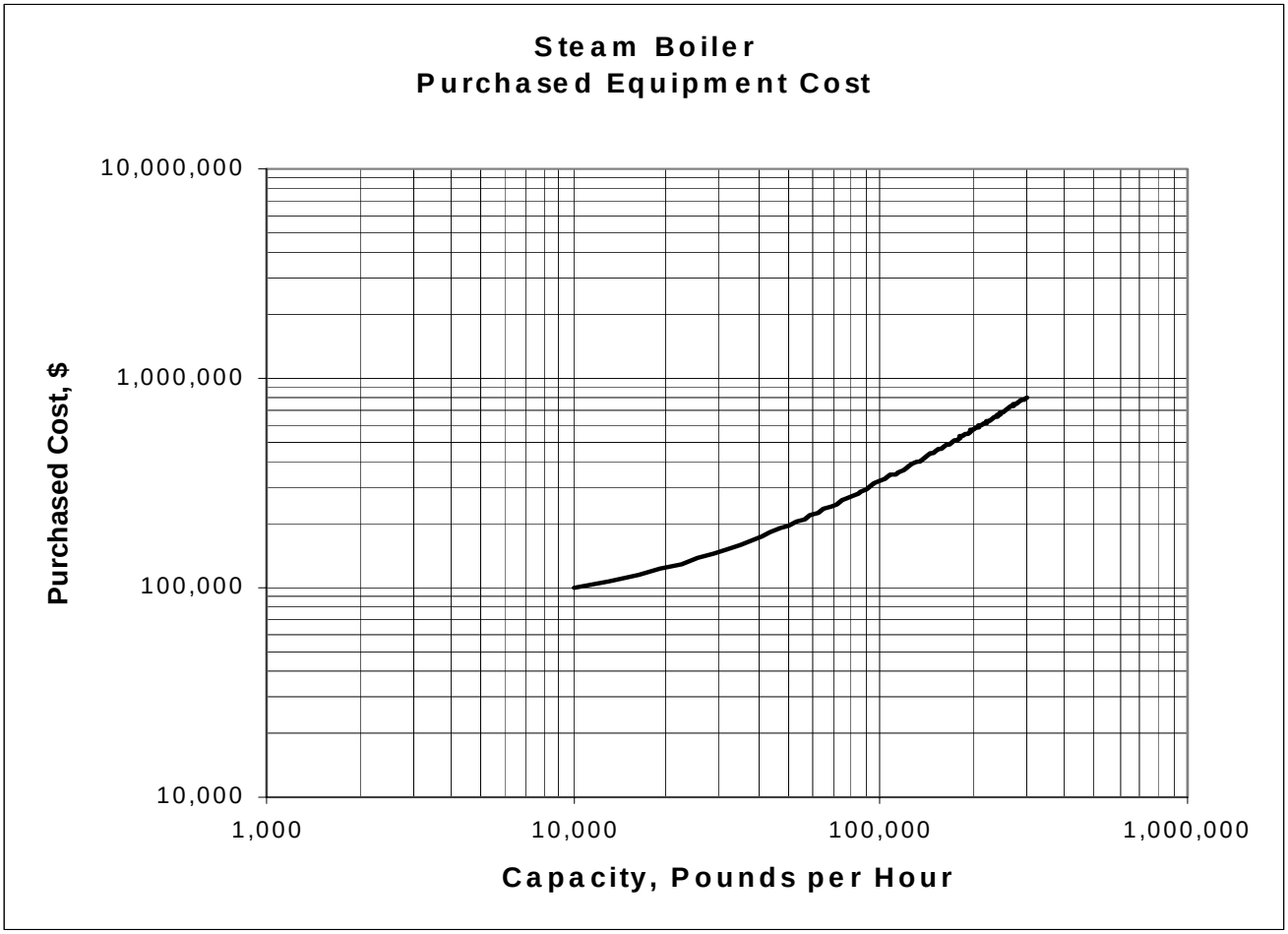
Temperature Range:	15 °F
Approach Gradient:	10 °F
Wet Bulb Temperature:	75 °F



Package Steam Boiler

Description: Package boiler unit includes forced draft fans, instruments, controls, burners, soot-blowers, feedwater deaerator, chemical injections system, steam drum, mud drum and stack. Shop assembled.

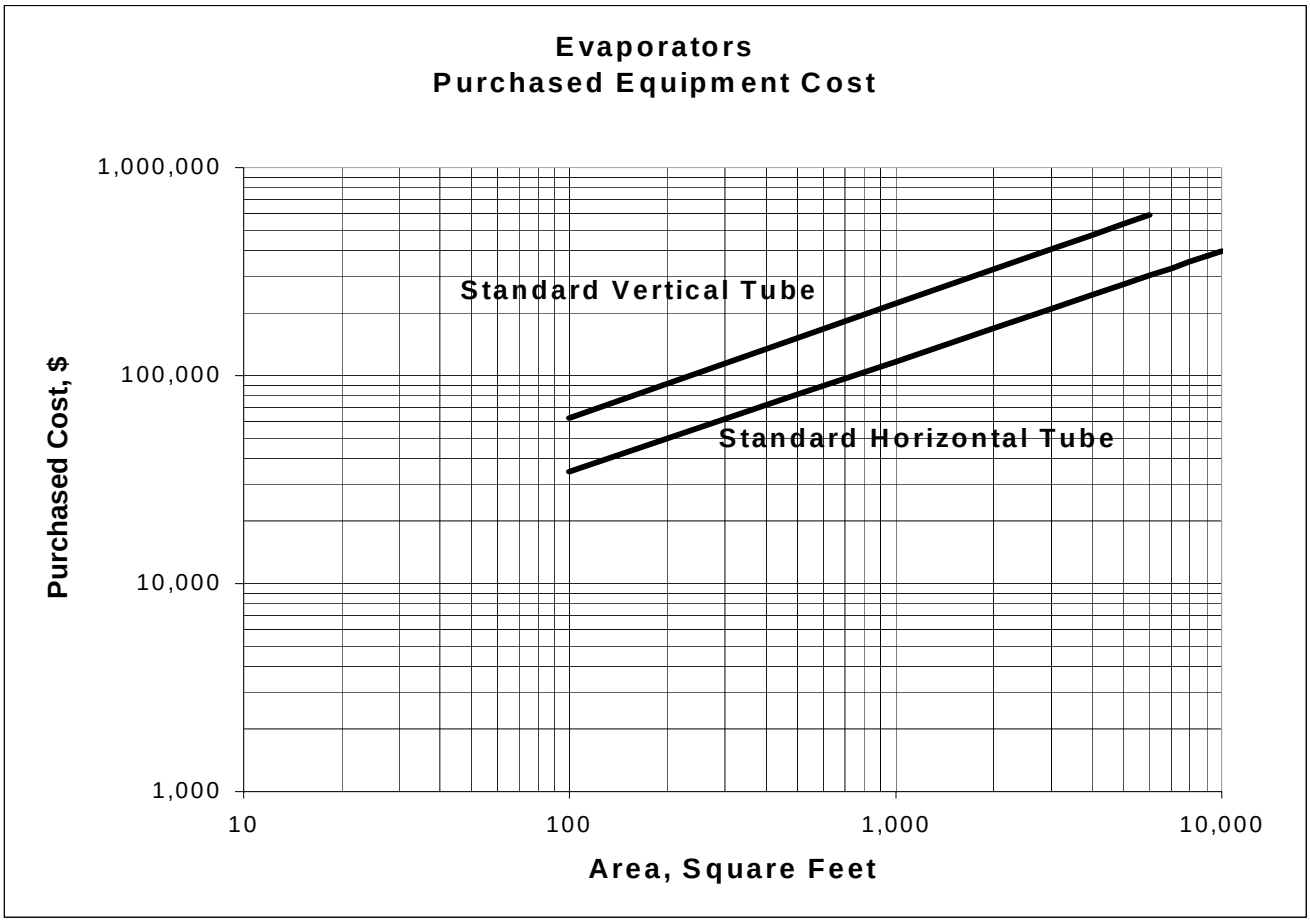
Design Basis:
1st Quarter 1998 Dollars
Material: A285C
(Low and intermediate strength carbon steel plates for pressure vessels.)
Pressure: 250 psig
Superheat: 100 °F



Evaporators

Description: Standard vertical tube evaporator and standard horizontal tube evaporator.

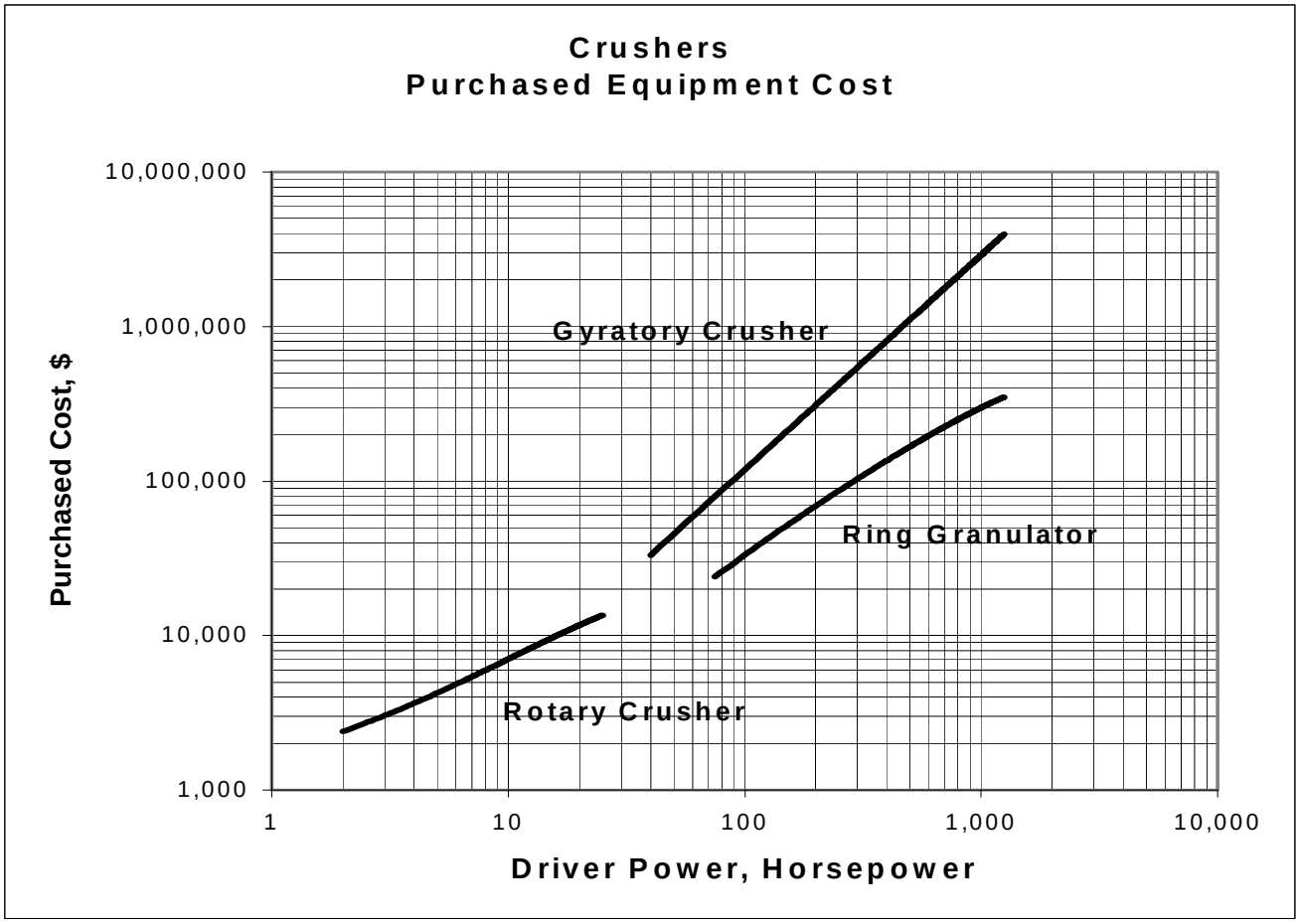
Design Basis:
1st Quarter 1998 Dollars
Material: A285C
(Low and intermediate strength carbon steel plates for pressure vessels.)
Tube Material: Carbon Steel



Crushers

Description: All crushers include motor and drive unit.
Gyratory: Primary crushing of hard and medium hard materials.
Rotary: For course, soft materials.
Ring Granulator: For primary and secondary crushing of bituminous and subbituminous coals, lignite, gypsum and some medium hard minerals.

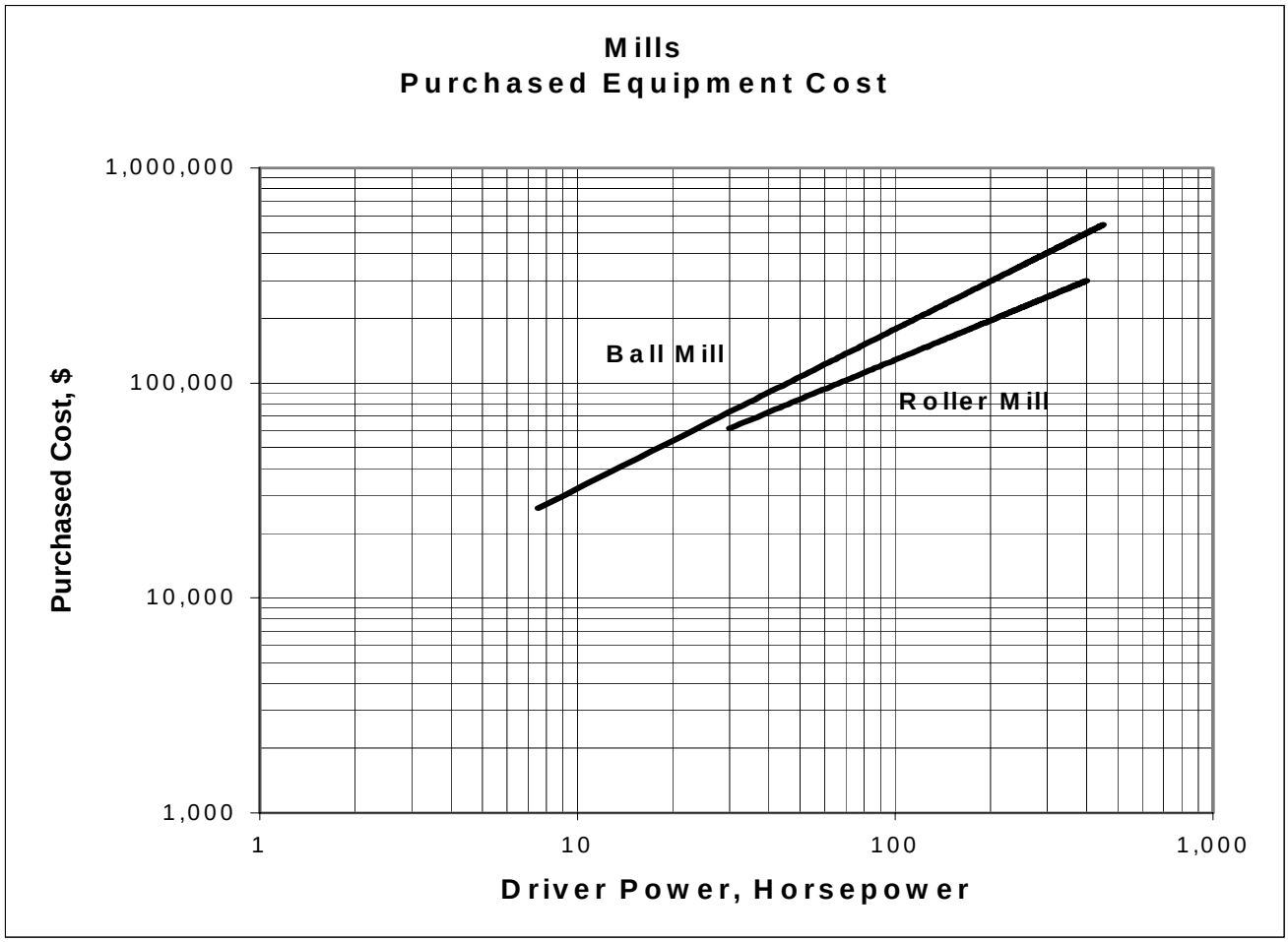
Design Basis:
1st Quarter 1998 Dollars
Material: A285C
(Low and intermediate strength carbon steel plates for pressure vessels.)



Mills

Description: All units include mill, bearings, gears, lube system and vendor-supplied instruments. Ball mill includes initial ball charge.

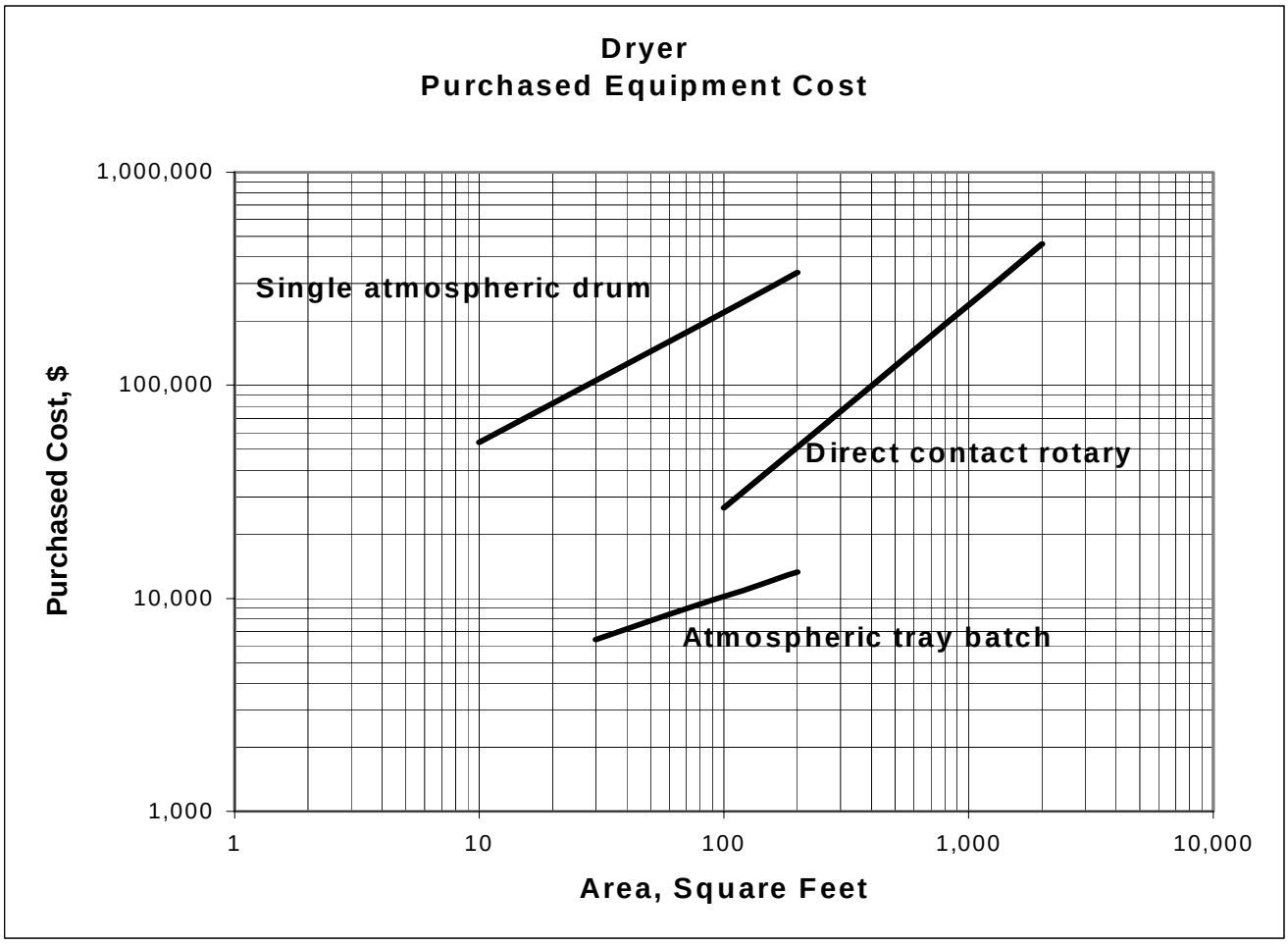
Design Basis:
1st Quarter 1998 Dollars
Material: A285C
(Low and intermediate strength carbon steel plates for pressure vessels.)



Dryers

Description:
Atmospheric tray batch dryer includes solid materials.
Rotary and Drum dryers include motor and drive unit.

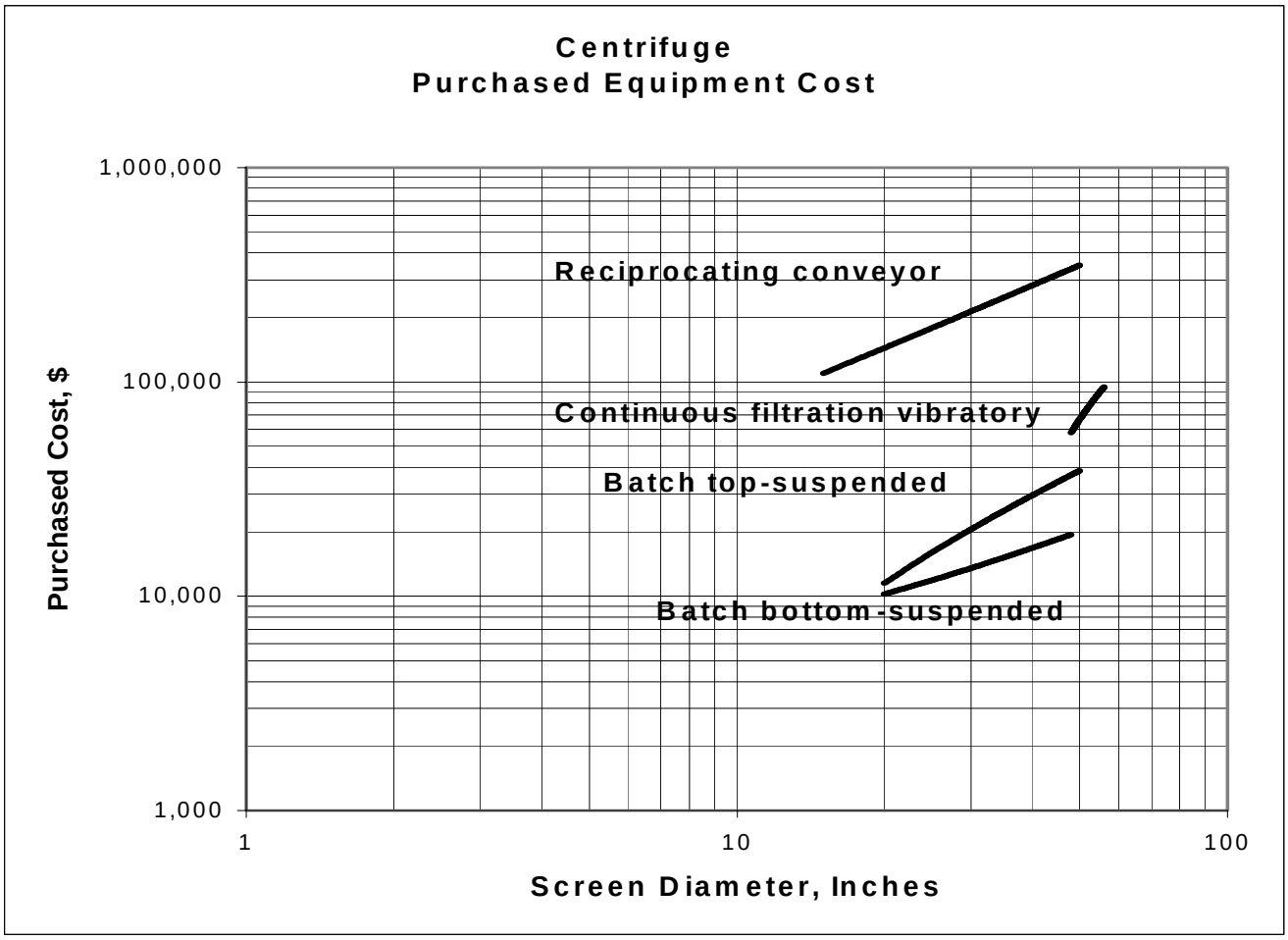
Design Basis:
1st Quarter 1998 Dollars
Material: A285C
(Low and intermediate strength carbon steel plates for pressure vessels.)



Centrifuges

Description: Centrifuges include motor and drive unit.
Reciprocating Conveyor with continuous filtering centrifuge for free-draining granular solids, horizontal bowl, removal by reciprocating piston.
Continuous Filtration Vibratory Centrifuge with solids removal by vibratory screen for dewatering of course solids.

Design Basis:
1st Quarter 1998 Dollars
Material: A285C
(Low and intermediate strength carbon steel plates for pressure vessels.)



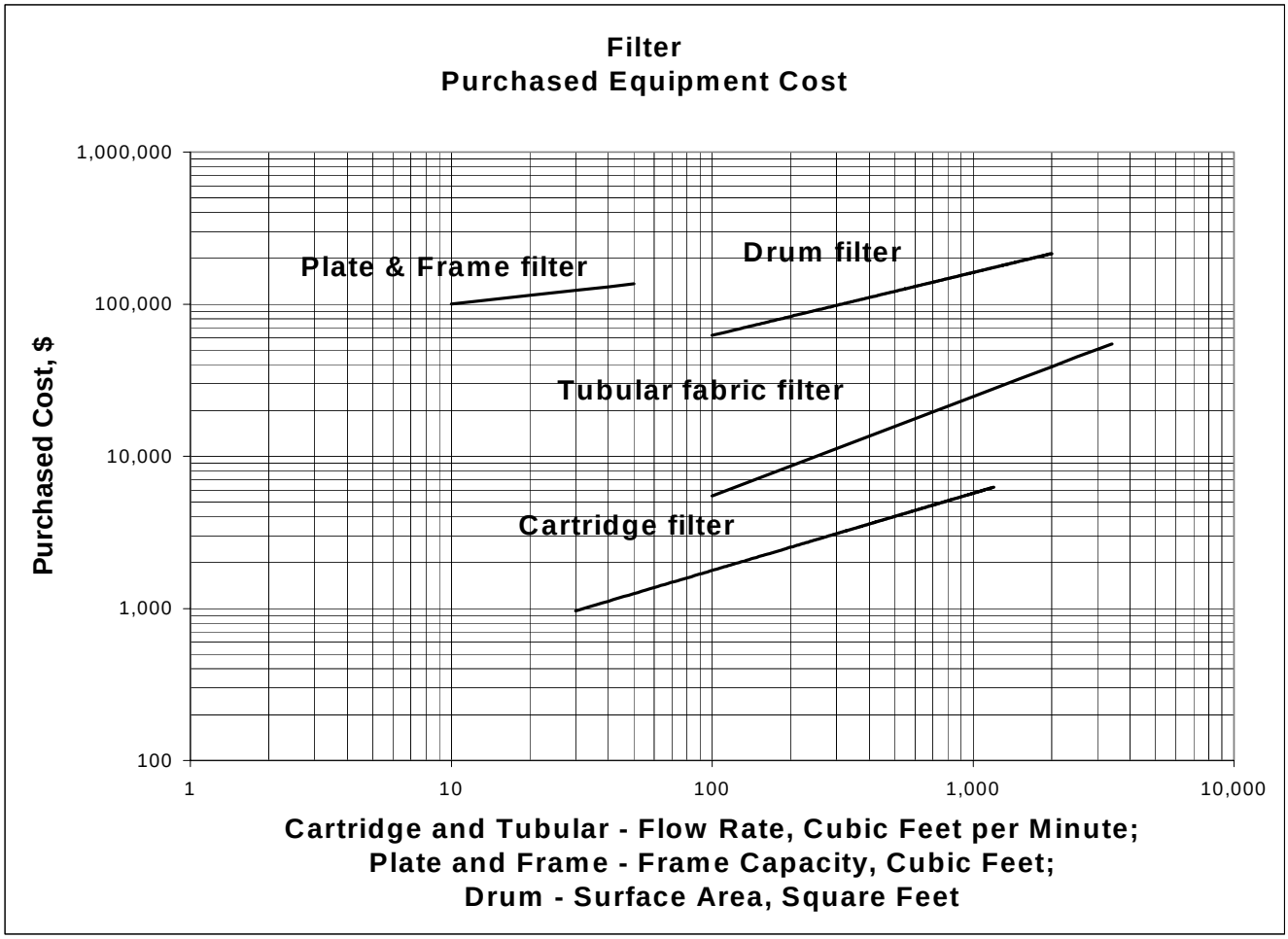
Filters

Description:
Cartridge Filter consists of a tank containing one or more disposable cartridges. Contains 5-micron cotton filter.
Drum Filter is a vacuum type, multi compartment cylinder shell with internal filtrate piping with polypropylene filter cloth, feed box with inlet and drain nozzles, suction valve, discharge trough, driver consisting of rotor, drive motor base plate, worm, gear reducer and two pillow block bearing with supports.

Defaults for Drum Filter
medium filtration rate,
0.5 tons per day/ square feet solids handling rate,
20% consistency (percent of solids in feed stream).

Tubular Fabric Filters are a bank of three without automatic cleaning option.
Plate and Frame Filter default material is rubber-lined carbon steel.

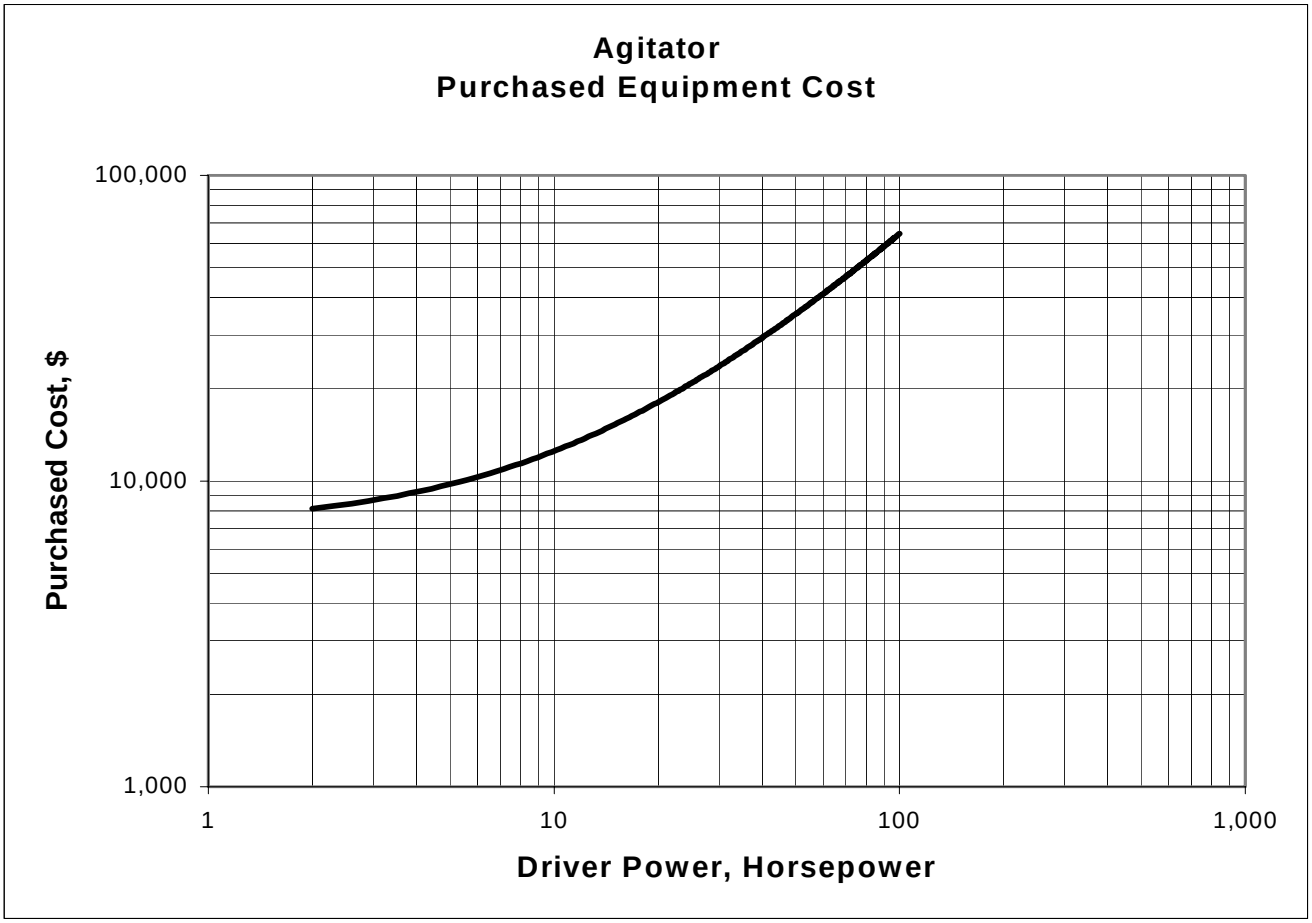
Design Basis:
1st Quarter 1998 Dollars
Material: A285C
(Low and intermediate strength carbon steel plates for pressure vessels.)



Agitator

Description: Fixed propeller mixer with motor and gear drive. Includes motor, gear drive, shaft and impeller.

Design Basis:
1st Quarter 1998 Dollars
Material: A285C
(Low and intermediate strength carbon steel plates for pressure vessels.)
Speed: 1800 RPM

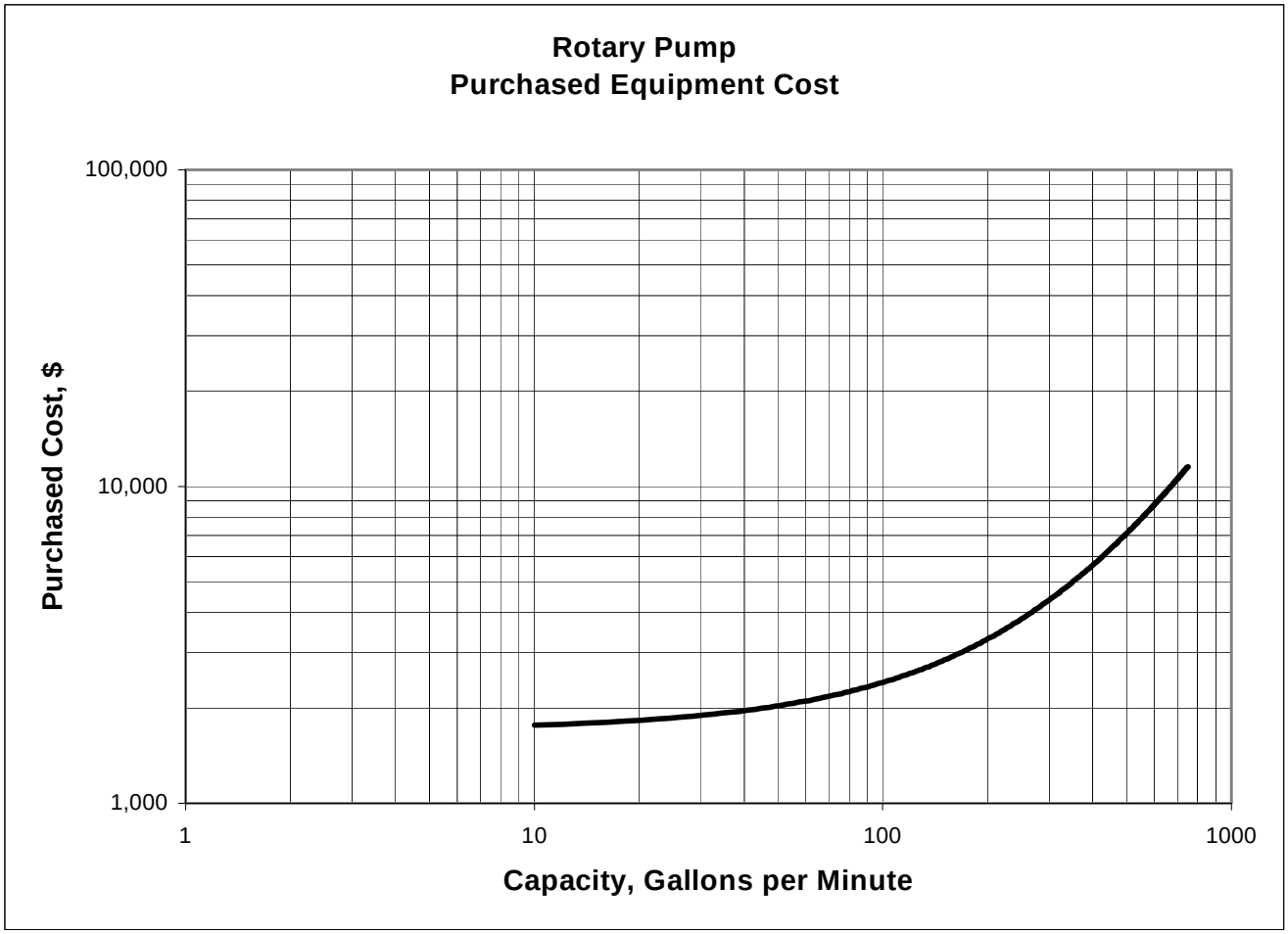


Rotary Pump

Description: Rotary (sliding vanes) pump includes motor driver.

Design Basis:
1st Quarter 1998 Dollars

Material:	Cast Iron
Temperature:	68 °F
Power:	25 – 20 Horsepower
Speed:	1800 RPM
Liquid Specific Gravity:	1
Efficiency:	82%



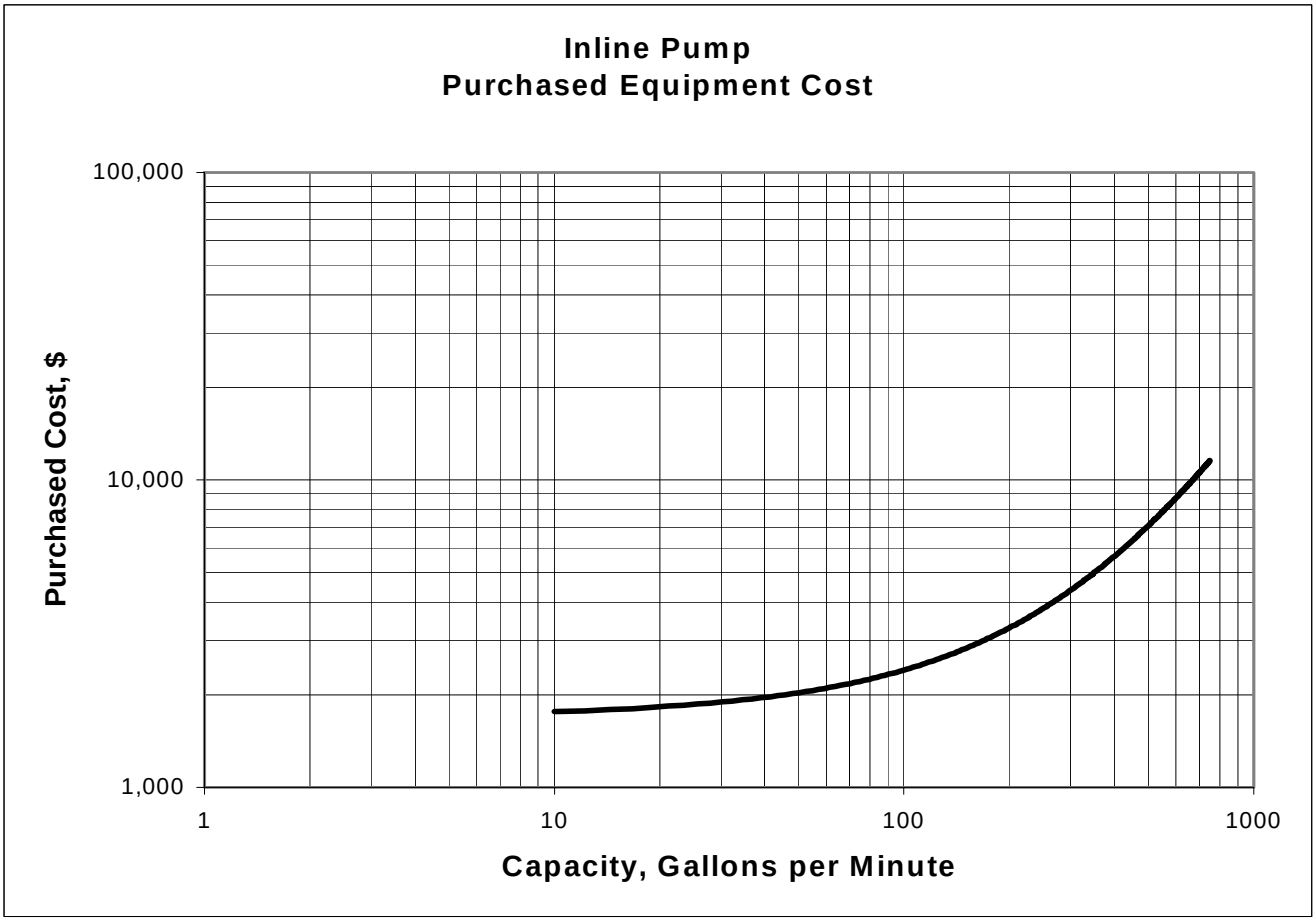
Inline Pump

Description: General service in-line pump includes pump and motor driver.

Design Basis:

1st Quarter 1998 Dollars

Material:	Carbon Steel
Temperature:	120 °F
Speed:	1800 RPM
Liquid Specific Gravity:	1
Efficiency:	<50 GPM = 60%
	50 – 199 GPM = 65%
	100 – 500 GPM = 75%
	> 500 GPM = 82%
Driver Type:	Standard motor
Seal Type:	Single mechanical seal



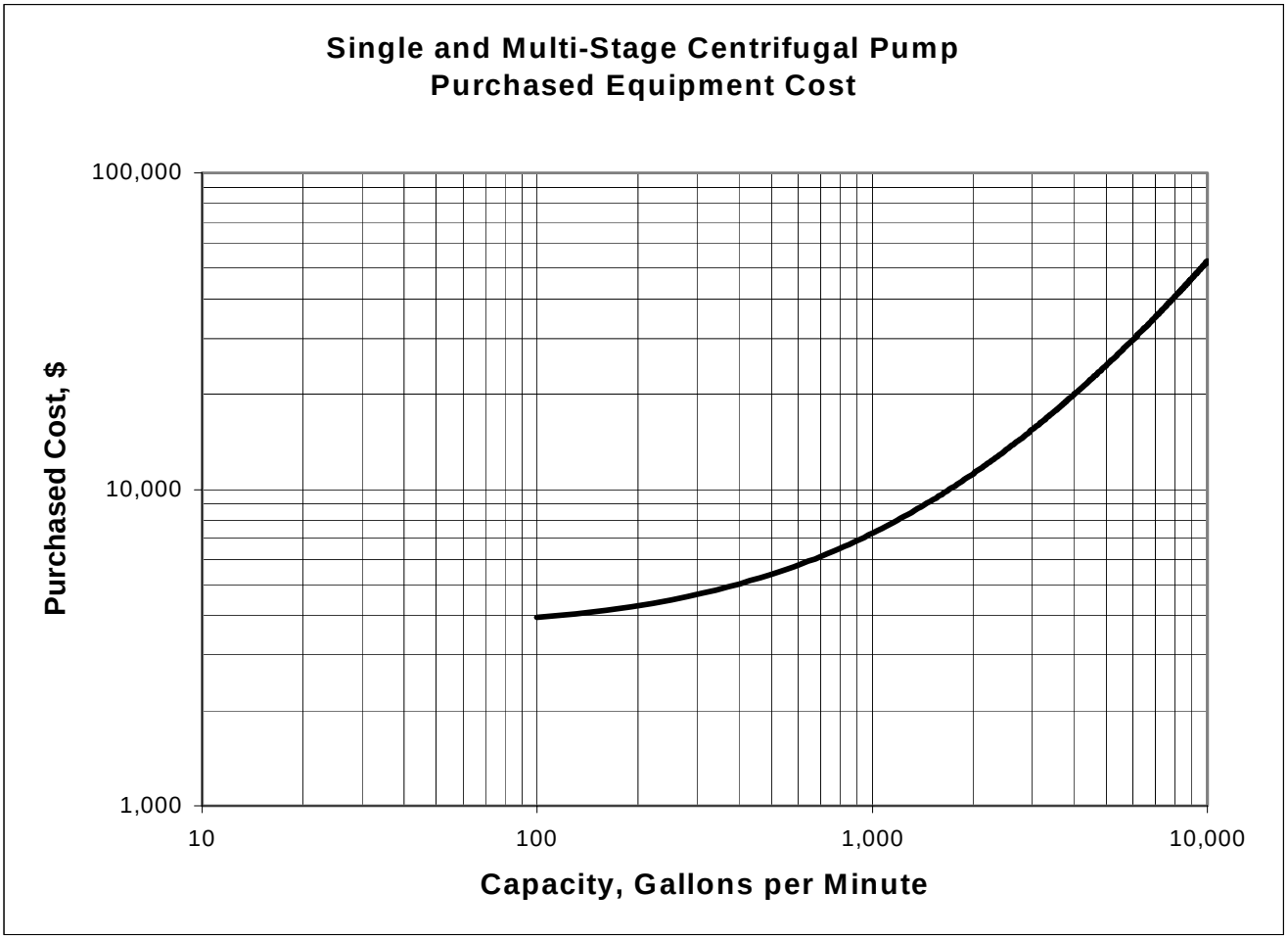
Centrifugal Pump

Description: Single and multistage centrifugal pumps for process or general service when flow/head conditions exceed general service. Split casing not a cartridge or barrel. Includes standard motor driver.

Design Basis:

1st Quarter 1998 Dollars

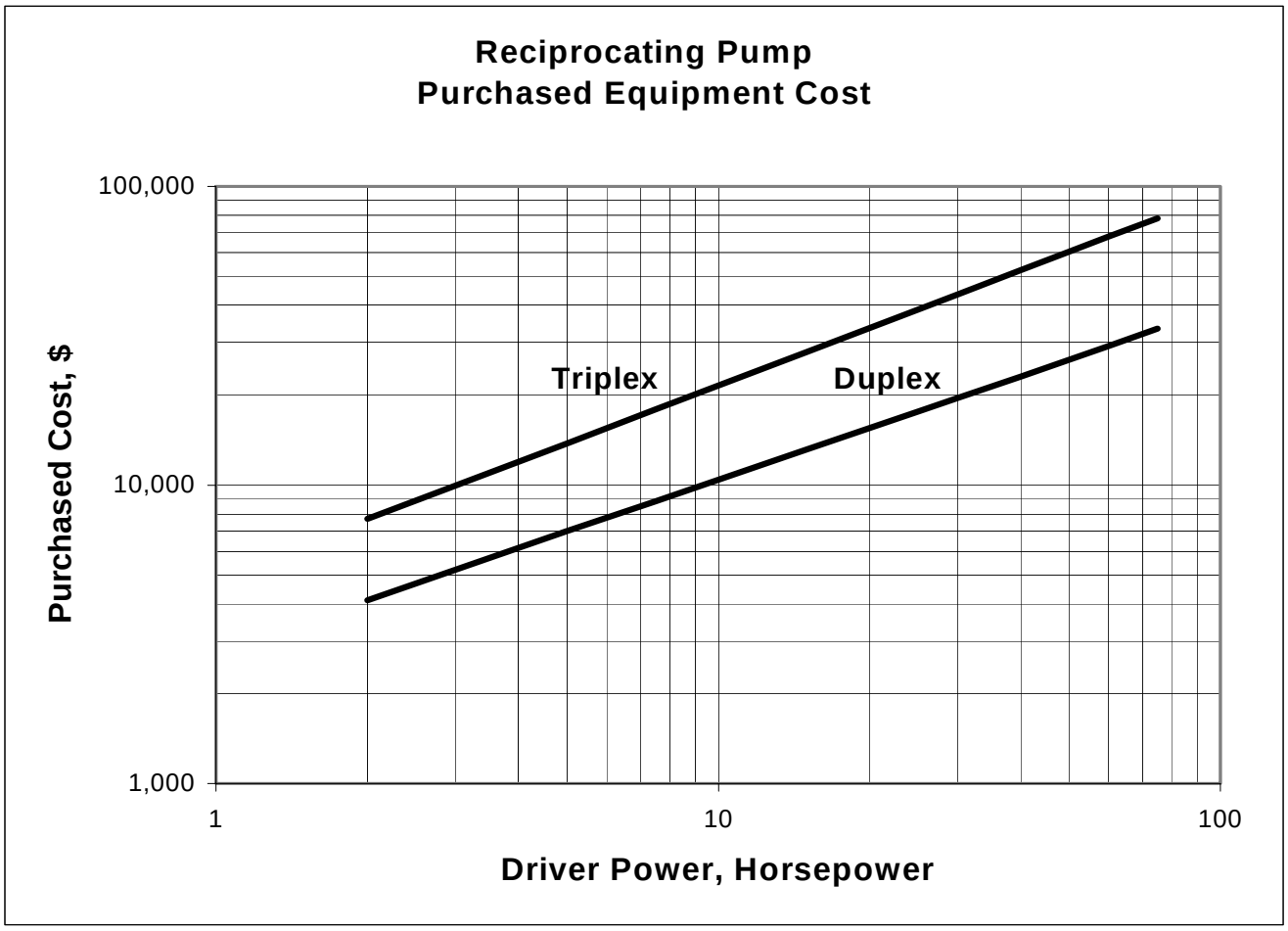
Material:	Carbon Steel
Design Temperature:	120 °F
Design Pressure:	150 psig
Liquid Specific Gravity:	1
Efficiency:	<50 GPM = 60%
	50 – 199 GPM = 65%
	100 – 500 GPM = 75%
	> 500 GPM = 82%
Driver Type:	Standard motor
Seal Type:	Single mechanical seal



Reciprocating Pump

Description: Reciprocating duplex with steam driver. Triplex (plunger) with pump-motor driver.

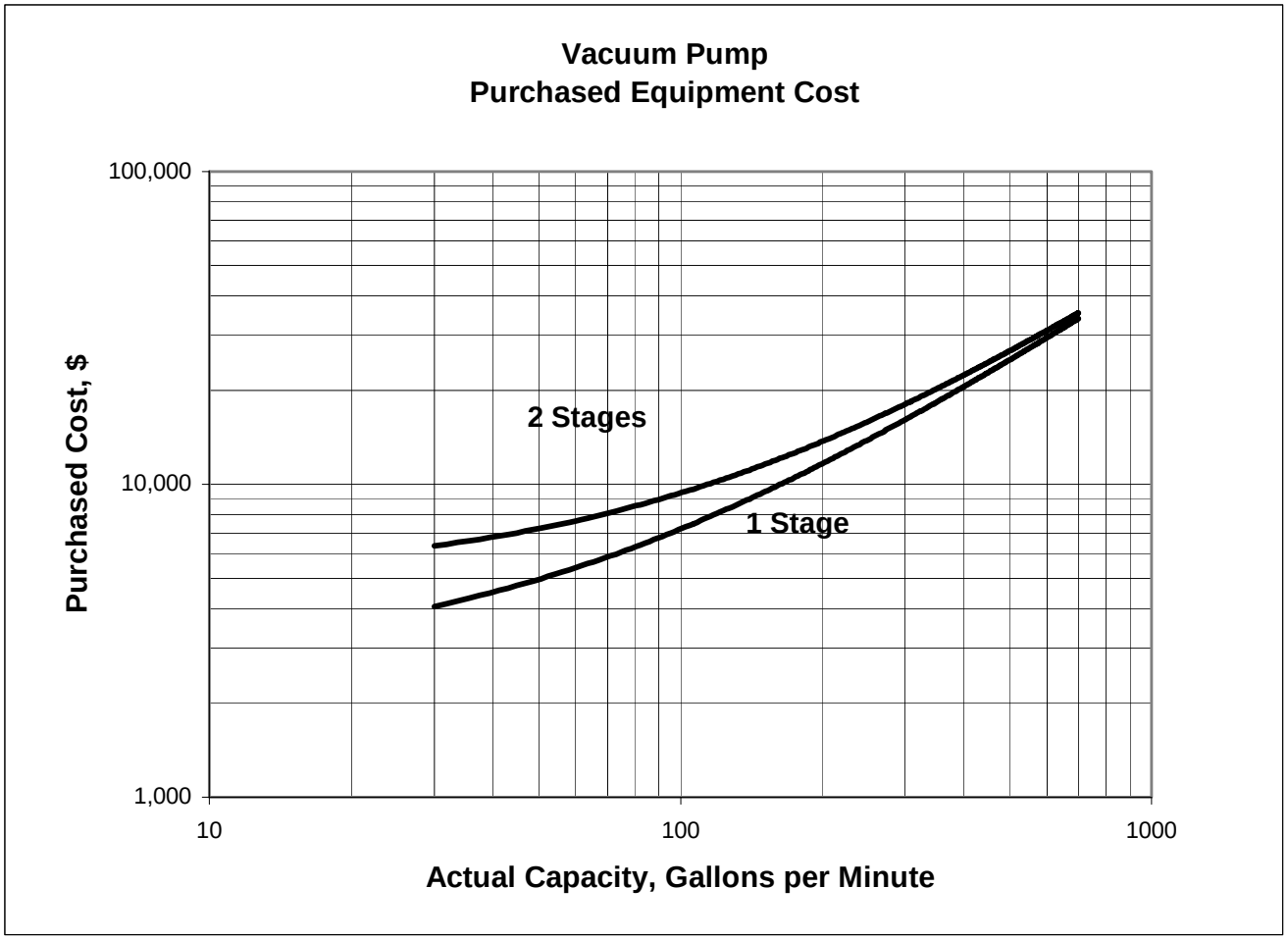
Design Basis:
1st Quarter 1998 Dollars
Material: Carbon Steel
Design Temperature: 68 °F
Liquid Specific Gravity: 1
Efficiency: 82%



Vacuum Pump

Description: Mechanical oil-sealed vacuum pump includes pump, motor and drive unit.

Design Basis:
1st Quarter 1998 Dollars
Material: Carbon Steel
First Stage: 0.01 MM HG (Mercury)
Second Stage: 0.0003 MM HG (Mercury)

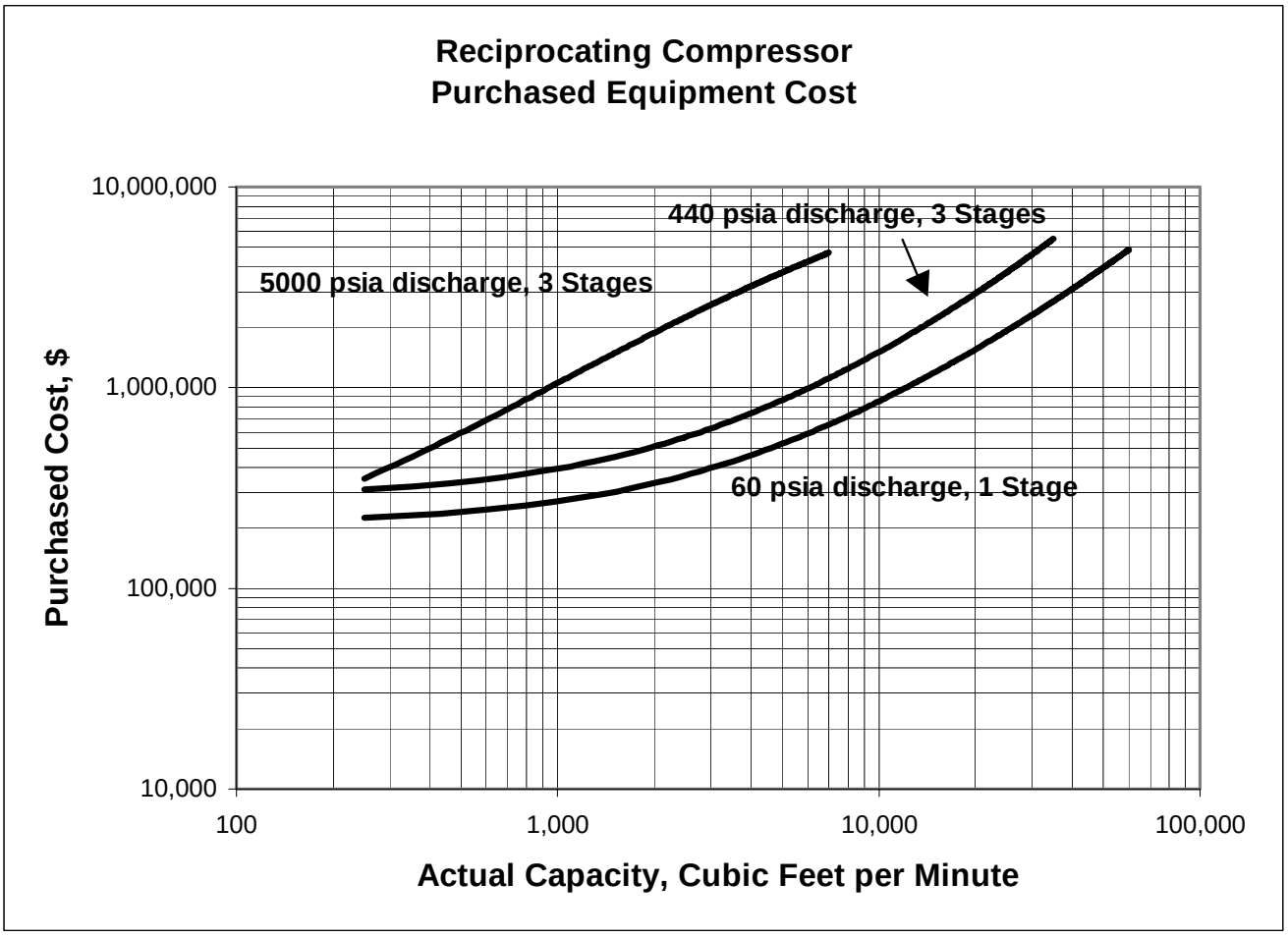


Reciprocating Compressor

Description: Reciprocating compressor with gear reducer, couplings, guards, base plate, compressor unit, fittings, interconnecting piping, vendor-supplied instruments, lube/seal system. Does not include intercoolers or aftercoolers and interstage knock-out drums.

Design Basis:
1st Quarter 1998 Dollars

Material:	Carbon Steel
Inlet Temperature:	68 °F
Inlet Pressures:	14.7/ 14.7/ 165 psia
Pressure Ratios:	4:1/ 30:1/ 30:1
Molecular Weight:	30
Specific Heat Ratio:	1.22

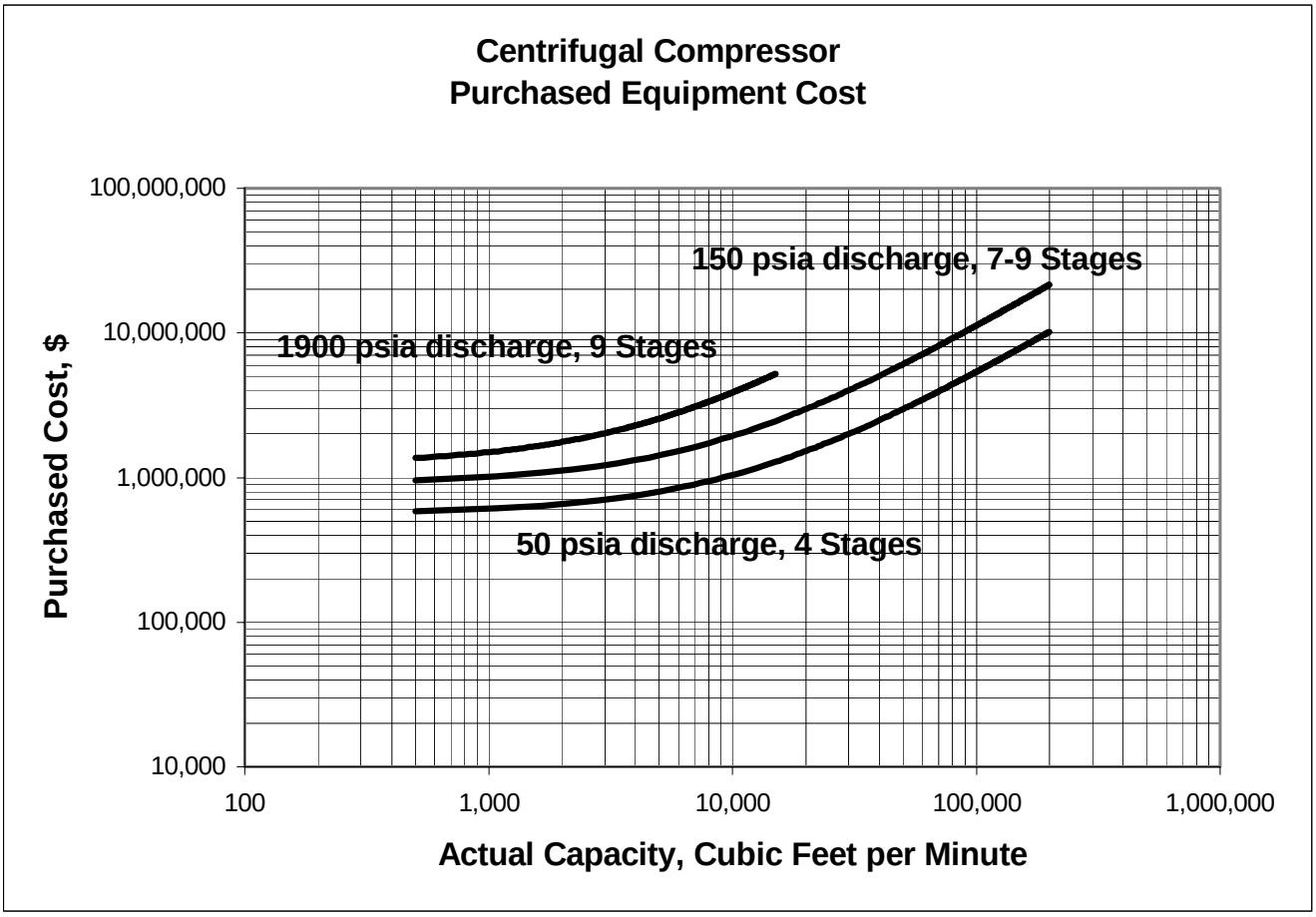


Centrifugal Compressor

Description: Axial (inline) centrifugal gas compressor with motor driver. Excludes intercoolers and knock-out drums.

Design Basis:
1st Quarter 1998 Dollars

Material:	Carbon Steel
Inlet Temperature:	68 °F
Inlet Pressures:	14.7/ 14.7/ 190 psia
Pressure Ratios:	3:1/ 10:1/ 10:1
Molecular Weight:	29
Specific Heat Ratio:	1.4

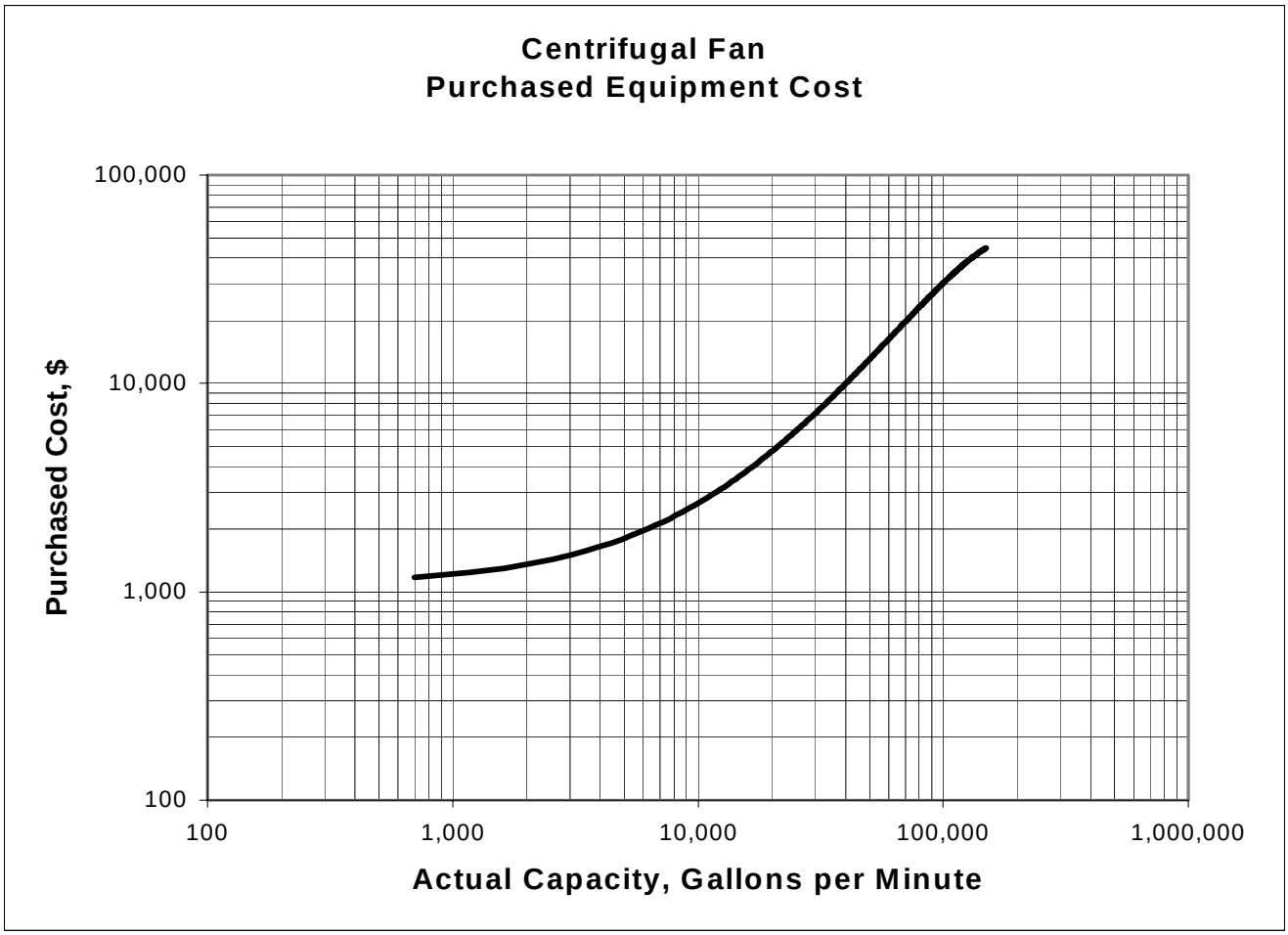


Centrifugal Fan

Description: Centrifugal fans move gas through a low pressure drop system. Maximum pressure rise is about 2 PSI.

Design Basis:
1st Quarter 1998 Dollars

Material:	Carbon Steel
Power:	1.5 - 300 Horsepower
Speed:	1800 RPM
Exit Pressure:	6 In H2O

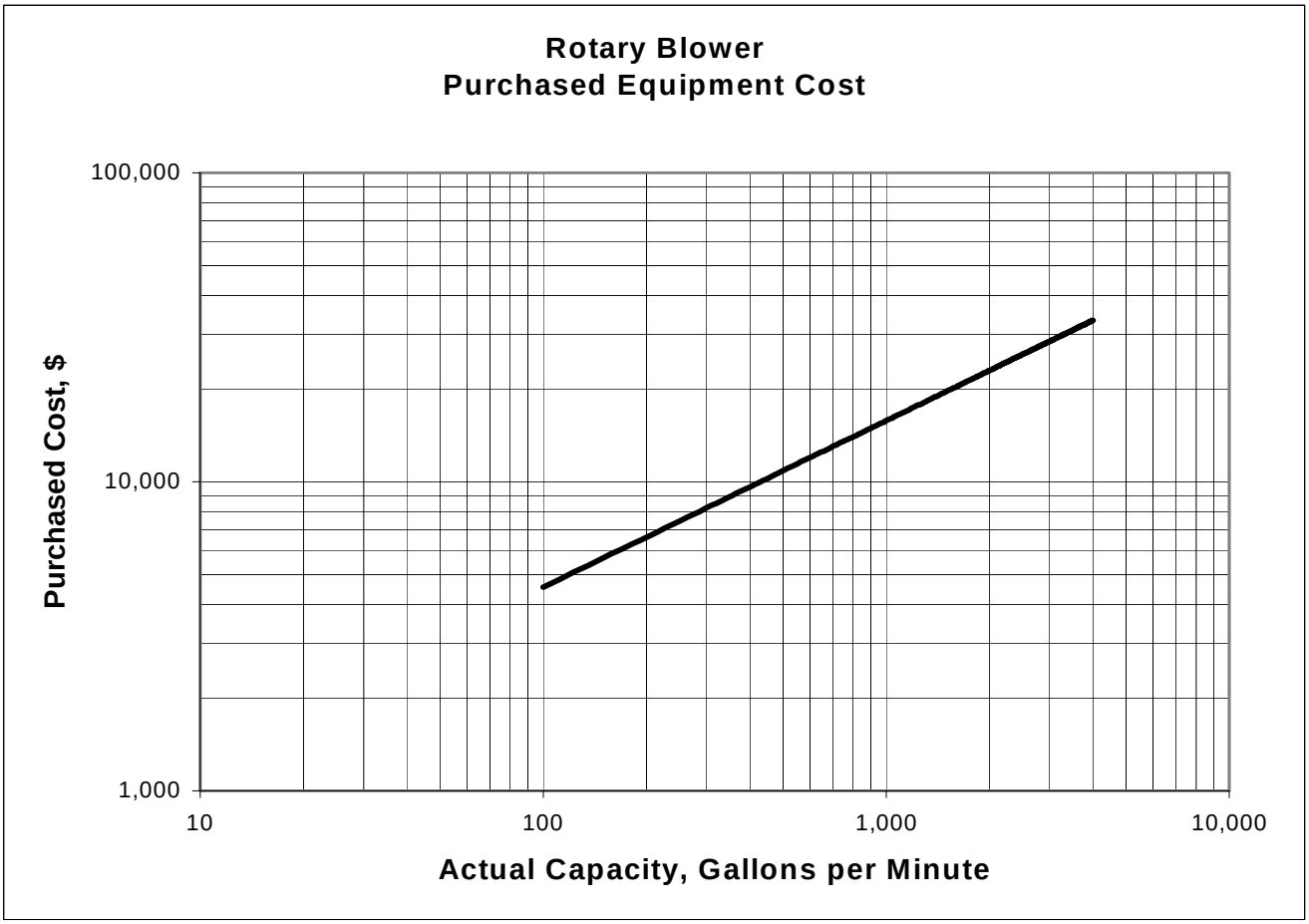


Rotary Blower

Description: This general-purpose blower includes inlet and discharge silencers. The casing of the rotary blower is cast iron and the impellers are ductile iron.

Design Basis:
1st Quarter 1998 Dollars

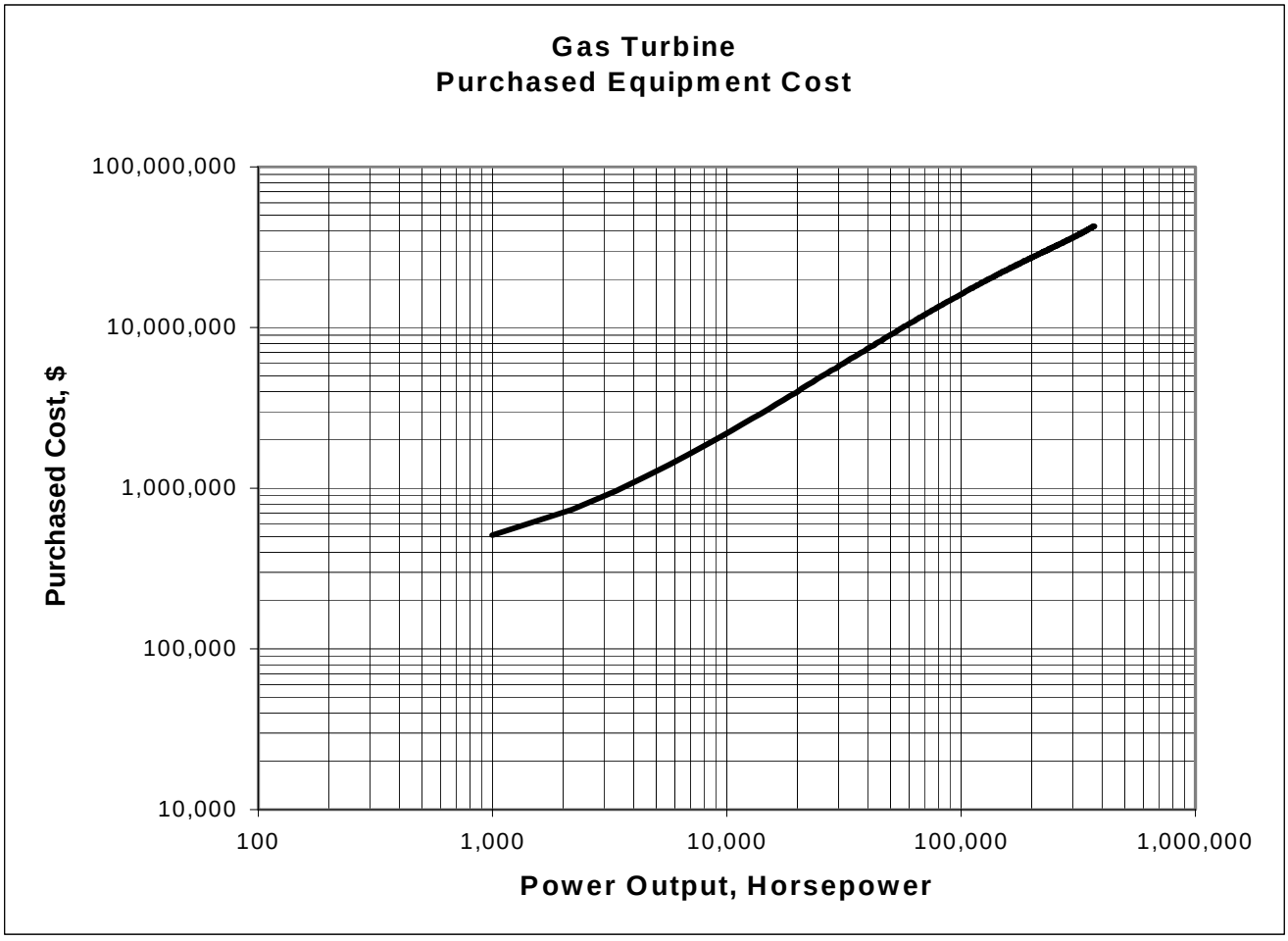
Material:	Carbon Steel
Power:	5 - 200 Horsepower
Speed:	1800 RPM
Exit Pressure:	8 psig



Gas Turbine

Description: Gas turbine includes fuel gas combustion chamber and multi-stage turbine expander.

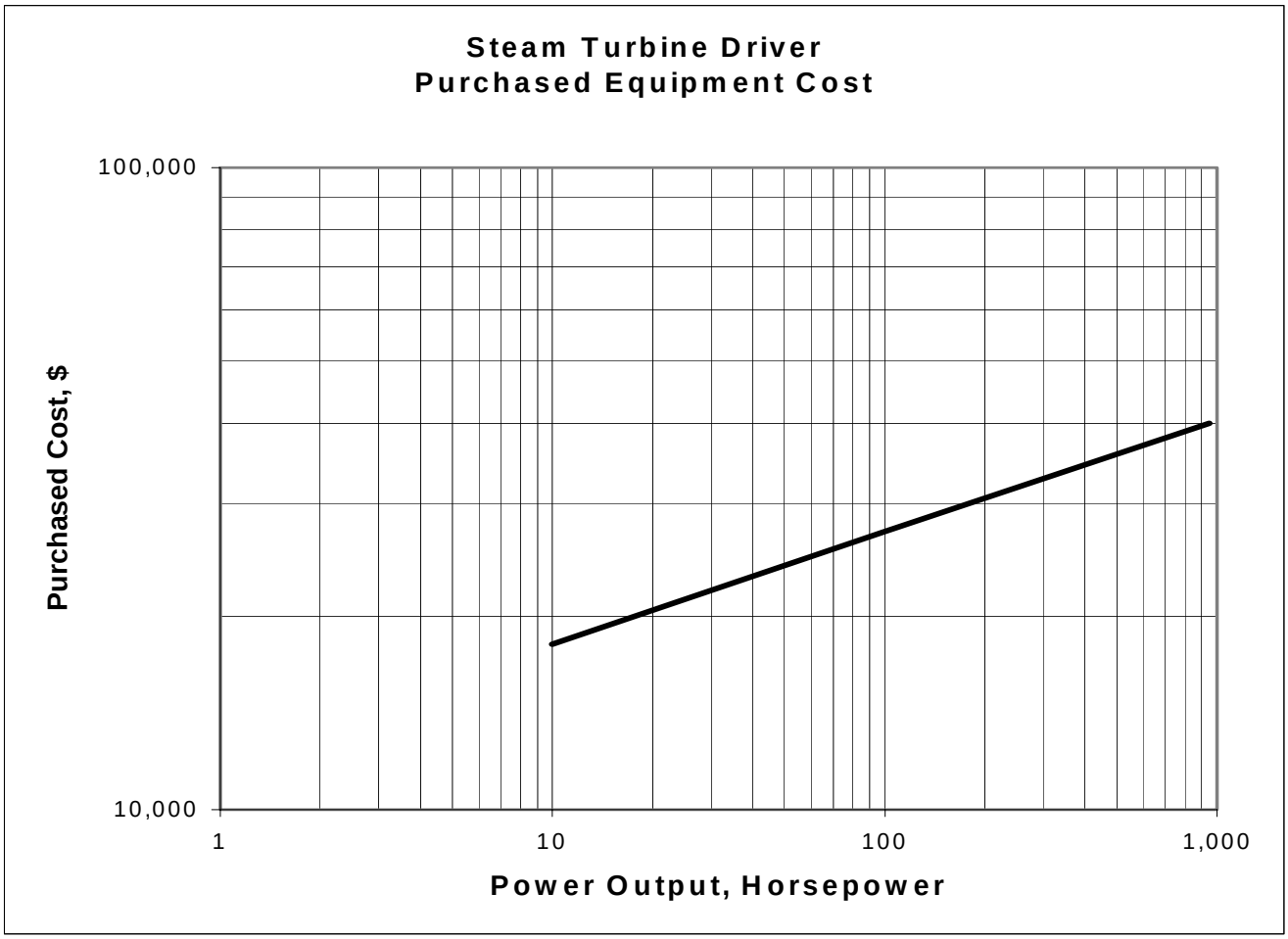
Design Basis:
1st Quarter 1998 Dollars
Material: Carbon Steel



Steam Turbine – under 1000 Horsepower

Description: Steam turbine driver includes condenser and accessories.

Design Basis:
1st Quarter 1998 Dollars
Material: Carbon Steel
Steam Pressure: 400 psig
Speed: 3600 RPM



Steam Turbine – over 1000 Horsepower

Description: Steam turbine driver includes condenser and accessories.

Design Basis:
1st Quarter 1998 Dollars
Material: Carbon Steel
Steam Pressure: 400 psig
Speed: 3600 RPM

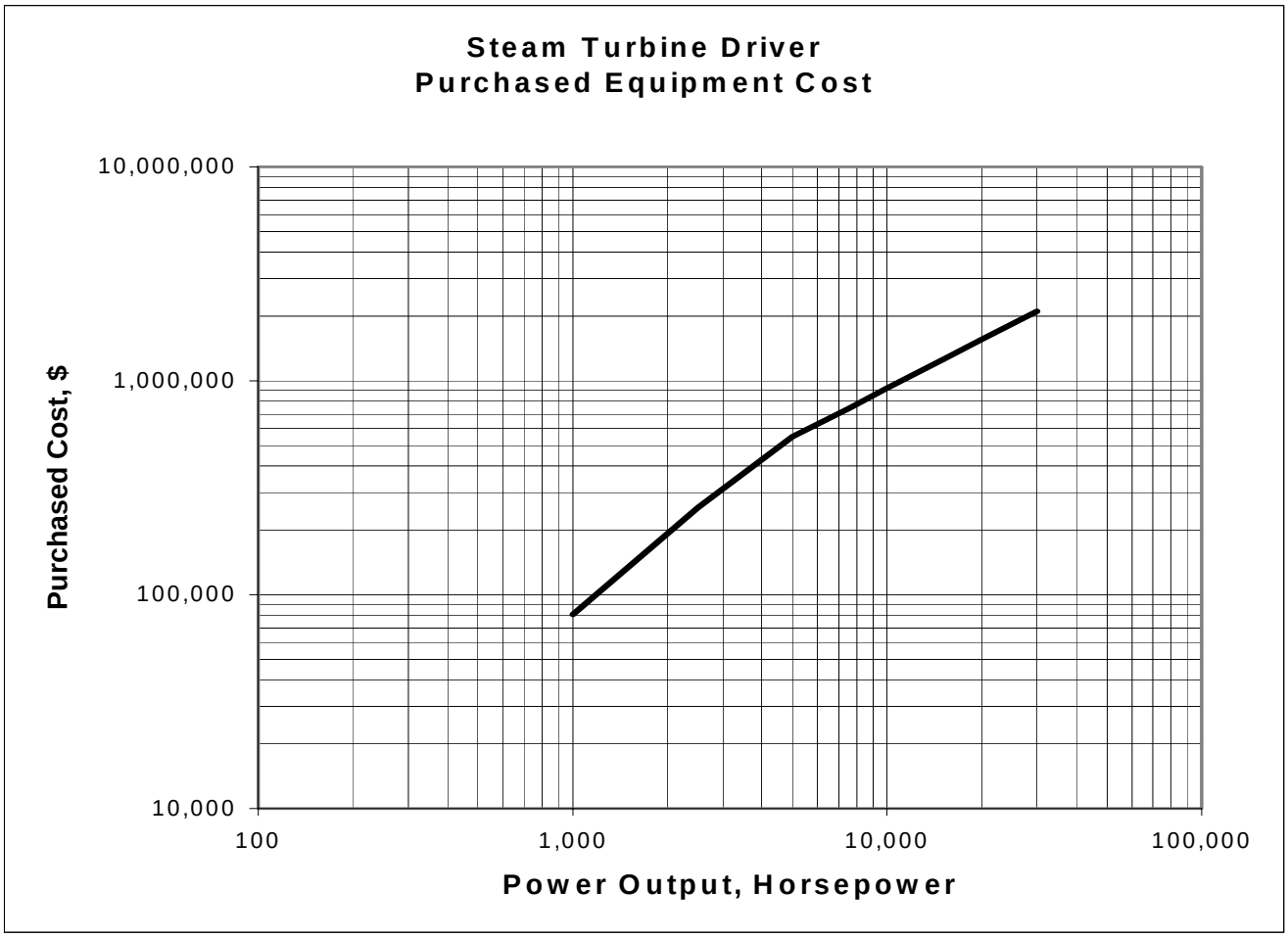


Table 2

Distributive Factors for Bulk Materials - Solids Handling Processes

Temperature		**≤400 °F (%)**	**>400 °F (%)**
Foundations	*Material*	4	5
	Labor	133	133
Structural Steel	*Material*	4	2
	Labor	50	100
Buildings	*Material*	2	2
	Labor	100	100
Insulation	*Material*	---	1.5
	Labor	---	150
Instruments	*Material*	6	6
	Labor	10	40
Electrical	*Material*	9	9
	Labor	75	75
Piping	*Material*	5	5
	Labor	50	50
Painting	*Material*	0.5	0.5
	Labor	300	300
Miscellaneous	*Material*	3	4
	Labor	80	80

Table 3

Distributive Factors for Bulk Materials – Solids - Gas Processes

Temperature		**≤400 °F**		**>400 °F**	
Pressure		**≤ 150 psig (%)**	**>150 psig (%)**	**≤ 150 psig (%)**	**>150 psig (%)**
Foundations	*Material*	5	6	6	6
	Labor	133	133	133	133
Structural Steel	*Material*	4	4	5	6
	Labor	100	100	50	50
Buildings	*Material*	2	2	5	4
	Labor	100	50	50	100
Insulation	*Material*	1	1	2	2
	Labor	150	150	150	150
Instruments	*Material*	2	7	7	8
	Labor	40	40	40	75
Electrical	*Material*	6	8	7	8
	Labor	75	75	75	75
Piping	*Material*	35	40	40	40
	Labor	50	50	50	50
Painting	*Material*	0.5	0.5	0.5	0.5
	Labor	300	300	300	300
Miscellaneous	*Material*	3.5	4	4	4.5
	Labor	80	80	80	80

Table 4

Distributive Factors for Bulk Materials - Liquid and Slurry Systems

Pressure		**≤ 150 psig (%)**	**>150 psig (%)**
Foundations	*Material*	5	6
	Labor	133	133
Structural Steel	*Material*	4	5
	Labor	50	50
Buildings	*Material*	3	3
	Labor	100	100
Insulation	*Material*	1	3
	Labor	150	150
Instruments	*Material*	6	7
	Labor	40	40
Electrical	*Material*	8	9
	Labor	75	75
Piping	*Material*	30	35
	Labor	50	50
Painting	*Material*	0.5	0.5
	Labor	300	300
Miscellaneous	*Material*	4	5
	Labor	80	80

Table 5

Distributive Factors for Bulk Materials - Gas Processes

Temperature		**≤400 °F**		**>400 °F**	
Pressure		**≤ 150 psig (%)**	**>150 psig (%)**	**≤ 150 psig (%)**	**>150 psig (%)**
Foundations	*Material*	5	6	6	5
	Labor	133	133	133	133
Structural Steel	*Material*	5	5	5	6
	Labor	50	50	50	50
Buildings	*Material*	3	3	3	4
	Labor	100	100	100	100
Insulation	*Material*	1	1	2	3
	Labor	150	150	150	150
Instruments	*Material*	6	7	7	7
	Labor	40	40	75	40
Electrical	*Material*	8	9	6	9
	Labor	75	75	40	75
Piping	*Material*	45	40	40	40
	Labor	50	50	50	50
Painting	*Material*	0.5	0.5	0.5	0.5
	Labor	300	300	300	300
Miscellaneous	*Material*	3	4	4	5
	Labor	80	80	80	80

Table 6

Distributive Labor Factors for Setting Equipment

Equipment Type	**Factor** (%)	**Equipment Type**	**Factor** (%)
Absorber	20	Hammermill	25
Ammonia Still	20	Heater	20
Ball Mill	30	Heat Exchanger	20
Briquetting machine	25	Lime Leg	15
Centrifuge	20	Methanator (catalytic)	30
Clarifier	15	Mixer	20
Coke Cutter	15	Precipitator	25
Coke Drum	15	Regenerator (packed)	20
Condenser	20	Retort	30
Conditioner	20	Rotoclone	25
Cooler	20	Screen	20
Crusher	30	Scrubber (water)	15
Cyclone	20	Settler	15
Decanter	15	Shift converter	25
Distillation column	30	Splitter	15
Evaporator	20	Storage Tank	20
Filter	15	Stripper	20
Fractionator	25	Tank	20
Furnace	30	Vaporizer	20
Gasifier	30		

Table 7

Factors for Converting Carbon Steel to Equivalent Alloy Costs

Material	Pumps, etc.	Other Equipment
All Carbon Steel	1.00	1.00
Stainless Steel, Type 410	1.43	2.00
Stainless Steel, Type 304	1.70	2.80
Stainless Steel, Type 316	1.80	2.90
Stainless Steel, Type 310	2.00	3.33
Rubber-lined Steel	1.43	1.25
Bronze	1.54	
Monel	3.33	

Material	Heat Exchangers
Carbon Steel Shell and Tubes	1.00
Carbon Steel Shell, Aluminum Tubes	1.25
Carbon Steel Shell, Monel Tubes	2.08
Carbon Steel Shell, 304 Stainless Steel Tubes	1.67
304 Stainless Steel Shell and Tubes	2.86

Cost Indexes

Cost indexes are used to update costs from the base time, in this case First Quarter 1998 dollars, to the present time of the estimate. Cost indexes are used to give a general estimate, but can not take into account all factors. Some limitations of cost indexes include:[3]

1. Accuracy is very limited. Two Indexes may yield much different answers.
2. Cost indexes are based on averages. Specific cases may be much different from the average.
3. At best, 10% accuracy can be expected for periods up to 5 years.
4. For periods over 10 years, indexes are suitable only for order of magnitude estimates.

The most common indexes are Engineering News-Record Construction Cost Index, Table 8, (published in the *Engineering News-Record*), Marshall and Swift Equipment Cost Indexes, Table 9, (published in *Chemical Engineering*), Nelson-Farrar Refinery Construction Cost Index, Table 10, (published in the *Oil and Gas Journal*) and the Chemical Engineering Plant Cost Index, Table 11, (published in *Chemical Engineering*). Annual averages for each of these indexes are included in this report.

The Marshall and Swift Equipment Cost Indexes are divided into two categories, the all-industry equipment index and the process-industry equipment index. The indexes take into consideration the cost of machinery and major equipment plus costs for installation, fixtures, tools, office furniture, and other minor equipment. The Engineering News-Record Construction Cost Index shows the variation in the labor rates and materials costs for industrial construction. The Nelson-Farrar Refinery Construction Cost Index uses construction costs in the petroleum industry as the basis. The Chemical Engineering Plant Cost Index uses construction costs for chemical plants as the basis.

Two cost indexes, the Marshall and Swift equipment cost indexes and the Chemical Engineering plant cost indexes, give very similar results and are recommended for use with process-equipment estimates and chemical-plant investment estimates. The Engineering News-Record construction cost index, relative with time, has increased much more rapidly than the other two because it does not include a productivity improvement factor. Similarly, the Nelson-Farrar refinery construction index has shown a very large increase with time and should be used with caution and only for refinery construction.[4]

---

[3] Humphreys, Dr. Kenneth K. PE CCE, "Preliminary Capital and Operating Cost Estimating (for the Process and Utility Industries)," course notes.

[4] Peters, Max S. and Klaus D. Timmerhaus, "Plant Design and Economics for Chemical Engineers" McGraw-Hill, Inc. 1991.

Table 8

Engineering News Record Construction Cost Index
Published in the *Engineering News-Record*

Year	Annual Average
1913	**100**
1960	824
1965	971
1970	1381
1975	2212
1980	3237
1985	4195
1990	4732
1995	5471
1996	5620
1997	5825
1998	5920
1999	6060
2000	6222
2001	
January	6281
February	6273
March	6280
April	6286
May	6288

Table 9

Marshall and Swift Installed-Equipment Index
Published in *Chemical Engineering*

	Annual Average	
Year	**All Industry**	**Process Industry**
1926	**100**	**100**
1964	242	241
1965	245	244
1970	303	301
1975	444	452
1980	560	675
1985	790	813
1990	915	935
1995	1027.5	1037.4
1996	1039.2	1051.3
1997	1056.8	1068.3
1998	1061.9	1075.9
1st Quarter	1061.2	1074.6
2nd Quarter	1061.8	1075.2
3rd Quarter	1062.4	1077.2
4th Quarter	1062.3	1076.6
1999	1068.3	1083.1
1st Quarter	1062.7	1078.8
2nd Quarter	1065.0	1080.7
3rd Quarter	1069.9	1084.0
4th Quarter	1075.6	1088.7
2000	1089.0	1102.7
1st Quarter	1080.6	1093.5
2nd Quarter	1089.0	1102.2
3rd Quarter	1092.0	1106.3
4th Quarter	1094.5	1108.7
2001		
1st Quarter	1092.8	1106.9

Table 10

Nelson-Farrar Refinery Construction Index
Published in the *Oil and Gas Journal*

Year	Annual Average	Pumps, Compressors, etc	Heat Exchangers	Misc. Equipment Average
1946	**100**			
1964	252			
1965	261			
1970	365			
1975	576			
1980	823	777.3	618.7	578.1
1985	1074	969.9	520	673.4
1990	1225.7	1125.6	755.7	797.5
1995	1392.1	1316.7	758.6	879.5
1996	1418.9	1354.5	793.3	903.5
1997	1449.2	1383.9	773.6	910.5
1998	1477.6	1406.7	841.1	933.2
1999	1497.2	1433.5	715.8	920.3
2000	1542.7	1456.4	662.2	917.8
2001				
January	1565.9	1473.2	722.7	936.2
February	1563.6	1478.9	722.7	937.1

Table 11

Chemical Engineering Plant Cost Index
Published in *Chemical Engineering*

Year	Annual Average
1957-59	**100**
1964	103
1965	104
1970	126
1975	182
1980	261
1985	325
1990	357.6
1995	381.1
1996	381.8
1997	386.5
1998	389.5
1999	390.6
2000	394.1
2001	
January	395.4

Appendix A

The following is an example of the usage of the cost curves and tables to estimate the installed cost of a 5,000 square foot gas-gas shell and tube heat exchanger with a design temperature of 650°F and a design pressure of 150 psig.

From the chart on page 16, the estimated purchased equipment cost is $62,000. From Table 6, the factor for setting a heat exchanger is 20%. Column 3 of Table 5 is used to estimate the bulk material and labor costs.

Bare cost:		$62,000
Setting Cost:	$62,000*0.2	$12,400
Bulk Installations:		
Foundations		
Material	$62,000*0.06	$3,720
Labor	$3,720*1.33	$4,948
Structural Steel		
Material	$62,000*0.05	$3,100
Labor	$3,100*0.5	$1,550
Buildings		
Material	$62,000*0.03	$1,860
Labor	$1,860*1.0	$1,860
Insulation		
Material	$62,000*0.02	$1,240
Labor	$1,240*1.5	$1,860
Instruments		
Material	$62,000*0.07	$4,340
Labor	$4,340*0.75	$3,255
Electrical		
Material	$62,000*0.06	$3,720
Labor	$3,720*0.4	$1,488
Piping		
Material	$62,000*0.4	$24,800
Labor	$24,800*0.5	$12,400
Painting		
Material	$62,000*0.005	$310
Labor	$310*3.0	$930
Miscellaneous		
Material	$62,000*0.04	$2,480
Labor	$2,480*0.8	$1,984
Total Installed Cost:		$150,245

From ICARUS-generated results (page 59):

Purchased Equipment Cost	$62,100
Total Installed Cost	$141,800

Appendix B

Vertical Vessels
1st Quarter 1998 dollars

15 psig					
Diameter (Feet)	**Height (Feet)**	**Capacity (Gallons)**	**Total Weight (Pounds)**	**Purchased Equipment Cost ($)**	**Installed Cost ($)**
2.5	2.7	100	1,000	$6,400	$51,800
3.0	4.7	250	1,400	$7,400	$61,000
4.0	5.3	500	2,000	$9,800	$68,400
4.0	8.0	750	2,700	$12,200	$89,700
5.0	6.8	1,000	3,000	$13,000	$96,000
6.0	9.5	2,000	4,200	$16,500	$122,300
7.0	10.4	3,000	5,200	$18,000	$132,300
7.0	13.9	4,000	6,300	$18,600	$135,100
8.0	13.3	5,000	7,100	$21,000	$139,700

150 psig					
Diameter (Feet)	**Height (Feet)**	**Capacity (Gallons)**	**Total Weight (Pounds)**	**Purchased Equipment Cost ($)**	**Installed Cost ($)**
2.5	2.7	100	1,300	$7,000	$48,800
3.0	4.7	250	1,800	$8,300	$52,500
4.0	5.3	500	2,800	$11,300	$60,900
4.0	8.0	750	3,600	$13,700	$76,900
5.0	6.8	1,000	4,500	$15,600	$84,800
6.0	9.5	2,000	7,000	$20,900	$100,700
7.0	10.4	3,000	9,600	$24,200	$112,800
7.0	13.9	4,000	11,400	$24,900	$115,800
8.0	13.3	5,000	14,200	$30,500	$124,000

Horizontal Vessels
1st Quarter 1998 dollars

15 psig					
Diameter (Feet)	**Length (Feet)**	**Capacity (Gallons)**	**Total Weight (Pounds)**	**Purchased Equipment Cost ($)**	**Installed Cost ($)**
2.0	4.3	100	1,100	$5,700	$51,900
2.5	6.8	250	1,500	$7,400	$62,200
3.0	9.5	500	2,200	$8,900	$79,600
4.0	8.0	750	2,600	$10,200	$81,600
4.0	10.6	1,000	3,000	$11,200	$88,500
6.0	14.2	3,000	5,600	$17,500	$24,600
7.0	17.4	5,000	7,600	$21,800	$32,300
8.0	18.6	7,000	9,400	$24,800	$144,800
9.0	21.0	10,000	11,500	$29,500	$153,100
11.0	35.2	25,000	21,500	$40,100	$202,600
14.0	43.4	50,000	33,300	$58,200	$251,500
14.5	60.7	75,000	47,000	$76,400	$304,900
14.5	81.0	100,000	59,400	$94,800	$383,500

150 psig					
Diameter (Feet)	**Length (Feet)**	**Capacity (Gallons)**	**Total Weight (Pounds)**	**Purchased Equipment Cost ($)**	**Installed Cost ($)**
2.0	4.3	100	1,400	$6,300	$48,900
2.5	6.8	250	1,800	$8,000	$53,200
3.0	9.5	500	2,500	$9,700	$66,000
4.0	8.0	750	3,500	$12,000	$69,200
4.0	10.6	1,000	4,000	$13,100	$76,400
6.0	14.2	3,000	8,900	$23,500	$104,800
7.0	17.4	5,000	13,500	$32,100	$117,200
8.0	18.6	7,000	18,300	$39,900	$148,000
9.0	21.0	10,000	24,800	$51,800	$163,800
11.0	35.2	25,000	54,100	$90,300	$267,800
14.0	43.4	50,000	101,900	$160,400	$373,200
14.5	60.7	75,000	155,000	$230,300	$482,200
14.5	81.0	100,000	198,700	$285,700	$606,700

Storage Tanks
1st Quarter 1998 dollars

Diameter (Feet)	Height (Feet)	Total Weight (Pounds)	Capacity (Gallons)	Purchased Equipment Cost ($)	Installed Cost ($)
Floating Roof					
17.0	32.0	41,300	50,000	$118,000	$163,400
20.0	32.0	46,700	75,000	$128,200	$180,700
24.0	32.0	55,000	100,000	$143,200	$205,100
37.0	32.0	89,300	250,000	$197,700	$250,000
47.0	40.0	142,400	500,000	$267,800	$332,400
57.0	40.0	195,000	750,000	$335,700	$411,700
66.0	40.0	245,700	1,000,000	$396,600	$480,200
134.0	48.0	858,900	5,000,000	$1,061,200	$1,250,900
175.0	56.0	2,219,100	10,000,000	$2,273,000	$2,564,300
Cone Roof					
17.0	32.0	21,000	50,000	$42,400	$87,800
20.0	32.0	26,400	75,000	$48,900	$101,400
24.0	32.0	34,800	100,000	$59,200	$121,100
37.0	32.0	69,400	250,000	$98,600	$150,900
47.0	40.0	123,100	500,000	$157,800	$222,400
57.0	40.0	176,400	750,000	$214,800	$296,800
66.0	40.0	228,000	1,000,000	$266,100	$349,700
134.0	48.0	853,600	5,000,000	$864,300	$1,054,000
175.0	56.0	2,226,100	10,000,000	$2,040,700	$2,332,000

Valve Tray Columns
1st Quarter 1998 dollars

		15 psig		150 psig	
Diameter (ft)	**Number of Trays**	**Purchased Equipment Cost ($)**	**Installed Cost ($)**	**Purchased Equipment Cost ($)**	**Installed Cost ($)**
5	2	$30,600	$159,500	$35,200	$161,300
5	6	$42,300	$175,700	$50,000	$180,600
5	10	$49,000	$192,100	$57,300	$192,000
5	14	$56,100	$203,400	$67,300	$206,200
5	20	$69,700	$225,900	$84,700	$232,500
5	26	$82,300	$246,200	$95,800	$251,000
5	34	$99,800	$285,800	$118,500	$285,300
5	40	$115,200	$310,300	$134,500	$315,300
5	46	$132,000	$335,200	$145,000	$332,700
5	52	$164,900	$378,000	$185,200	$382,600
5	60	$204,900	$429,700	$226,000	$435,000
10	2	$62,500	$249,000	$89,600	$269,500
10	6	$88,400	$282,100	$122,800	$309,900
10	10	$109,700	$311,100	$151,800	$346,700
10	14	$128,600	$349,700	$180,700	$386,000
10	20	$160,400	$394,800	$220,900	$443,400
10	26	$188,500	$436,200	$254,200	$492,200
10	34	$233,600	$498,700	$312,500	$565,800
10	40	$263,800	$558,700	$356,300	$624,000
10	46	$297,100	$605,000	$391,300	$678,300
10	52	$343,000	$666,100	$450,000	$754,600
10	60	$388,400	$727,700	$501,900	$822,100
15	2	$119,900	$396,200	$221,500	$475,100
15	6	$171,000	$469,300	$293,000	$559,000
15	10	$225,700	$539,500	$364,500	$652,400
15	14	$262,500	$587,100	$425,800	$725,200
15	20	$332,400	$677,700	$522,400	$843,700
15	26	$387,000	$767,500	$600,200	$943,900
15	34	$473,900	$878,600	$722,100	$1,089,500
15	40	$538,600	$958,700	$808,900	$1,191,500
15	46	$620,900	$1,061,600	$907,000	$1,314,300
15	52	$689,200	$1,147,900	$997,700	$1,423,400
15	60	$786,500	$1,269,800	$1,145,800	$1,594,100
20	2	$174,900	$574,900	$402,000	$806,800
20	6	$247,900	$674,400	$517,300	$945,200
20	10	$359,400	$815,300	$605,100	$1,064,600
20	14	$421,000	$892,200	$715,700	$1,190,500
20	20	$508,000	$1,023,200	$857,000	$1,363,200
20	26	$585,300	$1,114,100	$993,600	$1,520,800
20	34	$726,300	$1,285,400	$1,203,000	$1,762,200
20	40	$834,300	$1,421,000	$1,347,900	$1,931,400
20	46	$952,800	$1,560,900	$1,526,400	$2,138,200
20	52	$1,051,100	$1,682,200	$1,669,100	$2,314,600
20	60	$1,195,500	$1,856,100	$1,892,600	$2,568,700

Sieve Tray Columns
1st Quarter 1998 dollars

			15 psig		150 psig	
Diameter (ft)	Number of Trays	Tangent/ Tangent Height	Purchased Equipment Cost ($)	Installed Cost ($)	Purchased Equipment Cost ($)	Installed Cost ($)
5	2	17	$30,000	$158,900	$34,700	$160,800
5	6	25	$41,200	$174,600	$48,900	$179,500
5	10	33	$47,500	$190,600	$55,800	$190,500
5	14	41	$54,200	$201,400	$65,400	$204,300
5	20	53	$67,400	$223,500	$82,300	$230,000
5	26	65	$79,500	$243,200	$93,000	$248,100
5	34	81	$96,300	$282,200	$115,000	$281,700
5	40	93	$111,000	$305,900	$130,300	$310,900
5	46	105	$126,800	$329,700	$140,200	$327,700
5	52	117	$159,500	$372,400	$179,800	$377,000
5	60	133	$203,300	$428,100	$218,900	$427,500
10	2	17	$60,600	$247,100	$87,700	$267,600
10	6	25	$84,600	$278,200	$119,000	$306,100
10	10	33	$104,500	$305,800	$146,500	$341,300
10	14	41	$122,100	$343,100	$174,200	$379,400
10	20	53	$152,300	$386,500	$212,800	$435,000
10	26	65	$178,900	$426,300	$244,700	$482,300
10	34	81	$221,100	$485,700	$300,000	$552,800
10	40	93	$248,400	$542,700	$341,500	$608,600
10	46	105	$280,200	$587,400	$374,400	$661,000
10	52	117	$324,600	$647,000	$430,900	$735,100
10	60	133	$366,300	$704,700	$479,800	$798,100
15	2	17	$115,900	$392,100	$217,600	$471,200
15	6	25	$163,200	$461,400	$285,200	$551,100
15	10	33	$214,900	$528,600	$353,700	$641,300
15	14	41	$249,100	$573,400	$412,300	$711,400
15	20	53	$315,600	$660,400	$505,600	$826,600
15	26	65	$367,100	$746,900	$580,400	$923,600
15	34	81	$446,800	$850,800	$696,200	$1,063,100
15	40	93	$509,300	$928,700	$778,400	$1,160,300
15	46	105	$585,800	$1,025,700	$871,800	$1,278,100
15	52	117	$645,700	$1,103,400	$958,000	$1,382,600
15	60	133	$739,400	$1,221,700	$1,100,000	$1,546,900
20	2	17	$168,200	$568,100	$395,400	$800,100
20	6	25	$234,600	$661,000	$504,000	$931,700
20	10	33	$341,200	$796,700	$586,800	$1,046,100
20	14	41	$398,500	$869,100	$693,100	$1,167,600
20	20	53	$479,700	$994,300	$828,800	$1,334,500
20	26	65	$551,900	$1,080,000	$960,300	$1,486,500
20	34	81	$681,100	$1,239,200	$1,159,400	$1,717,400
20	40	93	$781,300	$1,365,200	$1,296,600	$1,876,900
20	46	105	$892,200	$1,498,500	$1,467,400	$2,075,600
20	52	117	$988,200	$1,624,000	$1,602,400	$2,246,100
20	60	133	$1,120,200	$1,778,700	$1,815,600	$2,489,600

Packed Columns
1st Quarter 1998 dollars

				15 psig		150 psig	
Diameter (Feet)	Tangent/ Tangent Height (Feet)	Packed Height (Feet)	Number of Sections	Purchased Equipment Cost ($)	Installed Cost ($)	Purchased Equipment Cost ($)	Installed Cost ($)
1	10	8	1	$6,700	$64,000	$6,600	$62,000
1	20	18	3	$8,700	$73,400	$9,000	$67,800
1.5	10	8	1	$10,300	$75,500	$11,300	$69,800
1.5	20	18	2	$13,900	$83,000	$15,400	$77,600
1.5	30	28	3	$16,600	$89,700	$18,700	$84,800
2	10	8	1	$12,900	$82,800	$13,900	$76,500
2	20	18	2	$16,900	$90,900	$18,500	$85,000
2	30	28	2	$18,600	$97,000	$20,100	$90,900
2	40	38	3	$21,500	$105,500	$23,600	$101,400
2.5	10	8	1	$14,700	$92,200	$15,400	$82,400
2.5	20	18	1	$16,700	$98,700	$17,600	$89,000
2.5	30	28	2	$22,400	$112,000	$23,800	$104,200
2.5	40	38	2	$23,200	$116,000	$24,600	$108,000
2.5	50	48	3	$30,000	$127,800	$31,800	$119,800
3	10	8	1	$16,200	$98,700	$17,200	$89,400
3	20	18	1	$21,900	$110,800	$23,500	$101,900
3	30	28	2	$24,300	$119,700	$25,900	$112,100
3	40	38	2	$26,500	$125,300	$29,200	$118,500
3	50	48	3	$31,200	$135,400	$34,700	$129,500
3	60	58	3	$35,400	$147,400	$37,500	$135,900
3.5	10	8	1	$20,600	$112,300	$23,100	$100,000
3.5	20	18	1	$26,400	$125,000	$30,600	$118,200
3.5	30	28	2	$30,400	$135,800	$35,000	$126,300
3.5	40	38	2	$31,500	$140,800	$36,300	$131,300
3.5	50	48	3	$38,700	$157,600	$45,000	$145,700
3.5	60	58	3	$43,400	$166,600	$48,000	$152,500
3.5	70	68	4	$48,400	$178,500	$57,600	$168,000

Shell and Tube Heat Exchangers
1st Quarter 1998 dollars

Surface Area, (Square feet)	Purchased Equipment Cost ($)	Installed Cost ($)
100	$13,200	$48,300
200	$13,600	$55,800
300	$14,500	$57,300
400	$16,100	$59,100
500	$16,200	$68,000
600	$16,600	$68,400
700	$18,000	$70,000
800	$18,400	$70,400
900	$20,300	$72,600
1000	$20,800	$73,100
2000	$31,900	$95,800
3000	$44,700	$109,600
4000	$53,900	$132,900
5000	$62,100	$141,800
6000	$70,800	$151,100
7000	$99,600	$203,500
8000	$107,900	$212,400
9000	$117,100	$222,100
10000	$124,200	$229,800
15000	$186,300	$321,500
20000	$248,400	$427,000
30000	$354,000	$573,900
40000	$479,100	$767,500
50000	$582,500	$953,000
60000	$708,300	$1,106,600
70000	$839,000	$1,425,600

Air Cooler
1st Quarter 1998 dollars

Surface Area, (Square feet)	Purchased Equipment Cost ($)	Installed Cost ($)
100	$21,300	$47,600
200	$24,100	$51,800
300	$26,100	$54,800
400	$29,100	$58,100
500	$30,900	$59,900
600	$33,000	$62,000
700	$36,000	$65,300
800	$38,100	$67,400
900	$40,300	$69,900
1,000	$42,000	$71,600
2,000	$60,800	$94,100
4,000	$96,900	$144,700
6,000	$135,400	$184,700
8,000	$179,100	$239,000
10,000	$217,300	$278,200

Spiral Plate Heat Exchanger
1st Quarter 1998 dollars

Heat Transfer Area, (Square feet)	Purchased Equipment Cost ($)	Installed Cost ($)
40	$6,700	$19,200
100	$9,100	$25,100
200	$13,200	$34,000
300	$21,100	$49,400
400	$25,500	$57,400
500	$29,900	$65,000
600	$34,400	$72,400
700	$42,600	$85,300
800	$35,500	$74,200
900	$40,000	$81,300
1,000	$44,700	$88,500
1,100	$49,600	$95,700
1,200	$54,700	$102,900
1,300	$60,100	$110,400

Furnace
1st Quarter 1998 dollars

Heat Duty (MMBTU per hour)	Purchased Equipment Cost ($)	Installed Cost ($)
2	$124,600	$96,300
10	$263,100	$355,100
25	$399,000	$518,600
50	$625,400	$771,100
100	$1,081,500	$1,272,800
200	$1,868,900	$2,641,500
300	$2,573,100	$3,534,400
400	$3,228,000	$4,354,800
500	$3,848,400	$5,126,000

Cooling Tower
1st Quarter 1998 dollars

Water Rate (Gallons/ minute)	Purchased Equipment Cost ($)	Installed Cost ($)
150	$4,000	$60,200
300	$6,500	$65,000
600	$11,400	$70,500
1,000	$18,000	$81,700
2,000	$34,400	$106,100
3,000	$50,900	$134,200
4,000	$67,100	$158,800
5,000	$83,200	$180,400
6,000	$99,200	$211,100

Package Steam Boiler
1st Quarter 1998 dollars

Capacity (Pound per hour)	Purchased Equipment Cost ($)	Installed Cost ($)
10,000	$91,700	$283,100
25,000	$148,100	$368,900
50,000	$212,700	$468,900
100,000	$305,700	$607,300
150,000	$439,400	$783,600
200,000	$568,400	$920,600
250,000	$694,000	$1,109,100
300,000	$816,900	$1,238,600

Evaporator
1st Quarter 1998 dollars

	Vertical Tube		Horizontal Tube	
Area (Square feet)	Purchased Equipment Cost ($)	Installed Cost ($)	Purchased Equipment Cost ($)	Installed Cost ($)
100	$62,600	$120,800	$34,500	$73,300
500	$151,600	$273,500	$81,100	$161,300
1,000	$221,900	$388,400	$117,100	$226,300
2,000	$324,700	$555,200	$169,000	$317,100
3,000	$405,700	$689,100	$209,500	$386,300
4,000	$475,200	$803,300	$244,100	$444,300
5,000	$537,100	$904,700	$274,400	$496,800
6,000	$593,700	$997,000	$302,600	$545,600
7,000			$328,300	$590,500
8,000			$352,400	$632,400
9,000			$375,100	$671,900
10,000			$396,600	$709,200

Crusher
1st Quarter 1998 dollars

Diameter (Inches)	Driver Power (Horsepower)	Purchased Equipment Cost ($)	Installed Cost ($)
Gyratory Crusher			
20	40	$29,300	$52,400
40	150	$253,600	$294,400
60	350	$698,200	$787,200
80	600	$1,400,900	$1,553,600
100	900	$2,415,500	$2,666,100
120	1250	$3,778,800	$4,171,200
Rotary Crusher			
	2	$2,300	$5,200
	4	$3,700	$6,800
	8	$6,100	$9,500
	12	$8,100	$11,800
	16	$9,900	$13,900
	20	$11,600	$15,800
	25	$13,600	$18,100
Ring Granulator			
	75	$23,400	$28,100
	125	$50,700	$58,000
	250	$75,900	$85,900
	600	$197,400	$218,700
	1000	$303,300	$335,600
	1250	$346,400	$382,200

Mill
1st Quarter 1998 dollars

Diameter/ Length (Inches)	Driver Power (Horsepower)	Purchased Equipment Cost ($)	Installed Cost ($)
Ball Mill			
3/3	7.5	$25,100	$62,900
4/4	20	$57,500	$97,900
5/5	50	$109,100	$153,500
6/6	100	$182,900	$234,400
	200	$255,600	$311,700
	300	$411,300	$478,500
	400	$492,200	$573,100
	450	$585,200	$673,100
Roller Mill			
	30	$61,400	$76,900
	75	$107,500	$131,100
	150	$164,200	$197,000
	200	$195,800	$233,100
	250	$224,400	$265,800
	300	$250,900	$296,100
	350	$275,700	$324,400
	400	$299,100	$351,000

Dryers
1st Quarter 1998 dollars

Area (Square feet)	Driver Power (Horsepower)	Purchased Equipment Cost ($)	Installed Cost ($)
Direct Contact Rotary Dryer			
100		$26,500	$42,400
400		$99,500	$142,800
800		$192,700	$264,800
1200		$283,600	$380,800
1600		$373,100	$493,400
2000		$461,500	$603,500
Single Atmospheric Drum Dryer			
10	5	$53,900	$73,800
40	10	$125,800	$162,900
80	15	$192,300	$243,800
120	20	$246,500	$309,100
160	20	$293,900	$365,900
200	25	$337,100	$417,400
Atmospheric Tray Batch Dryer			
30		$6,400	$10,900
60		$8,400	$13,900
90		$9,800	$16,000
120		$10,900	$17,700
150		$11,900	$19,200
180		$12,800	$20,500
200		$13,300	$21,300

Centrifuge
1st Quarter 1998 dollars

Screen Diameter (Inches)	Driver Power (Horsepower)	Purchased Equipment Cost ($)	Installed Cost ($)
Batch Bottom-Suspended Filtering Centrifuge			
20	1.5	$10,100	$21,500
25	2	$11,900	$23,500
30	3	$13,600	$25,500
35	5	$15,300	$27,400
40	7.5	$16,900	$29,300
45	10	$18,400	$31,100
48	10	$19,300	$32,200
Batch Top-Suspended Filtering Centrifuge			
20	1.5	$12,000	$23,400
25	2	$16,000	$27,700
30	3	$20,200	$32,300
35	5	$24,700	$37,100
40	7.5	$29,300	$42,100
45	10	$34,100	$47,300
50	15	$39,100	$52,800
Continuous Filtration Vibratory Centrifuge			
48	30	$58,600	$91,900
50	40	$66,700	$100,900
52	50	$75,500	$113,000
54	60	$85,000	$124,000
56	75	$95,400	$135,800
Reciprocating Conveyor, w/Continuous Filtering Centrifuge			
15		$112,900	$140,500
25		$175,200	$213,200
35		$246,100	$295,100
45		$317,200	$376,200
50		$352,900	$416,800

Filter
1st Quarter 1998 dollars

Flow Rate (Gallons per minute)	Frame Capacity (Cubic feet)	Surface Area (Square feet)	Purchased Equipment Cost ($)	Installed Cost ($)
Cartridge Filter				
30			$1,100	$5,200
100			$1,700	$6,800
300			$2,400	$8,300
600			$4,200	$10,300
900			$5,800	$13,500
1200			$7,300	$15,200
Automatic Plate and Frame				
	10		$100,200	$145,500
	20		$114,200	$160,400
	30		$123,300	$170,100
	40		$130,200	$177,500
	50		$135,900	$183,600
Tubular Fabric Filter				
100			$5,500	$13,000
500			$15,700	$27,100
1000			$24,700	$39,900
1500			$32,200	$51,200
2000			$38,800	$59,500
2500			$44,900	$69,200
3000			$50,600	$76,400
3400			$54,900	$81,700
Drum Filter				
		100	$63,400	$104,200
		250	$87,700	$134,400
		500	$120,200	$175,400
		750	$145,000	$205,200
		1000	$168,900	$237,400
		1500	$192,900	$275,700
		2000	$208,300	$298,900

Agitators
1st Quarter 1998 dollars

Driver Power (Horsepower)	Purchased Equipment Cost ($)	Installed Cost ($)
2	$7,700	$9,500
10	$13,900	$15,900
25	$19,500	$21,600
50	$35,400	$37,700
75	$50,200	$52,700
100	$64,300	$67,000

Rotary Pump
1st Quarter 1998 dollars

Capacity (Gallons/ minute)	Purchased Equipment Cost ($)	Installed Cost ($)
10	$1,500	$9,000
50	$2,100	$10,900
100	$2,400	$12,600
150	$3,000	$13,200
200	$3,400	$13,700
250	$4,100	$16,000
300	$4,400	$16,300
400	$5,300	$17,300
500	$7,000	$19,200
600	$8,700	$21,000
700	$10,700	$25,700
750	$11,600	$26,600

Inline Pump
1st Quarter 1998 dollars

Capacity (Gallons/ minute)	Purchased Equipment Cost ($)	Installed Cost ($)
10	$1,500	$9,000
50	$2,100	$10,900
100	$2,400	$12,600
150	$3,000	$13,200
200	$3,400	$13,700
250	$4,100	$16,000
300	$4,400	$16,300
400	$5,300	$17,300
500	$7,000	$19,200
600	$8,700	$21,000
700	$10,700	$25,700
750	$11,600	$26,600

Centrifugal Pump
1st Quarter 1998 dollars

Capacity (Gallons/ minute)	Purchased Equipment Cost ($)	Installed Cost ($)
100	$3,400	$22,800
200	$4,100	$23,800
300	$4,700	$27,700
400	$5,300	$28,500
500	$5,800	$29,000
1,000	$8,700	$37,500
2,000	$10,200	$44,800
3,000	$15,200	$58,100
4,000	$19,500	$72,300
5,000	$23,800	$77,100
6,000	$28,400	$93,400
7,000	$37,800	$103,000
8,000	$41,300	$119,700
9,000	$47,300	$126,200
10,000	$51,200	$144,800

Reciprocating Pump
1st Quarter 1998 dollars

		Duplex		Triplex	
Capacity (Gallons/ minute)	Driver Power (Horse-power)	Purchased Equipment Cost ($)	Installed Cost ($)	Purchased Equipment Cost ($)	Installed Cost ($)
25	2	$4,100	$10,600	$7,700	$15,500
50	5	$7,000	$14,600	$13,800	$22,700
100	7.5	$8,800	$17,800	$17,900	$28,200
200	15	$13,100	$22,500	$27,900	$38,600
300	25	$17,600	$28,800	$38,700	$51,200
400	30	$19,600	$31,000	$43,500	$56,200
500	40	$23,100	$34,700	$52,300	$65,300
600	50	$26,300	$38,100	$60,300	$73,400
700	60	$29,200	$43,700	$67,800	$83,700
800	60	$29,200	$43,700	$67,800	$83,800
900	75	$33,300	$48,100	$78,200	$94,500
1,000	75	$33,300	$48,200	$78,200	$94,500

Vacuum Pump
1st Quarter 1998 dollars

Capacity (Gallons/ minute)	Stages	Purchased Equipment Cost ($)	Installed Cost ($)
30	1	$4,100	$18,600
75	1	$6,400	$21,100
150	1	$8,900	$24,000
200	1	$11,500	$26,900
300	1	$16,200	$32,300
400	1	$20,800	$37,100
500	1	$25,200	$41,800
600	1	$29,500	$46,300
700	1	$33,700	$50,800
30	2	$6,100	$20,600
75	2	$8,500	$23,200
150	2	$11,000	$26,100
200	2	$13,600	$29,000
300	2	$18,500	$34,600
400	2	$22,900	$39,200
500	2	$27,100	$43,700
600	2	$31,000	$47,800
700	2	$34,800	$51,900

Reciprocating Compressor
1st Quarter 1998 dollars

Stages	Actual Capacity (Cubic feet/ minute)	Driver Power (Horsepower)	Purchased Equipment Cost ($)	Installed Cost ($)
1	250	40	$186,200	$245,500
1	500	75	$233,700	$300,300
1	1,000	125	$301,700	$380,400
1	5,000	600	$589,600	$717,500
1	10,000	1,250	$810,400	$970,700
1	25,000	3,000	$1,891,500	$2,139,000
1	50,000	5,500	$4,024,800	$4,469,700
1	60,000	7,000	$4,837,400	$5,354,000
3	250	100	$297,000	$358,800
3	500	150	$355,400	$422,200
3	1,000	300	$431,400	$509,700
3	5,000	1,500	$822,400	$932,300
3	10,000	3,000	$1,489,700	$1,646,100
3	25,000	7,000	$3,794,300	$4,135,200
3	35,000	10,000	$5,519,000	$6,038,600
3	250	800	$389,400	$467,200
3	500	1,500	$534,100	$627,400
3	1,000	3,000	$1,080,700	$1,211,500
3	5,000	15,000	$3,750,700	$4,211,800
3	7,000	22,500	$4,712,700	$5,317,700

Centrifugal Compressor
1st Quarter 1998 dollars

Stages	Actual Capacity (Cubic feet/ minute)	Driver Power (Horsepower)	Purchased Equipment Cost ($)	Installed Cost ($)
4	500	60	$595,400	$702,700
4	1,000	125	$626,400	$749,300
4	5,000	600	$719,700	$907,100
4	10,000	1,250	$1,114,800	$1,339,000
4	50,000	6,000	$2,699,800	$3,247,700
4	100,000	12,000	$5,275,800	$6,142,000
4	150,000	17,000	$8,722,600	$9,735,100
4	200,000	25,000	$9,627,600	$10,980,400
9	500	125	$975,600	$1,066,700
9	1,000	250	$1,011,200	$1,118,500
9	5,000	1,250	$1,146,600	$1,286,000
9	10,000	2,500	$1,889,300	$2,060,500
8	50,000	12,000	$4,821,600	$5,356,700
8	100,000	25,000	$12,444,800	$13,267,000
7	150,000	37,500	$18,991,500	$19,966,000
7	200,000	50,000	$19,394,300	$20,624,400
9	500	1,750	$1,446,400	$1,548,200
9	1,000	3,500	$1,560,500	$1,680,300
9	5,000	16,000	$2,258,600	$2,527,000
9	10,000	32,500	$4,053,700	$4,467,800
9	15,000	50,000	$5,171,000	$5,718,400

Centrifugal Fan
1st Quarter 1998 dollars

Actual Capacity (Gallons/ minute)	Purchased Equipment Cost ($)	Installed Cost ($)
700	$1,100	$7,000
1,500	$1,100	$7,400
5,000	$1,800	$9,800
10,000	$2,500	$13,100
25,000	$6,700	$27,900
50,000	$13,300	$49,900
75,000	$19,900	$64,900
100,000	$31,400	$93,400
150,000	$44,600	$126,500

Rotary Blower
1st Quarter 1998 dollars

Actual Capacity (Gallons/ minute)	Purchased Equipment Cost ($)	Installed Cost ($)
100	$4,800	$11,500
500	$10,400	$19,100
1,000	$15,000	$24,900
2,000	$22,000	$34,800
3,000	$28,100	$44,400
4,000	$36,700	$54,600

Gas Turbine
1st Quarter 1998 dollars

Power Output (Horsepower)	Purchased Equipment Cost ($)	Installed Cost ($)
1,000	$476,200	$565,200
5,000	$1,254,100	$1,376,400
10,000	$1,903,000	$2,051,300
50,000	$9,639,300	$9,975,400
100,000	$16,148,100	$16,738,600
150,000	$21,837,300	$22,659,400
200,000	$27,052,000	$28,056,000
250,000	$31,940,100	$33,192,400
300,000	$36,583,000	$37,998,000
350,000	$41,031,000	$42,609,000
370,000	$42,764,000	$44,407,000

Steam Turbine
1st Quarter 1998 dollars

Power Output (Horsepower)	Purchased Equipment Cost ($)	Installed Cost ($)
10	$19,100	$36,000
50	$25,200	$46,500
100	$28,500	$53,600
500	$37,700	$108,800
950	$42,100	$126,700
1,000	$85,000	$169,800
2,500	$269,000	$364,400
5,000	$575,000	$688,000
7,500	$781,400	$907,900
10,000	$971,400	$1,106,600
15,000	$1,320,100	$1,477,100
20,000	$1,641,100	$1,825,200
30,000	$2,230,200	$2,447,300