1970
STUDENT CONTEST PROBLEM

Each year the Student Chapters Committee of AIChE publishes a practical design problem to which the seniors in AIChE Student Chapters are invited to provide solutions. The first prize, the A. McLaren White Award, is $300, the A. E. Marshall Award carries with it $200, the third prize is $100, and there are usually three papers receiving honorable mention.

Winners of the first, second, and third prizes in 1970 were Fred D. Grosse, Drexel University; Bruce A. Whipple, University of Colorado; and Larry W. Stinnett, Oklahoma State University. Steven R. Auvil, Michigan State University; Loren B. Schreiber, University of Illinois; and Danley B. Wolfe, Ohio State University, received honorable mention. The awards will be made during the President's Luncheon at the Annual Meeting in Chicago on November 30, at which the recipients will be guests.

A committee from Diamond Shamrock Corporation, Cleveland, Ohio, prepared the problem and judged the solutions. Members of the committee were W. A. Gallup, chairman, and E. M. Norin, L. T. Novak, and C. G. Vinson, Jr.

Judges' Comments

This year's Student Contest Problem was selected as a typical industrial process design problem to offer challenge and yet to be simple enough to be completed within the allotted time. A good solution required a working knowledge of chemical engineering principles, an exercise of judgment, and a degree of creativity. Detailed information was provided for plant investment and manufacturing cost estimates to simplify this portion of the problem. The intent was to enable the student to spend most of his effort on technical design considerations but still to be aware of the importance of costs and returns for optimization.

The committee was encouraged to find evidence that many contestants dug into the literature to review cited references and related articles. It was also evident that many hours of effort went into the solutions. Unfortunately, many errors were also uncovered that likely would have been caught in a team effort such as that practiced in chemical engineering design courses as well as in industry.

The better reports included (1) an opening summary of the salient features of the design and the conclusions drawn, (2) an enumeration of the assumptions made, (3) details of the approaches taken or rejected in the solution, (4) a presentation of the final design with qualitative and quantitative flow sheets, (5) a detailed list of equipment specifications, (6) a tabulation of process economics, and (7) sample calculations including graphs and computer calculations if used.

The design required an optimization of the reaction, purification, and recycle sections of the process. The forward reaction rate had to be calculated by a manipulation of expressions for the equilibrium constant and the reverse reaction rate derived from the data given. The forward rate constant increased with increasing temperature, and the equilibrium constant decreased. Hence, to minimize reactor volume a series of stirred tank reactors with descending temperatures or a plug-flow reactor with a downward temperature gradient from feed to discharge end would be suggested. It was disappointing that only one contestant tackled the difficult integration of a nonisothermal plug-flow reactor. Most of the contestants had their thinking locked in on a single isothermal stirred-tank reactor.

Separation of normally gaseous reactants from the 65°C. meltpoint product was a formidable problem, and several examples of good judgment were demonstrated in the varied solutions. These were the estimation of the solubility of butadiene sulfone below its melting point, the minimization of the concentration of product in the recycle stream, and the awareness of the process implications of the melting point and the decomposition rate of the product.

It was a rewarding experience to review this year's contest problem solutions; in fact, the judges learned some things about chemical engineering practice from them. The contestants are to be commended on their demonstration of analytical ability, imagination, and diligence. The profession can be thankful for a number of well-qualified graduates.

1970 Student Contest Committee

Problem

TO THE CONTESTANT:

This year's student contest problem simulates a make-or-buy study by a chemical manufacturing company. You, as a chemical engineer, are assigned to make this study. You are to design a plant and to develop the associated economics so that a make-or-buy decision may be made.

The information required for this study will be presented in a conference. Extensive data are included with the problem to save you the task of finding it. If you need other data, be sure to reference it. Remember that in case of conflicting data, you are to use the data given in this problem.

To be eligible for the national competition, the solution to the problem must be arrived at by individual effort. In working the problem you should allow yourself 40 to 60 hours to complete it.

The results of your study should be in the form of a design report. The judges will consider the problem from both its nontechnical and technical aspects. The nontechnical area includes the report appearance, English, and organization. Your understanding of engineering concepts, of technical methods, and of the problem will comprise the technical area.

Good luck!

CONFERENCE NOTES:

Present: Don Leader (Manager, Process Engineering) Frank Fells (You, Process Engineer) Bob Adams (Another Process Engineer).

D. Leader: Jim, our Research Department has developed a number of products which are derivatives of butadiene sulfone. As we will be operating our butadiene sulfone derivatives plant at full capacity by the end of 1971, we would like to know whether we should buy or make our own butadiene sulfone.

From our market projections, we have determined the butadiene sulfone demand to be 10 million pounds a year. The project life is expected to be 10 years, and we can get a long-term contract on butadiene sulfone at 25¢/lb. (delivered) to fit our projected demand.

Bob has done some preliminary work on the problem, but he is needed now for a plant start-up. I would like you to shelve your other work temporarily and devote your time to this evaluation.

F. Fells: How far did Bob get in his work?

B. Adams: I've narrowed the butadiene sulfone process down to a continuous process. The batch process would not be competitive enough.

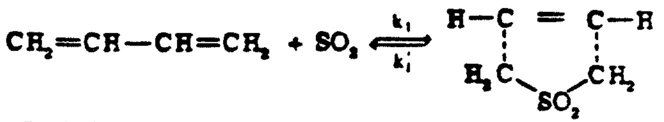
F. Fells: Could you tell me about the derivatives plant?

B. Adams: The butadiene sulfone derivatives plant is a continuous process and should have a 90% onstream factor (330 days/year operation). The derivatives plant is designed to accept molten butadiene sulfone with the following specifications:

Butadiene	≤ 0.5 wt. %
Sulfur dioxide	≤ 0.3 wt. %

F. Fells: Do we have enough information to design a butadiene sulfone plant?

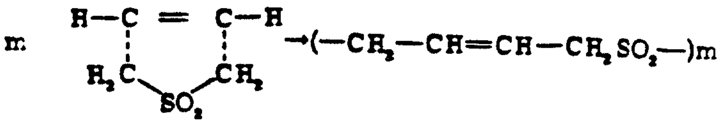
B. Adams: Yes, I believe I have all the information you will need for the butadiene sulfone plant design. The physical properties and thermodynamic data for butadiene and butadiene sulfone are presented in Table 1. The data on sulfur dioxide can be found in Perry's. Even though we know that the butadiene-sulfur dioxide-butadiene sulfone system does not form an ideal solution, variation from ideality is probably small. In the absence of activity coefficient data, assume the mixture to be ideal. Figures 1 and 2 contain the equilibrium and rate data for the reaction:



F. Fells: What is the reaction mechanism?

B. Adams: The reaction mechanism is given by the stoichiometric equation. There are, however, some side reactions which can occur; for example,

$$mCH_2{=}CH{-}CH{=}CH_2 + mSO_2 \longrightarrow (-CH_2{-}CH{=}CH{-}CH_2SO_2{-})m$$



The polymeric butadiene sulfone is amorphous and undesirable as it will build up on the walls of equipment.

F. Fells: How can its formation be minimized?

B. Adams: For all practical purposes the side reactions do not occur if the following conditions are met. Air should be excluded from the process system. The sulfur dioxide-to-butadiene mole ratio should be kept at one or greater than one. Finally,

TABLE 1

Butadiene Sulfone Properties (5)	
Heat Capacity, Cp (s)	35 cal./mole °C. at 25°C.
Heat Capacity, Cp (1)	51 cal./mole °C. at 25°C.
Density, (1)	1.24 gm./cc. at 72°C.
Viscosity, (1)	0.4 centipoise at 80°C.
Melt point	65°C.
Heat of fusion (2), ΔH_f	2.5 Kcal./mole at 25°C.
Heat of vaporization, ΔH_v	12.3 Kcal./mole at 132°C.
Normal boiling point (2)	151°C.
Butadiene Properties (6)	
Heat Capacity, Cp (1)	0.58 cal./(gm.) (°C.) at 40°C.
Heat Capacity, Cp	0.83 cal./(gm.) (°C.) at 130°C.
Heat Capacity, Cp (g)	0.37 cal./(gm.) (°C.) at 40°C. 0.45 cal./(gm.) (°C.) at 130°C.
Density (1)	0.57 gm./cc. at 40°C. 0.43 gm./cc. at 130°C.
Viscosity (1)	0.15 centipoise at 40°C. 0.08 centipoise at 130°C.
Viscosity (g)	81 micropoise at 40°C. 106 micropoise at 130°C.
Enthalpy of formation (7) ΔH (1) formation	21.2 Kcal./mole at 35°C. (8)

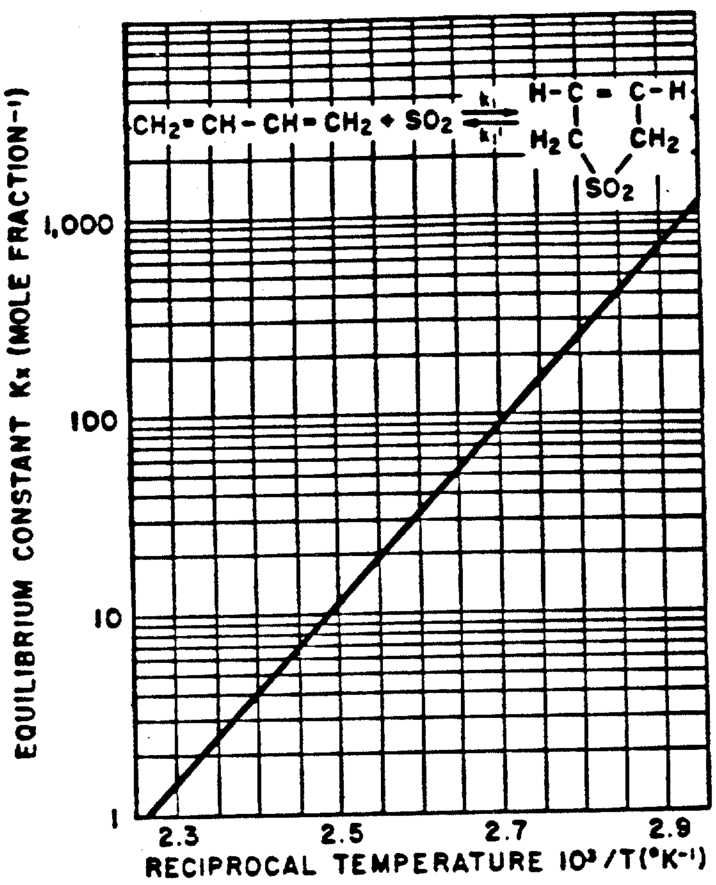


Figure 1. Equilibrium Data (5).

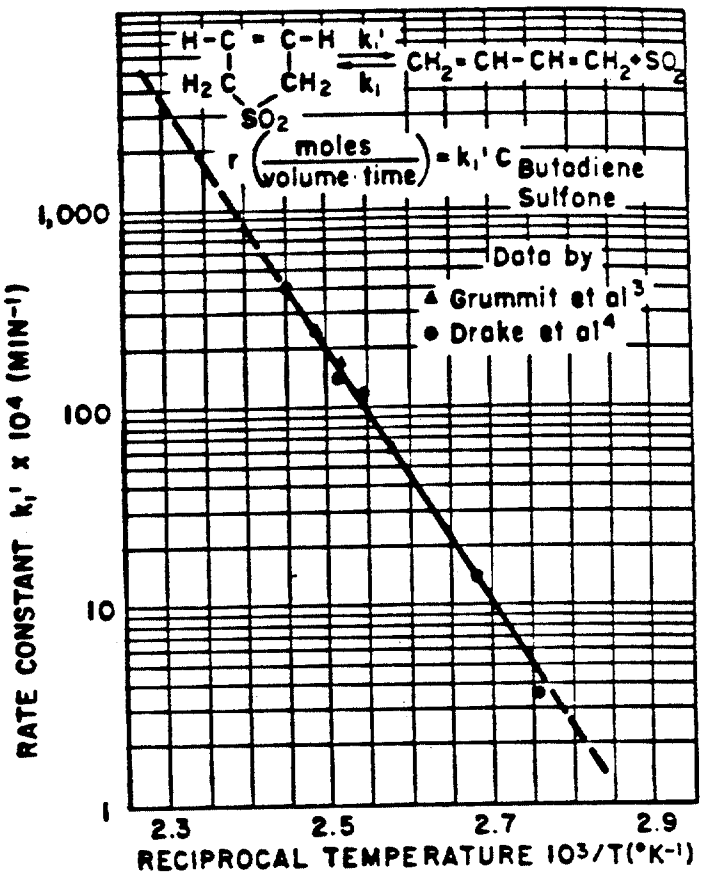


Figure 2. Kinetic Data.

TABLE 2

Raw Material Costs	
1,3-Butadiene (liq.)	0.09 \$/lb. (delivered)
Sulfur dioxide (liq.)	0.035 \$/lb. (delivered)
Sulfur (crude)	40 \$/long ton (delivered)
t-Butyl catechol	2.0 \$/lb. (delivered)
Utilities	
Steam (150 lb./sq. in. gauge)	0.80 \$/1,000 lb.
(15 lb./sq. in. gauge)	0.50 \$/1,000 lb.
Fuel gas	0.50 \$/million B.t.u.
Electricity	0.7 ¢/kw.-hr.
Well water (70°F.)	0.10 \$/1,000 gal.
River water (90°F.)	0.03 \$/1,000 gal.
Overhead	
Operating labor	5 \$/hr.
Supervision	15% operating labor
Repair supplies and labor	5% FCI (fixed capital investment)
Operating supplies	6% operating labor
Indirect payroll	25% operating labor + 25% supervision
General works expense, including taxes and insurance	8% FCI
Depreciation	10% FCI

tert-butyl catechol should be used at a level of 200 parts per million of butadiene in all process streams.

F. Fells: What information do you have on costs?

B. Adams: Raw material, utility, and overhead costs are given in Table 2. These cost estimations were recommended by our economic specialist. The butadiene sulfone plant, if built, will be located near Houston, Texas, on a developed site alongside our butadiene sulfone derivatives plant. Utilities will be available from the derivatives plant.

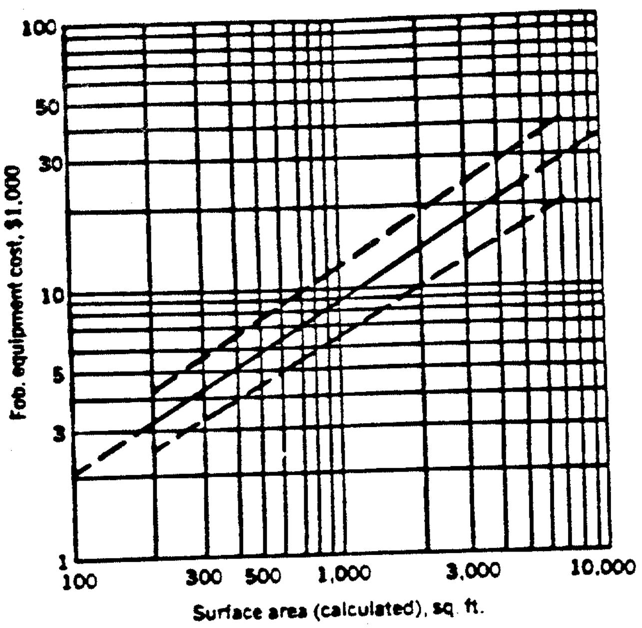
In my earlier work I used a recent article on cost estimating which uses the module technique (1). The bare module cost includes the purchase cost of the particular piece of equipment and all other costs associated with installing the piece of equipment with its necessary piping, instrumentation, insulation, etc. The sum of the bare module cost of each piece of major equipment represents the fixed capital investment for a battery limits plant. The cost-versus-capacity curves for various equipment appear in Figures 3 through 9.

F. Fells: By the way, John, you haven't mentioned anything about materials of construction. Are there any special corrosion problems?

B. Adams: No, there are not any unusual corrosion problems, and steel can be used throughout the process.

F. Fells: Well, thank you, John. I believe I have all the information I'll need.

B. Adams: O.K., and good luck to you.



Required
Surface area, sq. ft.
Design type
Tube, shell material
Design pressure
Design temperature

Basis of chart
Floating head
Carbon steel construction
Design pressure, 150 psi.

Time base
Mid-1968

Exponent
Size component 0.65

Included
Complete fabrication

Exchanger Cost, $ = [Base cost ($F_d + F_p$) × F_m] Index

Adjustment factors

Design Type	F_d
Kettle, reboiler	1.35
Floating head	1.00
U tube	0.85
Fixed tube sheet	0.80

Design Pressure, Psi		F_p*
Up to	150	0.00
	300	0.10
	400	0.25
	800	0.52
	1,000	0.55

*If these factors are used individually, add 1.00 to these values.

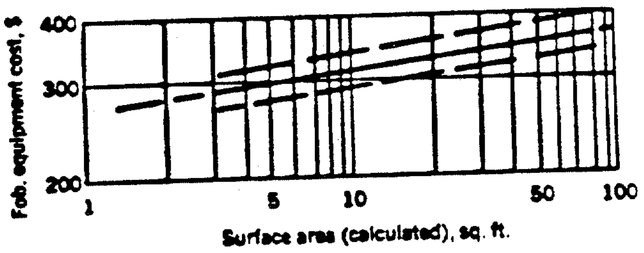
Shell/Tube Materials, F_m

Surface Area, Sq. Ft.			CS/CS	CS/Brass	CS/Mo	CS/SS	SS/SS	CS/Monel	Monel/Monel	CS/Ti	Ti/Ti
Up to		100	1.00	1.05	1.60	1.54	2.50	2.00	3.20	4.10	10.28
100	to	500	1.00	1.10	1.75	1.78	3.10	2.30	3.50	5.20	10.60
500	to	1,000	1.00	1.15	1.82	2.25	3.26	2.50	3.65	6.15	10.75
1,000	to	5,000	1.00	1.30	2.15	2.81	3.75	3.10	4.25	8.95	13.05
5,000	to	10,000	1.00	1.52	2.50	3.52	4.50	3.75	4.95	11.10	16.60

Field installation modules

Module	3A	3B	3C	3D	3E
Base dollar magnitude, $100,000	Up to 2	2 to 4	4 to 6	6 to 8	8 to 10
Equipment fob. cost, *E*	100.0	100.0	100.0	100.0	100.0
Piping	45.6	45.1	44.7	44.4	44.3
Concrete	5.1	5.0	5.0	5.0	5.0
Steel	3.1	3.0	3.0	3.0	3.0
Instruments	10.2	10.1	10.0	9.9	9.8
Electrical	2.0	2.0	2.0	2.0	2.0
Insulation	4.9	4.8	4.7	4.7	4.7
Paint	0.5	0.5	0.5	0.5	0.5
Field materials, *m*	71.4	70.5	69.9	69.5	69.3
Direct material, *E* + *m* = *M*	171.4	170.5	169.9	169.5	169.3
Material erection	55.4	54.7	54.2	53.9	53.8
Equipment setting	7.6	6.5	5.9	5.5	5.2
Direct field labor, *L*	63.0	61.2	60.1	59.4	59.0
Direct *M* & *L* cost	234.4	231.7	230.0	228.9	228.3
Freight, insurance, taxes	8.0	8.0	8.0	8.0	8.0
Indirect cost	86.7	78.8	75.9	75.5	73.0
Bare module cost	329.1	318.5	313.9	312.4	309.5
***L/M* ratios**	0.37	0.36	0.35	0.35	0.35
Material factor, *E* + *M*	1.71	1.70	1.70	1.69	1.69
Direct cost factor, *M* & *L*	2.34	2.32	2.30	2.29	2.28
Indirect factor	0.37	0.34	0.33	0.33	0.32
Module factor (norm)	3.29	3.18	3.14	3.12	3.09

Note All data are based on 100 for equipment, *E*.
Dollar magnitudes are based on carbon steel.



Double-pipe exchanger costs (for process requirements less than 100 sq. ft. Specify double pipe units).

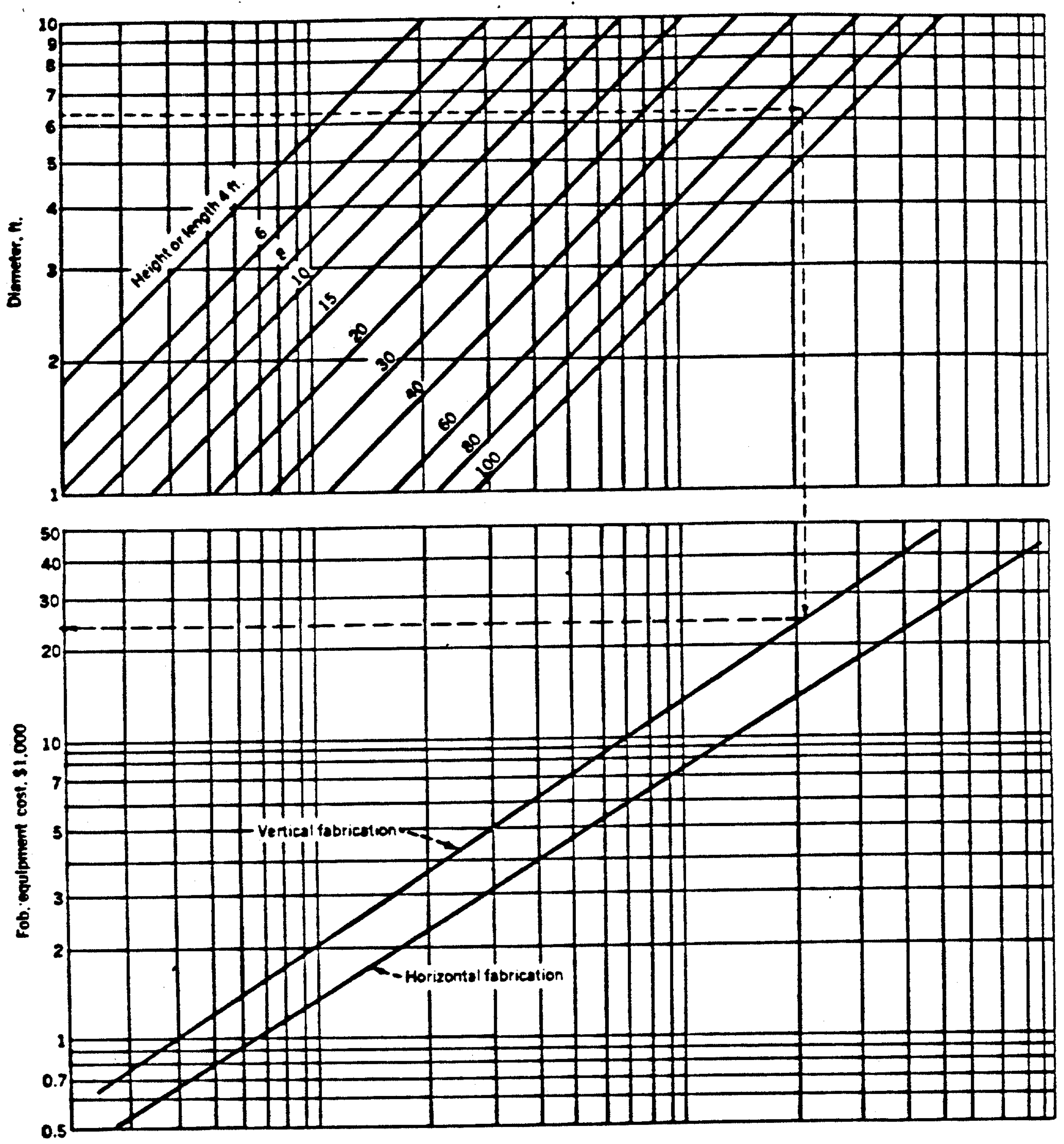
Adjustment factors

Material: CS/CS = 1.0, CS/SS = 1.85
Pressure: up to 600 psi. 1.00
900 1.10
1000 1.25

Module factors

Field installation	1.35
Module factor (norm)	1.83

Figure 3. Capital Cost of Heat Exchangers (1).



Required
Diameter, ft.
Length, ft.
Design pressure, psig.
Shell material
Fabrication (horiz. or vert.)

Basis of chart
Carbon steel material
50-psi. design pressure
Average nozzles and manways
ASME code construction
Shop fabrication

Time base
Mid-1968

Exponent
Size exponent vertical 0.65
horizontal 0.60

Included
Vertical:
Shell and 2 heads
Nozzles and manways
Skirt, base ring and lugs
Tray supports
Horizontal:
Shell and 2 heads
Nozzles and manways
Saddles, 2

Figure 4A. Capital Cost of Pressure Vessels (1).

Process Vessel Cost, $ = (Base cost × F_m × F_p) Index

Adjustment factors

Shell Material	F_m Clad	F_m Solid
Carbon steel	1.00	1.00
Stainless 316	2.25	3.67
Monel	3.89	6.34
Titanium	4.25	7.89

Pressure Factor Psi.	F_p
Up to 50	1.00
100	1.05
200	1.15
300	1.20
400	1.35
500	1.45
600	1.60
700	1.80
800	1.90
900	2.30
1,000	2.50

Field installation modules

Vertical fabrication

Module	5A (V)	5B (V)	5C (V)	5D (V)	5E (V)
Base dollar magnitude, $100,000	Up to 2	2 to 4	4 to 6	6 to 8	8 to 10
Equipment fob cost, E	100.0	100.0	100.0	100.0	100.0
Piping	60.0	59.6	59.5	59.4	59.3
Concrete	10.0	9.9	9.8	9.8	9.8
Steel	8.0	7.9	7.8	7.8	7.8
Instruments	11.5	11.5	11.4	11.3	11.3
Electrical	5.0	4.9	4.9	4.9	4.9
Insulation	8.0	8.0	8.0	8.0	8.0
Paint	1.3	1.3	1.3	1.3	1.3
Field materials, m	103.8	103.1	102.7	102.5	102.4
Direct material, E + m = M	203.8	203.1	202.7	202.5	202.4
Material erection	84.0	83.5	83.2	83.0	82.9
Equipment setting	15.2	14.9	14.0	13.5	13.2
Direct field labor, L	99.2	98.4	97.2	96.5	96.1
Direct M & L cost	303.0	301.6	299.9	299.0	298.5
Freight, insurance, taxes	8.0	8.0	8.0	8.0	8.0
Indirect cost	112.0	102.5	96.9	96.7	95.5
Bare module cost	423.0	412.1	404.8	403.7	402.0
L/M ratios	0.48	0.47	0.47	0.47	0.46
Material factor, E + m	2.04	2.03	2.03	2.02	2.02
Direct cost factor, M & L	3.03	3.02	3.00	2.99	2.98
Indirect factor	0.37	0.34	0.33	0.33	0.32
Module factor (norm)	4.23	4.12	4.07	4.06	4.02

Note: All data are based on 100 for equipment, E.
Dollar magnitudes are based on carbon steel.

Field installation modules

Horizontal fabrication

Module	5A (H)	5B (H)	5C (H)	5D (H)	5E (H)
Base dollar magnitude, $100,000	Up to 2	2 to 4	4 to 6	6 to 8	8 to 10
Equipment fob cost, E	100.0	100.0	100.0	100.0	100.0
Piping	41.1	40.1	39.7	39.4	39.2
Concrete	6.2	6.1	6.0	5.9	5.9
Steel	–	—	–	–	–
Instruments	6.2	6.1	6.0	5.9	5.9
Electrical	5.2	5.1	5.0	5.0	5.0
Insulation	5.2	5.1	5.0	5.0	5.0
Paint	0.5	0.5	0.5	0.5	0.5
Field materials, m	64.5	63.0	62.2	61.7	61.5
Direct material, E + m = M	164.5	163.0	162.2	161.7	161.5
Material erection	52.2	51.0	50.4	50.0	49.8
Equipment setting	9.3	8.3	7.7	7.2	7.0
Direct field labor, L	61.5	59.3	58.1	57.2	56.8
Direct M & L cost	226.0	222.3	220.3	219.0	218.3
Freight, insurance, taxes	8.0	8.0	8.0	8.0	8.0
Indirect cost	83.6	75.6	72.7	72.3	69.8
Bare module cost	317.6	305.9	301.0	299.3	296.1
L/M ratios	0.37	0.36	0.35	0.35	0.35
Material factor, E + m	1.64	1.63	1.62	1.62	1.61
Direct cost factor, M & L	2.26	2.22	2.20	2.19	2.18
Indirect factor	0.37	0.34	0.33	0.33	0.32
Module factor (norm)	3.18	3.06	3.01	2.99	2.96

Note: All data are based on 100 for equipment, E.
Dollar magnitudes are based on carbon steel.

Trays, packings, and linings

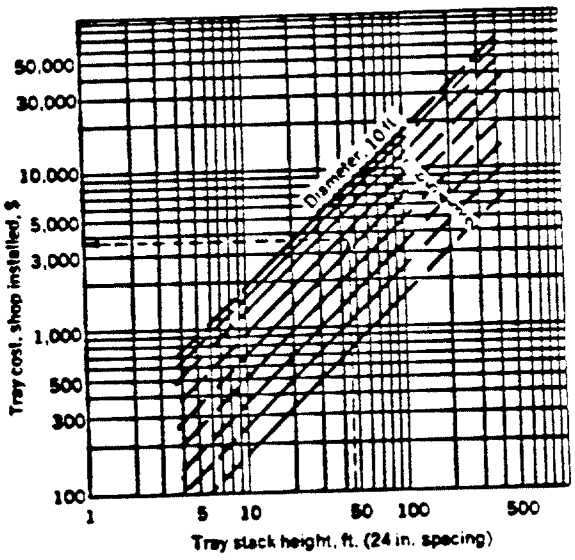
Packings

Raschig Rings	Size, In. 1	1½	2	3
	Materials & Labor, $/Cu. Ft.			
Stoneware	5.2	4.3	3.5	2.9
Porcelain	7.0	5.8	4.7	3.9
Stainless	70.2	45.8	32.5	22.8
Berl saddles	3/4	1	1½	
Stoneware	18.0	14.5	7.8	
Porcelain	20.7	15.9	8.7	

	M & L, $/Cu. Ft.
Activated carbon	14.2
Alumina	12.6
Coke	3.5
Crushed limestone	5.8
Silica gel	27.2

Linings

	In. Thick	M & L, $/Sq. Ft.
Acid brick	3	3.80
	4	5.50
	6	8.25
Firebrick	4½	7.16
	9	10.79
Rubber	3/16	4.57
	1/4	4.75
Refractory	2	7.50
	4	10.52
Gunite	2	3.20
	4	4.55
Chemical lead	3 lb.	6.25
	10	7.15
	15	8.06



Required	**Exponent**
Tray stack height, ft.	Size exponent 1.0
Tray diameter, ft.	
Tray spacing, in.	**Included**
Tray type	Trays (as specified)
Material	Supports
	All fittings
Time base	Shop fabrication
Mid-1968	Shop installation

Tray Cost, $ = (Base cost(F_s + F_t + F_m))Index

Adjustment factors

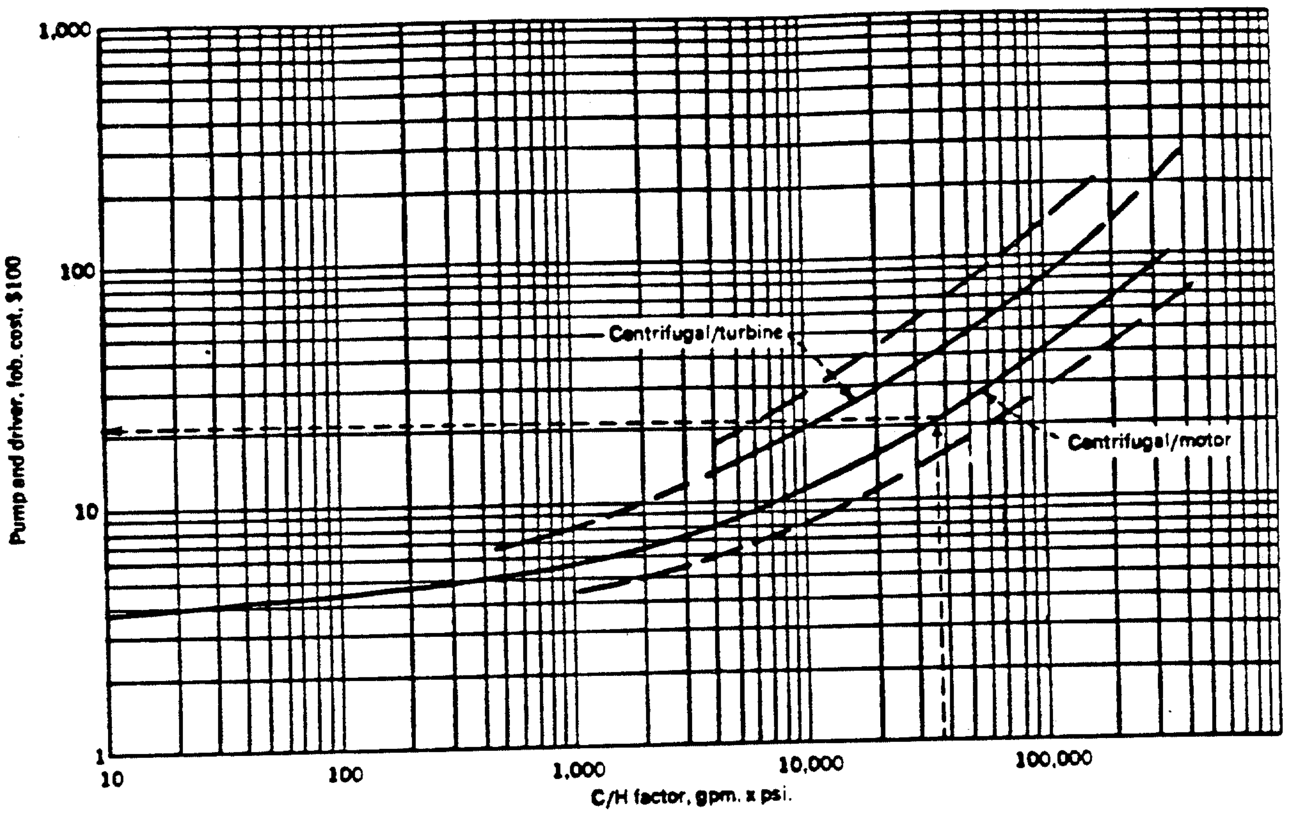
Tray Spacing, In.	F_s
24	1.0
18	1.4
12	2.2

Tray Type	F_t*
Grid (no downcomer)	0.0
Plate	0.0
Sieve	0.0
Trough or valve	0.4
Bubble cap	1.8
Koch Kascade	3.9

Tray Material	F_m*
Carbon steel	0.0
Stainless	1.7
Monel	8.9

*If these factors are used individually, add 1.00 to the above values.

Figure 4B. Capital Cost of Pressure Vessels and Column Internals (1).



Required
Capacity, gpm.
Differential pressure, psi.
Suction pressure, psig.
System temp.,°F.
Casing material

Time base
Mid-1968

Exponent
Average exponent 0.52

Included
Pumping unit
Driver and coupling
Base plate

Centrifugal Pump Cost, $ (Base cost × F_m × F_o)Index

Adjustment factors

Material	F_m
Cast iron	1.00
Bronze	1.28
Cast steel	1.32
Stainless	1.93
Carpenter 20	2.10
Worthite	2.44
Hastelloy C	2.89
Monel	3.23
Nickel	3.48
Titanium	8.98

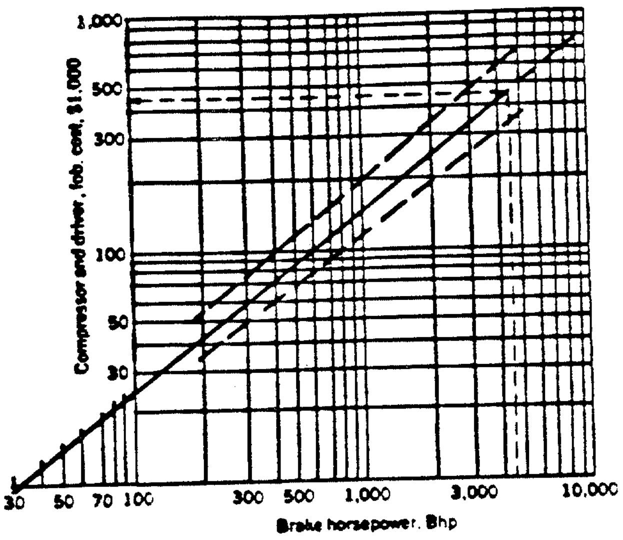
Operating Limits	Max. value		
Suction pressure, psig	150	500	1,000
System temperature, °F.	250	550	850
Factor F_o	1.0	1.5	1.9

Field installation modules

Module	6A	6B	6C	6D	6E
Base dollar magnitude, $100,000	Up to 2	2 to 4	4 to 6	6 to 8	8 to 10
Equipment fob. cost, *E*	100.0	100.0	100.0	100.0	100.0
Piping	30.2	29.8	29.6	29.5	29.4
Concrete	4.0	3.9	3.9	3.9	3.9
Steel	–	–	–	–	–
Instruments	3.0	2.9	2.9	2.9	2.9
Electrical	31.0	30.5	30.3	30.3	30.2
Insulation	2.5	2.5	2.5	2.4	2.4
Paint	0.8	0.8	0.8	0.8	0.8
Field materials, *m*	71.5	70.4	70.0	69.8	69.6
Direct material, *E* + *m* = *M*	171.5	170.4	170.0	169.8	169.6
Material erection	60.0	59.2	59.0	58.6	58.5
Equipment setting	9.7	9.2	8.9	8.7	8.6
Direct field labor, *L*	69.7	68.4	67.9	67.3	67.1
Direct *M* & *L* cost	241.2	238.8	237.9	237.1	236.7
Freight, insurance, taxes	8.0	8.0	8.0	8.0	8.0
Indirect cost	89.2	81.2	78.5	78.2	75.7
Bare module cost	338.4	328.0	324.4	323.3	320.4
L/M ratios	0.41	0.40	0.40	0.40	0.40
Material factor, *E* + *m*	1.72	1.70	1.70	1.70	1.69
Direct cost factor, *M* & *L*	2.41	2.39	2.38	2.37	2.36
Indirect factor	0.37	0.34	0.33	0.33	0.32
Module factor (norm)	3.38	3.28	3.24	3.23	3.20

Note. All data are based on 100 for equipment, *E*.
Dollar magnitudes are based on carbon steel.

Figure 5. Capital Cost of Centrifugal Pumps and Drivers (1).



Required
Compressor type
Brake horsepower

Basis of chart
Centrifugal compression
Carbon steel circuit
Maximum pressure, 1,000 psi.

Time base
Mid-1968

Exponent
Size exponent 0.82

Included
Centrifugal machine
Motor drive
Base plate and coupling

Compressor Cost, $ = (Base cost × F_d)Index

Design Type	F_d
Centrifugal motor	1.00
Reciprocating steam*	1.07
Centrifugal turbine*	1.15
Reciprocating motor*	1.29
Reciprocating gas engine*	1.82

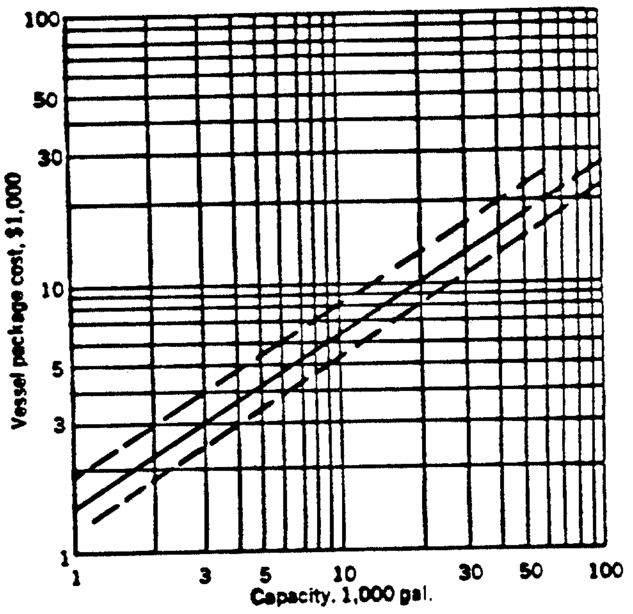
*Includes interstage pots and coolers but not snubbers or other flow dampening devices

Field installation modules

Module	8A	8B	8C	8D	8E
Base dollar magnitude, $100,000	Up to 2	2 to 4	4 to 6	6 to 8	8 to 10
Equipment fob cost, E	100.0	100.0	100.0	100.0	100.0
Piping	20.6	20.2	20.1	20.0	19.9
Concrete	12.3	12.1	12.0	11.9	11.9
Steel	–	–	–	–	–
Instruments	8.2	8.0	8.0	8.0	8.0
Electrical	15.4	15.2	15.0	14.9	14.8
Insulation	2.6	2.6	2.5	2.5	2.5
Paint	0.5	0.5	0.5	0.5	0.5
Field materials, m	59.6	58.6	58.1	57.8	57.6
Direct material E + m = M	159.6	158.6	158.1	157.8	157.6
Material erection	49.8	49.0	48.5	48.0	47.8
Equipment setting	11.6	10.9	10.7	10.5	10.4
Direct field labor, L	61.4	59.9	59.7	58.5	58.2
Direct M & L cost	221.0	218.5	217.3	216.3	215.8
Freight, insurance, taxes	8.0	8.0	8.0	8.0	8.0
Indirect cost	81.8	74.3	71.7	71.4	69.1
Bare module cost	310.8	300.8	297.0	295.7	292.9
L/M ratios	0.38	0.38	0.37	0.37	0.37
Material factor, E + m	1.59	1.58	1.58	1.58	1.57
Direct cost factor, M & L	2.21	2.18	2.17	2.16	2.16
Indirect factor	0.37	0.34	0.33	0.33	0.32
Module factor (norm)	3.11	3.01	2.97	2.96	2.93

Note: All data are based on 100 for equipment, E.
Dollar magnitudes are based on carbon steel.

Figure 6. Capital Cost of Process Gas Compressors and Drivers (1).



Required
Capacity, gal.

Basis of chart
Carbon steel
Design pressure, 150 psi.
ASME code construction
Min. nozzles and manways

Time base
Mid-1968

Exponent
Size exponent 0.65

Included
Pressure storage vessel
Foundations
Saddle supports
Relief valves

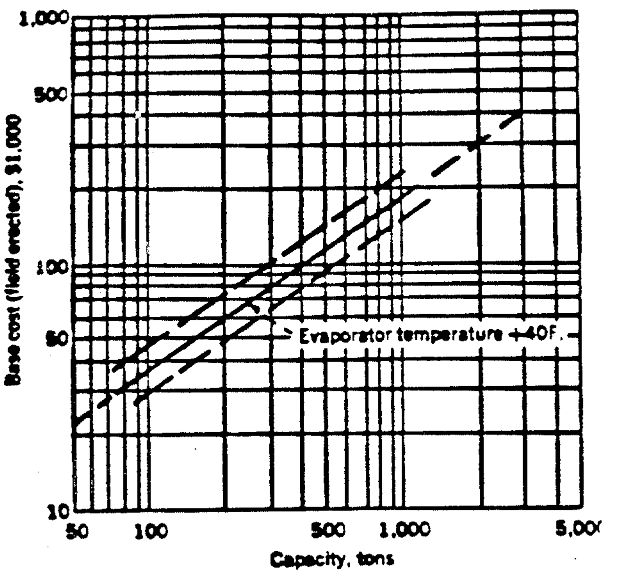
Pressure Storage Cost, $ = (Base cost × F_p)Index

Adjustment factors

Storage Pressure, Psi.	F_p
150	1.00
200	1.15
250	1.32

Installation (Prime contractor work only)	
Field installation (M & L)	1.20
Bare module factor	2.20
L/M ratio	0.36

Figure 7. Capital Cost of Horizontal Pressure Storage Vessels (1).



Required
Capacity, tons
Evaporator temp., °F.

Basis of chart
Evaporator temperature +40F.

Time base
Mid-1968

Exponent
Size exponent 0.70

Included
Centrifugal compression
Evaporators
Condensers
Field erection
Subcontractor indirects

Refrigeration System, $ = [Base cost × F_t] index

Adjustments

Evaporator Temperature, °F	F_t
+40	1.00
+20	1.95
0	2.25
−20	3.95
−40	4.54

Installation (Prime contractor work only)	
Field installation (M & L)	1.31
Bare module factor	1.42
L/M ratio	0.82

Figure 8. Capital Cost of Mechanical Refrigeration (1).

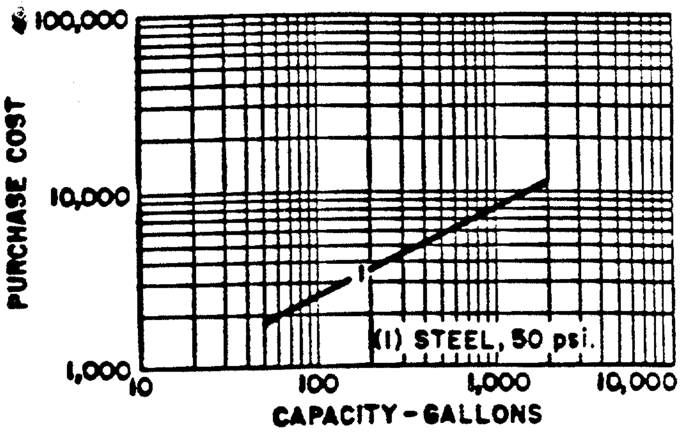


Figure 9. Capital Cost of Agitated, Jacketed Reactors (8).

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Answer to Brain Twister on page 45.

629