



DESIGN PRACTICES

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Revision Memo

- 12/98** Highlights of this revision are:
1. Updated references.
 2. Recommended using the sieve tray correlations for spray/froth transition, entrainment, and weeping to check valve tray performance.
 3. Information on the various types of valve trays from the leading vendors has been included, i.e., description, dimensions, open area.
 4. Operating limits for valve trays have been added.
 5. New guidelines for low liquid rate tray design have been added.
 6. The methods for calculating valve tray open area have been updated.
 7. The section on computer programs has been updated.
 8. Corrected 8 gage thickness.
 9. Updated dry tray pressure drop coefficients.
 10. Mentioned other vendors as possible valve tray suppliers.
 11. Revised design drawing notes.
 12. Indicated V-Grid valves on Nutter Package trays are SVG valves.
 13. Included design criteria for ACN extractive distillation systems.



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SCOPE

This section covers the techniques for specifying or rating the process design features of valve trays for new designs or revamps. It is assumed that the designer has already read [Section III-A](#) (*Device Selection and Basic Concepts*) and determined that valve trays are the best choice for the design. Detailed mechanical design as well as beam and valve layout are normally handled by the tray fabricator. A calculation form, showing the step-by-step calculation procedure, is given at the end of this section. Computer Programs 1134 and 1143 are available to perform these calculations rapidly (see discussion under *Computer Programs* later in this section). A list of FRACTIONATION SPECIALISTS to contact for help is provided at the beginning of Section III.

For the design of tray-related tower internals, such as nozzles, drawoff boxes and reboiler connections, refer to [Section III-H](#), *Tower Internals*. For the design of heat transfer trays, see [Section III-F](#). To calculate tray efficiency, see [Section III-I](#).

REFERENCES

Some of the following literature has been used in the preparation of this section. The rest is listed for convenient reference.

INTERNATIONAL PRACTICE

[IP 5-2-1](#), Internals for Towers, Drums, and Fixed Bed Reactors

OTHER LITERATURE

1. Becker, P. W., *Sieve Tray Capacity Correlations Have Been Improved*, Report No. EE.76E.72, June, 1972.
2. Bell, A. M., *Nutter V-Grid Trays*, 93CET211 (August 13, 1993).
3. Kokoska, R. J. and Perry, D., *Downcomer Capacity Correlations Have Been Improved*, Report No. EE.49E.80 June, 1980.
4. Niedzwiecki, J. L., Computer Program Update, *Sieve Tray Design Program #1133*, CPEE-0009, January, 1990.
5. Niedzwiecki, J. L., Computer Program Update, *Valve Tray Rating/Design Program #1134*, CPEE-0013, October, 1990.

BACKGROUND

- The equations given in this section for predicting valve tray capacity, downcomer limitations and clear liquid height are identical to those used for sieve trays. The turndown and dry tray pressure drop equations, however, are specific to valve trays. They have been derived largely from Fractionation Research, Inc., (FRI) data, supplemented by data from simulator and commercial tests. These equations represent the data far more accurately than do the correlations prepared by FRI, various vendors, or those available in the literature. Sieve tray correlations for entrainment, spray/froth transition, and weeping should be used to check valve tray performance until similar correlations for valve trays are available.

DEFINITIONS / EQUATIONS

For a discussion of such concepts as jet flooding, efficiency, flexibility, etc., see [Section III-A](#), *Device Selection and Basic Concepts*. See the *Nomenclature* section for symbol definitions.

All equations in the text of this section are numbered in the same way as they appear on the *Valve Tray Calculation Forms*. Those equations not discussed in the text are shown in the appropriate section of the *Valve Tray Calculation Forms*. Wherever possible both the customary and the metric equations are shown in the text, the latter shown with an "M." However, if the equation is complex, the metric version has been omitted in the text for clarity but can be found on the *Valve Tray Calculation Form (Metric)*.

APPLICATION

For most towers, sieve trays with 2/1 or 3/1 flexibility are normally adequate and should be used. If greater flexibility is required, valve trays can be specified. Several examples of services requiring wide flexibility are:

- When vapor rates change appreciably (and often unpredictably) over a given section of a tower.
- When a tower is utilized in blocked operation at varying rates and/or feed compositions.
- When seasonal fluctuations in feed rate, customer demand, etc., necessitate operating a tower at very low rates (less than 30% of design).
- When servicing of auxiliary equipment necessitates operating the entire unit at low rates.

APPLICATION (Cont)

- ◆ Valve trays contain proprietary devices. Exxon has commercial and/or FRI experience with certain valves manufactured by Koch-Glitsch Inc., Norton, and Nutter Engineering. The valve size, shape, weight and other parameters vary from vendor to vendor (see **Tables 3A** and **3B** and **Figures 9A, 9B, 9C, 10** and **11**). For design purposes the capacity and peak efficiency of valve trays recommended in this section are assumed to be about equal to that of a sieve tray, but their cost is roughly 10% higher. At times the cost difference between valve trays and sieve trays is negligible and valve trays would be preferred to maximize flexibility. There are various other vendors who make trays with proprietary valve units (e.g., Metawa (Sulzer) and Baretti). If valve trays from these vendors are being considered consult your FRACTIONATION SPECIALIST for Exxon commercial experience.
- ◆ Fixed valve trays can best be described as valve trays whose valve units are fixed in the fully open position (e.g., Glitsch V-O, Nutter V-Grid). The flexibility or turndown of such devices is generally better than that of a sieve tray, e.g., fixed valve trays have a turndown ratio of 3/1, but not as good as that of a movable valve tray. Also, fixed valve trays are generally less expensive than movable valve trays. Nutter Engineering's Small V-Grid (SVG) trays on triangular pitch are considered to be an alternative to sieve trays and generally have somewhat better turndown ratio (20% higher). Fixed valve trays may be useful for extending run lengths in some fouling services (but not where sticky material is entrained from below). Nutter Engineering's Larger V-Grid (LVG) and fixed valve trays on square pitch have lower capacity and should only be used upon consultation with a FRACTIONATION SPECIALIST.
- ◆ The **Nutter Mini V-Grid (MVG)** tray contains fixed mini-valves (**Figure 11**). At pressures under 50 psia (345 kPa), a well designed Nutter MVG tray has less liquid entrainment and possibly 10 - 15% jet flood capacity advantage when compared to a conventional sieve tray with approximately the same efficiency. Contact your FRACTIONATION SPECIALIST for more details if an application of fixed mini-valve trays is being considered.
 If Nutter valve or V-Grid trays are used, only small valve (BDH), small V-Grid (SVG), or MVG units **on triangular pitch** are acceptable. When revamping Nutter trays having large valve (BDP) or V-Grid (LVG) units, or if the units are on rectangular pitch, consult your FRACTIONATION SPECIALIST since these configurations may have less capacity than recommended designs.
 Valve trays are not recommended for fouling, corrosive, or coking service, such as steam cracker light ends debutanizers, visbreaker fractionators, and for these services, sieve trays are preferred. If severe coking is anticipated, shed baffles or disc and donuts should be used.
- ◆ **Figure 6** illustrates the effect of vapor rate on the efficiency of typical valve trays and compares this behavior with that of similar sieve trays with the same downcomer sizes, tray spacing, and outlet weir heights. As can be seen from this figure, the valve tray usually maintains high efficiency over a much wider range of vapor rates than does the sieve tray. However, details of the sieve and valve tray designs and the operating pressure can affect the efficiency, capacity and turndown of the tray.
- ◆ The table below, which is based on operating experience, lists the lower and upper operating limits for most valve tray designs. If your case does not fall within these limits, contact your FRACTIONATION SPECIALIST to see what, if any, problems may exist.

VARIABLE	LOWER LIMIT	UPPER LIMIT
Pressure, psia (kPa)	3 (21)	450 (3100) distillation 900 (6200) absorption
Temperature, °F (°C)	-130 (-90)	800 (430)
Diameter, ft (mm)	1.0 (300)	45 (13,700)
Physical properties		
surface tension, dyne/cm (mN/m)	1 (1)	75 (75)
liquid viscosity, cP (mPa•s)	0.05 (.05)	10 (10)
vapor density, lb/ft ³ (kg/m ³)	0.005 (.08)	5 (80)
liquid density, lb/ft ³ (kg/m ³)	20 (320)	80 (1300)
Tray spacing, in. (mm)	12 (300)	36 (910)
Open Area as % of A _b	5%	18%
DC Clearance, in. (mm)	1 (25)	3.5 (90)
DC Inlet area as % of A _s	7%	40% sloped; 25% straight
Number of Passes	1	4
Weir Height, in. (mm)	0 (0)	4 (100)
Hole/slot size, in. (mm)	0.25 (6.4)	1.53 (39)
Flow Path Length, in. (mm)	16 (410) for access	15 ft (4600 mm)

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APPLICATION (Cont)

CARTRIDGE TRAYS

For small diameter towers [less than about 2.5 ft (750 mm) in diameter] it is frequently more convenient to have sets of trays prefabricated so they can be inserted into the shell. This eliminates the need for welding tray support rings in a tight area and facilitates maintenance. Several vendors offer these cartridge type trays; but Exxon's experience shows that Nutter cartridge trays are superior to their competitor's trays. This is because Nutter cartridge trays have metal piston-type seal rings, which provide a much better circumferential seal than other devices marketed.

- Cartridge trays require more diameter than conventional trays due to waste area. Also, cartridge trays need a round tower with no interior welds/nozzles and a crane to properly install in a vessel.

Standard Nutter cartridge trays are available for tower inside diameters ranging from 12.0 to 30.5 in. (305 to 775 mm). The tray panels may be equipped with Nutter BDH valves or Nutter SVG V-Grid units **on triangular pitch**. Sieve holes may also be used. **Tables 4A** and **4B** give the vital information for each of Nutter's standard cartridge tray packages.

Note that the designer has the option of specifying any weir height, downcomer clearance, and tray spacing needed. The designer may also specify the number of BDH valves or V-Grid units per tray, as long as it is less than the maximum number listed in **Table 4A** or **4B**.

Note that Program 1134 cannot be used directly to design cartridge trays, since cartridge trays have waste area and frequently have unconventional (non-chordal) downcomers. The bubble area, downcomer area, and weir length (which is also the length under the downcomer except for the two sloped downcomer designs) listed in **Table 4A** or **4B** should be used in the calculation form at the end of this section. The waste area should be calculated per Note 5 of **Table 4A** or **4B**.

BASIC DESIGN CONSIDERATIONS

The design procedure outlined later in this section requires either: a) the selection of a trial diameter and tray layout for new designs, or b) tray hardware details for revamps. The design is then checked against critical performance limitations including jet flooding, ultimate capacity, downcomer limitations, etc. These limitations, which are common to all types of trays, are discussed fully in **Section III-A**. Only those items requiring further explanation are discussed below.

VAPOR CAPACITY LIMITATIONS

Jet Flooding - Occurs when the vapor rate is sufficiently high to "jet" liquid from a given tray to the tray above. It is the primary cause of tower flooding. It is a strong function of diameter and tray spacing and a lesser function of the number of liquid passes used. These relationships are discussed below.

- Tray Spacing** - The optimum combination of diameter, tray spacing, and number of liquid passes is the one which minimizes total investment, subject to the limitations outlined under *Detailed Design Procedure* discussed later in this section. The optimum spacing usually lies between 18-24 in. (450-600 mm). While the 1134 program selects tray spacings at 3 in. (75 mm) intervals for convenience, the designer is free to use any tray spacing desired as long as it's within the acceptable range (see **Table 1**).
- Number of Liquid Passes** - The vapor handling capacity of towers with high liquid rates can usually be increased by the use of multipass trays. Since multipass trays are more expensive than single pass trays, they can be justified only if their use reduces the overall tower cost. Generally, this means that a capacity advantage of at least 5 to 10% for multipass trays is required. However, each case must be studied on its own merits, since overall tower cost depends on many factors, including height, diameter, operating pressure and materials of construction. If the liquid rate is greater than 14 gpm/in. of weir/pass (35 dm³/s/m of weir/pass), the FRACTIONATION SPECIALIST should be consulted because of the lack of reliable design data above this liquid rate. More detailed selection criteria are given in **Table 1**. Specific guidelines for 3 and 4 pass trays are given in **Table 5** of **Section III-B**.

If the tower is limited by downcomer filling which cannot be reduced by other hardware changes, the use of multipass trays should also be considered.

- Tower Diameter** - The tower diameter must provide enough cross-sectional area to avoid both downcomer and jet flooding limitations. Downcomer sizing will be discussed later. The equations for jet flooding are given below. (The equation numbers are the same as those used on the *Valve Tray Calculation Forms*.)

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BASIC DESIGN CONSIDERATIONS (Cont)

- Jet Flooding Equations.**

For hydrocarbon systems:

$$\left[\frac{V_L}{A_f} \right]_{\text{Allow}} = 0.296 K_{HL} K_{\sigma\mu} \quad (\text{Customary}) \quad \text{Eq. (3c4)}$$

$$= 0.090 K_{HL} K_{\sigma\mu} \quad (\text{Metric}) \quad \text{Eq. (3c4)M}$$

For aqueous systems:

$$\left[\frac{V_L}{A_f} \right]_{\text{Allow}} = 0.204 K_{HL} K_{\sigma\mu} \quad (\text{Customary}) \quad \text{Eq. (3c5)}$$

$$= 0.0622 K_{HL} K_{\sigma\mu} \quad (\text{Metric}) \quad \text{Eq. (3c5)M}$$

where: V_L = Vapor load, ft³/s (m³/s) at conditions = $q_v \left[\frac{\rho_v}{\rho_L - \rho_v} \right]^{0.5}$.

A_f = Average free area, ft² (m²). See [Section III-A, Figure 13](#). For two pass trays, both passes must be checked.

K_{HL} = Tray spacing - liquid rate factor, dimensionless [[Figure 1A](#) for [Eq. \(3c4\)](#) and [Figure 1C](#) for [Eq. \(3c4\)M](#), [Figures 1B](#) for [Eq. \(3c5\)](#) and [Figure 1D](#) for [Eq. \(3c5\)M](#)]. When checking a two pass tray with inboard downcomers, the liquid rate, L , should be based on the inboard weir length l_o^* . The outboard pass should be based on l_o .

$K_{\sigma\mu}$ = Surface tension - viscosity factor, dimensionless ([Figures 2](#) and [3](#)).

q_v = Volumetric vapor rate, ft³/s (dm³/s) at conditions.

ρ_v = Vapor density at conditions, lb/ft³ (kg/m³).

ρ_L = Liquid density at conditions, lb/ft³ (kg/m³).

Equation (3c4) should be used for all hydrocarbon systems and for other systems when the surface tension is equal to or less than 40 dynes/cm (mN/m). **Equation (3c5)** should be used for aqueous systems and whenever surface tension is greater than 40 dynes/cm (mN/m). If a predominantly aqueous system has a surface tension equal to or less than 40 dynes/cm (mN/m) (e.g., alcohol/water), **Equation (3c4)** should be used. The following list outlines which equation to use for various systems. Any systems known to foam should be designed for 60% of the allowable jet flood velocity for that system. However, if the system is listed in Part 3 of [Table 2](#), use that value. If in doubt, contact your FRACTIONATION SPECIALIST.

EQUATION (3c4)	EQUATION (3c5)
All hydrocarbon light ends towers	Absorption of HCl, H ₂ SO ₄ , etc. in water
All sidestream and bottoms strippers	Amine and FLEXSORB scrubbers and regenerators
Aqueous systems containing alcohols, ketones, aldehydes, etc., if surface tension ≤ 40 dynes/cm (mN/m)	Ammonia fractionators
Other non-aqueous chemical plant towers (i.e., oxo-alcohols, butyl rerun, etc.)	Catacarb absorbers and regenerators
Aromatics separations	Caustic scrubbers
Atmospheric and vacuum pipestills	Sour water strippers
Cat, steam cracker, coker, FLEXICOKER, and HYDROCRACKER primary fractionators above the bottom pumparound	Water wash sections
Hydrocarbon absorbers	Foaming aqueous systems
Prefractionators and outboard flash towers	Other aqueous liquid/steam stripped towers

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BASIC DESIGN CONSIDERATIONS (Cont)

In addition, the above equations must be used in conjunction with the appropriate percentage of the jet flood velocity permitted by **Table 2**.

Ultimate Capacity. The ratio of design vapor load (V_L) to the vapor load for ultimate capacity $V_{L(Ult)}$ **Eq. (6a1)** must be kept below 90%. If necessary, the tower diameter must be increased, even though **Equation (3c4)** or **(3c5)** has already been satisfied for jet flooding. However, the diameter calculation from **Equation (3c4)** or **(3c5)** usually provides sufficient free area to satisfy the ultimate capacity limitation.

$$V_{L(Ult)} = 0.62 A_f \left[\frac{\beta}{1 + \beta} \right] \left[\frac{\sigma_L}{\rho_L - \rho_v} \right]^{0.25} \quad (\text{Customary}) \quad \text{Eq. (6a1)}$$

$$\text{where: } \beta = 1.4 \left[\frac{\rho_L - \rho_v}{\rho_v} \right]^{0.5}$$

For the metric equation **Eq. (6a1)M**, use a coefficient of 0.378 vs. the 0.62 shown above.

LIQUID CAPACITY LIMITATIONS

Downcomer Design Considerations

1. **Downcomer Sizing** - The required downcomer inlet area is set by froth disengaging limitations. This calculated velocity is a function of the froth density (Ψ) and the physical properties of the system and therefore varies from system to system. **Figures 4A & 4B** or **Table 2** provide the maximum allowable downcomer entrance velocity for most systems. However, if the ratio of ρ_v / ρ_L is greater than 0.03 then a velocity should be calculated from **Eq. (6c1)** below. The same equation is valid for customary or metric units. The designer should compare this value versus that obtained from **Figure 4A, 4B** or **Table 2** and use the **lower** velocity.

$$V_{di} = \frac{V_{L(Ult)} \left[\frac{\Psi}{1 - \Psi} \right]}{A_f \left[\frac{\rho_v}{\rho_L - \rho_v} \right]^{0.5}} \quad \text{Eq. (6c1)}$$

where: Ψ = Froth density, fraction of froth volume occupied by liquid, dimensionless. For two pass trays, use the **smaller value** of A_f .

For **foaming systems** a velocity of 0.2 ft/s (0.06 m/s) should be used. However, if the foam is very stable, even a very low velocity still may not prevent tower flooding. If the designer expects to face this situation, then

- a. Process changes should be considered to eliminate the source of the foaming (removal of entrained hydrocarbons into aqueous systems, elimination of suspended solids, etc.)
- b. Consider using packing and consult your FRACTIONATION SPECIALIST.
- c. If the foam source can't be eliminated, then an anti-foam agent may be required. This is usually an expensive solution to the problem since anti-foam must be added continuously.

Downcomer inlet sizing should also be checked for a possible **choking limitation**. The choking criterion is defined as a limiting froth height to downcomer inlet rise ratio as shown below:

- For outboard downcomers

$$\frac{h_f - h_{wo}}{1.3r} \text{ must be } \leq 1.0 \quad \text{Eq. (6d1)}$$

- For inboard downcomers

$$\frac{h_f - h_{wo}}{1.6(r/2)} \text{ must be } \leq 1.0 \quad \text{Eq. (6d2)}$$

If the above ratio > 1.0 , the downcomer rise should be increased.

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BASIC DESIGN CONSIDERATIONS (Cont)

When the liquid velocity entering the downcomer is greater than the velocity of the bubbles rising through it, vapor recycling occurs. The vapor cannot disengage and this results in vapor being swept through the downcomer and recycled onto the tray below. Thus, vapor recycling will cause an increase in the vapor load leaving a tray and will adversely affect both tray capacity and efficiency. Therefore, for both new designs and revamps, the downcomer size should be increased to avoid vapor recycle. See [Section III-A](#) for more background on vapor recycling.

Downcomer sloping criteria are discussed under *Detailed Design Procedure - Step 2 - Downcomer Area*. Areas and lengths of chords are given in [Section III-K](#).

2. **Downcomer Filling** - Downcomer filling as a percentage of tray spacing, should not exceed the values in [Figure 5A](#) or [5B](#). For hydrocarbon and aqueous systems that are known to foam, use 80% of the value given in [Figure 5A](#) or [5B](#). In addition, special downcomer filling criteria for specific aqueous towers are listed in [Table 2](#). If these criteria cannot be met by reducing the weir height, increasing the downcomer clearance, etc., the tray spacing, and/or the number of liquid passes should be increased.
3. **Downcomer Clearance** - Downcomer clearance (c) is the vertical distance between the bottom edge of the downcomer and the tray deck. This clearance should be no smaller than 1 in. (25 mm) and is based on a normal head loss (h_{ud}) of 0.5 to 1.5 in. (13 to 38 mm) of hot liquid, according to the submerged weir formula given below. This range was chosen to avoid excessive liquid velocity at the tray inlet.

$$h_{ud} = 0.06 \left[\frac{Q_L}{c N_p l_{ud}} \right]^2 \quad (\text{Customary}) \quad \text{Eq. (5d1)}$$

$$h_{ud} = 160 \left[\frac{1000 Q_L}{c N_p l_{ud}} \right]^2 \quad (\text{Metric}) \quad \text{Eq. (5d1)M}$$

where: Q_L = Liquid rate, gpm (dm³/s) at conditions
 N_p = Number of liquid passes
 l_{ud} = Length of bottom edge of downcomer, in. (mm)

In those cases where high liquid rates would require use of either a large downcomer clearance [over 3 in. (75 mm)] or a deep recessed inlet box, a shaped downcomer lip may be used instead (see figures in [Section III-A](#)). For these shaped lip downcomers, the coefficient in [Equation \(5d1\)](#) is reduced from 0.06 to 0.02 (160 to 53 for metric equation). However, a shaped downcomer lip must not be used when either a recessed inlet box or an inlet weir has been specified. This is because the obstruction presented by the vertical face of the recessed inlet box, or by the inlet weir, would cause turbulence and defeat the purpose of the shaped downcomer lip. The clearance with a shaped lip should also be set so as not to exceed 1.5 in. (38 mm) of head loss. For two pass trays, a shaped lip is usually used on both inboard and outboard passes.

4. **Downcomer Sealing** - To prevent some of the vapor from bypassing a tray by traveling up the downcomer, the downcomer must be sealed at minimum rates by the liquid on the tray below. Therefore, it is necessary to check the sum of the clear liquid height at the inlet to the tray or tray inlet head (h_i) and the head loss under the downcomer (h_{ud}) at the minimum liquid flow rate. This sum plus 1/4 in. (6 mm) must be at least equal to the downcomer clearance. If a seal is not obtained, consider:
 - Increasing the outlet weir height.
 - Reducing the clearance to 1 in. (25 mm) provided the downcomer filling is not exceeded at design rates.
 - Using a shaped downcomer lip if a wide range of rates must be handled. Do not use if a recessed box or inlet weir has already been specified.
 - Adding an inlet weir.
 - Using a recessed inlet box provided the liquid rate is below 11 gpm/in. of diameter/pass (28 dm³/s/m of diameter/pass).

Note that designing near the high end of the head loss range may unnecessarily increase downcomer filling if a higher clearance will still seal the downcomer. Therefore, there is no justification for setting downcomer clearance any lower than that required for downcomer sealing. See discussion and figures in [Section III-A](#) for more background.

5. **Anti-jump Baffles** - Must be provided on all inboard downcomer(s) of multipass trays if the liquid rate exceeds 4.2 gpm/in. of diameter/pass (10 dm³/sec/m of diameter/pass). This is to prevent liquid from jumping across (choking) the downcomer and causing premature flooding (see [Section III-A](#) for further background information on downcomer choking).

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BASIC DESIGN CONSIDERATIONS (Cont)

OTHER BASIC DESIGN CONSIDERATIONS

Tray Layout, Hole Area, and Valve Layout - Two important features of the **tray layout** are the bubble area A_b and the free area A_f (see **Figures 12 and 13** in **Section III-A**). These, in turn, depend on the liquid handling areas (downcomers) and waste area A_w , defined as any unperforated area farther than 3 in. (75 mm) from the edge of the nearest perforation. Normally, there is no waste area on a valve tray unless a very low hole area is required (part of the tray is left unperforated). However, due to their unique construction, cartridge trays have a significant amount of waste area. For these trays, refer to **Tables 4A or 4B** for the method to calculate A_w .

Methods of specifying open area or valve area on a tray are discussed under *Detailed Design Procedure, Step 4*. For new designs, the designer need not concern himself with valve layout, since the vendor normally handles this detail. However, for Nutter trays, be sure that only small valve or V-Grid units are used and that they are on **triangular pitch**.

In general, low open area trays have higher pressure drops, somewhat higher efficiencies, and greater flexibility. A good first guess at open area would be 12% A_o / A_b . If downcomer filling becomes excessive, tray spacing should be increased in preference to using a higher open area tray. If further measures are required to lower tray pressure drop or downcomer filling, then higher open areas may be used (up to 18%). However, it should be recognized that flexibility will be reduced.

The valve tray vendor should be told to check the final layout for a "blowing limitation." Glitsch's blowing criteria are described under *Detailed Design Procedure, Step 4*.

Tray Hydraulics - The final dry tray pressure drop will generally fall in the range of 1 to 4 in. (25 to 100 mm) of hot liquid. The effect of increasing dry tray pressure drop (reducing open area) on tray hydraulics and downcomer filling can be calculated from **Eq. (4a1) or (4a2)** on the calculation form.

Downcomer filling, as a percent of tray spacing, should not exceed the values given as a function of pressure in **Figure 5A or 5B**. In addition, special downcomer filling criteria for aqueous towers are given in **Table 2**. If downcomer filling is excessive, the tray spacing and/or the tower diameter should be increased.

- ✦ **Tray Turndown** - Turndown is the ratio of the maximum to minimum vapor loadings between which good tray efficiency is maintained. It is limited by jet flooding (excessive entrainment) at high vapor rates and by excessive weeping at very low vapor rates. The maximum turndown ratio for fixed valve trays is typically 3/1. A turndown ratio of between 3/1 and 4/1 is usually achievable with movable valve trays. If a very large turndown is required (about 5 to 1), more expensive two-stage opening valves are typically required.

Turndown requirements are dictated by combining two effects. The first is operating turndown and the second is the inherent variation in the loading profile over a tower section. If this loading variation is significant and the trays cannot meet the required turndown, consider breaking the original tower section into two (or more) smaller sections. If this reduces the loadings range to an acceptable level, develop a tray design for each of the new smaller sections.

Tray Mass-Transfer Efficiency and Heat Transfer - The designer should recognize that efficiency calculations are necessary for each section in a fractionation tower. In addition, the trays selected to check hydraulics are sometimes not suited for efficiency calculations due to concentration profile reversals or for other reasons. See **Sections III-I and F** for more information on tray mass-transfer efficiency and heat transfer respectively.

- ✦ **Low Liquid Rate Tray Design** - When designing a tray to operate at a low liquid rate, it may become necessary to modify the tray design in order to decrease the excessive entrainment that often occurs under **low liquid loads**.

On valve trays, entrainment can be reduced by increasing the valve area. Since a valve tray also provides good low-loading flexibility, turndown ratios of 2 to 1 or more can usually be maintained **for low liquid rates**. This compares favorably to the sieve tray where turndown is severely restricted at low liquid rate. If the liquid rate, L , lies between 0.25 to 1.5 gpm/in. of weir/pass (0.6 to 3.7 dm³/s/m of weir/pass) the dry tray pressure drop, h_{ed} , at design rates should be equal or less than 2.25 in (57 mm). If L is less than 0.25 (0.6), contact your FRACTIONATION SPECIALIST since picket fence weirs and inlet weirs may be required. (See **Section III-A** and its discussion on the "Operating Window" for more background.)

If the design liquid rate is ≤ 1.5 gpm/in. (3.7 dm³/s/m) of weir/pass at pressures under 50 psia (345 kPa), spray/froth transition, entrainment, and weeping may be a problem. Checks need to be done using the Sieve Tray Design Program #1133 since correlations for valve trays are not yet available. A hole size of 0.5 in. (13 mm) should be specified with an open area that gives a dry (sieve) tray pressure drop comparable to the valve tray prediction. If entrainment, spray/froth transition, or weeping exceed the recommended limits, consult with a FRACTIONATION SPECIALIST. The tray vendors may be able to provide guidance on valve tray weeping and entrainment predictions.

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BASIC DESIGN CONSIDERATIONS (Cont)

Startup Considerations - At very low vapor velocities (such as during startup), even valve trays may weep, with the result that insufficient liquid is maintained on the tray feeding the reboiler drawoff box. Hence, when thermosyphon reboilers are used on valve tray towers, special provisions may be necessary to ensure that the reboiler will have liquid feed during startup. This can be done by either:

- Installing a jumper line from the tower bottoms drawoff line to the reboiler inlet. The jumper line must have a valve, so that it can be closed when the reboiler is generating enough vapor to support the liquid on the drawoff tray or
- By providing a chimney tray as the drawoff tray. For the design of chimney trays, drawoffs and other tower internals, see [Section III-H](#).

DETAILED DESIGN PROCEDURE

The step-by-step procedure for designing or revamping a valve tray is given on the *Valve Tray Calculation Form*. A computer program (#1134) is available to perform these calculations. See discussion under *Computer Programs* later in this section.

For new designs, the procedure involves assuming a trial design with the help of the principles given above, checking it against various potential operating limitations, and then modifying it as required to arrive at the optimum tray design.

For revamps, all of the tower hardware is given. It must be checked against the various potential operating limits and modified as required. Deciding how to modify the various hardware parameters will require judgment and application of the basic design considerations already discussed as well as those contained in **Table 1**. If help is needed, contact your FRACTIONATION SPECIALIST. The calculation step numbers used below correspond to those used on the calculation form.

VAPOR AND LIQUID LOADINGS (STEP 1)

This information is normally calculated as part of the heat and material balance(s) for the tower and usually comes from a computer program like PRO/II or PROVISION. If minimum liquid and vapor loadings have not been specified, assume 33% of the design loadings. Vapor loadings are **to** the tray in question; liquid loadings are **from** the tray in question since these are nearly always the maximum values for the tray in question. However, the designer should be aware that loadings will occasionally increase significantly across a given theoretical tray. If this is the case and the overall efficiency is less than about 70%, the vapor loading from the tray in question may be higher. The designer must then prorate loadings between the loadings to and from the theoretical tray in question. In the case of bottoms and sidestream strippers for pipestills, guidelines are presented in [Section III-I](#), *Tray Efficiency*, for 4 and 6 tray strippers.

In the design of heavy hydrocarbon/steam strippers (e.g., pipestill sidestream and bottoms strippers), the tray hydraulics are normally checked for an assumed vapor rate to the top tray equal to the stripping steam rate plus 60 mole percent (for 4-tray strippers) of the total hydrocarbon vapor stripped out. Once the top tray is designed, lower trays may require modified designs due to the large decrease in vapor rate. The optimum design of trays for these strippers is detailed in [Section III-I](#), *Tray Efficiency*.

TRIAL TRAY SPACING, SIZE AND LAYOUT (STEP 2)

Tray Spacing - A low tray spacing between 18 and 24 in. (450 to 600 mm) is often the most economical. For the first trial, a tray spacing of 18 in. (450 mm) or that shown below (whichever is larger) should be used. The values given are the minima for most applications, as determined by maintenance considerations and support beam depth.

In special cases, however, even smaller spacings may be justified (especially if the required number of trays can be contained in one shell vs. two), but this makes maintenance more difficult. On the other hand, downcomer filling requirements may require the use of tray spacings larger than the minimum. Spacings up to 36 in. (900 mm) may be used to permit a higher superficial vapor velocity.

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DETAILED DESIGN PROCEDURE (Cont)

Tower Diameter, ft (mm)	CLEAN SERVICE		FOULING SERVICE			
	in.	mm	1-pass		2 or more passes	
			in.	mm	in.	mm
5 or less (≤ 1500)	12 *	300 *	18 *	450 *	---	---
> 5 to 8 (> 1500 to 2400)	12 *	300 *	21 *	525 *	18 *	450 *
> 8 to 10 (> 2400 to 3000)	15 *	375 *	24	600	21 *	525 *
> 10 to 20 (> 3000 to 6000)	18 *	450 *	27	675	24	600
greater than 20 (> 6000) **	21 *	525 *	30	750	27	675

* If there is no manhead between trays. Minimum tray spacing with a manhead present is 24 in. or 6 in. (600 mm or 150 mm) more than the manhead diameter, whichever is greater.

** For towers larger than 20 ft (> 6000 mm) in diameter, "lattice" type trusses must be used to facilitate maintenance and permit good vapor distribution. (See [Section III-H](#) for a picture of lattice truss.)

Trial Tower Diameter. The trial diameter (D_{tr}) is calculated from [Eq. \(2a4\)](#) on the calculation sheet. It may need to be adjusted either upward or downward when the trial design is checked against various performance limitations. [Eq. \(2a4\)](#) is a sieve tray capacity equation which has been verified with FRI and commercial valve tray data. It is the same equation used in [Section III-B](#) as [Eq. \(2a4\)](#).

Number of Liquid Passes - The number of passes should be selected on the basis of the criteria given in [Table 1](#). The number is not likely to change when the trial design is finalized, unless the tower diameter is changed substantially. The calculation sheet is designed to handle one and two pass trays. For three and four pass trays, refer to [Table 5](#) in [Section III-B](#) and [Program 1143](#). Note: Program 1143 will require some hand calculations since it is designed for use with sieve trays.

Downcomer Areas - The maximum velocity of the liquid entering the downcomer(s) should be determined from [Figures 4A & 4B](#), [Eq. \(6c1\)](#) or [Table 2](#), whichever gives the lower value. For known foaming systems, a very low downcomer inlet velocity (about 0.2 ft/s; 0.06 m/s) should be used. There is no lower limit on the downcomer inlet velocity. However, if long liquid residence time in the downcomer promotes fouling, consider either the use of modified arc downcomers or sloping to reduce downcomer volume.

When revamping vendor designed trays with **swept back outlet weirs**, the unperforated area between the weir and the downcomer should be considered as additional disengaging area for downcomer inlet velocity calculations. Consult your FRACTIONATION SPECIALIST should any questions arise on these rarely used trays.

For a sloped or stepped downcomer, the downcomer outlet area is based on the following table:

MAXIMUM V_{di}		MAXIMUM V_{do}	
ft/s	m/s	ft/s	m/s
< 0.3	< 0.09	2 times maximum entrance velocity	
> 0.3 and < 0.6	> 0.09 and < 0.18	0.6	0.18
> 0.6	> 0.18	Equal to V_{di} (downcomers are straight)	

As a general rule, a **sloped or stepped downcomer** should be used if A_{di} is greater than 12% of A_s . To ensure good liquid distribution to the tray below, however, the downcomer outlet area also must be at least 6.8% of A_s . This applies to all single pass trays and the outboard downcomer of multipass trays. This assures that the chord length is at least 65% of the tower diameter for chordal downcomers. If the tower diameter exceeds 6 ft (1800 mm) and the liquid rate requires a downcomer area much less than 6.8% of A_s , consider the use of a **segmental downcomer** (modified arc). If a segmental downcomer is used, it must be at least 6 in. (150 mm) wide. (See [Section III-K](#), [Figure 3](#), for sizing modified arc downcomers.)

If the sum of $A_{di} + A_{do}$ exceeds 60% of A_s , the tower diameter should be increased **and both** K_{HL} and A_f corrected. Remember that K_{HL} is based on the liquid rate per in. (m) of weir length and will change if the diameter changes. In addition, for modified arc downcomers, use the projected weir length, not the total weir length. (See discussion in [Section III-A](#) on downcomers for more details.)

This sets the downcomer areas to be used for the first trial. However, any changes in tower diameter made during the remainder of the design procedure could also necessitate changes in downcomer sizing.

Outlet Weirs and Downcomer Clearances - Criteria for selecting outlet weir heights and downcomer clearances are given in [Table 1](#). For tray geometry relationships, see [Section III-K](#).

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FINAL TRAY SPACING, SIZE AND LAYOUT (STEP 3)

Tower Area - To permit the trial design to be checked against the jet flooding and ultimate capacity limitations, the quantities listed under Step 3a on the calculation form must first be calculated, based on the trial design.

Ultimate Capacity - The vapor load factor corresponding to ultimate capacity is calculated from **Equation (6a1)**. The ratio of design to the ultimate capacity vapor rate must be kept below 90%.

Jet Flooding - The allowable vapor load for jet flooding is calculated from **Equations (3c4)** and **(3c5)**. The ratio of the design vapor load to that for jet flooding should not exceed the percentages recommended in **Table 2**. For systems not covered by **Table 2**, your FRACTIONATION SPECIALIST should be consulted for the proper value.

Trays With Drawoff Sumps - A drawoff box generally creates waste area (A_w) on the tray and may also obstruct the flow of vapor from the tray below. This dictates a conservative design approach. The design criteria for such trays are outlined in **Section III-H, Tower Internals**.

OPEN AREA, PRESSURE DROP AND TURNDOWN (STEP 4)

Open Area and Layout - The valve tray vendor should be told to check the final tray design for blowing. (Glitsch uses the criteria that blowing occurs when the dry tray pressure drop, in in. (mm) of hot liquid, exceeds 20% of the tray spacing.)

Nutter proposals should be checked to ensure that only small valve or V-Grid units have been provided and that they are on **triangular pitch**.

Turndown Requirements - There are many ways that valve tray vendors have to achieve the turndown ratio desired. The more important ones include:

- Using movable valves.
- Using valves that have different thicknesses (weights). That is, have light and heavy valves in different rows or in some alternating pattern within the same row.
- Using various ratios of light to heavy valves (i.e., 25% light; 75% heavy; 50/50, etc.).
- Varying the number of valves per unit of contacting area or using valves with longer legs - thereby providing more slot area.
- Placing a light and a heavy valve in the same retaining cage - like the Glitsch A-1. This produces a staged opening effect at each valve location. Such valves are, however, more expensive.

It is important to recognize that each vendor has their own unique way of designing valve trays for a given turndown ratio. Thus, for new jobs where competitive bidding is used, the final tray design isn't known until bidding completion. At this point, the vendor then prepares the detailed tray and valve layout. Only then can the designer check the turndown expected for the tray in question.

Therefore, for **new designs** it is important that the designer tell the vendors in the Design Specification what turndown ratio is required and what maximum dry tray pressure drop is acceptable. By specifying the dry tray pressure drop, the designer will know that the downcomer filling is within acceptable design limits for the tray spacing used. To permit these calculations, the vendor must be given a table of maximum and minimum tray loadings. When supplying these loadings, the tower should be split into sections ("sectioned") such that the vapor turndown in each section is preferably not more than 3 or 4 to 1. Also, see subsequent material under *Information Required By Valve Tray Vendor*.

For revamps, the more detailed calculation procedure outlined below can be used for movable valves where the tray details are known. This procedure is based on the fact that most valve tray vendors use both light and heavy valves on their trays when the turndown ratio exceeds 2/1. The rationale for this procedure is discussed in the next paragraph and is best understood by referring to **Figure 7**.

Each valve contains several "dimples" around its periphery that prevent the valve from completely shutting off. Thus, a uniform bubbling action is maintained across the tray even at very low vapor rates. As the vapor rate is increased, the light valves begin to open (Region 1, **Figure 7**). As the vapor rate is increased further (Region 2), pressure drop increases until the heavy valves begin to open (Region 3). Once the heavy valves are fully open (Region 4), the resulting pressure drop follows the standard orifice pressure drop line. These various regions are defined by transition velocities (i.e., $V_{o(T1)}$, etc.) which are calculated from the equations shown below and on the *Calculation Form*.

When rating a valve tray that contains only **ONE VALVE WEIGHT** (a rare case), calculate $V_{o(T3)}$ from **Eq. (4a3)**. If the actual V_o is less than $V_{o(T3)}$, calculate H_{ed} from **Eq. (4b6)**. If the actual V_o is greater than $V_{o(T3)}$ calculate h_{ed} from **Eq. (4b7)**. Calculate the fraction of valves open from **Eq. (4b5)** by setting $A_1 = 0$ and $A_2 = A_o$. Trays with only one valve weight should be checked carefully, since they are more prone to valve pulsation and thus may experience shortened valve life due to excessive valve wear.

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Transition velocity at which the lighter valves are fully open, $V_{o(T1)}$

$$V_{o(T1)} = \left[\frac{1.35 t_1 \frac{\rho_m}{\rho_v}}{\frac{K_2}{(A_1 / A_o)^2} - K_1} \right]^{0.5} \quad (\text{Customary and Metric}) \quad \text{Eq. (4a1)}$$

where: A_1 = Open area of lighter valves, ft² (m²)
 A_2 = Open area of heavier valves, ft² (m²)
 A_o = Total valve open area, ft² (m²) ($A_o = A_1 + A_2$)
 K_1 = Dry tray pressure drop coefficient (from **Table 3C**)
 K_2 = Dry tray pressure drop coefficient (from **Table 3C**)
 q_v = Vapor rate at conditions, ft³/s (m³/s)
 t_1 = Thickness of lighter valves, in. (mm) (from **Table 3C**)
 t_2 = Thickness of heavier valves, in. (mm) (from **Table 3C**)
 ρ_L = Liquid density at conditions, lb/ft³ (kg/m³)
 ρ_m = Metal density, lb/ft³ (kg/m³) (from **Table 3C**)
 ρ_v = Vapor density at conditions, lb/ft³ (kg/m³)
 V_o = Average hole velocity (q_v / A_o), ft/s (m/s)

Transition velocity where heavier valves begin to open, $V_{o(T2)}$

$$V_{o(T2)} = \left[\frac{1.35 t_2 \frac{\rho_m}{\rho_v}}{\frac{K_2}{(A_1 / A_o)^2} - K_1} \right]^{0.5} \quad (\text{Customary and Metric}) \quad \text{Eq. (4a2)}$$

Transition velocity where heavier valves are fully open, $V_{o(T3)}$

$$V_{o(T3)} = \left[\frac{1.35 t_2 \frac{\rho_m}{\rho_v}}{K_2 - K_1} \right]^{0.5} \quad (\text{Customary and Metric}) \quad \text{Eq. (4a3)}$$

Once the transition velocities have been calculated, it is then possible to calculate the fraction of valves open (f_1 , f_2 , etc.) as well as the dry tray pressure drop, h_{ed1} , h_{ed2} , etc. in each region. This can be done using the equations below. Reminder: it is only necessary to do the calculations below for the region(s) of interest.

REGION 1 — Where the average hole velocity (V_o) is less than $V_{o(T1)}$ and $f_2 = 0$.

$$f_1 = \left[\frac{\frac{K_2}{(A_1 / A_o)^2}}{K_1 + \frac{1.35 t_1 \rho_m}{V_o^2 \rho_v}} \right]^{0.5} \quad (\text{Customary and Metric}) \quad \text{Eq. (4b1)}$$

where: f_1 = Fraction of lighter valves open
 f_2 = Fraction of heavier valves open
 f = Fraction of total valves open, ($f_1 + f_2$)
 h_{ed} = Dry tray pressure drop, in. (mm) of hot liquid

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$$f = f_1 \left[\frac{A_1}{A_o} \right] + f_2 \left[\frac{A_2}{A_o} \right] \quad (\text{Customary and Metric}) \quad \text{Eq. (4b2)}$$

$$h_{ed1} = 1.35 t_1 \frac{\rho_m}{\rho_L} + K_1 V_o^2 \frac{\rho_v}{\rho_L} \quad (\text{Customary and Metric}) \quad \text{Eq. (4b3)}$$

REGION 2 — Where the average hole velocity (V_o) is $> V_{o(T1)}$, but $< V_{o(T2)}$
 Then, $f_1 = 1$ and $f_2 = 0$. Calculate f from **Eq. (4b2)** above.

$$h_{ed2} = K_2 \left[\frac{V_o}{A_1 / A_o} \right]^2 \frac{\rho_v}{\rho_L} \quad (\text{Customary and Metric}) \quad \text{Eq. (4b4)}$$

REGION 3 — Where the average hole velocity (V_o) is $> V_{o(T2)}$ but $< V_{o(T3)}$ and $f_1 = 1$.

$$f_2 = \left[\frac{V_o}{A_2 / A_o} \right] \left[\frac{K_2}{1.35 t_2 \frac{\rho_m}{\rho_v} + K_1 V_o^2} \right]^{0.5} - \frac{A_1}{A_2} \quad (\text{Customary and Metric}) \quad \text{Eq. (4b5)}$$

f , calculate from **Eq. (4b2)** above

$$h_{ed3} = 1.35 t_2 \frac{\rho_m}{\rho_L} + K_1 V_o^2 \frac{\rho_v}{\rho_L} \quad (\text{Customary and Metric}) \quad \text{Eq. (4b6)}$$

REGION 4 — Where the average hole velocity (V_o) $> V_{o(T3)}$
 $f_1 = 1.0$ (all the valves are fully open)

$$h_{ed4} = \frac{K_2 V_o^2 \rho_v}{\rho_L} \quad (\text{Customary and Metric}) \quad \text{Eq. (4b7)}$$

- ♦ Vendors have indicated that valve trays work well only when a certain minimum fraction of the valves are open at design rates and at turndown. The turndown of valve trays may be restricted by channeling (poor vapor distribution) or by pulsation at low vapor rates. Vapor channeling induces non-uniform weeping and a reduction in tray efficiency. To minimize vapor channeling, valve trays should be designed to exceed a minimum f ratio. The following minimum values of f are recommended at turndown conditions. Trays which meet or exceed these ratios are acceptable. If these ratios cannot be met, selected valves should be blanked, the valve density should be reduced, or the ratio of light to heavy valves should be increased.

1-pass trays	$f = 0.35$
2-pass trays	$f = 0.50$
3 or 4-pass trays	$f = 0.70$

Note that if the desired turndown cannot be achieved with standard valve trays, vendors can design trays with special valves (e.g., two-stage opening as provided by Glitsch's A-1 valve tray). If a very large turndown is required (about 5 to 1), the more expensive two-stage opening valves **must be specified**.

In addition, all valve tray specifications should include a note stating that "valve tray layout should be designed so that valve pulsation will not occur at minimum vapor rates." This is to insure maximum valve life. Vendors can achieve this by blanking, punching fewer openings, using varying valve weights, etc.

Calculating Open Area From Given Valve Tray Dimensions - The open area for the various types of valves can be determined from **Table 3B**, **Figure 10**, and **Figure 11**. Note that the open area for some valves is based on the hole area punched in the tray deck. Whereas, the open area for other valves is based on the peripheral escape or slot area.

Information Required by Valve Tray Vendor - A typical design specification for a valve tray will include the specification of all tray geometry (weir heights, downcomer clearances, downcomer rises, etc.), but will not include the number or type of valves used on the tray. Instead, a table consisting of the maximum and minimum tray liquid and vapor loadings and densities for each section of the tower should be supplied. In addition, the following notes should be included with the tray drawings.

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DETAILED DESIGN PROCEDURE (Cont)

Drawing Notes

- The number of valves on a given tray in each tower section should be designed so that the dry tray pressure drop at the maximum vapor rate is close to (i.e., within $\pm 10\%$) but does not exceed the following values in in. (mm) of hot liquid:

TRAY #	MAX. DRY TRAY ΔP
To be specified by designer	To be specified by designer

- Valve layout should be designed so that valve pulsation will not occur at the minimum vapor rate in each section. This is to insure maximum valve life.
- All valve tray drawings shall be submitted for approval by the Owner's Engineer before approval for fabrication is granted. Vendor's "For Approval" drawings shall show number, lift, and size of each valve type; the valve layout on tray deck, including distance from valves to downcomers, tray support rings, and tray panel edges; and typical valve pitch.
- Valve units must be of dimpled obstruction, unless otherwise specified. If carbon steel tray decks are used, the valve units must be alloy. Valves shall incorporate an anti-rotation feature that will prevent spinning of the element.
- Mechanical design of trays and material selection shall be in accordance with Exxon International Practices [IP 5-2-1](#).
- Vendor shall check layout for "blowing" limitation and confirm that weeping will not be more than 10% of the liquid rate at the minimum vapor rate.
- Nutter quotations are to be based on trays having only small valve (BDH) or small V-Grid (SVG) units on triangular pitch. Large valves (BDP) or large V-Grid (LVG) units are not acceptable. The use of rectangular pitch with any size unit is also unacceptable.
- Valve layout should include alternate pairs of rows of light and heavy valve if multi-weight valves are used. The first two rows and last two rows should be light valves to maximize bubble area.
- Tray vendor shall provide a minimum open area to bubble area ratio of 5%.

Blanking - For revamps, the ways to reduce valve area are to use blanking strips or replace the tray deck panels with ones having a smaller number of valves. For valves contained in a "cage," contact the vendors for their proprietary blanking devices. The valves **must** be removed prior to blanking. If blanking 50% or less of the hole area, blank single rows or pairs of rows of holes. Leave at least two consecutive rows unblanked.

For large amounts of blanking:

- Use a combination of items mentioned above plus waste area.
- Consider adding vertical baffles to restrict flow path width. (See [Figure C](#) in [Section III-I](#) under *How Can Trays Be Improved*.)
- Check adverse impact on tray efficiency (if any) because of the added waste area. Consider running parametric cases on Program 1134 with varying amounts of inputted waste area.

TRAY HYDRAULICS AND DOWNCOMER FILLING (STEP 5)

This part of the calculation form permits calculation of the various components of tray pressure drop and downcomer filling. Recommended values for downcomer filling as a percentage of the tray spacing for specific services are given in [Table 2](#). For all other services, use the value obtained from [Figure 5A](#) or [5B](#).

[Figures 8A](#) through [8H](#) are used to calculate the tray clear liquid height and froth density. Their use is restricted to towers between 4 and 20 ft (1200 to 6000 mm) in diameter. For designs falling outside this range, the more rigorous trial-and-error procedure presented in [Tables 3A](#) or [3B](#) of [Section III-B](#) must be used. A deviation of $\pm 10\%$ between the rigorous and short cut methods is both normal and acceptable. While the rigorous correlation was developed for sieve trays, it can be easily adapted to valve trays by using a hole diameter (d_o) of 0.5 in. (13 mm) in the rigorous equations for all types of valve trays.

The clear liquid height (h_{cl}) on the tray must be checked at the minimum liquid flow rates to make sure that the downcomer is sealed (see earlier discussion under *Downcomer Sealing*). If a seal is not obtained, consider the use of a higher outlet weir, a smaller downcomer clearance, a shaped downcomer lip, or a recessed inlet box.

The dry tray pressure (h_{ed}) should not exceed 2.25 in. (57 mm) for foaming systems and 4.5 in. (114 mm) for non-foaming systems.

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DETAILED DESIGN PROCEDURE (Cont)

CHECKING PROCESS LIMITATIONS (STEP 6)

After the tray design has been established, be sure that the ultimate capacity and the downcomer entrance velocity for high-pressure systems have been met. If any of these criteria have been violated, the trial tray design must be modified. If all of the criteria cannot be met simultaneously, consult your FRACTIONATION SPECIALIST.

TRAY EFFICIENCY (STEP 7)

The tray efficiency should be calculated by the modified procedure given in [Section III-I](#) for valve trays. The number of actual trays required is then calculated by dividing the number of theoretical trays (which are developed during the process simulation stage of the design) by the efficiency expressed as a fraction.

BALANCED DESIGN (STEP 8)

Even when a new tray design or revamp meets all the above criteria, the designer should check to see if the design is as "balanced" as possible. That is, the "ideal" balanced design would have the jet flood velocity, the downcomer entrance velocity and downcomer filling all at approximately the same percentage of their respective limits (e.g., say 85% of maximum jet flood, 85% of the allowable downcomer entrance velocity, and 85% of the allowable downcomer filling limits respectively). This prevents building a potential bottleneck into a tower and permits the unit to be pushed to its maximum by plant personnel. The designer should consider running parametric computer cases to balance a design rather than carrying out several lengthy calculations by hand.

Likewise, the designer should try to get all sections of the tower as balanced as possible (i.e., above the feed vs. below the feed, etc.).

TOWER CHECKLIST (STEP 9)

[Table 7](#) of [Section III-A](#) contains a detailed tower checklist that should be reviewed for all new designs as well as revamps.



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NOMENCLATURE

A_b	=	Bubble Area ft ² (m ²) (see Figure 12 in Section III-A)
A_{di}	=	Total downcomer inlet area, ft ² (m ²)
A_{do}	=	Total downcomer outlet area, ft ² (m ²)
A_f	=	Average tower free area, ft ² (m ²) (superficial area minus arithmetic average of inlet and outlet area of downcomer(s) above the tray minus the waste area); for multipass trays, use the tray having the smallest value of A_f . (See Figure 13 in Section III-A .)
A_o	=	Total valve open area, ft ² (m ²) (ALSO, $A_o = A_1 + A_2$)
A_1	=	Open area of lighter valves, ft ² (m ²)
A_2	=	Open area of heavier valves, ft ² (m ²)
A_s	=	Superficial (total) tower area, ft ² (m ²)
A_w	=	Waste area, ft ² (m ²) (normally zero for valve trays)
c	=	Clearance between tray and downcomer apron at tray inlet, in. (mm) (see Figure 6 in Section III-A)
C_s	=	Capacity factor based on cross-sectional area, V_L / A_s , ft/s (m/s)
d_o	=	Hole diameter, in. (mm) (Used only in rigorous clear liquid height calculations)
D_t	=	Tower diameter, ft (mm)
D_{tr}	=	Trial tower diameter, ft (mm)
E_o	=	Overall efficiency, % (see Section III-I)
f	=	Fraction of total valves open
f_1	=	Fraction of lighter valves open
f_2	=	Fraction of heavier valves open
H	=	Tray spacing, in. (mm)
h_c	=	Clear liquid height on tray, in. (mm) of hot liquid
h_d	=	Downcomer filling, in. (mm) of hot liquid
h_{ed}	=	Effective dry tray pressure drop, in. (mm) of hot liquid. With subscripts 1, 2, 3 and 4 added, it refers to the pressure drop in Regions 1, 2, 3 and 4 of Figure 7 , respectively.
h_f	=	Tray froth height, in. (mm) of hot liquid
h_i	=	Tray inlet head, in. (mm) of hot liquid
h_t	=	Total tray pressure drop, in. (mm) of hot liquid
h_{ud}	=	Head loss under downcomer or splash baffle, in. (mm) of hot liquid
h_{wi}	=	Inlet weir height, in. (mm) (see Figure 11 , Section III-A)
h_{wo}	=	Outlet weir height, in. (mm) (see Figure 6 , Section III-A)
K_{HL}	=	Tray spacing - liquid rate factor, dimensionless (see Figures 1A through 1D)
K_n	=	Constant for calculating open area for Nutter rectangular valves
$K_{\sigma\mu}$	=	Surface tension-viscosity factor, dimensionless (see Figure 3)
K_{VE}	=	Factor for graphical solution of clear liquid height (see Figures 8B and 8D)
K_w	=	Factor for graphical solution of clear liquid height (see Figures 8E and 8G)
K_1	=	Dry tray pressure drop coefficient (see Table 3C)
K_2	=	Dry tray pressure drop coefficient (see Table 3C)
L	=	Liquid rate, gpm/in. of weir /pass, (dm ³ /s/m of weir /pass)
L'	=	Liquid rate, gpm/in. of diameter /pass (dm ³ /s/m of diameter /pass)
L_L	=	Liquid load, ft ³ /s (dm ³ /s) at conditions
$L_{L(Min)}$	=	Minimum liquid load, ft ³ /s (dm ³ /s) at conditions
l_i	=	Inlet weir length, in. (mm)



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NOMENCLATURE (Cont)

l_o	=	Outlet weir length, in. (mm) (see Figures 9 and 12 in Section III-A)
l_o^*	=	Outlet weir length on inboard tray, in. (mm) (see Figure 12 in Section III-A)
l_{ud}	=	Length of bottom edge of outboard downcomer, in. (mm) (see Figure 12 in Section III-A)
l_{ud}^*	=	Length of bottom edge of inboard downcomer, in. (mm)
N_A	=	Number of actual trays
N_p	=	Number of liquid passes
N_T	=	Number of theoretical trays
P_{VE}	=	Vapor energy parameter (see Figures 8A and 8C)
Q_L	=	Liquid rate, gpm (dm ³ /s) at conditions
q_v	=	Volumetric vapor rate, ft ³ /s (m ³ /s) at conditions
r	=	Downcomer inlet rise for chordal downcomers or downcomer inlet width for inboard downcomers, in. (mm)
r_o	=	Inboard downcomer rise (width) at bottom of downcomer, in. (mm)
t_1	=	Thickness of lighter valves, in. (mm)
t_2	=	Thickness of heavier valves, in. (mm)
t_m	=	Valve metal thickness, in. (mm)
V_{di}	=	Velocity of clear liquid entering downcomer, ft/s (m/s)
V_{do}	=	Downcomer outlet velocity, ft/s (m/s)
V_f	=	Vapor velocity based on tower free area, ft/s (m/s)
V_L	=	Design vapor load = $q_v \left[\frac{\rho_v}{\rho_L - \rho_v} \right]^{0.5}$ at conditions ft ³ /s (m ³ /s)
$V_{L(Min)}$	=	Minimum vapor load. See appropriate Calculation Form. Eq. (1a4) for definition, ft ³ /s (m ³ /s)
$V_{L(Ult)}$	=	Ultimate capacity vapor load dependent on system properties, ft ³ /s (m ³ /s) at conditions
V_o	=	Vapor velocity through the total valve (punched) area, ft/s (m/s) for round movable valves. For round fixed and Nutter valves it is the peripheral area between the tray deck and the fully open valve element.
w_L	=	Liquid mass flow rate, klb/hr (kg/s)
w_v	=	Vapor mass flow rate, kib/hr (kg/s)
β	=	Factor in ultimate capacity equation, $1.4 \left[\frac{\rho_L - \rho_v}{\rho_v} \right]^{0.5}$ (Customary and Metric)
μ_L	=	Liquid viscosity at conditions, cP (mPa•s)
μ_v	=	Vapor viscosity at conditions, cP (mPa•s)
ρ_L	=	Liquid density at conditions, lb/ft ³ (kg/m ³)
ρ_m	=	Valve metal density, lb/ft ³ (kg/m ³)
ρ_v	=	Vapor density at conditions, lb/ft ³ (kg/m ³)
σ_L	=	Liquid surface tension at conditions, dynes/cm (mN/m)
σ_{STD}	=	Standard liquid surface tension, dynes/cm (mN/m) (see Figure 2)
Ψ	=	Froth density, fraction of froth volume occupied by liquid, dimensionless



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COMPUTER PROGRAMS

- For up-to-date information on available programs and how to use them, affiliate personnel should contact their FRACTIONATION SPECIALIST. A site's TECHNICAL COMPUTING CONTACT can also provide help on accessing available programs. The valve tray programs can be accessed through three sources.

AVAILABLE PROGRAMS

SOURCE	PROGRAM NAME OR NUMBER	VERSION NUMBER
PEGASYS	Fractionating Towers, Valve Tray	2.3
PRO/II	Valve Tray Program	2.3
Stand Alone	#1134	2.3

The Valve Tray programs utilize the design equations contained in this section, **Table 1**, and the equations on the *Valve Tray Calculation Form*. They can be used for both designing new towers or trays, and rating existing trays. Existing tray designs can be rated by specifying some or all of the tray hardware dimensions. The programs also include an option to calculate valve tray efficiency (see **Section III-I**).

An input form for the stand-alone program (1134) is available in Computer Program Update, Valve Tray Rating Design Program #1134, CPEE-0013, October, 1990. This memorandum contains a detailed description of the program, output sheets, and a step-by-step procedure illustrating how various cases are arranged. The program's input and output can be in either customary or metric units.

- When rating fixed valve trays, the K_1 coefficient is not used to calculate the dry tray pressure drop. Specify a low valve thickness (0.037 in., 0.91 mm) and check that all valves are fully open at design and minimum rates when using the valve tray programs.
- For valve tray spray/froth transition, weeping, and entrainment estimates the Sieve Tray Design Program (#1133) should be used. A hole size of 0.5 in. (13 mm) should be specified with an open area that gives a dry (sieve) tray pressure drop comparable to the valve tray prediction.

There is no multipass (3 or 4 pass) design program for valve trays. However, since many of the design equations for sieve trays are also common to valve trays, the sieve tray Multipass Design Program (#1143) can be used as a starting point for multipass valve tray design. The FRACTIONATION SPECIALIST should always be contacted for guidance in determining what supplemental hand calculations are required.

