**Table 15-15 General guidelines to assist drying equipment selection†**

| Equipment types considered | Solids drying compatibility | Equipment advantages | Equipment limitations |
|---|---|---|---|
| Mechanically aided | | | |
| Tunnel dryer (continuous) | Sludges, pastes, large solids, heat-sensitive materials | Can process many materials, conveyors simplify handling, good temperature control | High labor requirement, vacuum impractical, unsuitable for dusty materials |
| Rotary dryer | Fine, granular or fibrous materials | High capacity, flexibility, good efficiency | Unsuitable for slurries, pastes, sludges, or heat-sensitive materials |
| Vacuum dryer | Fine flowing powders, granular or fibrous solids | Handles heat sensitive and nonsticking materials | Unsuitable for slurries, gummy pastes, sludges, batch operation, high cost |
| Tower contactor | Fine, free-flowing solids | Operation with controlled process and temperature feasible | Limited capacity, structured constraints, high investment |
| Vibrating conveyor contactor | Fine, free-flowing powders, small granular solids | Provides fluid bed action for particles up to 0.15 mm, high heat transfer | Limited to particles that can be fluidized |
| Drum dryer (indirect heating) | Slurries or solutions, flowing pastes and sludges | Provides drying of liquid solutions impractical by other means, high maintenance cost | Drying limited to solutions adhering to a drum, low capacity, high energy costs |
| Screw conveyor (indirect heating) | Gummy and sticky materials, sludges | Dries difficult-to-handle materials, operates under pressure and vacuum | Low capacity |
| Fluid-activated | | | |
| Fluid bed | Fine, free-flowing powders, very small granules or fibrous solids | High capacity, low cost, high heat transfer, uniform internal temperatures | Limited to solids that can be fluidized and not fractured in high-velocity gas streams |
| Spouted bed | Uniform granular solids | Handles granular solids up to 1 mm in diameter, relatively high capacity, good heat transfer | Limited to solids that can be agitated with a jet |
| Pneumatic conveyor | Very fine, free-flowing solids | High capacity, low processing time, good for heat-sensitive materials | Drying dependent on gas moisture and enthalpy content, generally requires recycling |
| Spray dryer | Slurries or solutions | Excellent for heat-sensitive materials, light and porous product | Handles only liquid mixtures that can be sprayed, verify pressure effects on liquid and solid |

†Summarized from data presented by C. G. Moyers and G. W. Baldwin, in *Perry's Chemical Engineers' Handbook*, 7th ed., R. H. Perry and D. W. Green, eds., McGraw-Hill, New York, 1997, Sec. 12, S. W. Walas, *Chemical Process Equipment*, Butterworth-Heineman, Newton, MA, 1990, G. D. Ulrich, *A Guide to Chemical Engineering Design and Economics*, J. Wiley, New York, 1984, and D. R. Woods, *Process Design and Engineering Practice*, Prentice-Hall, Englewood Cliffs, NJ, 1995.

**Table 15-16 Normal operating conditions associated with drying equipment**[†]

| Type of drying equipment | Approx. dimensions[‡] $D$, m | $L$, m | $L/D$ | Solids velocity, m/s | % $A_c$ used by solids[‡] | Gas velocity, m/s | Avg. heat-transfer coeff., J/s·m²·K | Avg. $G$,[‡] kg/s·m² | Thermal eff., % | Approx. power reqm't., kW |
|---|---|---|---|---|---|---|---|---|---|---|
| Mechanically aided | | | | | | | | | | |
| Tunnel dryer (continuous) | 0.5–4 | 5–20 | 5–10 | 0.006–0.2 | 10–20 | 1–5 | 30–50 | — | 20–50 | 0.035–12.5 |
| Rotary dryer (direct) | 1–3 | 4–20 | 4–6 | 0.02–0.1 | 10–15 | 0.3–1.0 | 60 $G^{0.67}$ | 0.5–5.0 | 55–75 | 8–27 |
| Vacuum dryer | 0.5–3 | 1.5–12 | 3–4 | — | 50–65 | — | 40–60 | Batch | 60–80 | 2–27 |
| Tower contactor | 2–10 | 2–20 | 1–2 | 0.006–0.8 (solid flow, kg/s) | NA | 0.6–3 | 40–70 | — | 55–75 | 1–300 |
| Vibrating conveyor contactor | 0.3–2 | 3–20 | 3–10 | 2–10 | 15–20 | — | $10^3$ ($G^{0.67}$) (volume) | — | — | 0.1–1.3 |
| Drum dryer | 0.6–3 | 0.6–5 | 1–8 | 0.0003–0.07 (solid flow, kg/s) | NA | — | $10^2$–$10^3$ | — | — | — |
| Screw conveyor | 0.1–0.7 | 1–6 | 3–10 | 0.01–0.1 | 40–50 | — | 15–60 | 0.05–0.5 | 30–60 | 0.01–2.3 |
| Fluid-activated | | | | | | | | | | |
| Fluid bed | 1–10 | 0.3–15 | 0.3–15 | — | 20–30 | 0.1–2 | $10^3$ ($G^{0.67}$) (volume) | — | 50–80 | 0.3–1200 |
| Spouted bed | 0.2–1 | 0.5–4 | 1–10 | — | 20–30 | — | $10^2$ ($G^{0.67}$) (volume) | — | 50–80 | 0.08–16 |
| Pneumatic conveyor | 0.2–1 | 10–30 | >50 | — | 5–10 | — | $10^3$–$2 \times 10^3$ (volume) | — | 55–75 | 3–230 |
| Spray dryer | 2–10 | 8–25 | 4–5 | — | NA | 0.2–3 | — | — | 40–60 | — |

[†]Summarized from data presented by G. D. Ulrich, *A Guide to Chemical Engineering Design and Economics,* J. Wiley, New York, 1984, D. R. Woods, *Process Design and Engineering Practice,* Prentice-Hall, Englewood Cliffs, NJ, 1995, and C. G. Moyers and G. W. Baldwin, in *Perry's Chemical Engineers' Handbook,* 7th ed., R. H. Perry and D. W. Green, eds., McGraw-Hill, New York, 1997, Sec. 12.

[‡]$D$ = diameter, m; $L$ = length, m; $G$ = mass flux, kg/s·m², $A_c$ = cross-sectional area of dryer, m².

For a particular type of dryer configuration and a required residence time, there are a variety of terminal temperatures and flow rates that will satisfy the mass and energy balances. However, the heat-transfer characteristics of the dryer uniquely establish these parameters. As noted above, the logarithmic-mean temperature driving force applies.

In this simplified design procedure for dryers, the analysis is normally overspecified because of some of the arbitrary assumptions that were made. One assumption is that the gas stream did not become saturated during its passage through the drier. It is important to check that saturation or near saturation has not occurred. Other restrictive assumptions may result in a design that either does not meet configurations normally available from vendors or is expensive to operate. At this point, the design should be reevaluated to determine whether other assumptions are justified or other equipment alternatives should be considered.

## Costs for Typical Dryers

The purchased and/or installed costs of dryers are presented in Figs. 15-29 through 15-35. Costs are available for tray, pan, rotary, drum, vibratory conveyor, fluid-bed, and spray dryers. The cost data cover both vacuum and atmospheric systems.

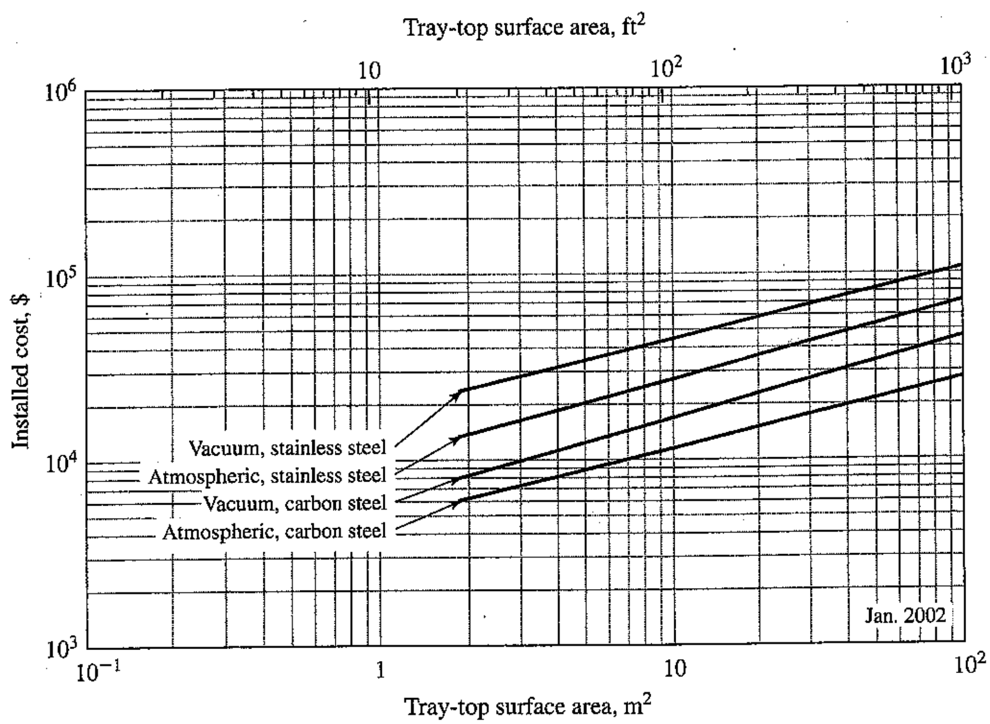
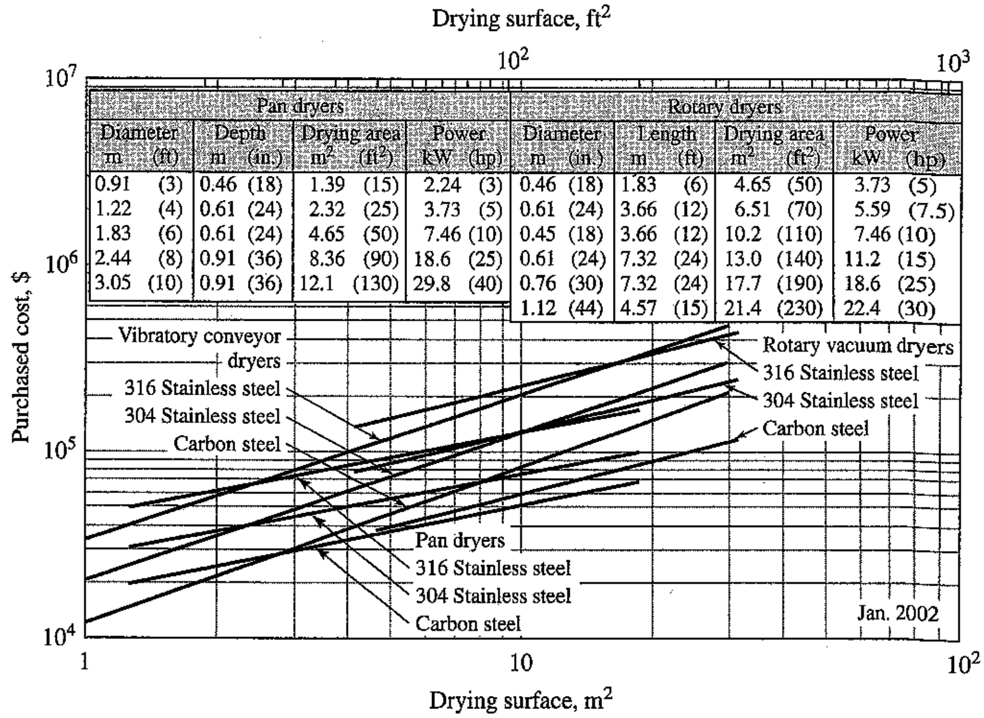



**Figure 15-29**
Installed cost of tray dryers



| Pan dryers | | | | Rotary dryers | | | |
|---|---|---|---|---|---|---|---|
| Diameter m (ft) | Depth m (in.) | Drying area $m^2$ ($ft^2$) | Power kW (hp) | Diameter m (in.) | Length m (ft) | Drying area $m^2$ ($ft^2$) | Power kW (hp) |
| 0.91 (3) | 0.46 (18) | 1.39 (15) | 2.24 (3) | 0.46 (18) | 1.83 (6) | 4.65 (50) | 3.73 (5) |
| 1.22 (4) | 0.61 (24) | 2.32 (25) | 3.73 (5) | 0.61 (24) | 3.66 (12) | 6.51 (70) | 5.59 (7.5) |
| 1.83 (6) | 0.61 (24) | 4.65 (50) | 7.46 (10) | 0.45 (18) | 3.66 (12) | 10.2 (110) | 7.46 (10) |
| 2.44 (8) | 0.91 (36) | 8.36 (90) | 18.6 (25) | 0.61 (24) | 7.32 (24) | 13.0 (140) | 11.2 (15) |
| 3.05 (10) | 0.91 (36) | 12.1 (130) | 29.8 (40) | 0.76 (30) | 7.32 (24) | 17.7 (190) | 18.6 (25) |
| | | | | 1.12 (44) | 4.57 (15) | 21.4 (230) | 22.4 (30) |



**Figure 15-30**
Purchased cost of drying equipment. Price includes motor and drive.

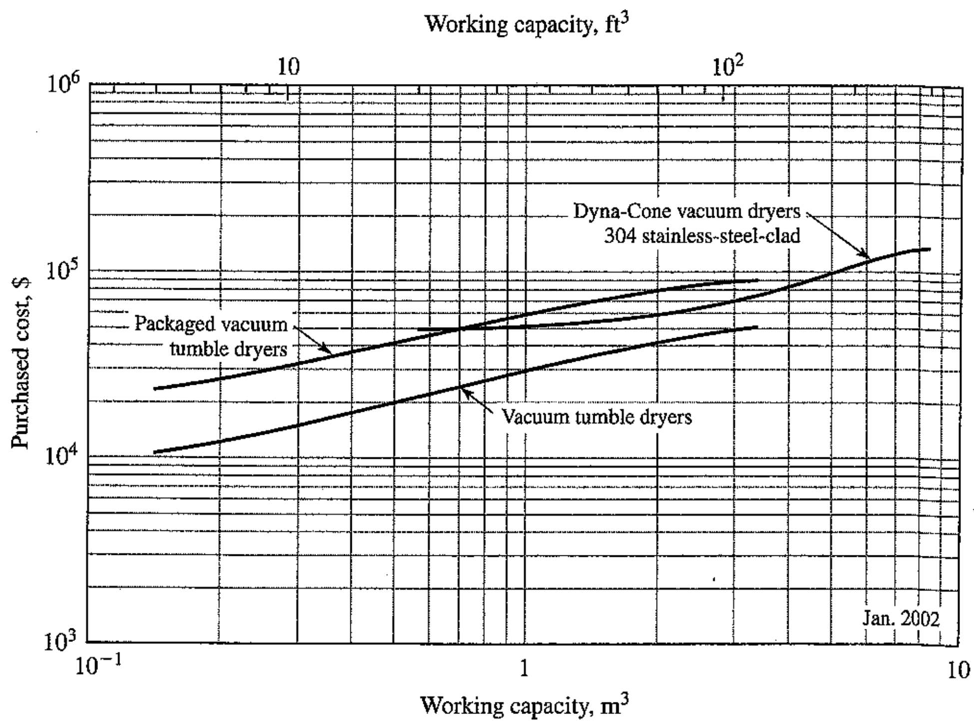



**Figure 15-31**
Purchased cost of tumble and Dyna-Cone vacuum dryers

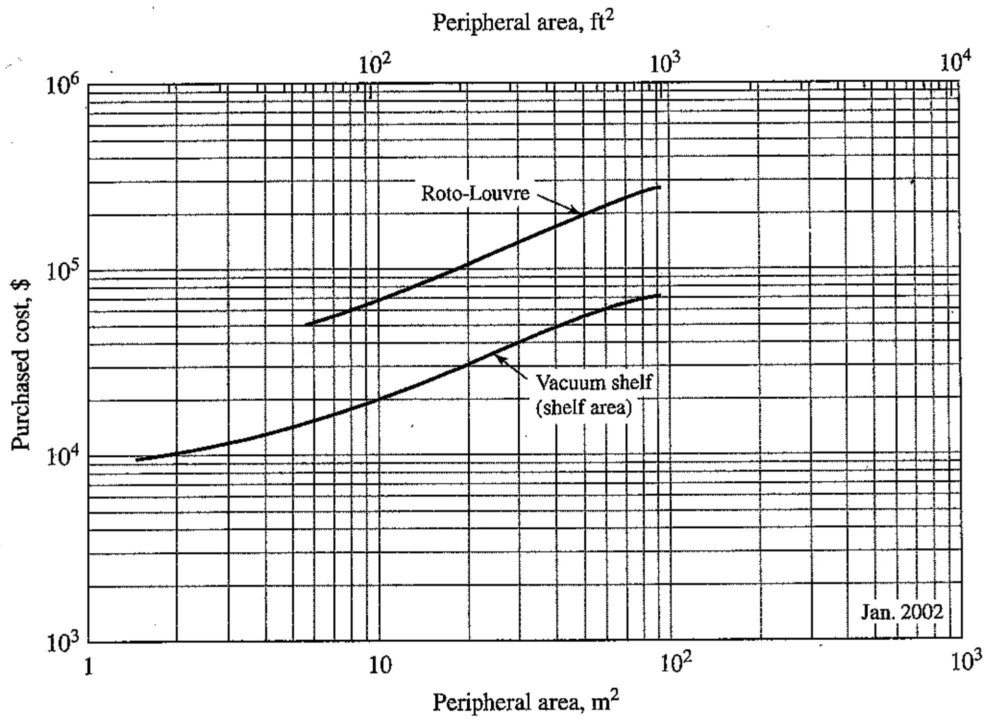



**Figure 15-32**
Purchased cost for Roto-Louvre and vacuum shelf dryers, carbon-steel construction. Price includes auxiliaries (motor, drive, fan, vacuum pump, condenser, and receiver).

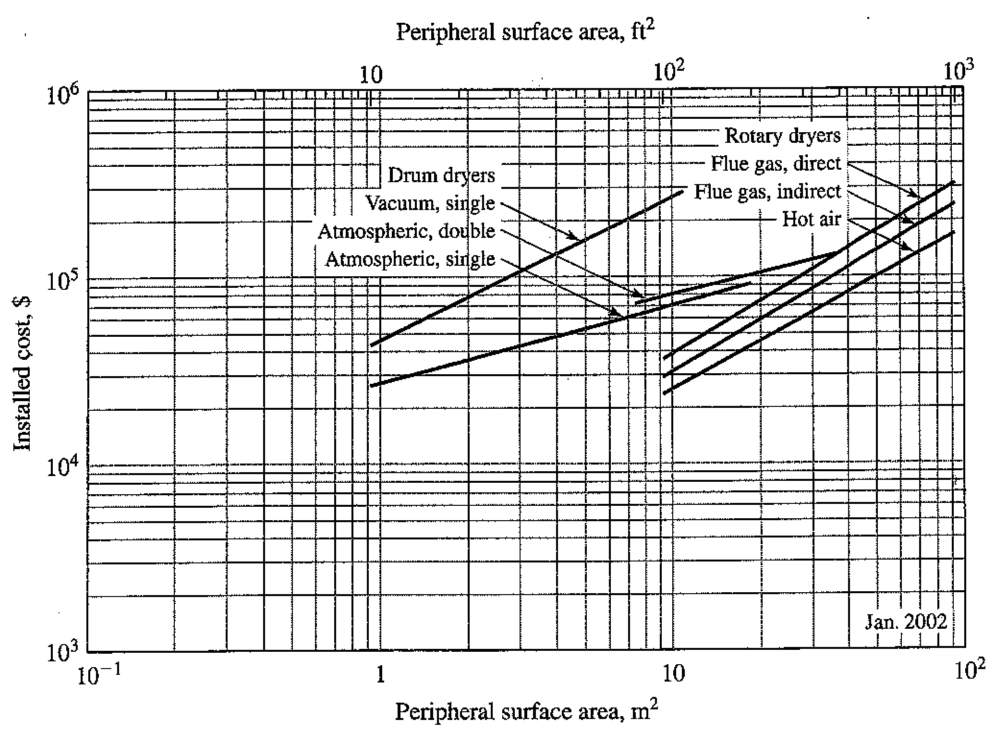



**Figure 15-33**
Installed cost of drum and rotary dryers

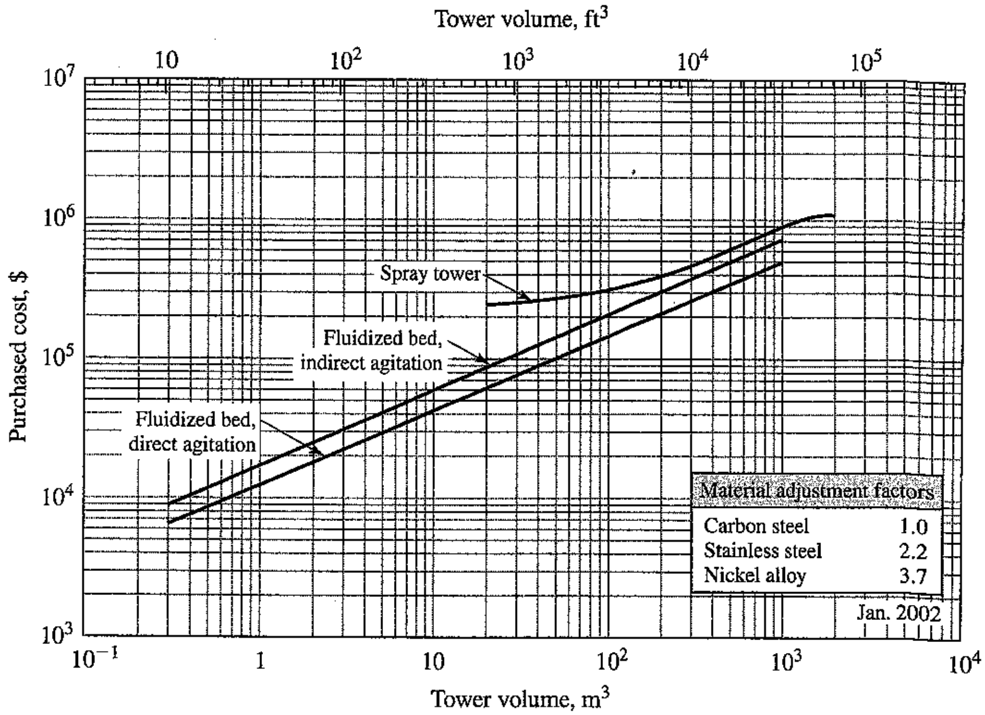



**Figure 15-34**
Purchased cost of fluidized-bed and spray tower contactors

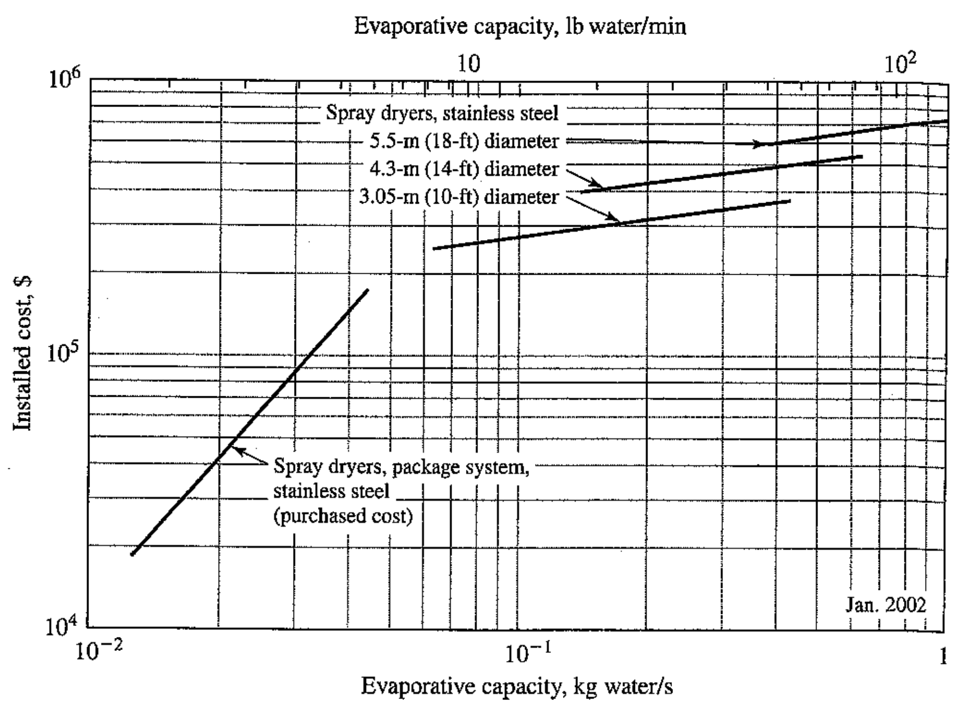



**Figure 15-35**
Purchased and installed cost of spray dryers

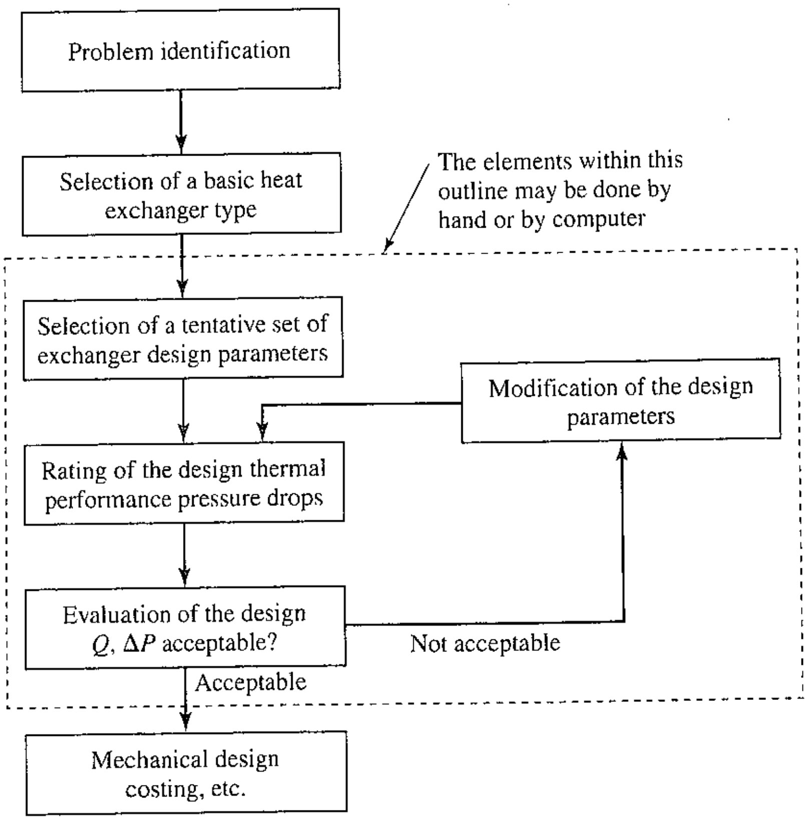



**Figure 14-39**
Structure for the process of heat exchanger design logic

convergence to an acceptable design is less important than being certain that the logical structure does not eliminate possible design options by imposing a poorly framed decision point. Even a modest-size design program may have 40 separate logical decisions that need to be made, leading to $2^{40}$, or $1.1 \times 10^{12}$, different paths through the logic. Since it is impossible to check all these possibilities, great care and conservatism must be exercised in spelling out these decision points.

For a typical design, the following parameters and constraints are usually given:

Fluids used and their properties
Inlet and exit fluid temperatures
Fluid flow rates
Operating pressure
Allowable pressure drop
Fouling resistances

For these given specifications, a design procedure will select designs that satisfy Eq. (14-5). In this design process, the exchanger configuration will also need to be evaluated against other specified constraints, such as

Maximum and minimum fluid velocities
Maximum and minimum temperatures

**Table 14-6 Criteria for the preliminary selection of the appropriate heat exchanger type**[†]

| Exchanger type | Max. pressure, approx. range, MPa | Temperature, approx. range, °C | Normal area, approx. range, $m^2$ | Fluid velocities, (shell/tube), m/s | Fluid limitations | Key features |
|---|---|---|---|---|---|---|
| Double-pipe<br>Multiple-pipe | 30 (shell)<br>140 (tube) | −100 – ~600 | 0.25 – 20<br>10 – 200 | Liq. (2–3)/(2–3)<br>Gas (10–20)/(10–20) | Materials of construction | Modular construction, small scale |
| Shell-and-tube | 30 | −200 – 600+ | 3 – 1000 | Liq. (1–2)/(2–3)<br>Gas (5–10)/(10–20) | Materials of construction | Very adaptable, many types |
| Scraped-wall | ~0.11 | Up to 200 | 2 – 20 | Liq. (1–2)/(1–2) | Liquids solidifying on hot surface | For viscous, crystallization systems |
| Gasketed plate | 0.1–2.5 | −25 – 175 | 1 – 2500 | Liq. (1–2)/(1–2)<br>Gas (5–10)/(5–10) | Limited to gasket material, avoid gas flow | Modular construction, minimal $/area cost |
| Welded plate | 3 | >400 | 1 – 2500 | Liq. (1–2)/(1–2)<br>Gas (5–10)/(5–10) | Materials of construction, avoid fouling fluids | $\Delta p$ between fluids <3 MPa |
| Spiral plate | 2 | Up to 300 | 10 – 200 | Liq. (1–2)/(1–2)<br>Gas (5–10)/(5–10) | Materials of construction | For viscous, corrosive fluids |
| Spiral tube | 50 | 350 | 1 – 50 | Liq. (2–3)/(2–3)<br>Gas (5–10)/(5–10) | Materials of construction | Adaptable, low maintenance |
| Compact | 3–10 | −270 – 80 with Al<br>−270 – 800 with ss | 10 – 30,000 | Gas (2–5)/(2–5) | Materials of construction, no corrosive fluids | Large area/volume, can operate with small $\Delta T$ |
| Gas-to-gas | ~0.11 | Up to 250 | 6–100 for low temperatures<br>1200–3000 for regenerators | Gas (5–10)/(5–10) | Materials of construction | Many types, some for corrosive gases |
| Air-cooled | Variable on tube side | Variable on tube side | 6 – 20,000 | Liq. (NA)/(2–3)<br>Gas (3–6)/10–20) | Materials of construction | Use for heat rejection, standardized design |

[†]Modified from data presented by G. F. Hewitt, G. L. Shires, and T. R. Bott, *Process Heat Transfer,* CRC Press, Boca Raton, FL, 1994, Sec. 4.3, and G. D. Ulrich, *A Guide to Chemical Engineering Design and Economics,* J. Wiley, New York, 1984.

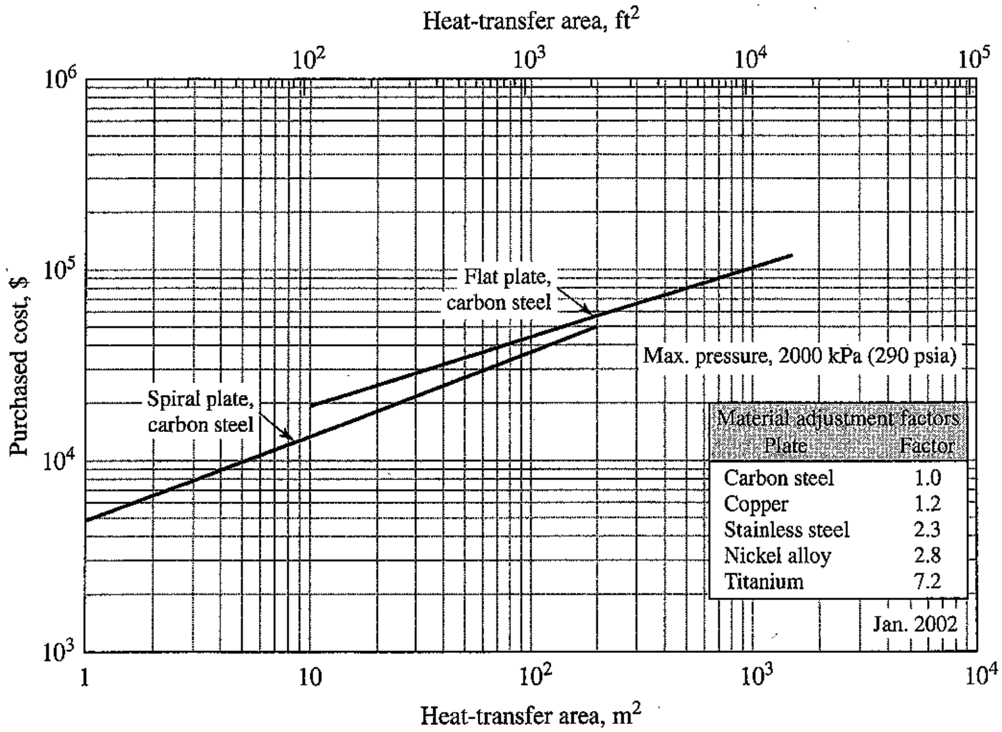



**Figure 14-27**
Purchased cost of spiral and flat-plate heat exchangers

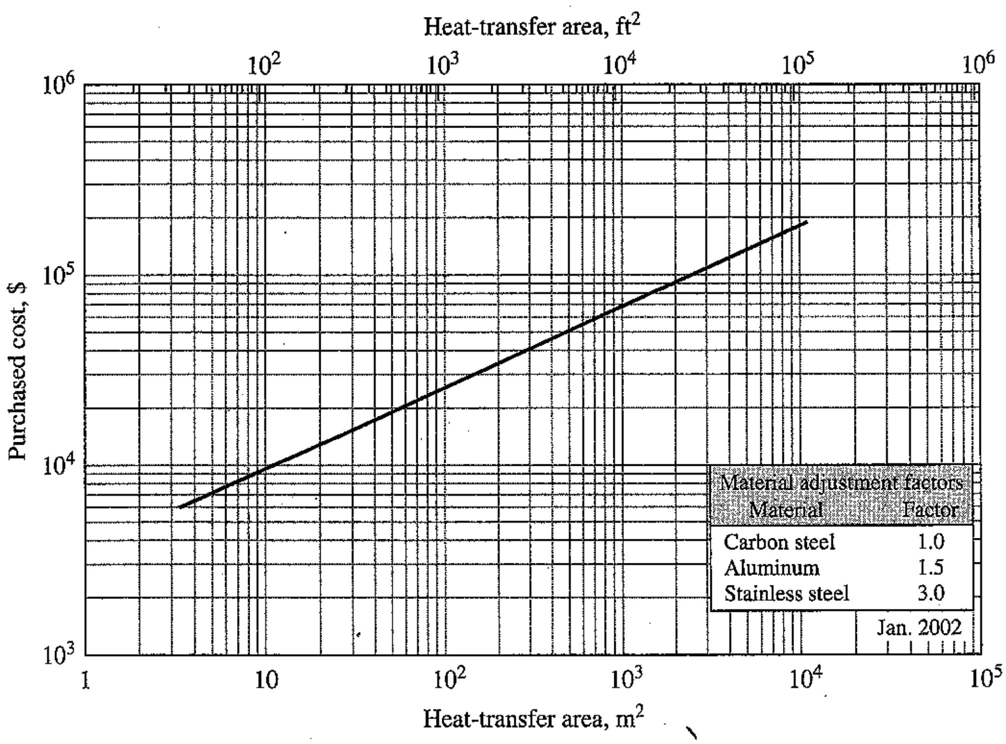



**Figure 14-28**
Purchased cost of air-cooled heat exchangers. Area is outside area of equivalent bare tubes, excluding fins.

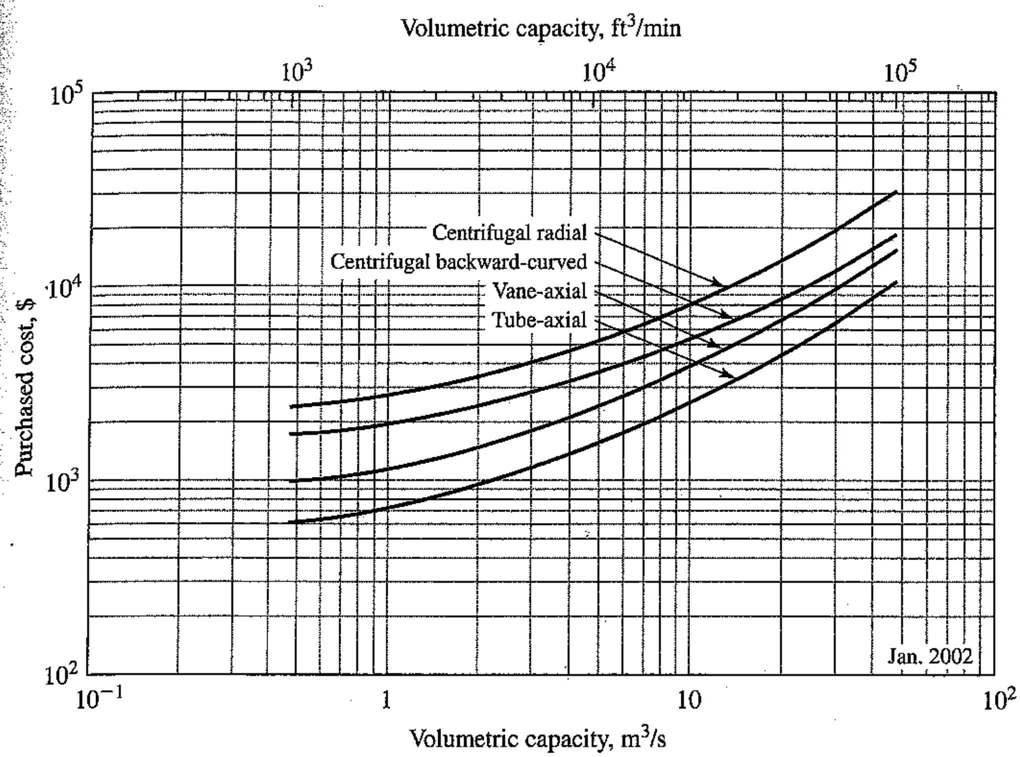



**Figure 12-31**
Purchased cost of centrifugal fans with electric drives

Fan , 1-1.5 m $H_2O$
Blower 5-1000 KPa
Compressor up to 10,000 KP
15 psia = 1 atm = 10 m $H_2O$ = 100 KPa

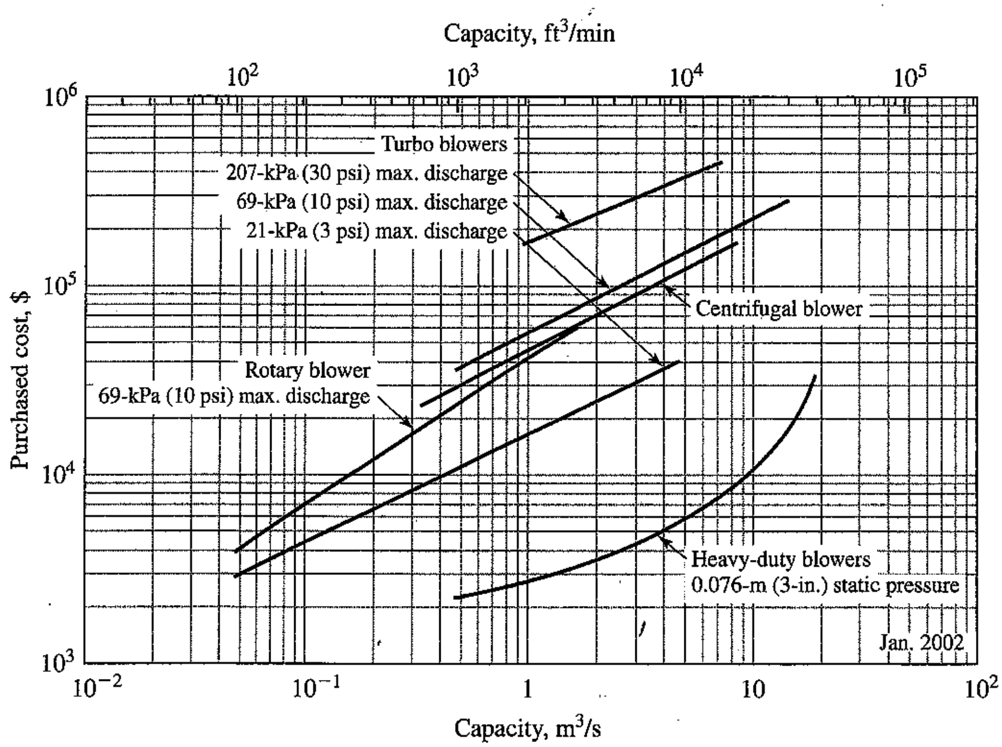



**Figure 12-32**
Purchased cost of blowers (heavy-duty, industrial type)