Estimate costs of distillation and absorption towers via correlations

Computer-developed formulas yield preliminary, study-grade (±30%) cost estimates of distillation towers and trays, absorption towers and packing, and column platforms and ladders.

Antonio Mulet, University of Palma de Mallorca, Armando B. Corripio, Louisiana State University, and Lawrence B. Evans, Massachusetts Institute of Technology

☐ Correlations for base cost, in carbon steel, of the shell (C_b) and of the platforms and ladders (C_{pl}) are given in both English and SI units in Tables I and II for distillation and absorption towers, respectively.

The standard deviations for the correlation of 200 distillation towers is 10.63% for shell cost and 3.35% for platform and ladder cost. For the correlation of 200 absorption towers, the standard deviations are 9.88% for shell cost and 8.88% for platform and ladder cost. That this last percentage is so much larger than its counterpart reflects the effect of correlating the discretely varying number (and cost) of platforms with a continuous variable, tower length. The effect of this error is much larger for the shorter absorption towers than for the taller distillation towers.

Other construction materials

To calculate shell cost in a material of construction other than carbon steel, use Eq. (1):

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$$C_s = F_M C_b \tag{1}$$

Material-of-construction factors, F_M, are given in Table III.

In the ASPEN cost estimation procedure, the cost of installation materials (foundation, structural, instrumentation, paint, insulation, electrical and piping) and of installation labor are estimated by means of factors related to the base cost in carbon steel.

In these correlations, tower cost represents the sum of

A previous article (Mulet, A., Corripio, A. B., and Evans, L. B., Estimate costs of pressure vessels via correlations, *Chem. Eng.*, Oct. 5, 1981, p. 145) gave cost correlations developed for ASPEN (*A*dvanced *S*ystem for *P*rocess *En*gineering) pressure-vessel cost-estimating subprograms. This article presents similar correlations for distillation and absorption towers.

ASPEN is a complete computer-simulation program developed at Massachusetts Institute of Technology, under the joint sponsorship of the U.S. Dept. of Energy and private industry, to determine the technical and economic feasibility of fossil-energy conversion and other chemical processes. For additional information about the ASPEN program, refer to the Oct. 5 article.

Correlations for cost of distillation towers — Table I

English units

Shell of carbon steel (W_s in lb, lower limit—W_s = 9,020, upper limit—W_s = 2,470,000 lb):

$$C_b = \exp\,[6.823 + 0.14178\,(\ln W_s) + 0.02468\,(\ln W_s)^2 + 0.01580\,(L_t/D_i)\ln(T_b/T_p)]$$

Platforms and ladders (D_i and L_t in ft, lower limit—D_i = 3, L_t = 57.5, upper limit—D_i = 24, L_t = 170):

$$C_{pl} = 151.81\,D_i^{0.63316}L_t^{0.80161}$$

SI units

Shell of carbon steel (W_s in kg, lower limit—W_s = 4,090, upper limit—W_s = 1,060,000):

$$C_b = \exp\,[6.950 + 0.1808\,(\ln W_s) + 0.02468\,(\ln W_s)^2 + 0.01580\,(L_t/D_i)\ln(T_b/T_p)]$$

Platforms and ladders (D_i and L_t in m, lower limit—D_i = 0.91, L_t = 17.53, upper limit—D_i = 7.32, L_t = 51.82):

$$C_{pl} = 834.86\,D_i^{0.63316}L_t^{0.80161}$$

Correlations for cost of absorption towers — Table II

English units

Shell of carbon steel (W_s in lb, lower limit—W_s = 4,250, upper limit—W_s = 980,000):

$$C_b = \exp\,[6.329 + 0.18255\,(\ln W_s) + 0.02297\,(\ln W_s)^2]$$

Platforms and ladders (D_i and L_t in ft, lower limit—D_i = 3, L_t = 27, upper limit—D_i = 21, L_t = 40):

$$C_{pl} = 182.50\,D_i^{0.73960}L_t^{0.70684}$$

SI units

Shell of carbon steel (W_s in kg, lower limit—W_s = 1,930, upper limit—W_s = 445,000:

$$C_b = \exp\,[6.488 + 0.21887\,(\ln W_s) + 0.02297\,(\ln W_s)^2]$$

Platforms and ladders (D_i and L_t in m, lower limit—D_i = 0.91, L_t = 8.23, upper limit—D_i = 6.40, L_t = 12.19):

$$C_{pl} = 1{,}017.0\,D_i^{0.73960}L_t^{0.70684}$$

Constant material-of-construction factors	Table III
Material	**Cost factor, F_M**
Stainless steel, 304	1.7
Stainless steel, 316	2.1
Carpenter 20CB-3	3.2
Nickel-200	5.4
Monel-400	3.6
Inconel-600	3.9
Incoloy-825	3.7
Titanium	7.7

the costs of the shell, platforms and ladders, and internals, either trays or packing. The cost of the tower, which covers fabrication and prime painting in the shop, is f.o.b. manufacturer's plant.

Bases of the correlations

The shell-cost data on which the correlations are based include the cost of the skirt and a standard number and sizes of nozzles and manholes. These are functions of tower diameter, length and pressure rating.

Analysis of cost data for 200 distillation towers and 200 absorption towers revealed that shell cost (including skirt, nozzles and manholes) correlates equally well with both actual tower and shell weight. The latter is calculated (assuming 2 : 1 elliptic heads and ignoring the nozzles, manholes and skirt) from tower diameter, tangent-to-tangent length and design pressure (external or internal), by the same procedure outlined for pressure vessels in a previous article (see footnote). This procedure takes into account wind-load effects and allows for different shell thickness at the bottom and top of the tower.

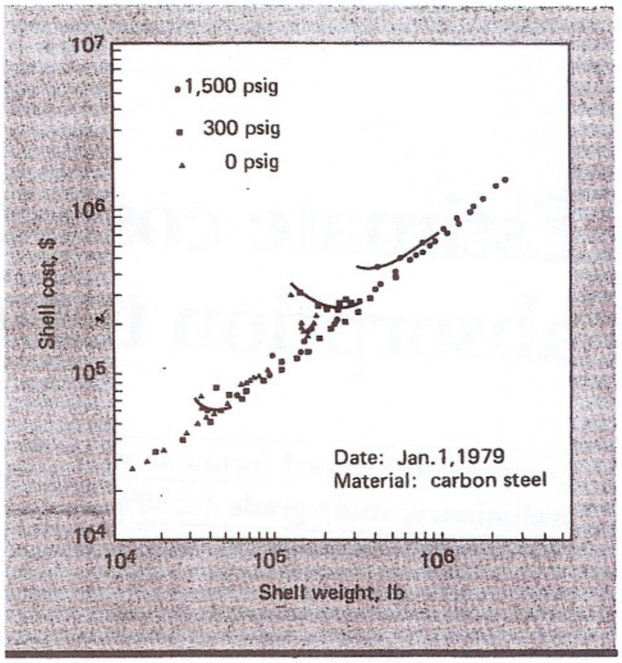
The cost of platforms and ladders is correlated against tower diameter and tangent-to-tangent length.

Graphs of shell cost vs. calculated shell weight are presented in Fig. 1 and 2 for distillation and absorption towers, respectively. Although most of the data points in both groups show good correlation between cost and weight, some in Fig. 1 show nonrandom deviation from the basic correlation. This discrepancy was traced to the additional labor cost required to fabricate a shell of thickness varying from top to bottom. This additional cost is significant only for towers having a high length-to-diameter ratio, as these must be thicker at the bottom to withstand wind loading. The discrepancy is smaller for towers of higher design pressure, because of the greater thickness at the top of such towers.

To account for the additional cost, a term has been added to the correlation equation for distillation towers. This term is a function of the ratios of tower length to diameter, and bottom to top thickness.

Cost of tower trays

Correlations for the base cost of valve trays in carbon steel (C_{bt}) are given as functions of tower diameter in both English and SI units in Table IV. The correlations were developed from cost data for Glitsch "Truss type" one-pass removable ballast trays.

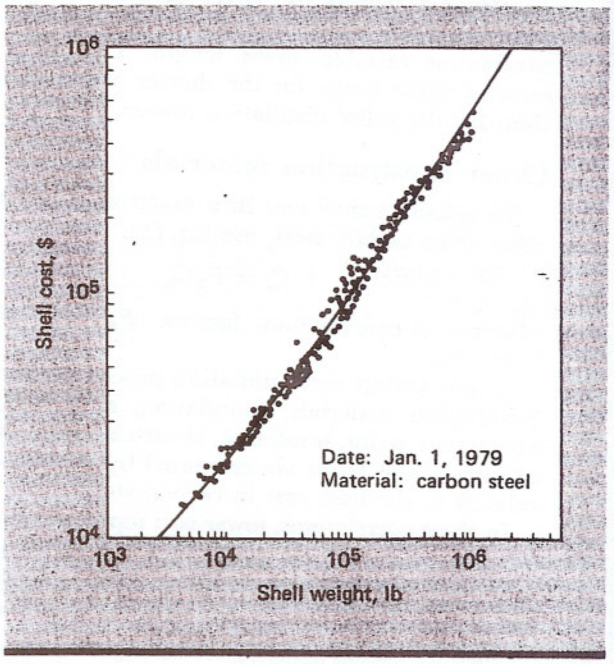


Correlation of cost data for distillation towers **Fig. 1**

For the correlation of 14 trays of different diameter, the standard deviation is 1.3%. Tray material-of-construction cost factors (F_{TM}) for 4 different materials were correlated against tower diameter, using 14 data points for each material. The correlations are given in Table IV.

For other than valve trays, a tray type factor (F_{TT}) must be applied (Table V).

If a design calls for fewer than 20 trays, the following



Correlation of cost data for absorption towers **Fig. 2**

Correlations for cost of trays — **Table IV**

English units

Cost per valve tray of carbon steel (D in ft, lower limit—$D = 2$, upper limit—$D = 16$):

$$C_{bt} = 278.38 \exp (0.1739\ D)$$

Material-of-construction cost factor (F_{TM}):

304 stainless steel, $F_{TM} = 1.189 + 0.0577\ D$
316 stainless steel, $F_{TM} = 1.401 + 0.0724\ D$
Carpenter 20CB-3, $F_{TM} = 1.525 + 0.0788\ D$
Monel, $F_{TM} = 2.306 + 0.1120\ D$

SI units

Cost per tray of carbon steel (D in m, lower limit—$D = 0.6$, upper limit—$D = 4.8$):

$$C_{bt} = 278.38 \exp (0.5705\ D)$$

Material-of-construction cost factors (F_{TM}):

304 stainless steel, $F_{TM} = 1.189 + 0.1894\ D$
316 stainless steel, $F_{TM} = 1.401 + 0.2376\ D$
Carpenter 20CB-3, $F_{TM} = 1.525 + 0.2585\ D$
Monel, $F_{TM} = 2.306 + 0.3674\ D$

number-of-trays factor (F_{NT}) recommended by Enyedy must be applied [3]:

$$\boxed{F_{NT} = 2.25/(1.0414)^{NT}} \quad (2)$$

The total estimated cost of a tray tower (C_t) is calculated by means of Eq. (3), in which the term N_T represents the number of trays required:

$$\boxed{C_t = C_bF_M + N_TC_{bt}F_{TM}F_{TT}F_{NT} + C_{pl}} \quad (3)$$

Cost factors for tray type — **Table V**

Tray type	Factor (F_{TT})
Valve	1.00
Grid	0.80
Bubble cap	1.59
Sieve (with downcomer)	0.85

Cost of tower packing per unit volume — **Table VI**

Packing type	$/ft³	$/m³
Ceramic Raschig rings, 1 in.	14.5	510
Metal Raschig rings, 1 in.	23.9	840
Intalox saddles, 1 in.	14.5	510
Ceramic Raschig rings, 2 in.	10.1	360
Metal Raschig rings, 2 in.	17.0	600
Metal Pall rings, 1 in.	23.9	840
Intalox saddles, 2 in.	10.1	360
Metal Pall rings, 2 in.	17.0	600

Cost of packed towers

Estimates of the cost of packing in a tower are based on required volume of packing and its cost per unit volume. Data for the latter taken from Pikulik and Diaz are listed in Table VI [5]. The data have been extrapolated to the first quarter of 1979 by means of *Chemical Engineering*'s Fabricated Equipment Index, the ratio being 252.5/200.8, or 1.257.

The total estimated cost of a packed tower is calculated via:

$$C_t = C_bF_M + (\pi D_i^2/4)H_pC_p + C_{pl} \quad (4)$$

Cost of towers having two diameters

The ASPEN programs allow for the design and cost estimation of distillation and absorption towers having more than one diameter. The cost of towers having two diameters may be estimated by means of the following correlations of Enyedy [3]:

$$C_b = (L_{t1}C_{b1} + L_{t2}C_{b2})/(L_{t1} + L_{t2}) \quad (5)$$

$$C_{pl} = (L_{t1}C_{pl1} + L_{t2}C_{pl2})/(L_{t1} + L_{t2}) \quad (6)$$

Here, C_{b1} and C_{pl1} are the base cost of the shell and of the platforms and ladders, respectively, calculated for a tower of diameter D_1 and the same total length as the two-diameter tower. The subscript 2 applies similarly for the D_2 tower diameter.

The cost of trays or packing is calculated separately for each of the two sections, and added. No analysis of the accuracy of Eq. (5) and (6) is known to exist.

Source of the cost data

Extensive data on the cost of distillation and absorption towers and valve trays in a wide range of lengths, diameters, design pressures, numbers of trays and materials of construction were acquired from PDQ$, Inc. [3]. Although some of the data were for January 1979, all of them were escalated to the first quarter of 1979 by means of the *Chemical Engineering* Fabricated Equipment Index (252.5 for first-quarter 1979). The tower designs conform to the ASME Code.

The packing cost data of Pikulik and Diaz [5] were escalated to the first quarter of 1979 by means of the same index. The cost factors for tray types other than valve trays were obtained from the FLOWTRAN tray-tower cost subprograms of Monsanto Co.

Towers taller than 40 feet (tangent-to-tangent) were classified as distillation towers, and those shorter as absorption towers, for data-grouping purposes. The result is that the cost of a tall absorption tower is calculated from the correlation for distillation towers, that of a short distillation tower from the absorption-tower correlation. Because the costs of trays and packing are calculated separately, however, this approach, despite its arbitrariness, does not affect cost estimates made with the correlations derived from the data.

Example illustrates the method

Estimate the cost of a carbon-steel distillation tower 3 ft in dia. and 57½ ft long (tangent-to-tangent), designed to withstand 320 psig, having a corrosion allowance of 1/32 in. and containing 32 valve trays of 304 stainless steel.

Nomenclature

- C_b Base cost of tower in carbon steel, $
- C_{bt} Base cost of valve trays in carbon steel, $
- C_p Cost of packing per unit volume
- C_{pl} Cost of platforms and ladders, $
- C_s Cost of shell (including skirt, nozzles and manholes), $
- C_t Total cost of tower (including trays or packing, skirt, nozzles and manholes), $
- D Tray diameter
- D_i Inside diameter
- D_o Outside diameter
- E Joint efficiency
- F_M Cost factor for material of construction (1.0 for carbon steel)
- F_{NT} Cost factor for number of trays
- F_{TM} Cost factor for tray material of construction (1.0 for carbon steel)
- F_{TT} Cost factor for tray type
- H_p Height of packing
- L_t Tangent-to-tangent length
- N_t Number of trays
- P_g Gage pressure
- R Inside radius
- S Maximum allowable stress
- T_a Additional thickness for corrosion allowance
- T_b Thickness at bottom of tower
- T_c Calculated wall thickness
- T_g Thickness to withstand internal pressure when girth seam controls
- T_p Thickness to withstand design pressure
- T_w Thickness to withstand wind load
- W_s Shell weight
- ρ Density of shell material

First calculate the tower's shell weight by the procedure outlined for pressure vessels in the Oct. 5 article (see footnote, p. 77):

For the thickness at the top of the distillation tower, $R = 1\frac{1}{2}$ ft, $P_g = 320$ psig, $E = 0.85$, and $S = 13{,}700$ psi (for a low alloy steel). The required thickness at the top (T_p) to withstand the 320-psig design pressure is therefore:

$$T_p = \frac{\overset{P_g}{(320)}\overset{R}{(1.5)}(12)}{\underset{S}{(13{,}700)}\underset{E}{(0.85)} - (0.6)\underset{P_g}{(320)}} = 0.5029$$

Rounding up the result to the next 1/32 in., $T_p = 0.53125$ in.

For the thickness at the bottom, assume $D_o = 36 + 1 = 37$ in. $L_t = (57\frac{1}{2}\text{ ft})(12\text{ in./ft}) = 690$ in. Find the thickness for wind load, T_w:

$$T_w = \frac{(0.22)(\overset{D_o}{37} + 18)\overset{(L_t)^2}{(690)^2}}{\underset{S}{(13{,}700)}(37)^2} = 0.3072\text{ in.}$$

When the girth seam controls internal thickness:

$$T_g = \frac{\overset{P_g}{(320)}\overset{R}{(1.5)}(12)}{[(2)\underset{S}{(13{,}700)}\underset{E}{(0.85)}] + [(0.4)\underset{P_g}{(320)}]} = 0.2460\text{ in.}$$

Therefore,

$$T_b = \overset{T_w}{0.3072} + \overset{T_g}{0.2460} = 0.4920\text{ in.}$$

Rounding up to the next 1/32 in., $T_b = 0.5000$ in.

Because the thickness required by the sum of T_w and T_g is less than that needed to withstand the internal pressure, the thickness of the tower is uniform at 0.53125 in. Adding the corrosion allowance thickness (T_a) of 1/32 in. puts the calculated shell thickness (T_c) at 0.5625 in.

With $\rho = 0.284$ lb/in.^{3} for carbon steel, the shell weight (W_s) is 12,994 lb:

$$W_s = \pi(3)[57.5 + 0.8116(3.0)](0.5625)(144)(0.284) = 12{,}994$$

Because L_t at $57\frac{1}{2}$ ft is greater than 40 ft, the base-cost correlation is chosen from Table I:

$$C_b = \exp[6.823 + 0.14178(\ln 12{,}994) + 0.02468(\ln 12994)^2 + 0.01580(57.5/3.0)\ln(0.5625/0.5625)] = \$32{,}220$$

The PDQ$, Inc. cost of $33,899 differs by 5.2%.

Calculating the cost of platforms and ladders with the Table I correlation:

$$C_{pl} = 151.81(3.0)^{0.63316}(57.5)^{0.80161} = \$7{,}830$$

The PDQ$, Inc. cost is $8,020.

Determining tray cost with the Table IV correlation:

$$C_{bt} = 278.38\exp[(0.1739(3.0)] = \$469$$

Finding the material-of-construction factor for stainless steel via the Table IV correlation:

$$F_{TM} = 1.189 + (0.0577)(3.0) = 1.362$$

The tray-type factor (F_{TT}) is 1.0 for valve trays, and so is the number-of-trays factor (F_{NT}), because there are more than 20 trays.

Tray cost = (32)(469)(1.362) = $20,440. Adding the tray cost to the shell cost of $32,220 and the platform and ladder cost of $7,830 results in a total tower cost estimate of $60,490.

Jay J. Matley, Editor

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