



DESIGN PRACTICES

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Revision Memo

12/98	Practice renumbered from Section III-N with withdrawal of Section III-M. Dualflow trays not recommended for tower diameter greater than 4 ft (1200 mm). Reference added to PEGASYS screening quality computer program. Additional information added on Ripple Trays.
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SCOPE

This section describes the techniques for specifying the process design features of downcomerless sieve trays (dualflow trays). Detailed mechanical design and hole arrangement are normally handled by the tray fabricator. Calculation forms outlining the stepwise design procedure are given herein in both Customary and Metric units. Since dualflow trays are infrequently used by Exxon, it is recommended that all dualflow tower designs be reviewed by your FRACTIONATION SPECIALIST.

The procedure for calculating overall efficiency for dualflow tray is also included in this section. For designing tray-related tower internals, such as reboiler connections, vapor distributors and liquid distributors, see [Section III-H](#).

REFERENCES

INTERNATIONAL PRACTICES

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

OTHER LITERATURE

Downcomer Capacity Correlations Have Been Improved (Dry Tray Pressure Drop), ER&E Report EE.49E.80.

Sieve Tray Capacity Correlations Have Been Improved (Ultimate Capacity), ER&E Report EE.76E.72.

BACKGROUND

The design equations and guidelines given in this section for predicting capacity, pressure drop, and efficiency were developed from data collected by Fractionation Research, Inc. (FRI) in their four ft (1200 mm) diameter high and low pressure columns. **The numbered equations referred to herein are those found on the calculation forms located at the end of this section.** Equations describing parameters shown on the various graphs have been omitted in this section due to the small number of dualflow tray applications. If the need arises, these equations can be made available via consulting your FRACTIONATION SPECIALIST.

DEFINITIONS

The following definitions are for those terms specific to the dualflow tray. For a discussion of such general concepts as jet flooding and flexibility, see [Section III-A](#), *Basic Concepts and Device Selection*.

- ♦ The **dualflow tray** is a perforated flat tray without downcomers. Because this tray type lacks downcomers, the holes have the dual function of passing both vapor and liquid countercurrently. The **Ripple® Tray**, marketed by Stone & Webster, is similar to the dualflow tray in design and operation, except the Ripple Tray is corrugated in the form of a sine wave. The design procedures in this section can be used to screen Ripple Trays. A FRACTIONATION SPECIALIST should be consulted for any Ripple Tray application to help evaluate this technology for Exxon application.

APPLICATIONS

The absence of downcomers provides both advantages and disadvantages. Because the entire plate is active, dualflow trays possess higher capacity than that of a sieve or valve tray. But, even at design liquid and vapor rates, efficiency is usually lower. However, for high pressure, high vapor density systems, the peak tray efficiency approaches that of a sieve tray.

Dualflow trays are particularly well-suited for the fractionation of polymerizable compounds or high solids content systems (i.e., slurries) because of the self-cleaning nature of the tray. When these applications involve heat transfer service, consult your FRACTIONATION SPECIALIST to determine the number of trays required.

FRI data have shown that the dualflow tray performs best in the operating region of 60 to 85 percent of flood, depending on the system being designed. The efficiency increases rapidly with vapor rate and reaches a maximum in the 75 to 80 percent of flood range. Although dualflow trays with greater than 20 percent hole area possess higher capacities than most other tray types and packings, their efficiency is normally low. Consequently, dualflow trays may be used to debottleneck existing towers only when a considerable sacrifice in efficiency can be tolerated.

The major disadvantage of dualflow tray is their poor turndown ratio resulting from the rapid fall off in efficiency as the vapor loading is decreased. Therefore, the dualflow tray must be properly designed and the operating vapor and liquid rate ranges must be kept small. The capacity credit will seldom justify dualflow trays as a first choice because of the tray's poor efficiency characteristics. Sieve or valve trays should always be considered first, depending on flexibility requirements.

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BASIC DESIGN CONSIDERATIONS

The dualflow tray design procedure requires the selection of a trial tower diameter, tray spacing, and tray layout. These are then checked against performance limitations.

TRAY SPACING

The optimum combination of tray spacing and tower diameter is the one which minimizes the total investment, subject to the limitations outlined under **DETAILED DESIGN PROCEDURE**. These limitations are a function of tower diameter, service, and maintenance requirements.

TOWER DIAMETER

In a grass-roots tower design, the approximate (first trial) tower area for design of dualflow trays can be estimated from **Eq. (2a1)** below. The metric equation **Eq. (2a1)M** can be found on the **DUALFLOW TRAY CALCULATION FORM (METRIC)**.

$$A_s = \frac{V_L}{K_{\sigma\mu} K_H K_{AD}} + 5.93 L_L \quad \text{Eq. (2a1)}$$

where: A_s = Tower cross-sectional area, ft²
 V_L = Vapor load at conditions, ft³/s, calculated using **Eq. (1a1)**
 L_L = Liquid rate at conditions, ft³/s
 $K_{\sigma\mu}$ = Surface tension-viscosity capacity factor, dimensionless (**Figures 2 and 3**)
 K_H = Tray spacing capacity factor, dimensionless (**Figure 4A**) (As first trial, use 18 in. tray spacing)
 K_{AD} = Open area-hole size capacity factor, dimensionless (**Figure 5**) (As first trial, use 20% open area and 1/2 in. hole size)

The percent of flood can then be calculated from **Eq. (2c2)** using the initial calculated tower area, or the existing tower area in tower revamp studies. The metric equation **Eq. (2c2)M** can be found on the **DUALFLOW TRAY CALCULATION FORM (METRIC)**.

$$\%F_c = \frac{100 \frac{V_L}{A_s}}{K_{\sigma\mu} K_H K_{AD} \exp \left[\frac{-5.93 L_L}{A_s} \right]} \quad \text{Eq. (2c2)}$$

The calculated percent of flood, % F_c , should be checked against the recommended design percent of flood, % F_d , found under the **DETAILED DESIGN PROCEDURE**. For the most economical new tower design and the highest possible efficiency at the given design loadings, the tower cross-sectional area should be adjusted such that the calculated percent of flood approaches the recommended design percent of flood. For the design of towers to be retrofitted with dualflow trays, the tray open area and/or the tray spacing can be adjusted to achieve the recommended design percent of flood.

If the tower diameter exceeds 4 ft (1200 mm), dualflow trays should not be used since operating instabilities can occur because of vapor and liquid maldistribution problems. Stone & Webster **Ripple® Trays** claim over 200 applications for towers up to 40 ft (12 m) in diameter and could be considered for towers greater than 4 ft (1200 mm) in diameter.

ULTIMATE CAPACITY

Eq. (2b1) or **Eq. (2b1)M** on the calculation forms give the limiting vapor load for ultimate capacity. If this load is exceeded, the liquid is broken up into such small droplets that increasing the tray spacing will not reduce the amount of liquid entrained to the tray above. The ratio of design vapor load to the vapor load for ultimate capacity must be kept below 90%. If necessary, the tower diameter must be increased to reduce the percent of ultimate capacity.

TRAY LAYOUT AND HOLE AREA

As shown in **Figure 1** where overall tray efficiency is plotted against vapor hole momentum for a typical FRI system, design tray efficiency is maintained only within a very narrow vapor rate range. The location and width of this range at which design efficiency can be maintained is a function of the tray open area and tray spacing as shown qualitatively in **Figure 1**.

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BASIC DESIGN CONSIDERATIONS (Cont)

Turndown is the ratio of maximum to minimum vapor loadings between which the tray efficiency is maintained at nearly the design value. For most dualflow trays this will be only 1.33 to 1 (i.e., the tray cannot be turned down more than 25%). For a specific set of design maximum and minimum tower loadings, a maximum tray spacing design with a ratio of hole area to bubble area of 15 - 20% will provide maximum turndown. However, for larger hole area ratios (25 - 30%), the peak efficiency is significantly lower than that of smaller hole area trays.

The allowable vapor loading increases as the percent hole area increases. However, the maximum tray efficiency is adversely affected for hole areas above 25 percent. The recommended hole area for use as a first trial for sizing new towers is 20 percent. Thus, a balance between capacity, efficiency, and turndown can be achieved by optimizing the hole area.

HOLE SIZE, SHAPE AND LAYOUT

In general, a hole diameter of 1/2 in. (13 mm) should be used. However, for fouling services containing solids or polymerizable compounds, holes sizes of 3/4 in. to 1-1/2 in. (19 - 38 mm) are recommended. The allowable range of hole sizes is outlined in [Table 1](#).

In the rare case in which the designer is specifying the tray layout, the hole pitch to diameter ratio should be checked against the criteria given in [Table 1](#). However, it is usually not necessary to specify the pitch in the final process drawings that are given to the tray fabricator. Hole diameter and area are sufficient for the fabricator to prepare the mechanical design and layout for the tray.

TRAY HYDRAULICS

The dry tray pressure drop, total tray pressure drop, and clear liquid height are calculated from the equations presented in the *Tray Hydraulics* section (Part 3) of the calculation forms.

TRAY EFFICIENCY

The method for predicting dualflow tray efficiency is based on the two resistance theory of mass transfer. Although the theory was developed for cross-flow contacting devices such as sieve and valve trays, it has been empirically modified to predict the efficiency of counter-current contacting on dualflow trays. For more background material on predicting efficiency, selecting key components, or sectioning a tower, see [Section III-I, Tray Efficiency](#).

DETAILED DESIGN PROCEDURE

The stepwise procedure for designing a dualflow tray is presented in the **DUALFLOW TRAY CALCULATION FORMS** found in this section. The procedure involves assuming a trial tray design with the help of the principles outlined above, checking the design against various potential operating limitations, and then modifying the trial design as required to achieve an optimum tray design. Deciding how to modify the trial design (changing the tower diameter, tray spacing, layout, etc.) will require judgment while applying the basic design considerations already discussed. The final design should then be reviewed by your FRACTIONATION SPECIALIST.

The calculation step numbers and equation numbers referred to below are those found on the calculation forms.

VAPOR AND LIQUID LOADINGS AT CONDITIONS (STEP 1)

This information is normally calculated as part of the heat and material balances for the tower. If the minimum liquid and vapor loadings have not been specified, assume 75% of the design loadings. Vapor loadings are to the tray in question; liquid loadings are from the tray in question.

TRAY SPACING, SIZE, AND LAYOUT (STEP 2)

Tray Spacing - A low tray spacing (between 18 and 24 in. [450 - 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 below are the minima for most applications as determined by considerations of maintenance and support beam depths.

In special cases, even smaller spacings may be justified. However, smaller tray spacings make maintenance more difficult. On the other hand, capacity requirements or foaming services may necessitate the use of tray spacings above 36 in. (900 mm).

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DETAILED DESIGN PROCEDURE (Cont)

TOWER DIAMETER, ft (mm)	MINIMUM TRAY SPACING, in. (mm) FOULING SERVICE
5 or less (1500 mm or less)	18 (450)*
5-1/2 to 7-1/2 (1650 to 2250 mm)	21 (525)*
8 to 10 (2400 to 3000 mm)	24 (600)*

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

Hole Area - For good efficiency at moderate capacity, 20 percent open area should be specified. If higher capacities are required and lower efficiencies can be tolerated, then the open area can be increased to as much as 30%.

Hole Size - For clean services, 1/2 in. (13 mm) diameter holes are generally specified. However, fouling services may require hole sizes of 3/4 in. (19 mm) or larger.

Tower Diameter - For new tower designs, the trial tower diameter, D_{tr} , is calculated from **Eq. (2a2) or (2a2)M**. It will be necessary to adjust the trial diameter in order for the calculated percent of flood to approach the recommended design values listed below. For existing towers to be retrofitted with dualflow trays, the open area and/or the tray spacing can be adjusted to obtain the recommended design values given below.

SERVICE	MAXIMUM DESIGN PERCENT OF FLOOD, %F _d
Hydrocarbon	85%
Aqueous	85
Foaming	60

♦ **Eq. (2c2) or (2c2)M** is the dualflow tray capacity correlation which was developed from FRI dualflow data collected in their four ft (1200 mm) diameter towers. As noted earlier, dualflow trays should not be used if their diameter exceeds 4 ft (1200 mm).

The recommended design percents of flood for dualflow trays applies only to those systems with surface tensions in excess of 5 dynes/cm (m/Nm). For systems with lower surface tensions, the allowable design percent of flood will be greatly reduced. A limited amount of data from FRI is available to assist in designing for these systems. For further guidance, consult your FRACTIONATION SPECIALIST.

Ultimate Capacity - The vapor load factor corresponding to ultimate capacity is calculated from **Eq. (2b1) or (2b1)M**. The ratio of design to ultimate capacity vapor rates must be kept below 90%.

TRAY HYDRAULICS (STEP 3)

This part of the calculation form outlines the prediction of the various components of tray pressure drop and froth height.

TRAY EFFICIENCY (STEP 4)

The tray efficiency calculation procedure is described in this part of the form. For a description of the recommended estimation techniques for liquid molecular diffusivity, see **Appendix II** of **Section III-G**.

From the tray efficiency calculations, the actual number of trays required for a specified separation can be determined from the overall efficiency and the number of theoretical trays.

TOWER CHECKLIST (STEP 5)

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

PROBABILITY OF SUCCESSFUL OPERATION

The capacity correlation given in this section is the most accurate one currently available for dualflow trays in both hydrocarbon and aqueous services. However, it must be used with care because no safety factor has been built into this correlation.

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NOMENCLATURE

A_b	=	Bubble area, ft ² (m ²)
A_o	=	Hole area, ft ² (m ²)
A_s	=	Tower cross-sectional area, ft ² (m ²)
A_w	=	Waste area, ft ² (m ²)
a	=	Interfacial area, cm ² /cm ³ (mm ² /mm ³) (see Figure 15)
C_L	=	Total tray pressure drop factor, dimensionless (see Figure 7)
D_L	=	Liquid molecular diffusivity, cm ² /s (m ² /s)
D_t	=	Tower diameter, ft (mm)
D_{tr}	=	Trial tower diameter, ft (mm)
d_o	=	Hole diameter, in. (mm)
E_{MV}	=	Murphree tray efficiency, dimensionless
E_O	=	Overall efficiency, dimensionless
E_{OG}	=	Point efficiency, dimensionless
$\%F_c$	=	Calculated percent of flood, %
$\%F_d$	=	Design percent of flood, %
F_r	=	Froude number, dimensionless [see Eq. (3d1) or (3d1)M]
G_m	=	Vapor rate, lb moles/h (kmol/s)
H	=	Tray spacing, in. (mm)
h_c	=	Clear liquid height, in. (mm) of hot liquid
h_{ed}	=	Dry tray pressure drop, in. (mm) of hot liquid at conditions
h_f	=	Froth height, in. (mm) of froth at conditions
h_t	=	Total tray pressure drop, in. (mm) of hot liquid
J_5	=	Dry tray pressure drop factor, dimensionless (see Figure 6)
K_{AD}	=	Open area-hole size factor, dimensionless (see Figure 5)
K_{DV}	=	Liquid phase mass transfer coefficient factor, dimensionless (see Figure 12)
K_{FL}	=	Vapor phase mass transfer coefficient factor, dimensionless (see Figure 14)
K_H	=	Tray spacing factor, dimensionless (see Figure 4)
K_{HD}	=	Vapor phase mass transfer coefficient factor, dimensionless (see Figure 13)
K_{LV}	=	Total tray pressure drop factor, dimensionless (see Figure 8)
K_p	=	Total tray pressure drop factor, dimensionless (see Figure 9)
K_Q	=	Clear liquid height factor, dimensionless (see Figure 10)
$K_{\sigma\mu}$	=	Surface tension-viscosity capacity factor, dimensionless (see Figure 3)
K_η	=	Froth density factor, dimensionless (see Figure 11)
k_G	=	Vapor phase mass transfer coefficient, cm/s (mm/s)
k_L	=	Liquid phase mass transfer coefficient, cm/s (mm/s)
L_b	=	Liquid velocity through the bubble area, ft/s (m/s)
L_L	=	Liquid load at conditions, ft ³ /s (dm ³ /s)
L_m	=	Liquid rate, lb moles/h (kmol/s)
L_o	=	Liquid velocity through the holes, ft/s (m/s)
m	=	Slope of y^* vs. x equilibrium curve
N_A	=	Number of actual trays
N_G	=	Vapor phase transfer unit, dimensionless

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NOMENCLATURE (Cont)

N_L	=	Liquid phase transfer unit, dimensionless
N_{OG}	=	Overall (vapor) mass transfer unit, dimensionless
N_T	=	Number of theoretical trays
Q	=	Ratio of vapor momentum to liquid momentum, dimensionless
q_v	=	Vapor rate at conditions, ft ³ /s (m ³ /s)
t	=	Tray thickness, in. (mm)
t_G	=	Vapor residence time, s
t_L	=	Liquid residence time, s
V_b	=	Vapor velocity through bubble area, ft/s (m/s)
V_L	=	Vapor load, ft ³ /s $\left[\frac{\rho_v}{\rho_L - \rho_v} \right]^{0.5}$ at conditions $\left(m^3/s \left[\frac{\rho_v}{\rho_L - \rho_v} \right]^{0.5} \right)$ at conditions
$V_{L(Ult)}$	=	Vapor load for ultimate capacity, ft ³ /s (m ³ /s)
V_o	=	Vapor velocity through holes, ft/s (m/s)
β	=	Ultimate capacity factor, dimensionless
η	=	Froth density parameter, dimensionless
λ	=	$m (G_m/L_m)$, dimensionless
μ_L	=	Liquid viscosity at conditions, cP (mPa·s)
ρ_L	=	Liquid density at conditions, lbs/ft ³ (kg/m ³)
ρ_v	=	Vapor density at conditions, lbs/ft ³ (kg/m ³)
σ_L	=	Surface tension at conditions, dynes/cm (mN/m)
σ_{STD}	=	Standard surface tension, dynes/cm (mN/m)
ψ	=	Froth density, dimensionless

COMPUTER PROGRAMS

- ♦ A dualflow tray design computer program is available through PEGASYS. This computer program is of screening quality only. Final designs should be done using the Dualflow Tray Calculations Forms provided in this design practices section. Final design should also be checked by a FRACTIONATION SPECIALIST.



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**TABLE 1
DUALFLOW TRAY DESIGN PRINCIPLES
(METRIC VALUES ARE IN PARENTHESES)**

DESIGN FEATURE	SUGGESTED VALUES	ALLOWABLE RANGE	COMMENTS	QUALITY OF DATA BACK-UP
1. Application				
a) Debottlenecking			Because the entire plate is active, dualflow trays possess higher capacities than either the sieve or the valve tray. However, dualflow trays exhibit very poor turndown ratios (about 1.33/1). This results in substantial efficiency debits as the percent of flood decreases (see Figure 1).	
b) Tower diameter		Equal or less than 4 ft (1200 mm)	Operating instability may occur for dualflow trays larger than 4 ft (1200 mm) in diameter. Ripple Trays may be considered for larger diameters.	Poor
c) Services			Always consider using other internals (i.e., sieve trays, valve trays, or packing) before resorting to dualflow trays. However, in fouling or slurry services, dualflow trays may provide the best performance.	
2. Hole Size and Layout				
a) Hole diameter	1/2 in. (13 mm) normal 3/4 in. to 1-1/2 in. for fouling service. (19 - 38 mm)	3/8 in. to 1-1/2 in. (9 - 38 mm)	Directionally, smaller holes have better capacity and efficiency characteristics for nonfouling systems. However, holes smaller than 3/8 in. (9 mm) on carbon steel trays tend to rust over during hydrostatic testing and should be avoided. The use of corrosion resistant alloys to overcome this problem may not be economically justified. Additionally, holes larger than 1/2 in. (13 mm) reduce both capacity and efficiency and increase the pressure drop. But in fouling services, these larger holes are necessary to reduce the tendency for the holes to become plugged.	Good
b) Ratio of hole area to bubble area, A_o/A_b , percent	15 to 25	10 to 30	In general, the lower the open area, the lower the capacity and the higher the pressure drop will be. A dualflow tray with 20 percent open area has good capacity and efficiency with a reasonable pressure drop. Higher open area trays may be necessary for increased capacity requirements, but they tend to exhibit lower efficiencies.	Good

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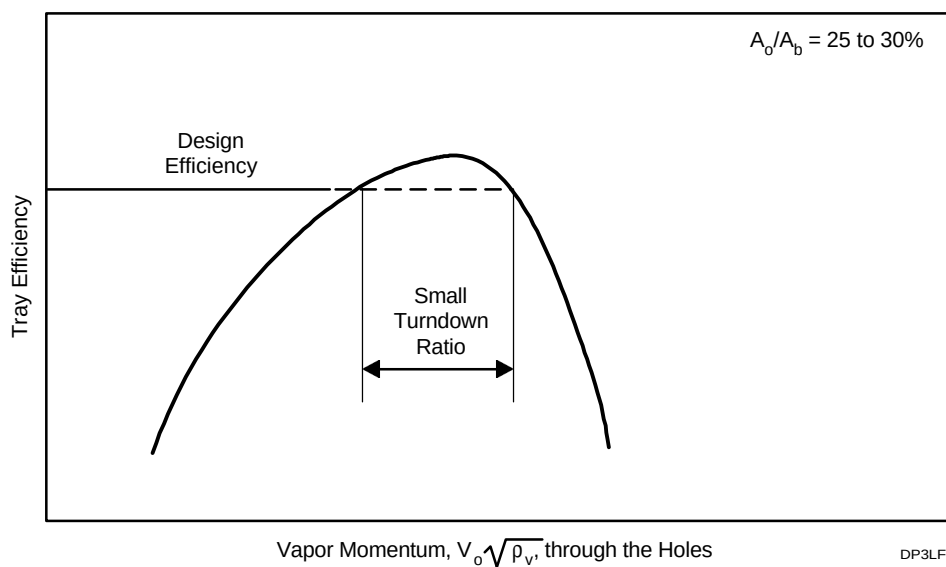
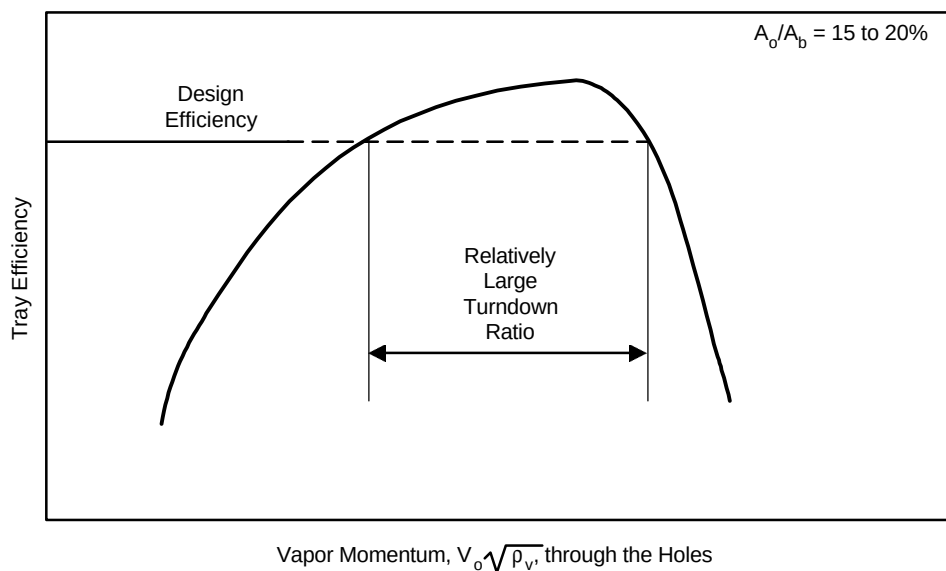
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TABLE 1 (Cont)
DUALFLOW TRAY DESIGN PRINCIPLES
(METRIC VALUES ARE IN PARENTHESES)

DESIGN FEATURE	SUGGESTED VALUES	ALLOWABLE RANGE	COMMENTS	QUALITY OF DATA BACK-UP
c) Hole distribution			It is important that the hole area be uniformly distributed on the tray deck to minimize vapor and liquid maldistribution. Indications of efficiency and capacity debits exist for trays with non-uniform hole distributions. For further details see IP 5-2-1 .	Fair
d) Ratio of hole pitch to hole diameter	2 or 3	1.7 to 3	A triangular pitch should be used.	Fair
e) Hole blanking			Blanking of dualflow trays is not recommended unless the tower is being sized for future service with higher capacity requirements. To maintain the best efficiency, it is important to blank the trays uniformly within the bubbling area and not around the periphery. See IP 5-2-1 for more details on tray blanking.	Poor
3. Tray spacing	18 in. to 30 in. (450 to 750 mm)	12 in. to 36 in. (300 to 900 mm)	Generally, lower tray spacings are more economical. However, tray capacity and efficiency increase with increasing tray spacing. Use of variable spacings to accommodate loading changes from tower section to tower section should be considered to minimize tower height, improve efficiency, and improve turndown.	Good



**FIGURE 1
EFFECT OF VAPOR MOMENTUM ON TRAY EFFICIENCY
(SAME FOR CUSTOMARY AND METRIC UNITS)**



DP3LF01