



Training Services

Column Sizing

IPD-2004/CS-1

Column Internal Design

- Counter Current Vapor/Liquid Contact
- Cross Flow Trays
 - Cheap
 - Rugged
 - Tolerant
- Other Types of Trays
- Packing

IPD-2004/CS-2

Cross Flow Trays

Features

- **Bubbling Area**
 - Shear vapor/liquid into small drops and bubbles
 - Upward vapor velocity must be below velocity that causes massive entrainment
- **Downcomer**
 - Separates entrained vapor from liquid
 - Directs liquid flow between trays

IPD-2004/CS-3

Cross Flow Trays

Features

- **Tray Spacing**
 - Increased spacing aids downcomer separation
 - Increased spacing reduces entrainment
- **Liquid is continuous phase and vapor is dispersed phase**

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Types of Cross Flow Trays

- Sieve
- Valve
- Bubble Cap

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Other Trays

- Dual Flow
- Side to Side
- Disc and Donut

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Tray Vendors

- Koch/Glitsch - Flexitray®, Ballast®, Triton®,
Bi-Frac®, Maxfrac®, Superfrac®,
Nye Trays®, Ultra-frac®
- Sulzer - Float Valve™, Snap-in™, V-Grid™,
Vortex Tray™, Calming Section™,
HiFi™, ConSep™, Swirl Tube™
- UOP - MD™, ECMD™, Slotted Sieve™

↑
Multiple
Downcomer

IPD-2004/CS-7

Mixing Devices (Hardware)

- Trays
 - Bubble cap
 - Rectangular
 - Round
 - Valve cap
 - Shape
 - Fixed
 - Floating
 - Sieve deck

} Typically used
for refinery

IPD-2004/CS-8

Mixing Devices (Hardware) ***(continued)***

■ Mechanical Problems - Trays

- Valves
 - Corrosion
 - Rust
 - Weeping/dumping at inlet

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Mixing Devices (Hardware) ***(continued)***

■ Packing

- Rings
- Saddles
- Structured

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Mixing Devices (Hardware) ***(continued)***

- **Major Differences - Trays and Packing**
 - Trays have downcomers
 - Continuous phase is reversed
 - Trayed column has larger liquid inventory
 - Packed columns require distribution internals

IPD-2004/CS-11

Mechanical Devices (Hardware) ***(continued)***

- **Mechanical Problems - Packing**
 - Ineffective distribution
 - Vapor
 - Liquid
 - Migration of packing
 - Support grid
 - Holddown grid
 - Coking

IPD-2004/CS-12

Column Economics

- Column plus trays cost 5 to 17% of total installation of fractionator
- Not wise to design too close to maximum capacity
- Suggested contingency
 - 110% reflux
 - 80% flood

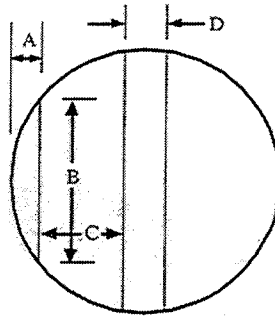
IPD-2004/CS-13

Service I. D. Trays	Extract Column 5'-6" 40	Debutanizer 7'-0"/9'-6" 40	Toluene Column 6'-6"/8'-0" 34	Debutanizer 9'-6"/14'-0" 30	Propane ¹ Column 18'-0" 215
Column & Receiver	113,600	240,000	122,100	470,400	2,355,500
Condensers	53,600 ²	269,500 ²	51,300 ²	269,900	1,101,800
Reboilers & Coolers	29,200	233,500	56,100	712,200 ³	236,700
Pumps	13,000	57,100	42,400	300,300 ³	236,700
Instruments	98,000	136,600	79,500	299,200	121,800
Piping	74,900	190,700	121,200	372,700	441,000
Other Material ¹	111,700	278,200	233,800	475,400	494,000
Field Labor	213,800	555,000	439,600	909,700	3,274,300 ⁴
Direct Field Cost	707,800	1,961,000	1,136,000	3,809,800	7,983,000
Indirect Field Cost	234,000	617,000	481,000	1,047,000	3,587,000
Total Field Cost	941,800	2,578,000	1,617,000	4,846,800	11,570,000
Eng'g Contractors Expense + Fee	318,000	506,000	562,000	886,000	2,210,000
Total Erected	\$1,269,800	\$3,084,000	\$2,179,000	\$5,732,800	\$13,780,000
¹ Maximum Field Fabrication					
² Air Cooled Condensers					
³ Fired Reboiler					

IPD-2004/CS-14

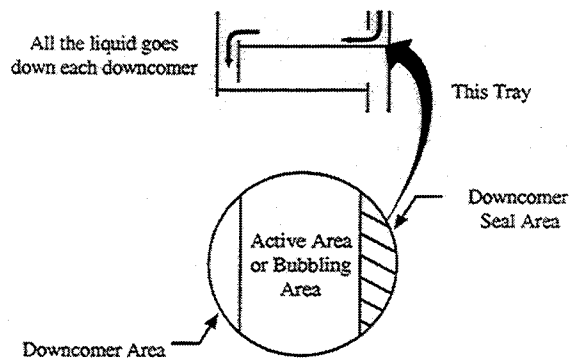
Some Tray Layout Definitions

- A - Chord Height
- B - Chord Length or Weir Length
- C - Flow Path Length
- D - Downcomer Width



TS-R00-01
IPO-2004/CS-15

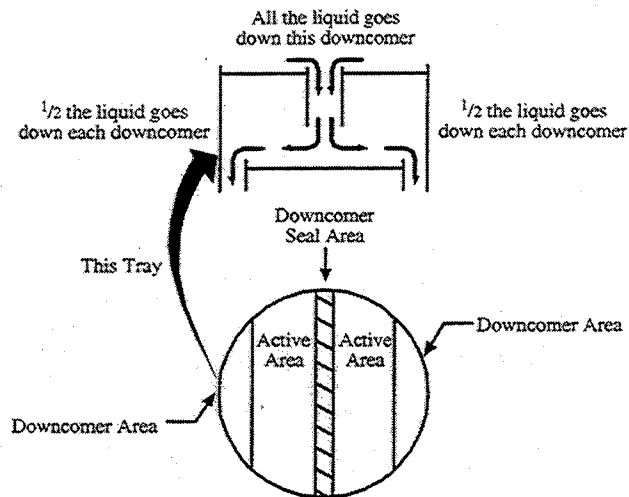
One Pass Tray



Odd and even trays are identical but are rotated 180° from each other

TS-R00-02
IPO-2004/CS-16

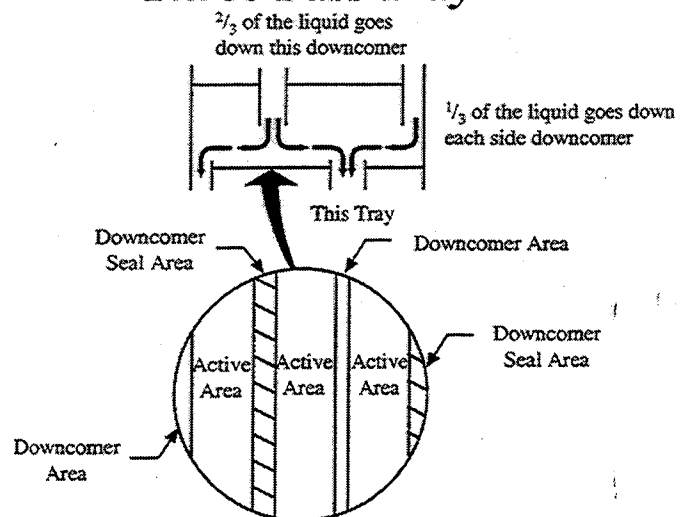
Two Pass Tray



Odd and even trays are not the same

TS-R00-03
IPD-2004/CS-17

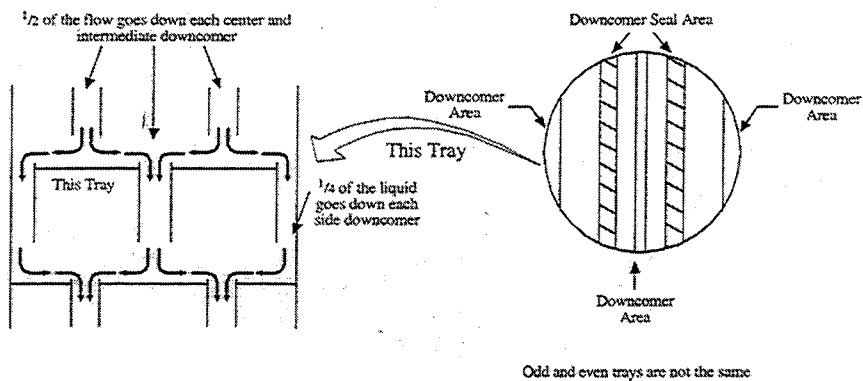
Three Pass Tray



Odd and even trays are identical but are rotated 180° from each other.

TS-R00-04
IPD-2004/CS-18

Four Pass Tray



TS-R00-05
IPD-2004/CS-19

Sizing - Tray Layouts

1. Center downcomer area = diameter x width
2. Intermediate downcomer on 3 pass tray

$$\text{Assume } \frac{\text{Chord height}}{\text{Diameter}} = 0.25$$

(Rule of thumb)

$$\text{Weir length} = 0.9426 \times \text{diameter}$$

$$\text{Downcomer area} = 0.9426 \times \text{diameter} \times \text{width}$$

IPD-2004/CS-20

Sizing - Tray Layouts ***(continued)***

3. Intermediate downcomer on 4 pass tray

$$\text{Assume } \frac{\text{Chord height}}{\text{Diameter}} = 0.25$$

Weir length = 0.866 x diameter

Downcomer area = 0.866 x diameter x width

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Major Tray Design Considerations ***Hardware***

- Tray Spacing
- Downcomer Area
- Bubbling and Hole Area
- Number of Passes
- Other Items (Weir Height, DC Clearance, etc.)

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Major Tray Design Considerations

Process Items

- Jet Flood, Entrainment
- Weeping
- Efficiency
- Turndown
- Pressure Drop
- Downcomer Backup

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Hardware Selection

Fractionation Research Institute
Movie on Tray Principles

Note:

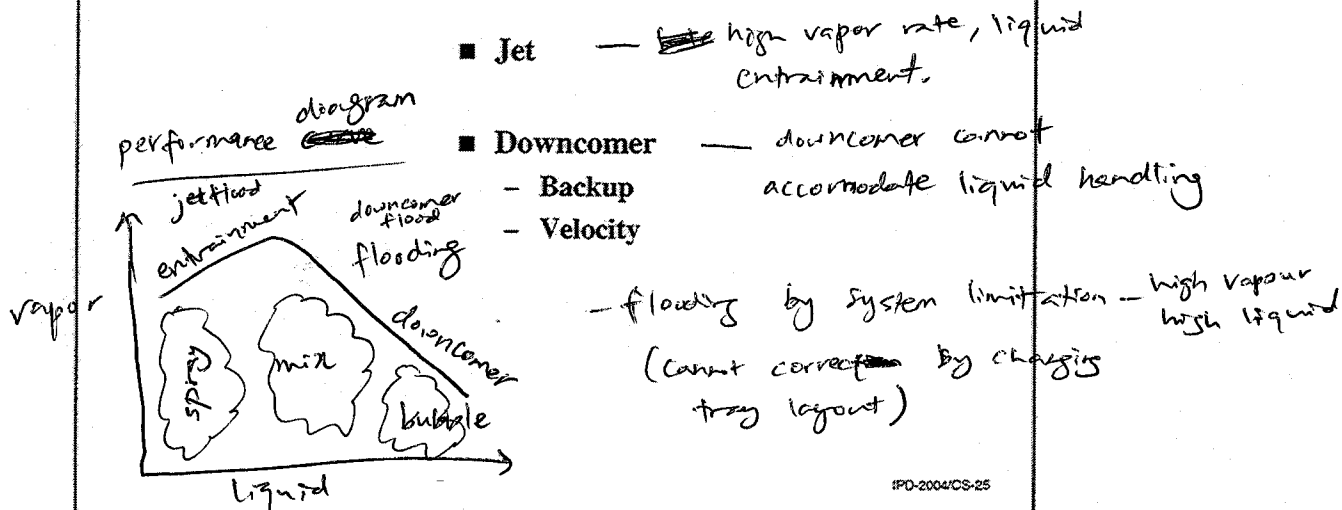
- Tray Height Gauge
- Valve Harmonics
- Flow Regime
 - Spray
 - Mix
 - Bubbly
- Tray Weep and Dump Points

↙ worst weeping
scenario

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Bubble cap — good turndown ratio (0%)

Types of Flood



Jet Flood

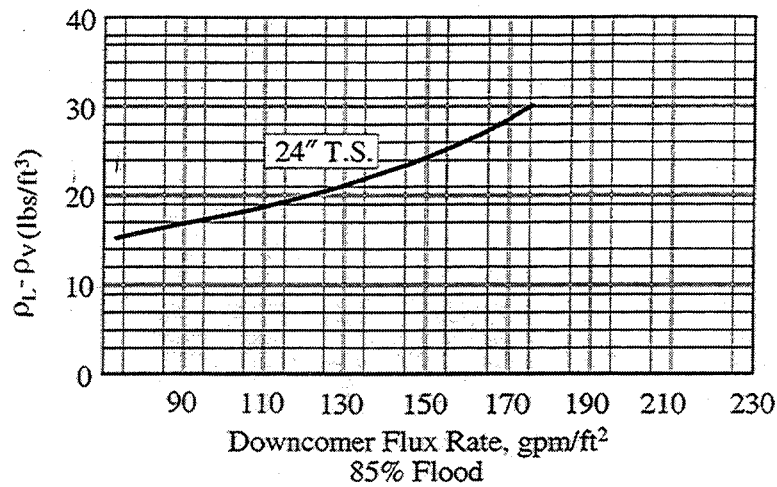
■ Liquid Entrained in Vapor

$$■ \text{ V Load} = Q_V \sqrt{\frac{\rho_V}{\rho_L - \rho_V}}$$

■ Capacity or C Factor

$$C = \frac{Q_V}{A} \sqrt{\frac{\rho_V}{\rho_L - \rho_V}}$$

Downcomer Sizing



IPD-R02-66
IPD-2004/CS-27

Downcomer Velocity Limit

- Vapor Entrained in Liquid
 - Tray spacing
 - Vapor and liquid densities

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Downcomer Backup

- Exit Loss
- Liquid Head on Tray
- Tray Pressure Drop
 - Dry pressure drop
 - Head on tray

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Downcomer Backup Limit

- High Vapor Density
 - ~33% tray spacing
- Low Vapor Density
 - ~50% tray spacing

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Tray Spacing

- 24" If Not More Than 60 Trays
- 18" If More Than 60 Trays
- 30" or 36" If Governing Pump Around
- Additional Considerations
 - Downcomer backup
 - Jet flood for given diameter
 - Column L/D ratio

IPD-2004/CS-31

Tray Spacing (continued)

- Capacity correlations are based upon 24 inch tray spacing
- Capacity is corrected by a tray spacing factor (TSF) if other than 24 inch spacing is used
- Typical factors are:

<u>Tray Spacing</u>	<u>Vapor Density Less 1.5 lb/cf</u>	<u>Vapor Density More 1.5 lb/cf</u>
12	0.65	0.65
18	0.84	0.84
24	1.00	1.00
30	1.14	1.12
36	1.22	1.15

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Setting Number of Passes

- Weir rate of 50 to 100 gpm/ft desirable
- Fewer passes desirable
- 16" minimum flow path length

Number of Passes	Recommended Minimum Diameter
2	4.5 ft
3	9 ft
4	12 ft

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Downcomer Clearance

- The larger of
 - 1.5 inches
 - Height to yield exit velocity of 1.5 ft/s

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Weir Height

- Set to provide downcomer seal
- Normal weir height is 0.25 to 0.5 inches more than downcomer clearance

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Number of Valves or Sieve Holes

- Vapor velocity prevents weeping
- Vapor velocity contributes to downcomer backup and entrainment

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Foaming Derating Factor

- Systems that are known to foam are normally derated by a factor
- This normally applies to both downcomer and bubbling areas
- Foaming Systems
 - Amines
 - Carbonates
 - Caustics
 - MEK

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High Vapor Density Derating Factor

- For $\rho_v > 1.8 \text{ lb/ft}^3$, derate capacity by system factor = $1.21 / (\rho_v)^{0.32}$

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Downcomer Width

- Side downcomer 5 inch minimum
- Center downcomer 8 inch minimum
- Intermediate downcomer 8 inch minimum

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Changing Diameter May Be Cost Effective If

- Diameter difference is 1.5 ft or more
- Diameter difference is 20% or more of column diameter

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Tray Sizing Procedure

1. Estimate preliminary diameter and number of passes
2. Make trial layout of tray
3. Rate tray
4. Repeat Steps 1-3 until done

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Tray Sizing Procedure ***(continued)***

■ Next Diameter Guess

$$d_2^2 = d_1^2 \frac{\text{Percent Flood 1st Trial}}{\text{Percent Flood Desired}}$$

Where d_1 = Previous diameter tried

d_2 = Next diameter to try

IPD-2004/CS-42

Preliminary Diameter Estimate

$$\text{Diameter, ft} = \sqrt{\frac{\text{Basis, BPD}}{\text{Barrel Factor}}}$$

Service	Barrel Factor	Basis
Crude Tower	100 – 150	lift
Vacuum Tower	50 – 65	lift
Sidecut Stripper	450	product
Debutanizer	175 – 250	feed
Deethanizer	100	feed
C ₃ /C ₄ Splitter	150 – 200	feed
Universal	250	reflux + feed

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Preliminary Diameter Estimate

■ Heat Factor

$$d = \sqrt{\frac{Q}{350,000}}$$

Where Q = reboiler duty in Btu/h

d = column bottom diameter in feet

IPD-2004/CS-44

Kerosine Stripper (Koch Method)

■ Loadings

Vapor Rate	V	(cfs)	62.2
Vapor Density	d_v	(lb/ft ³)	0.146
Liquid Rate	L	(gpm)	763
Liquid Density	d_l	(lb/ft ³)	41.9

IPD-2004/CS-45

System Factor (Koch Page 6)

- The system is non-foaming; therefore, the system factor is 1.0
- The vapor density is less than 1.8; therefore the system factor is 1.0
- Design rating procedure
 - Tray space factor
 - Use 24" tray spacing
(therefore, the tray space factor, with a vapor density less than 1.5 lb/ft³, is 1)

IPD-2004/CS-46

Preliminary Sizing (Koch Page 7)

- Get the Vapor Rate

$$ACFS = 62.2 \text{ (from loadings)}$$

- Calculate the Square Root Factor

$$Factor = \sqrt{\frac{d_v}{d_l - d_v}} = \sqrt{\frac{0.146}{41.9 - 0.146}} = 0.059$$

- Calculate the V_{load}

$$V_{load} = ACFS \sqrt{\frac{d_v}{d_l - d_v}} = (62.2)(0.059) = 3.68$$

IPD-2004/CS-47

Preliminary Sizing (Koch Page 7)

- Calculate the Corrected V_{load} and Liquid Rate

$$Corrected \text{ Vapor Load Factor} = \frac{V_{load}}{(TSF)(SF)} = \frac{3.68}{(1)(1)} = 3.68$$

$$Corrected \text{ Liquid Rate} = \frac{gpm}{(TSF)(SF)} = \frac{763}{(1)(1)} = 763$$

IPD-2004/CS-48

Preliminary Sizing (Koch Page 7)

- Plot on Chart A (Koch Page 13)

Estimated Diameter = 5.2 ft (Double Flow)

- Try 5 ft - 6 in diameter with 2 passes and 24 inch tray spacing

$$A_T = \frac{(\pi)(5.5)^2}{4} = 23.76 \text{ ft}^2$$

2-Pass:

$$\frac{L}{(NP)(DT)} = \frac{763}{(2)(5.5)} = 69.4 \text{ gpm/ft (Good)}$$

IPD-2004/CS-49

Preliminary Sizing Barrel Factor

- Kerosine Product - 14950 bpsd

- Stripper Barrel Factor - 450

$$d = \left(\frac{14950}{450} \right)^{1/2}$$
$$= 5.76 \text{ ft}$$

IPD-2004/CS-50

Detailed Sizing

- Vapor Rate = 62.2 cfs (use non-corrected values)
 - Liquid rate = 763 gpm
- Size the Downcomers
 - We must correct the Koch correlation to a basis of 75 percent flood

$$\frac{75}{85} (175 \text{ gpm} / \text{ft}^2) = 154 \text{ gpm} / \text{ft}^2$$

IPD-2004/CS-51

Detailed Sizing (continued)

(a) Minimum downcomer area

Koch Equation 1

$$A_{dc} = \left(\frac{\text{gpm}}{154} \right) \left(\frac{24}{TS} \right) \left(\frac{1}{SF} \right) = \left(\frac{763}{154} \right) \left(\frac{24}{24} \right) \left(\frac{1}{1} \right) = 4.95 \text{ ft}^2$$

- (b) Doesn't apply here since $d_1 - d_v = 41.75 \text{ lb/ft}^3$;
therefore, no need to use Chart B.

IPD-2004/CS-52

Detailed Sizing (continued)

- Find side downcomer chord height using Koch Chart D
 - Remember that it's a 2-pass tray, so side downcomer area equals $(4.95/2) = 2.475 \text{ ft}^2$
- From UOP Charts:

$$\frac{A_D}{A_T} = \frac{2.475}{23.76} = 0.1042$$

$$H/D = 0.1610$$

$$H = (0.1610)(5.5)(12) = 10.6 \text{ in}$$

IPD-2004/CS-53

Detailed Sizing (continued)

- Koch doesn't indicate how to calculate the center downcomer width, so we'll do it this way.

$$\text{Center DC Width} = \frac{\text{DC Area}}{\text{Tray Diameter}}$$

$$\text{Center DC Width} = \frac{4.95}{5.5} = 0.9 \text{ ft} = 10.8 \text{ in}$$

IPD-2004/CS-54

Detailed Sizing ***(continued)***

■ **Bubbling Area**

$$A_b = A_t - A_{dt} - A_{db} - A_e$$

A_t = Tower Cross Sectional Area

$$A_t = \pi D^2 / 4 = (\pi)(5.5)^2 / 4 = 23.76 \text{ ft}^2$$

A_{dt} = Downcomer Area at Top = 4.95 ft²
(2 side downcomers each with 2.475 ft²)

IPD-2004/CS-55

Detailed Sizing ***(continued)***

■ **Bubbling Area**

A_{db} = Downcomer Area at Bottom

(center downcomer bottom seal area is 4.95 ft²)

A_e = Edge Loss ≈ 0 (because column > 3 ft - 6 in)

Therefore, $A_b = 23.76 - 4.95 - 4.95 - 0 = 13.86 \text{ ft}^2$

IPD-2004/CS-55

Detailed Sizing (continued)

- Find side downcomer chord length (weir length) using Koch Chart E or UOP table

$$A_D / A_T = 0.1042$$

$$L/D = 0.7351$$

$$L = (0.7351)(5.5) = 4.043 \text{ ft}$$

$$\text{Note that total } L_w = (4.043)(2) = 8.086 \text{ ft}$$

IPD-2004/CS-57

Detailed Sizing (continued)

- Calculated Tray Capacity
- Koch Equation 3

$$\text{pct Capacity} = \frac{(100)}{(TSF)(SF)(0.506)} \left[C_{sf(net)} + (0.01327) \frac{\text{gpm}}{L_w} \right]$$

IPD-2004/CS-58

Detailed Sizing (continued)

– Where

$$C_{sf(net)} = \left(\frac{ACFS}{A_b} \right) \sqrt{\frac{d_v}{d_l - d_v}}$$

$$C_{sf(net)} = \frac{62.2}{13.86} \sqrt{\frac{0.146}{41.9 - 0.146}} = 0.265$$

$$pct \text{ Tray Capacity} = \frac{(100)}{(1.0)(1.0)(0.506)} \left[0.265 + (0.001327) \left(\frac{763}{(8.086)} \right) \right] = 77.1 \text{ pct}$$

IPD-2004/CS-59

Detailed Sizing (continued)

■ Downcomer Capacity (Koch Page 9)

Koch Equation 4

$$pct \text{ Capacity} = \left(\frac{gpm}{A_d} \right) \left(\frac{75}{154} \right) \left(\frac{1}{SF} \right) \left(\frac{24}{TS} \right)$$

$$pct \text{ Capacity} = \left(\frac{763}{4.95} \right) \left(\frac{75}{154} \right) \left(\frac{1}{1} \right) \left(\frac{24}{24} \right) = 75 \text{ pct}$$

(Note the modification of Koch Equation 4 to be consistent with 75 percent of flood)

IPD-2004/CS-60

Detailed Sizing ***(continued)***

- Compare tray capacity and downcomer capacity

pct Tray Capacity = 77.1

pct Downcomer Capacity = 75.0

- Close enough to be a balanced design

IPD-2004/CS-81

Detailed Sizing ***(continued)***

- We'll use a 2 inch weir
- For downcomer clearance, we'll use 1.75 inches

IPD-2004/CS-82

Pressure Drop

- Convert Vapor Rate to Air Equivalent

$$CFM(Air\ Equiv) = (60)(ACFS) \sqrt{\frac{d_v}{0.0735}}$$

$$CFM(Air\ Equiv) = (60)(62.2) \sqrt{\frac{0.146}{0.0735}} = 5260$$

IPD-2004/CS-63

Pressure Drop (continued)

- Use 11 valves per ft² (Koch Page 10)
- Calculate cfm (air equivalent) per valve

$$CFM/Valve = \frac{5260}{(11)(13.86)} = 34.5$$

- From Koch Chart G, using "A" type valves (typical)

$$Dry\ Tray\ \Delta P = 2.0\ in\ H_2O$$

IPD-2004/CS-64

Pressure Drop ***(continued)***

- Read effective depth of liquid from Koch Chart J

$$\left(\frac{763}{8.086} \right) = 94.4 \text{ gpm / ft weir}$$

2.1 Inches Clear Liquid

IPD-2004/CS-65

Pressure Drop ***(continued)***

- Convert effective liquid depth to inches of water

$$\begin{aligned} \text{Liquid } \Delta P &= (\text{Effective Liquid Depth}) \left(\frac{d_l}{62.4} \right) \\ &= 2.1 \left(\frac{41.9}{62.4} \right) = 1.41 \text{ in } H_2O \end{aligned}$$

IPD-2004/CS-66

Pressure Drop (continued)

■ **Total Tray $\Delta P = \text{Dry Tray } \Delta P + \text{Liquid } \Delta P$**

$$\text{Total Tray } \Delta P = 2.0 + 1.41$$

$$\text{Total Tray } \Delta P = 3.41 \text{ in } H_2O$$

IPD-2004/CS-67

Pressure Drop (continued)

■ **Convert to mmHg**

$$\text{Total Tray } \Delta P = (3.41)(1.865) = 6.4 \text{ mmHg}$$

IPD-2004/CS-68

Downcomer Backup

$$h_{dc} = 2(h_{wet}) + (h_{dry} + h_{vd}) \left(\frac{d_l}{d_l - d_v} \right)$$

h_{dc} = clear liquid downcomer backup

h_{wet} = wet tray pressure drop (Chart H - L)

h_{dry} = dry tray pressure drop (Chart G)

h_{vd} = head loss under downcomer (Chart F)

IPD-2004/CS-69

Downcomer Backup ***(continued)***

■ Chart F

$$\text{gpm/ft} = \frac{763}{8.086} = 94.4$$

Downcomer Clearance = 1.75 inches

$$h_{vd} = 1.2 \text{ inches liquid}$$

IPD-2004/CS-70

Downcomer Backup

(continued)

$$h_{dc} = 2(h_{wet}) + (h_{dry} + h_{vd}) \left(\frac{d_l}{d_l - d_v} \right)$$

$$h_{dry} = 2.0(62.4/41.9) = 2.98$$

$$h_{dc} = 2(2.1) + (2.98 + 1.2) \left(\frac{41.9}{41.9 - 0.146} \right)$$

$$h_{dc} = 8.4 \text{ inches liquid}$$

IPD-2004/CS-71

Flow Path Length

- **Note:** Koch does not check for a sufficient flow path length. In this example, the flow path length is:

$$FPL = \frac{(12)(5.5) - (2)(10.8) - 11.1}{2} = 16.65 \text{ in}$$

- **This is sufficient**

IPD-2004/CS-72

Web Sites

- <http://www.koch-glitch.com>
- <http://www.sulzerchemtech.com>
- <http://uop.com>
- <http://fri.org> ← fractionation research institute

IPD-2004/CS-73

Class Problem #1

- Use the Koch method to size the following column section
- Use a 24" tray spacing and 75% flood

Known Data		Summer Operation	Winter Operation/
Vapor Rate	ft ³ /s	16.56	12.19
Vapor Density	lb/ft ³	1.673	2.702
Liquid Rate	gpm	366.0	486.0
Liquid Density	lb/ft ³	31.1	29.39

IPD-2004/CS-74

INTRODUCTION

The diameter of a fractionating column is set by the fractionating trays, which will fit within it. A tray is basically made up of two parts, downcomers (including downcomer seal area) and bubbling area.

The downcomer must be large enough to disengage vapor from liquid and transport the liquid to the tray below. Downcomer seal area is the area below a downcomer not available as bubbling area.

The bubbling area must be sufficiently large to keep the vapor velocity below the point where a massive amount of liquid is entrained to the deck above.

It is interesting to note that, as far back as the 1930's, Souders and Brown tackled column sizing when they wrote a force balance on a drop of unknown size. They reasoned that when the drag exerted by upward flowing vapor on the average liquid droplet is equal to or greater than the force of gravity on that drop, massive entrainment occurs and flooding is the result. Equating the upward and downward forces, and combining the drag coefficient, acceleration of gravity and the unknown drop size into one empirical constant, results in an equation of the following form:

$$c = \frac{V}{A_a} \sqrt{\frac{d_v}{d_l - d_v}}$$

where: c is an empirical constant

V is vapor rate, ft^3/s

A_a is bubbling area, ft^2

d_v is vapor density, lb/ft^3

d_l is liquid density, lb/ft^3

The group on the right side of the equation is still used in most tower sizing methods. Glitsch calls the term on the right "V load" while Koch calls it "Csf".

What it comes down to is that all trays produce a highly agitated froth, which is, for the most part, independent of the type of contacting device. Therefore, tower bubbling area and downcomer area should not depend on the type or manufacturer of the tray actually installed.

The three major manufacturers of proprietary valve trays are Koch, Glitsch, and Nutter, whose trays are trade named, respectively, "Flexitray", "Ballast Tray", and "Float Valve Tray". Overseas licensors, while not using the name of the parent company, do use the tradename of the deck; thus, B-S-L in France manufactures "Ballast Trays" under their own name. These licensors have quite a bit of freedom so that a "Ballast Tray" laid out by B-S-L will be very similar, but not necessarily identical, to a "Ballast Tray" laid out by Glitsch in Dallas. Other manufacturers of valve trays include Wyatt in the United States, Hydronyl and Mass Transfer Ltd. in England, and Metawa in Holland. These firms have made a limited penetration into the market dominated by the big three. We will concentrate on the proprietary sizing methods of the two largest tray producers, Koch and Glitsch.

COST PERSPECTIVE

In order to maintain a proper perspective regarding relative costs, the following tables show a cost breakdown of various common fractionator installations. Note the relatively small percentage of the column itself.

Service I. D. Trays	Extract Column 5'-6" 40	Debutanizer 7'-0"/9'-6" 40	Toluene Column 6'-6"/8'-0" 34	Debutanizer 9'-6"/14'-0" 30	Propane ¹ Column 18'-0" 215
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Instruments	98,000	136,600	79,500	299,200	121,800
Piping	74,900	190,700	121,200	372,700	441,000
Other Material ¹	111,700	278,200	233,800	475,400	494,000
Field Labor	213,800	555,000	439,600	909,700	3,274,300
Direct Field Cost	707,800	1,961,000	1,136,000	3,809,800	7,983,000
Indirect Field Cost	234,000	617,000	481,000	1,047,000	3,587,000
Total Field Cost	941,800	2,578,000	1,617,000	4,846,800	11,570,000
Eng'g Contractors Expense + Fee	318,000	506,000	562,000	886,000	2,210,000
Total Erected	\$1,269,800	\$3,084,000	\$2,179,000	\$5,732,800	\$13,780,000
¹ Maximum Field Fabrication ² Air Cooled Condensers ³ Fired Reboiler					

The above tabulation shows normal columns running about 10 percent of the total installation. Even a superfractionator such as the propane column has a column cost only 17 percent of the total installation. This is somewhat misleading because, while some other items do scale directly with column size (such as foundation work and insulation which are covered in "other material" and field labor plus "sub-contracts"), it is obvious that, with all else being equal, six inches more or less on diameter or a few extra trays are insignificant in the total cost. This is something which both the designer and purchaser must bear in mind.

A copy of "Fractionating Column Economics" by E. A. Jones and M. E. Melborn (Chemical Eng'g Progress (CEP), May, 1982) has also been provided for your reference.

PRELIMINARY DIAMETER ESTIMATE

All column sizing methods have the same three stages: preliminary diameter estimate, trial layout, and rating. The Koch and Glitsch methods we will be using offer charts to estimate the first guess at a column's diameter. Following are some additional methods UOP has developed through the years.

Similar Column Comparison

Because we frequently use almost identical reflux-to-feed ratios for columns performing the same separation, it stands to reason that the cross-sectional area should be proportional to feed rate – hence the "barrel factor" equals feed rate (in bbls/day) divided by the diameter (in feet) squared. A table of barrel factors for some common fractionators follows:

Service	Barrel Factor	Basis
Crude Tower	100-150	lift
Vacuum Tower	50-65	lift
Sidecut Stripper	450	product
Debutanizer	175-250	feed
Deethanizer	100	feed
C ₃ /C ₄ Splitter	150-200	feed
Note: These should only be used for preliminary sizing because reflux ratio, amount of preheat, and product specifications can affect the barrel factor		

General Factor

One general factor relates column size to heat input. Although this varies with pressure, a reasonable average is $Q/D^2 = 350,000$ (where Q equals reboiler duty in Btu/h and d equals diameter in feet). Another general factor is $(R + F)/d^2 = 250$ (where R and F are reflux and feed in bbls/day).

Next Diameter Guess

Because column sizing is a trial-and-error solution, the preliminary diameter estimate is not always the last.

If the calculated percent of flood is different from the target, the next diameter may be estimated by remembering that percent flood is inversely proportional to tower area. Thus:

$$d_2^2 = d_1^2 \frac{\text{Percent Flood 1st Trial}}{75 \text{ pct (or other desired value)}}$$

TRAY SPACING

Tray spacing is selected on the basis of both process and mechanical limitations, although the majority of columns are normally found to be at 24-inch tray spacing.

The main process limitations for tray spacing are jet flooding and downcomer flooding. Jet flooding can be defined as the point at which liquid froth on a tray extends to the tray above. For systems which are vapor loaded, the percent jet flood is inversely proportional to tray spacing at constant diameter. Downcomer flooding occurs when the length of the downcomer is insufficient to disengage the frothy vapor-liquid mixture that enters. From pressure drop, we can calculate an equivalent clear liquid backup. To account for the froth, most people agree that the calculated clear liquid backup should not exceed 50 percent of the tray spacing. Tray spacing is often varied to accomplish the following (process constraints must always be satisfied):

- Decrease costs by reducing height on columns with more than 40 to 50 trays.
- Avoid swagging a column by changing the tray spacing for various column sections.
- Minimize column length/diameter ratio; any column with a length/diameter ratio over 14 may warrant special structural considerations.

The mechanical limitations which affect tray spacing occur when column diameter forces the major support beams to increase in depth and obstruct tray flow. Trouble with support beam depth can normally be avoided by increasing tray spacing. The following guidelines relate tray spacing to diameter and number of flow passes. This relationship is for **informative** purposes and is **not a requirement**.

Tray Spacing (in)	Recommended Maximum Vessel Diameter Number of Tray Passes			
	1	2	3	4
18	9'-0"	11'-6"	14'-0"	16'-0"
24	12'-0"	15'-0"	18'-0"	21'-0"
30	15'-0"	18'-6"	22'-0"	25'-0"

For cases exceeding the above guidelines, there are alternate structural techniques which can be utilized (e.g. open truss-type tray supports). Other mechanical limitations are sometimes encountered when distributors or drawoff wells obstruct tray flow.

NUMBER OF PASSES

Figures VII-2 through VII-5 depict trays with 1-4 flow passes. In general, it is best to use the fewest number of passes that can adequately do the job without increasing the column diameter. This is qualitatively confirmed by the Fractionation Research Institute efficiency measurements. Flow path lengths should be a minimum of 15 inches (for mechanical reasons, 16 inches is the smallest standard internal manway that can be installed). The following table gives minimum sizes versus number of passes.

Number of Passes	Absolute Mechanical Minimum	Recommended Minimum
2	4'-6"	4'-6"
3	7'-6"	8'-6"
4	10'-0"	12'-0"

The above table does not mean that three passes should be used in a ten-foot tower if two are adequate. It merely says that three passes should not normally be used in a tower less than 8'-6" in diameter, and three passes cannot possibly be used in a tower less than 7'-6". One guideline is that:

$$4 < \frac{L}{NW} < 8$$

where: L = total liquid, gpm

N = number of passes

W = average flow path width, inches

In the above, it is obviously impossible to hold to the minimum in a large, single pass tower. Alternately, much higher rates can and have been used successfully. The guideline should only be used as a starting point in setting a tower design.

Regarding cost, although more passes must mean higher prices, the differential is less than the accuracy of an estimate.

SWAGING OF TOWERS

There are two kinds of swages: (1) the downward swage above the feed point because of low loadings in the upper sections and, (2) the downward swage in the column bottom to minimize the time at high temperature for thermally sensitive materials. The following discussion is entirely concerned with the above feed swage, which is where controversy arises.

The only argument for swaging above the feed is that of the cost. The main arguments against swaging of the top section break down into two categories: (1) tangible real probabilities, and (2) general operating philosophy. These points are as follows.

Real Probabilities

- The amount of money saved by swaging the top portion of a tower is generally such a small portion of the total installed cost that the saving is negligible.
- A change in operating conditions or yield pattern of the unit producing the column feed could make the swaged section a future bottleneck (the advent of riser cracking has made swaged naphtha sections the bottleneck on some FCC Main Columns).

Intangible Arguments

- If feed composition changes in the future, the feed cannot be relocated upward.
- It is much more difficult to switch the tower to another service in the future. (The traditional gas con revamp is to convert the primary absorber to sponge absorber, the stripper to primary absorber, and the debutanizer into the stripper while building a new debutanizer. This is only possible if the debutanizer is not swaged).

In general, we should worry primarily about tangible items unless management instructs otherwise. As the arguments above boil down to capital now versus flexibility later, some minimum guidelines are in order. One rule is that a diameter change of 1'-6" is required in order to justify a change in diameter. Another rule (for columns less than 10'-0" in diameter) is that a swage is justified if the ratio of top section to bottom section areas is less than 0.6. Above 10'-0" diameter, the 1'-6" rule applies.

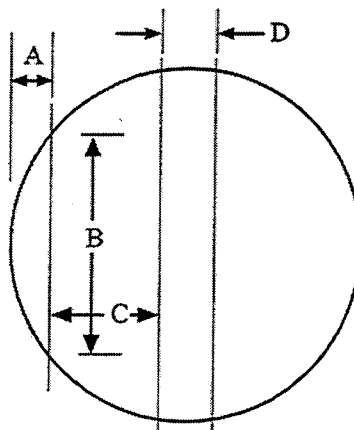
One additional type of swage not mentioned above is when the bottom portion of the column below the last tray is swaged outward to accommodate a stabbed in reboiler or to act as a surge drum. This is frequently more economical than an external reboiler (in the first case) or an additional surge drum.

GUIDELINES NORMALLY EMPLOYED BY UOP	
Item	Guidelines
Jet Flood	80 percent max.
Downcomer Backup (max.) Vacuum to 300 psig 300 psig +	50 percent of tray space 33 percent of tray space
Liquid Rate Over the Weir	120 gpm/ft max.
Pressure Drop (normal) Vacuum Columns Pressure Columns	2.5-3 mmHg 4-6 mmHg
Velocity Under Downcomer	2 ft/s max.
Side Downcomer Chord Height	5 in min.
Center Downcomer Width	8 in min.
Intermediate Downcomer Width	8 in min.
Flow Path Length	16 in min.
Weir Height (normal)	2 in
Downcomer Clearance (normal)	1.5 in

Figure VII-1

Some Tray Layout Definitions

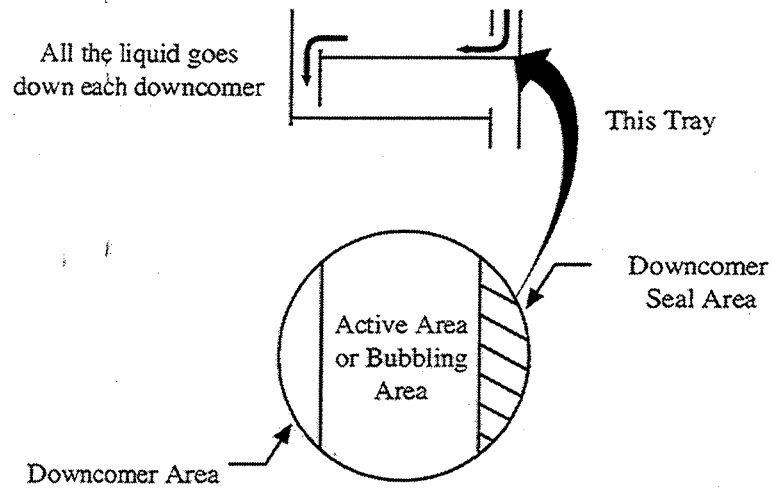
- A - Chord Height
- B - Chord Length or Weir Length
- C - Flow Path Length
- D - Downcomer Width



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Figure VII-2

One Pass Tray

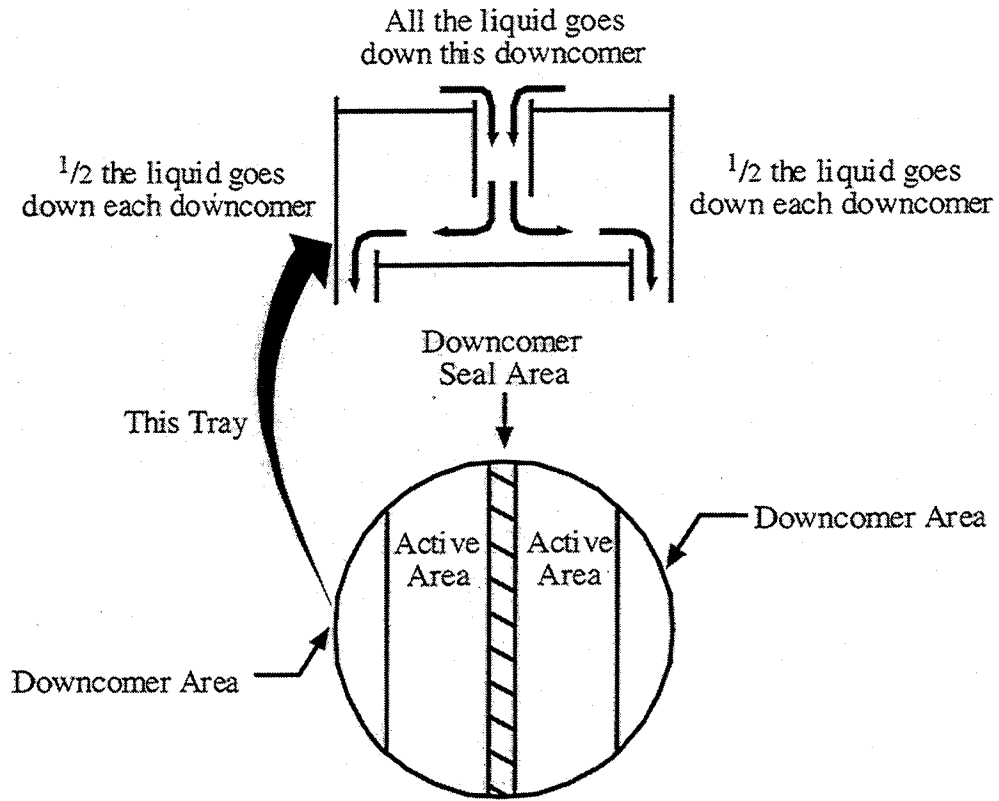


Odd and even trays are identical but are rotated 180° from each other

TS-R00-02

Figure VII-3

Two Pass Tray

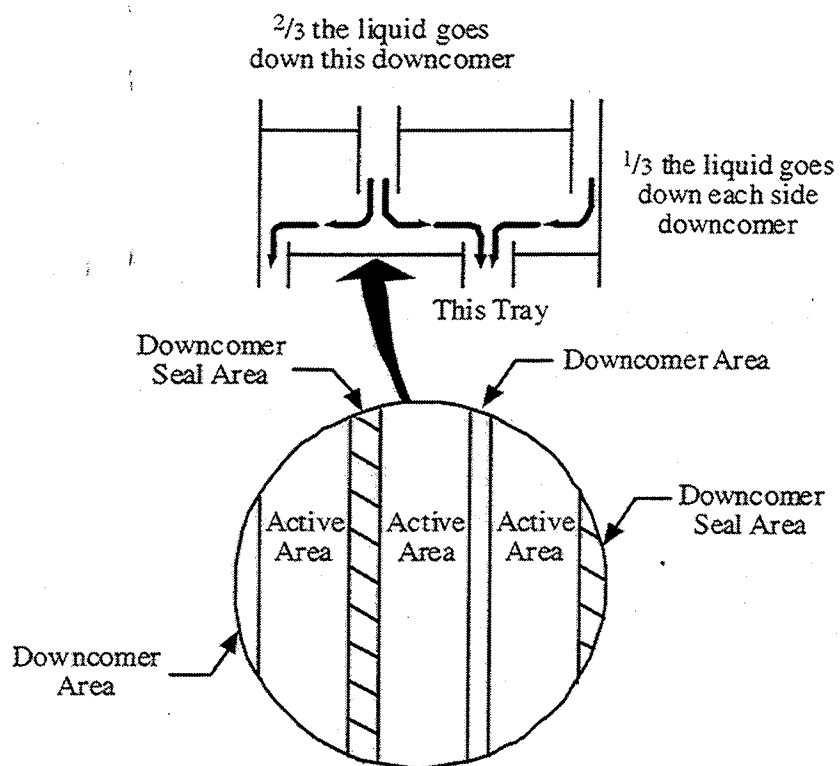


Odd and even trays are not the same

TS-R00-03

Figure VII-4

Three Pass Tray

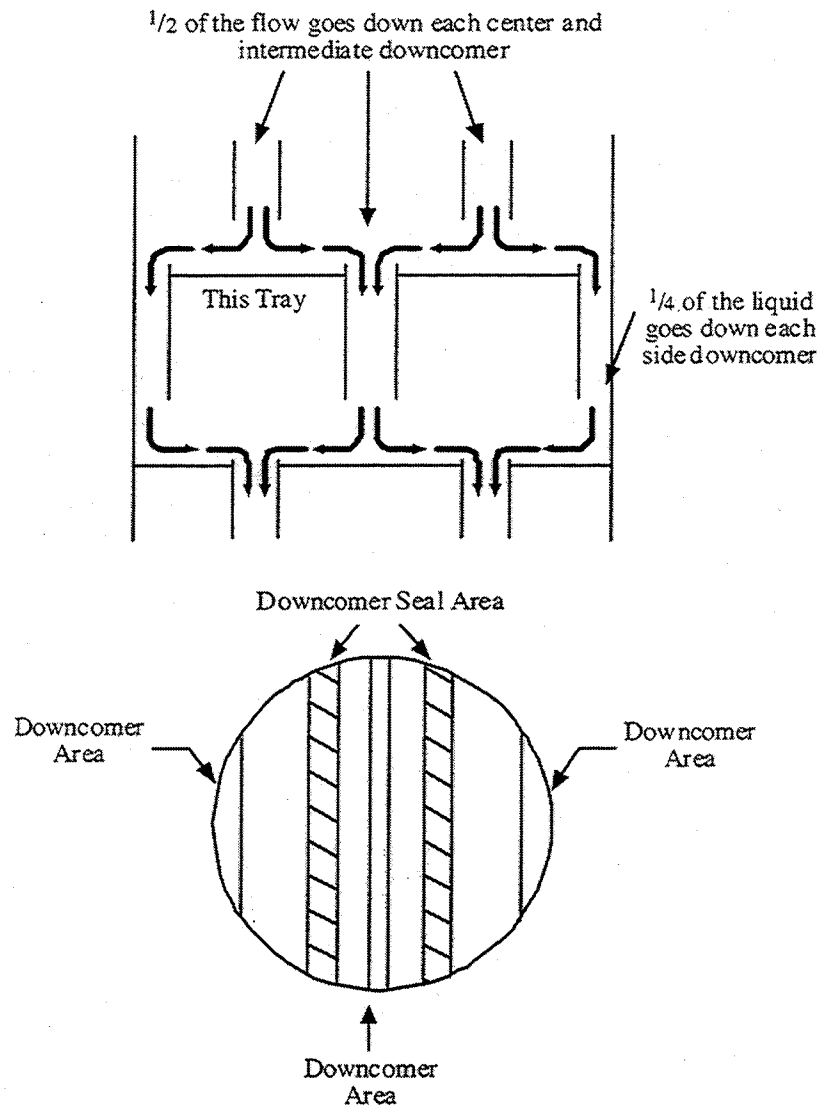


Odd and even trays are identical but are rotated 180° from each other

EDS-R00-0404

Figure VII-5

Four Pass Tray



Odd and even trays are not the same

EDS-R00-0405

KOCH FLEXITRAY RATING SHEET

LOADINGS

Vapor, lb/h

Vapor Density, lb/cf

Liquid, lb/h

Liquid Density, lb/cf

Tray Spacing, inches

TRAY DIMENSIONS

ID

H sdc

L sdc

A sdc

H cdc

L cdc

A cdc

H idc

L idc

A idc

ONE PASS

TWO PASS

FOUR PASS

CALCULATED LOADINGS

CFS

Density Factor

V_{LOAD}

GPM

$$\sqrt{\rho_V / (\rho_L - \rho_V)}$$

CFS x Density Factor

RATING SHEET

ID, ft

A, sf

Passes

A_{BUB}, SF

V_{LOAD}/A_{BUB}

L_{WEIR}, ft

GPM/L_{WEIR}

% TRAY CAP

TS = 18 in

TS = 24 in

TS = 30 in

$$[100 / (TSF \times SF \times 0.51)] \times [(V_{LOAD} / A_{BUB}) + (GPM / 754 \times L_{WEIR})]$$

% DNC CAP

TS = 18 in

TS = 24 in

TS = 30 in

$$[(GPM / A_{DC}) (85 / 175) (1 / SF) (24 / TS)]$$

FRACTIONATING COLUMN ECONOMICS

by

Evan A. Jones and Marvin E. Mellbom

**UOP Process Division
UOP Inc.
Des Plaines, Illinois**

**For presentation at the
Fall Annual Meeting of the
American Institute of Chemical Engineers
New Orleans, Louisiana
November 8-12, 1982**

FRACTIONATING COLUMN ECONOMICS

by

Evan A. Jones and Marvin E. Mellbom

UOP Process Division

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Many industrial users and designers of fractionating systems make decisions on the sizing of new columns without a good appreciation of the incremental costs associated with the columns as a part of the whole fractionating system. In addition, other factors such as the operating pressure, number of trays, tray spacing and whether vacuum design should be included are also rather vague. This paper will attempt to shed some light on costs related to these systems and also will try and show some of the reasons why the fractionating column proper should not be designed too tightly.

Fractionation is, undoubtedly, one of Chemical Engineering's most useful and costly unit operations. The art of fractionation has been practiced for centuries, but most of the real advancements in it have been made in the last 50 years with our increasing knowledge of vapor/liquid equilibrium and in the contacting devices used for accomplishing it. The greatest progress in reduction of fractionating column sizes and costs was made in the early 1950's with the introduction of valve-type trays and the organization of Fractionation Research, Inc. (FRI) shortly thereafter. The valve tray vendors and FRI have done an excellent job in research leading to development of reliable fractionator sizing methods. Next, in the late fifties, computers came into use for calculating the fractionator loadings to a greater precision than had been done previously by hand methods. The result has been that design loadings were lowered for many services as well as accurately defining the column ultimate capacity in most instances. The combination of better sizing methods and lowered calculated loadings has reduced the specified column areas for many services by as much as 40 percent or more under what they were only about 20 years ago.

The resulting reduction in fractionating column capital cost was indeed welcome, but it has not been without some penalty since it has resulted in units which are much more difficult to revamp

for increased capacity. Today, the direction that some designers are now taking is to design for higher percentages of flood in order to reduce the column diameters even further. It is this trend toward myopic economics to which we would like to direct attention and, hopefully, bring it into proper focus.

Design Background

Before looking at the cost factors, it seems appropriate to discuss some of the process steps that are involved in leading up to the comprehensive design of a fractionating column, and to show some of the uncertainties and gray areas involved in the procedures. The process design of a fractionating column involves the following steps::

1. Calculations of reflux, number of trays, and feed tray number
2. Heat and weight balance calculations
3. Calculation of tray loadings
4. Determination of fluid properties
5. Column diameter and tray spacing calculations

Calculation of the column reflux and theoretical and actual stages is relatively straightforward for most systems. For some systems, however, determining the tray efficiency can be rather arduous and is subject to even further uncertainties due to the tray design itself. Occasionally, some tray efficiencies have been substantially below those of others in the same service, and have to be attributable to the tray configuration. Determination of the proper feed tray is usually predictable if the feed composition remains fairly constant, and the tray efficiencies above and below the feed are known.

The overall heat and weight balance for the column is probably the most straightforward of the steps and is usually quite accurate.

Calculation of the tray loadings is done by an internal heat and weight balance and is usually quite accurate. However, for some cases, at the bottom of the fractionator, the loadings may be subject to a number of uncertainties due to a dependence on the tray efficiencies, the type of reboiler, and a rigorous heat balance.

Determination of the fluid properties is difficult for some systems, particularly in those with foaming tendencies. Proper identification is critical, however, because foam can derate a system and increase the required column area by as much as 100 percent. Other properties such as surface tension and vapor density may contribute additional derating factors and are not always clear cut.

Finally, the calculation of the column diameter and tray spacing is done by one or more of a number of methods published by the various fractionator tray vendors in their design manuals or by the methods of Fractionation Research, Inc. The main difficulty here is that for some services there are differences in the diameters calculated by the various methods, giving at least a 10 percent difference in tower areas. Some methods are more conservative for high pressure systems and others for low pressure systems. The decision on what percentage of flood to use in column design is not difficult after looking at the relative costs of the fractionating tower plus trays to the total fractionating system, including the condensers, reboilers, piping, instruments, insulation, etc., as will be discussed later. At UOP our normal design factor is 75 percent of flood on most fractionating systems and our base case, in the study described later in this paper, is for this percent of jet flood. Our main reason for using 75 percent has been to provide for dynamic changes in the system caused by variations in the feed composition as well as the feed and reflux rates. Another reason is to provide some small margin for additional capacity in the column, since it is the most difficult part of the system to enlarge, if it is ever required.

With the uncertainties of the sizing methods used and the actual loadings and properties of some of the systems still in mind, incremental tower costs can be examined to see whether they are significant enough to be worthy of all the efforts to reduce them to an absolute minimum. In order to obtain the best numbers available, the UOP Process Division Estimating Department developed the data presented here based on first quarter 1981, U.S. Gulf Coast costs. Where total costs are given, they are erected costs, including contractor's engineering charges and fees. No offsite or site preparations are included. Six fractionator designs ranging from 5 ft-0 inches diameter to 29 ft-0 inches diameter were estimated with the number of trays varying from 30 to 150, design pressures from 50 to 150 pounds per square inch, gauge, and trays spacings from 10 to 24 inches. The bulk of the materials of construction was assumed to be carbon steel.

Results of the Study

The total fractionation system cost is given in Figure 1 for a 30-tray column of various diameters at 50, 100 and 150 pounds per square inch, gauge design pressures. Note the small differences in total cost between the 50 and 150 pound lines, which are about 8 percent for a 15 foot diameter column and 13 percent for 29 feet.

The percent of the total cost contributed by the fractionator and trays is shown in Figure 2 for the three pressure levels used in Figure 1. Note that the fraction of the total cost of the fractionator and trays at 12 feet diameter is only about 8 percent, and is between 12 and 18 percent at 29 feet. Obviously, the only cost difference in the three pressure ranges used is in the column itself, since the trays would be the same for all the pressures at a given diameter.

The total fractionation system cost for a 100 pound per square inch, gauge design pressure for various diameters with 30, 90 and 150 trays is given in Figure 3. Note that for the smaller diameters, the cost difference between 30 and 150 trays is about 58 percent, while at 29 feet the difference is about 77 percent.

Figure 4 shows the percent of the total cost contributed by the fractionator and trays for the system given in Figure 3, at the three tray levels given. The percent cost contributed by the fractionator and trays is less than 20 percent for 150 trays for a diameter of 10 feet, and between 15 and 35 percent for 29 feet, depending on the number of trays involved.

The difference in cost, in percent of the total system, between 24 inch tray spacing and spacings down to 10 inch for a 12 foot diameter, 80 tray fractionating column designed for a pressure of 100 pounds per square inch, gauge is shown in Figure 5. Figure 6 shows the percent of jet flood corresponding to the various tray spacings at constant tray loadings. Note that the small difference in total cost between 18 and 12 inch tray spacing is only 3.1 percent, while the jet flood is increased from 83 to 100 percent, corresponding to a reduction in capacity of about 20 percent.

Figure 7 shows the percent change in the fractionating system cost for a change of 10 percent in the jet flood of a tray. This chart is the most significant in terms of column economics since it

shows that, for a change from 75 to 85 percent of jet flood, there is only about a 2.3 percent savings in the total system cost for a 12 foot diameter, 80 tray column and about 4.5 percent for a 29 foot diameter, 100 tray column. This small cost savings would reduce the operating capacity of both column sizes by over 13 percent, which is a high price to pay in decreased operating flexibility and future capacity. The large difference in capacity reduction versus the small capital reduction is due entirely to the fact that the fractionator and trays are normally not a large percentage of the cost of the overall fractionation system.

Another item that is frequently neglected in a vain attempt to reduce costs is the matter of vacuum design of fractionation systems. Our studies have indicated that the costs are practically insignificant in terms of the overall cost, even for field fabricated systems. The 12 foot diameter fractionator used in our study with 90 trays and designed for an internal pressure of 100 pounds per square inch, gauge, would cost about 3.6 percent more for the fractionator alone and only about 0.5 percent more for the entire system to be designed for full vacuum.

Conclusion

The total costs associated with a fractionating system are not significantly affected by designing for a high percent of flood; however, the capacity and operating flexibility are severely restricted. The costs are somewhat more dependent on the number of trays in the fractionator and to a much lesser extent on trays spacings, although the latter effect is even less when the diameter is adjusted for a constant percent of flood. When designing any fractionating system, the primary consideration should be the process requirements and the operating flexibility of the system. Future capacity should also be given some consideration, since the column is, without a doubt, the most difficult item to replace when expanding a unit.

Acknowledgment

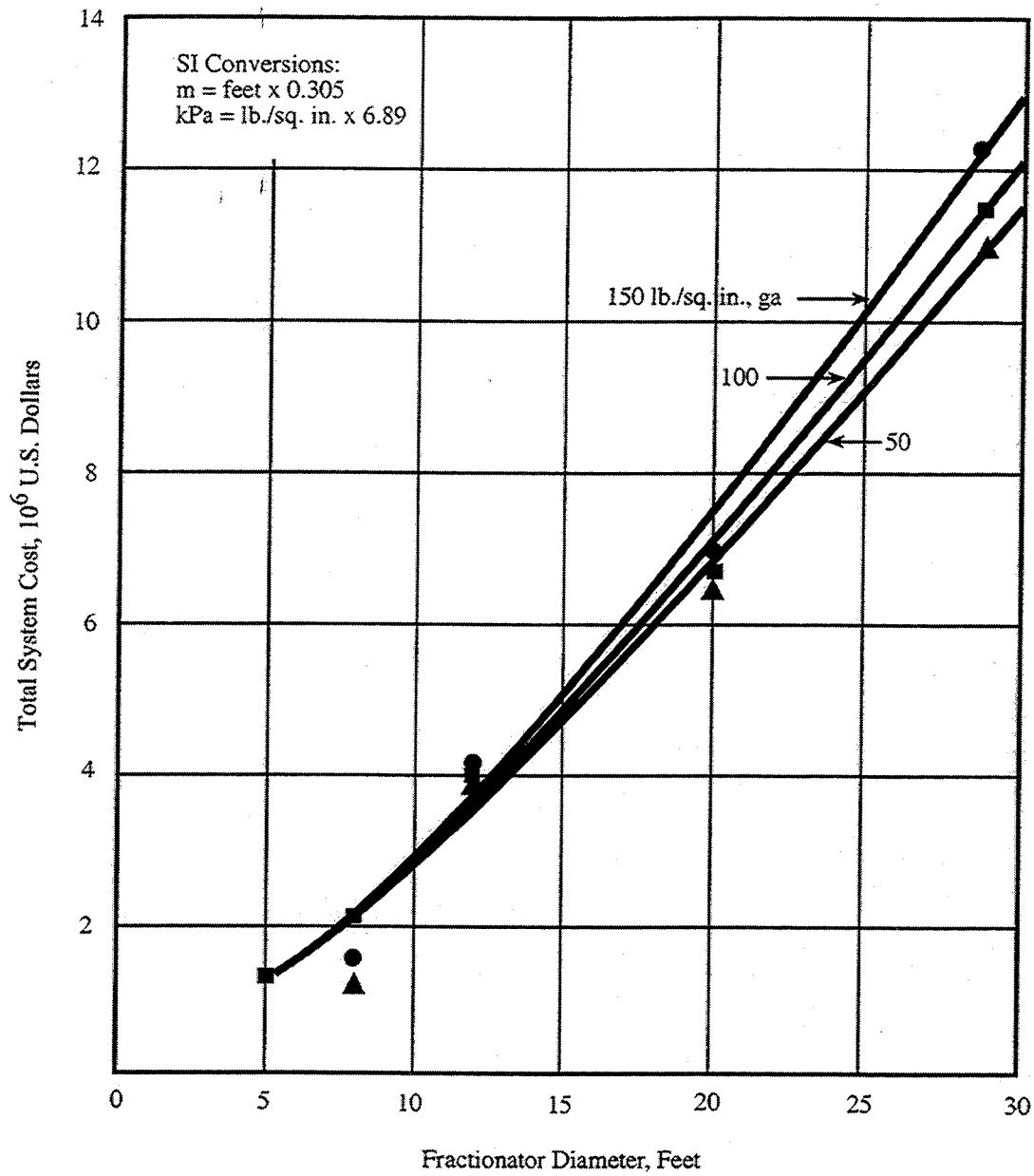
The authors wish to thank Mr. K. D. Uitti, UOP Process Division, retired, for his valuable background contributions to this article.

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2. Fractionator and Tray Cost as Percent of System Cost – 30 Trays at 24 Inch Spacing
3. System Cost as Function of Number of Trays
4. Fractionator and Tray Cost as Percent of System Cost – Pressure 100 psig
5. Percent Savings from 24 Inch Spacing
6. Percent of Jet Flood at Constant Tray Loadings at Various Tray Spacings
7. Cost of 10 Percent Change in Tray Jet Flood

FIGURE 1

System Cost as Function of Pressure
30 Trays at 24 Inch Spacing



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FIGURE 2

*Fractionator and Tray Cost
as Percent of System Cost*

30 Trays at 24 Inch Spacing

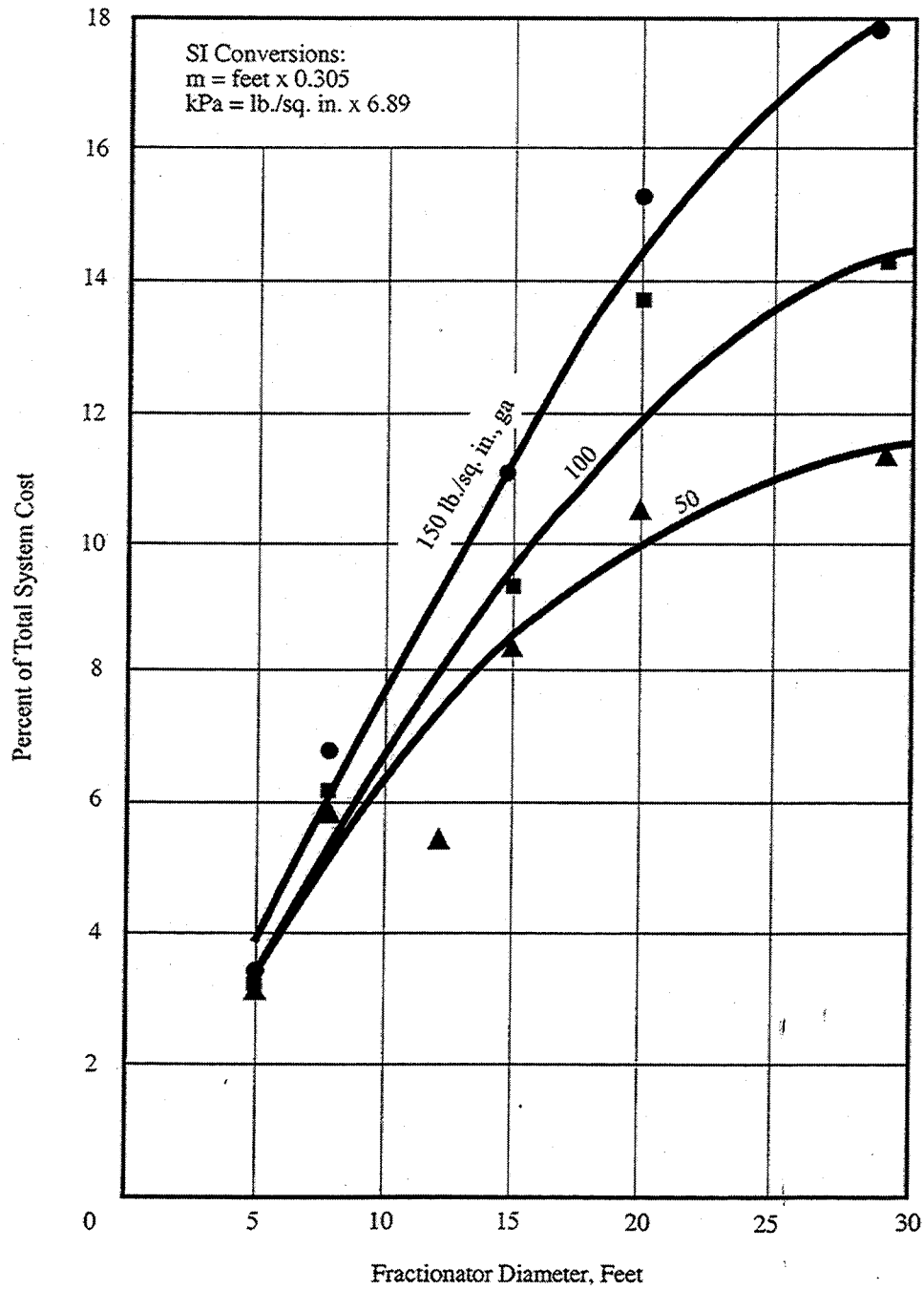
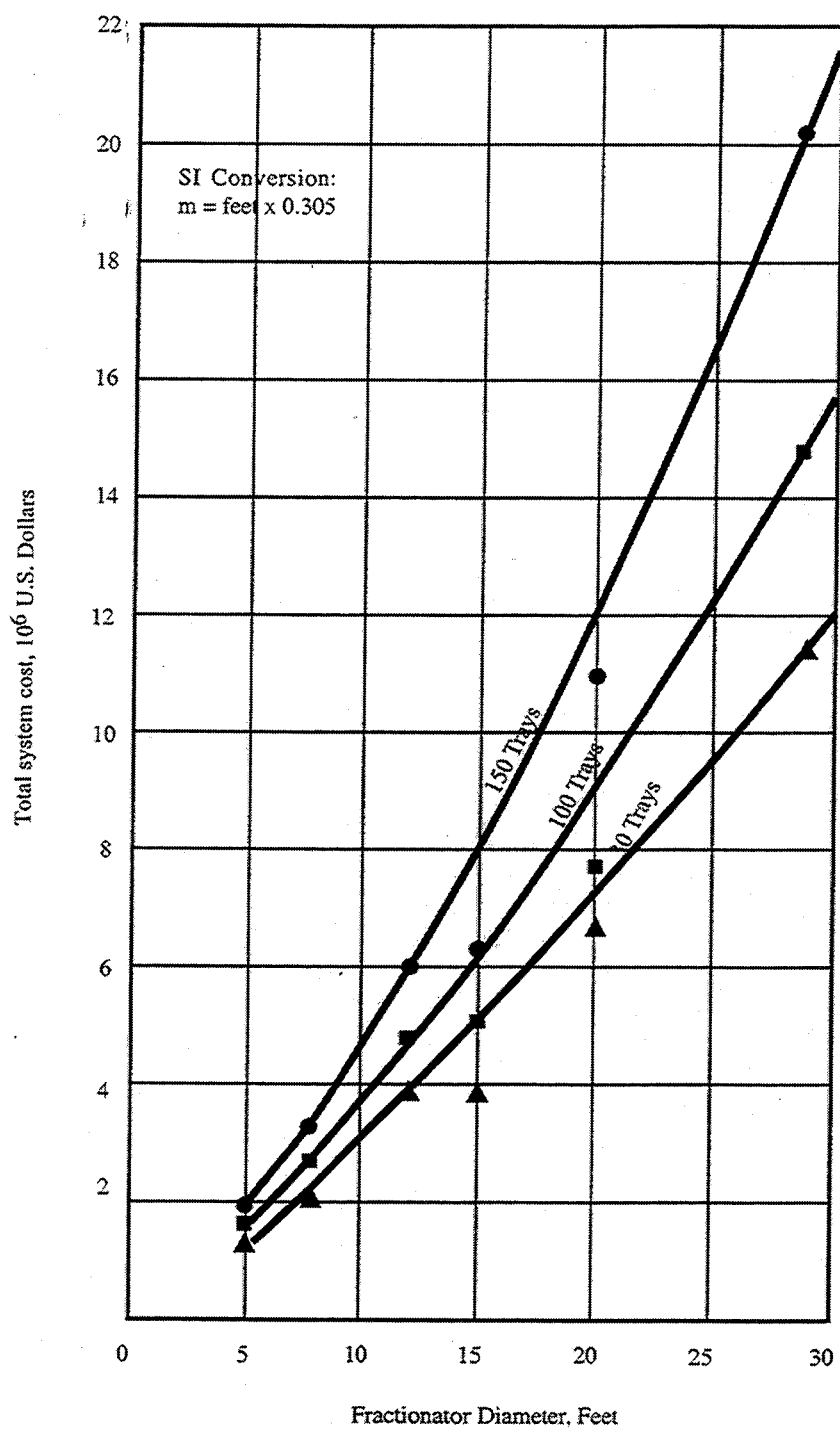


FIGURE 3

System Cost as Function of Number of Trays
Pressure 100 psig



TS-R00-11

FIGURE 4

*Fractionator and Tray Cost
as Percent of System Cost
Pressure 100 psig*

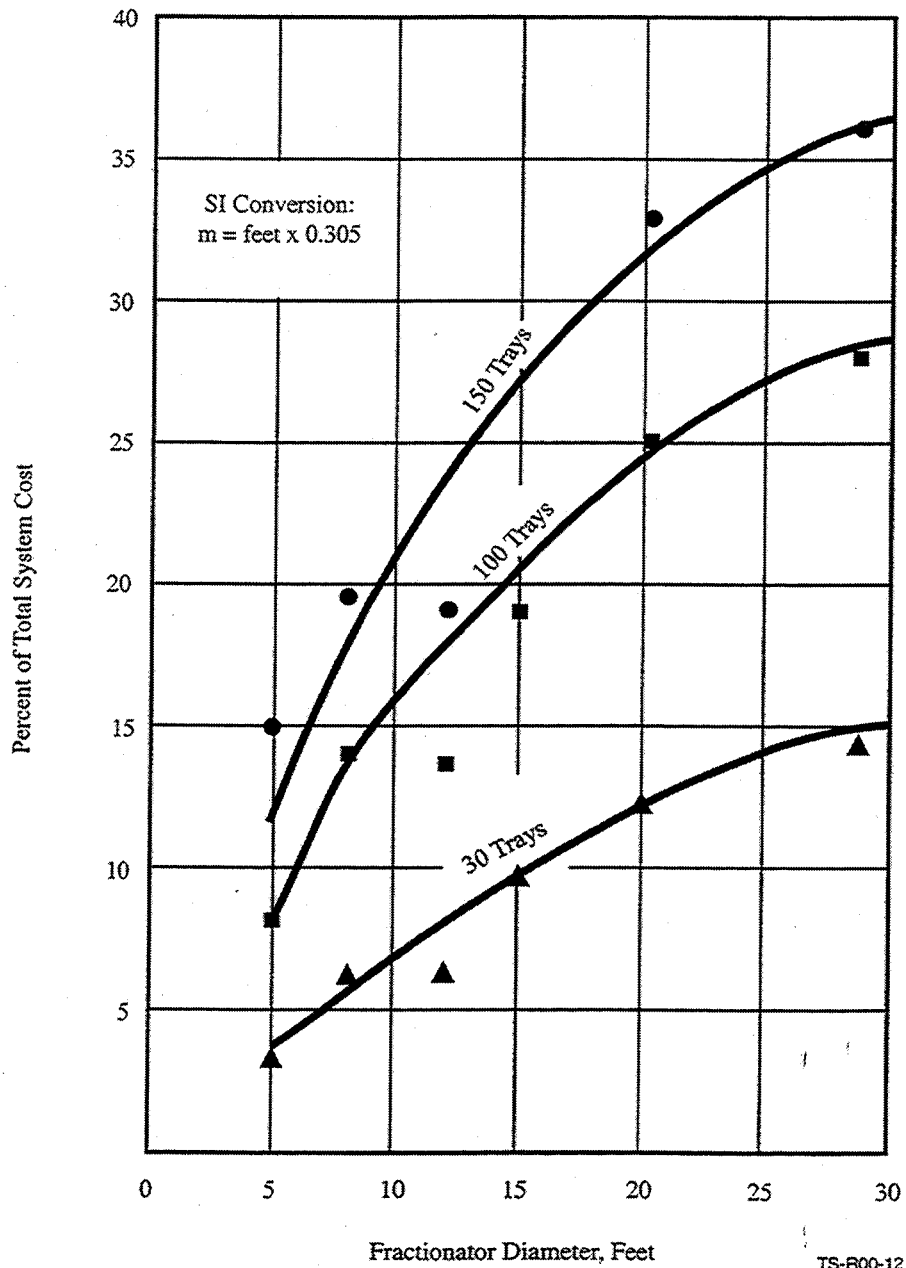
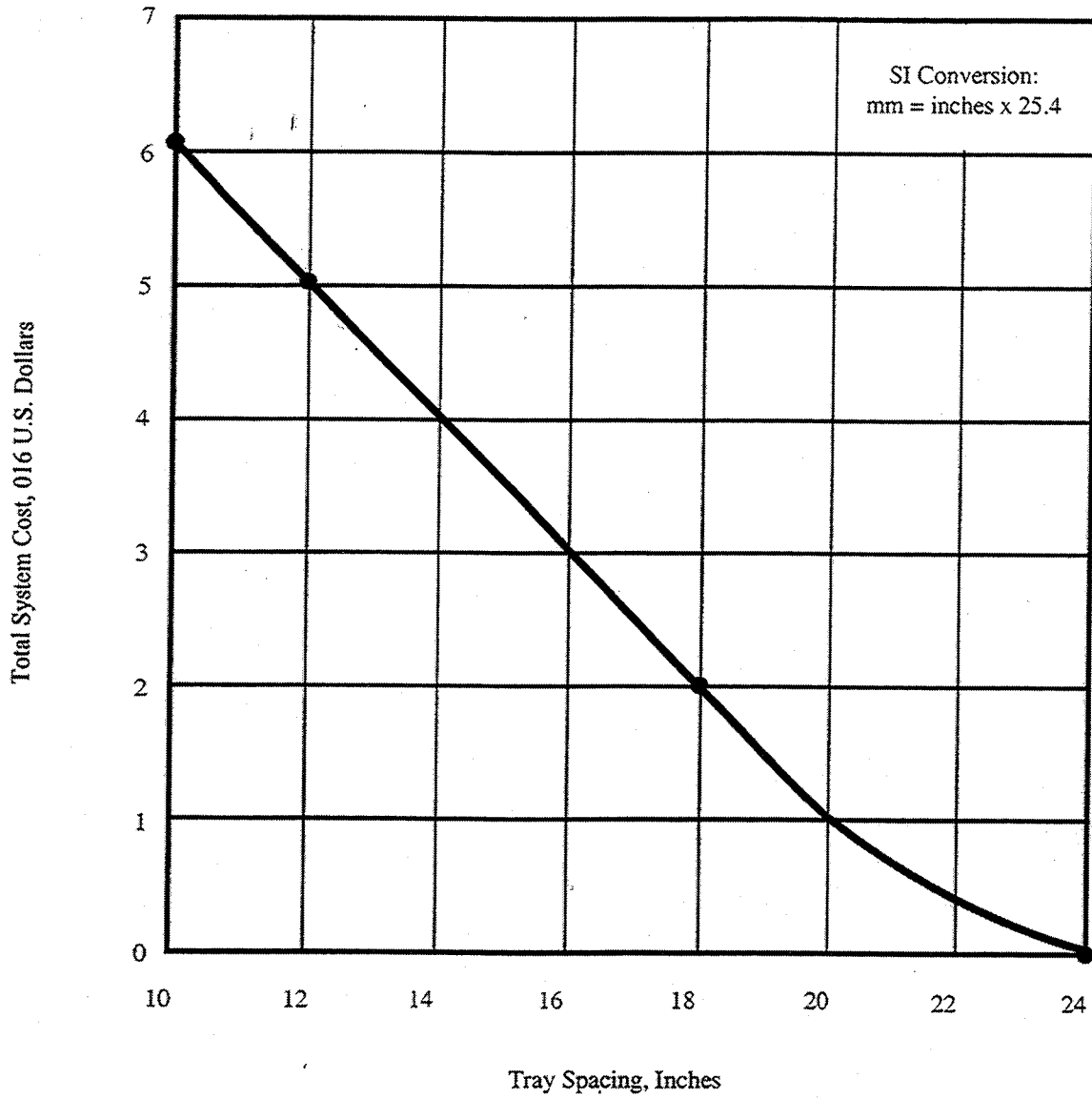


FIGURE 5

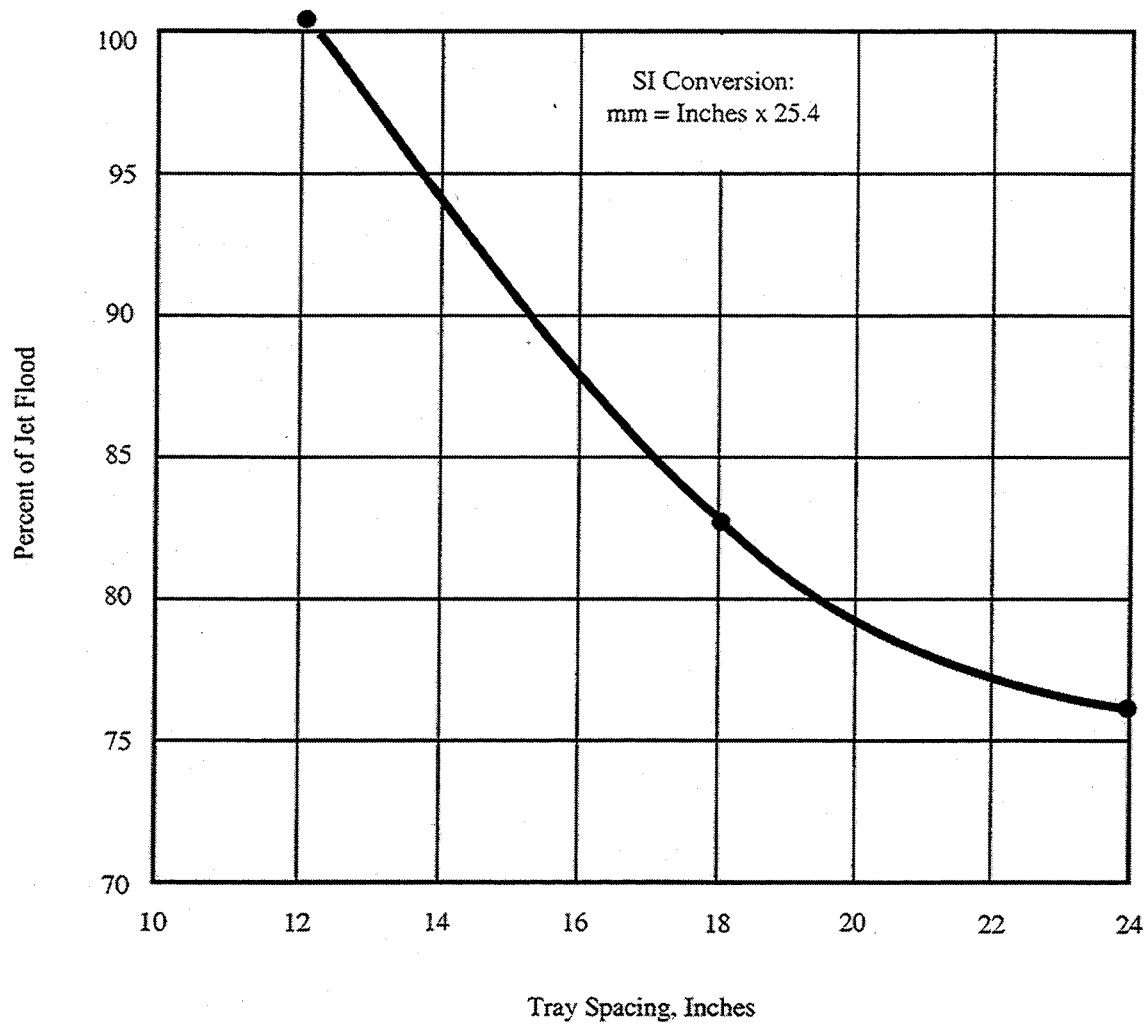
*Percent Savings
From 24 Inch Spacing
12 Feet Diameter, 80 Tray,
100 psig Fractionator*



TS-R00-13

FIGURE 6

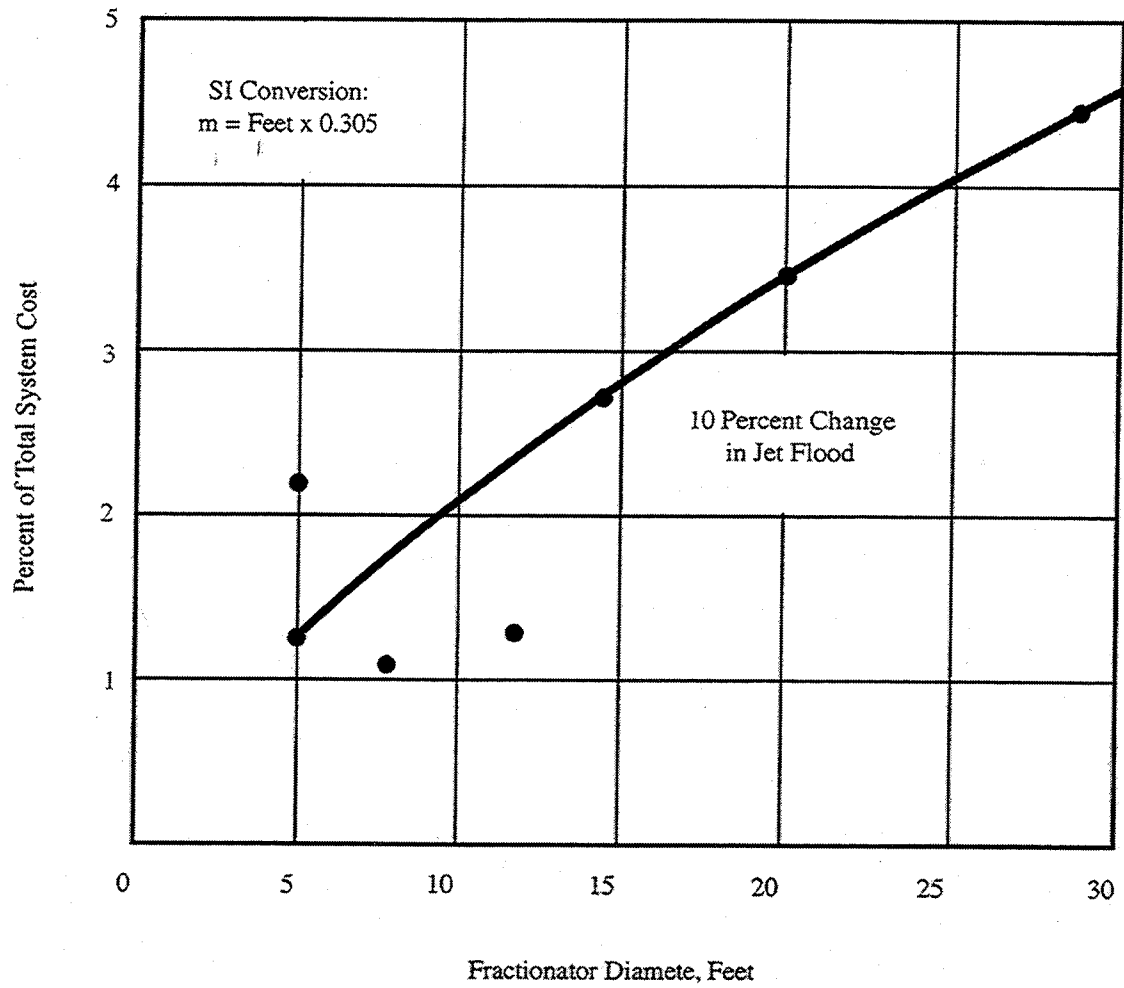
*Percent of Jet Flood
at Constant Tray Loading
at Various Tray Spacings
Medium Pressure Fractionator*



TS-R00-14

FIGURE 7

*Cost of 10 Percent Change
in Tray Jet Flood
Medium Pressure Fractionator*

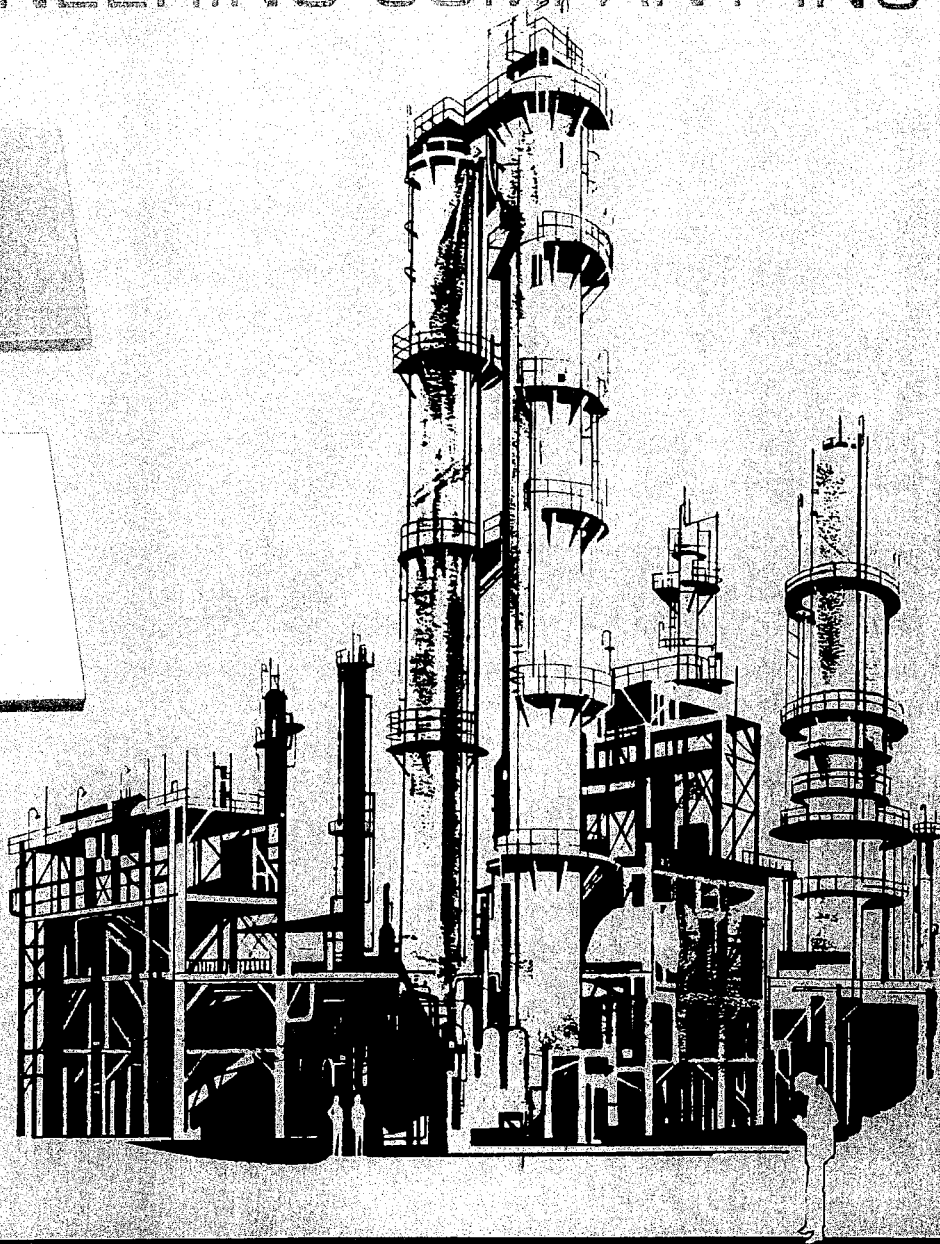
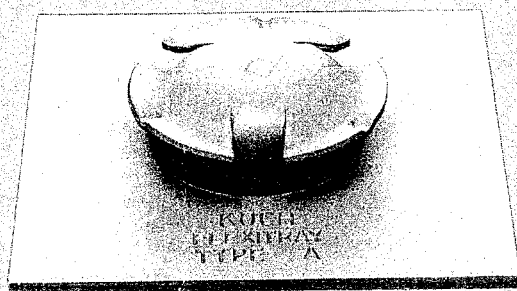
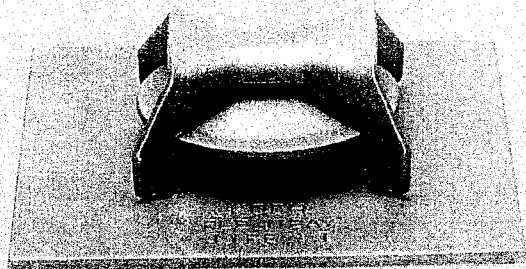


TS-R00-15

K KOCH®

Bulletin 960-1

KOCH ENGINEERING COMPANY INC



DESIGN MANUAL

FLEXITRAY®

Valve Trays

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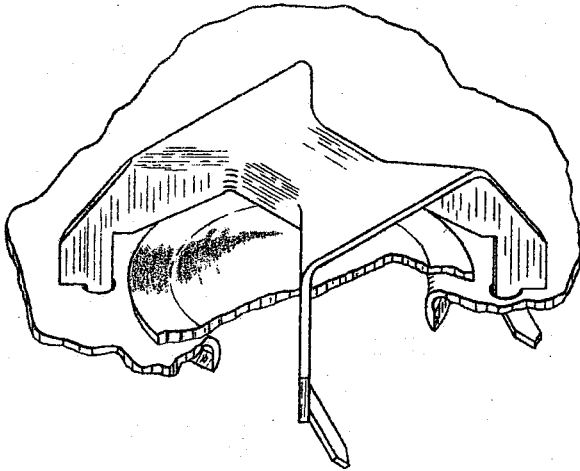
KOCH FLEXITRAY® DESIGN AND RATING PROCEDURE INTRODUCTION

The FLEXITRAY® is a valve type tray having liftable valves, approximately 2 inches in diameter, which operate like check valves. These valves have a limited lift and are spaced on 3 to 6 inch centers. The capacity of the FLEXITRAY exceeds that of a well designed sieve tray and maintains almost constant tray efficiency over a wide operating range.

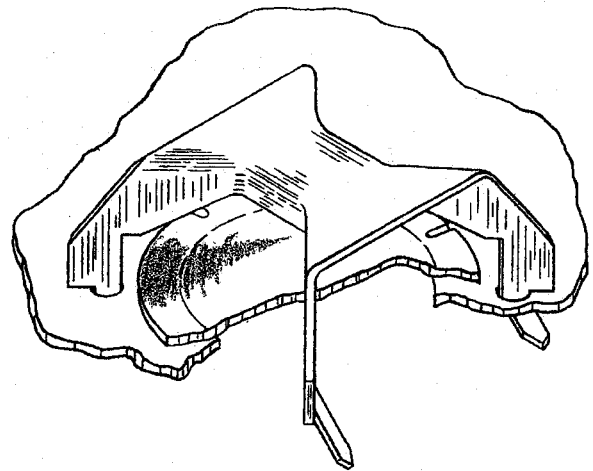
There are basically two variations of the valve assembly, type "T" and type "A." The "T" assembly has a movable valve contained by a four-legged hold-down cage attached firmly to the tray deck. The "A" assembly is a movable round valve with integral guide legs and lift stops.

The FLEXITRAY is available with several valve designs for specific purposes as shown below.

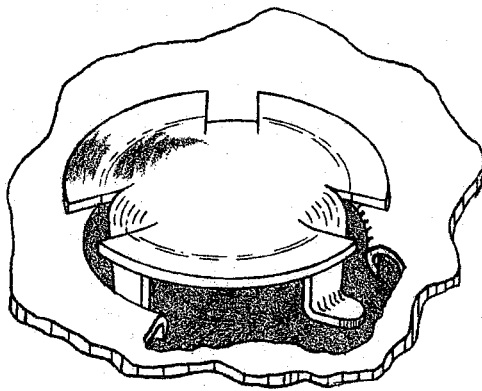
Valve Type	Tray Description
"A"	With type "A" valve assembly and standard hole in tray floor.
"A _o "	With type "A" valve assembly and a special shaped contoured hole in the tray floor for <u>lower dry tray pressure drop</u> than the standard hole.
"T"	With type "T" valve assembly and a standard hole in tray floor. This type valve has been used successfully for many years in the dirtiest of services including slurries. It is also the preferred choice for corrosive services.
"T _o "	With type "T" valve assembly and a special shaped contoured hole in the tray floor for <u>lower dry tray pressure drop</u> than the standard hole.
"S"	With valve punched up in tray deck, yet still attached, making it a stationary assembly.



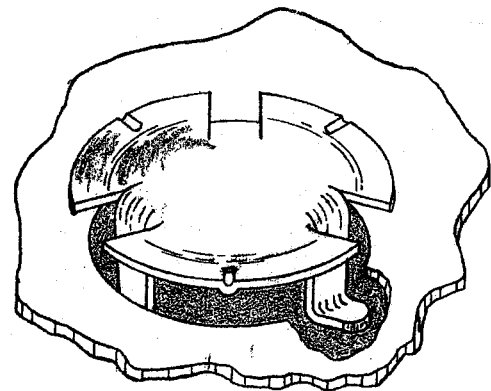
TYPE "T₀"



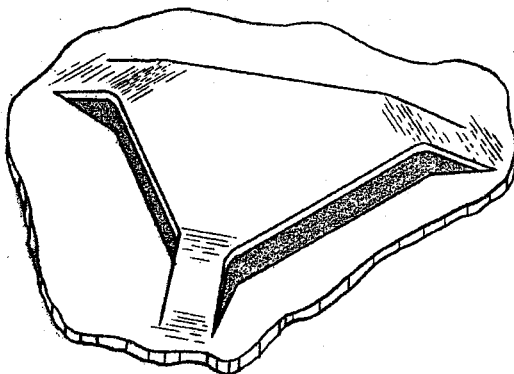
TYPE "T"



TYPE "A₀"



TYPE "A"



TYPE "S"

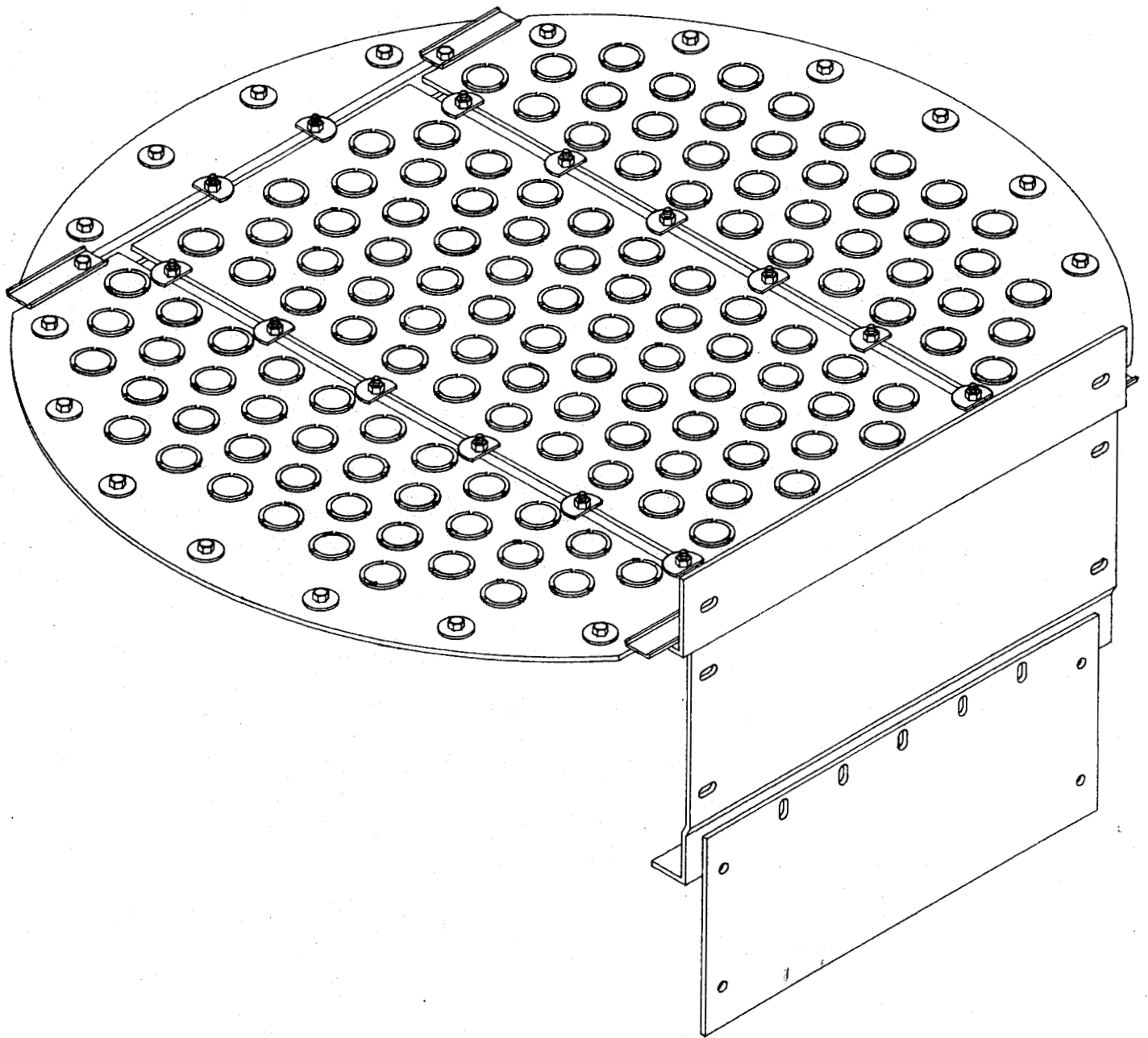
INTRODUCTION (cont.)

All types, excluding type "S," have equal capacity and a wide operating range.

Usually two weights of valves are used on type "A" and "T" trays. The different valve weights alternate in rows parallel to the outlet weir and insure vapor distribution at lower vapor rates. The lighter valves open during the first 20-30% of tray capacity and the heavier valves open from 30-70% capacity. At higher rates, all valves are fully open. Because there is no measurable hydraulic gradient, a uniform vapor flow exists over the entire tray.

The many advantages of the FLEXITRAY compared to other trays are:

1. The FLEXITRAY has a high capacity for a given tower size. The FLEXITRAY exhibits lower entrainment than sieve trays because of the horizontal flow of vapor from the valves.
2. The FLEXITRAY has higher efficiency over a wider operating range. The horizontal vapor flow from the valves, distributed around the 360° valve perimeter at deck level, promotes maximum mixing with the liquid. Greater efficiency permits reduction of the reflux ratio for a given tower diameter or allows a smaller tower diameter for a given feed rate.
3. The FLEXITRAY is less sensitive to "out-of-levelness" than other tray types. Froth on the tray extends down to the deck in contrast to the geysers of froth on a sieve tray. This reduces the hydraulic imbalance.
4. The FLEXITRAY permits longer run lengths in fouling services because the horizontal radial vapor flow at the tray floor eliminates "dead spots" where solids may settle, polymer growth can start or decomposition (cooking) can occur. The type "T" valve tray is especially suited to these situations.
5. The FLEXITRAY has been in commercial use since 1952 in tens of thousands of installations. They have replaced bubble cap trays as a standard of performance and are accepted today as the proven performer in all liquid-vapor contacting applications.



KOCH FLEXITRAY®
TYPICAL 4'-0" SINGLE FLOW TYPE "A"

DESIGN DISCUSSION

Capacity Limitations

The capacity limitations of a tray may be caused by either flooding or blowing.

Flooding occurs when the downcomers fail to carry away the required amount of liquid, and the excess liquid fills the trays; resulting in loss of bottoms product, low tray efficiency, sharply increased pressure drop, insensitivity to control, etc. With a properly proportioned tray, flooding will be initiated by jetting, i.e., the top of the vapor-liquid contacting mass of large droplets will reach the tray above; resulting in massive entrainment which will in turn cause high pressure drop, high liquid recycling and flooding. If the downcomer is too small or tray pressure drop is too high, the tray will flood prematurely by downcomer backup, even though the height of the contacting mass would otherwise be low and entrainment negligible.

Blowing is the opposite of flooding in that the liquid is blown into a fine spray leaving the tray essentially dry. The resulting lack of contacting severely reduces tray efficiency. Blowing occurs only at a very high vapor- to- liquid ratio. The vapor velocity vector exiting the FLEXITRAY is directed horizontally rather than vertically as with sieve trays. Therefore, chances of "blowing" are greatly reduced when using the FLEXITRAY. "Picket fence" weirs are recommended to maintain a minimum weir loading of 5 GPM/ft.

Weir Height

A 3" weir height is normally used in pressure columns with 24" tray spacing. Little difference has been found in tray efficiency with weir heights varying from 1½" to 3"; however, a minimum weir height of 2" is recommended for all services except vacuum towers, where a 1" minimum weir height is recommended.

If more weir length is needed than is provided by the weir of a segmental downcomer, consider a swept-back weir.

The downcomer clearance is usually ½" less than the height of the outlet weir, although trays with unusually high liquid rates have been designed where the clearance is greater than the height of the weir. At low design liquid rates, ¾" to 1" clearance should be used to reduce column start-up time.

Tray Spacing

The choice of tray spacing is a function of desired tower length-to-diameter ratio, maintenance access and process load considerations. When a drawoff sump is required, special consideration should be given to the vapor-liquid disengaging space between the floor of the sump and the downcomer of the tray below. When the depth of a full chord sump exceeds 20 percent of the tray space, the tray capacity must be derated by reducing the effective tray space or additional tray spacing must be provided. The preferred tray spacing is generally specified by the customer. Tray spacing of 24" is considered normal and is standard for Charts A and C, discussed later in the design procedure.

Internal piping should be avoided where possible. If internal piping must be used, it should be arranged to avoid obstructing froth flow across the tray and maintenance access between the trays.

SYSTEM FACTORS

Systems with foaming tendencies are taken into account by using a factor to derate the capacity of a given tray design. A list of the more common foaming systems and their recommended factor is below.

SYSTEM	FACTOR
Absorbers (over 0°F)	.85
Absorbers (below 0°F)	.80
Amine Contactor	.80
Vacuum Towers	.85
Amine Stills (Amine Regenerator)	.85
H ₂ S Stripper	.85
Furfural Fractionator	.85
Top Section of Absorbing Type Demethanizer/Deethanizer	.85
Glycol Contactors	.50
Glycol Stills and Glycol Contactors in Glycol Synthesis Gas	.65
CO ₂ Absorber	.80
CO ₂ Regenerator	.85
Caustic Wash	.65
Caustic Regenerator, Foul Water, Sour Water Stripper	.60
Alcohol Synthesis Absorber	.35
Hot Carbonate Contactor	.85
Hot Carbonate Regenerator	.90
Oil Reclaimer	.70

The capacity of a given tray design used in high pressure fractionation service with a vapor density of 1.8 lb. per cu. ft. and higher should be derated by a system factor calculated by the following formula:

$$\text{system factor} = \frac{1.21}{(d_v)^{0.32}}$$

DESIGN RATING PROCEDURE

A quick approximation procedure for determining the diameter of a column equipped with the FLEXITRAY, followed by a detailed sizing procedure, is outlined in the following sections. This rating procedure has been in general use for more than 20 years and has proven to be extremely accurate in tens of thousands of installations.

A. Tray Space Factors

Tray space factors to be used with Charts A and C are as follows:

Tray Spacing Inches	Vapor Density Less than 1.5 lbs./ft ³ .	Vapor Density Greater than 1.5 lbs./ft ³ .
12	0.65	0.65
15	0.75	0.75
18	0.84	0.84
21	0.92	0.92
24	1.00	1.00
27	1.073	1.06
30	1.142	1.12
36	1.22	1.15

B. Preliminary Sizing

Chart A provides a quick approximation only of column diameter and should be verified by a detailed design before the column diameter is finalized.

The steps for using Chart A are as follows:

1. Determine the vapor rate in actual cubic feet-per-second (ACFS), the liquid rate in gallons-per-minute (GPM), the vapor and liquid densities in pounds-per-cubic foot, all at actual tower operating conditions of temperature and pressure. Then decide on the tray spacing to be used.
2. Calculate the square root factor,

$$\sqrt{\frac{d_v}{d_l - d_v}}$$

Where: d_v = vapor density, lbs./ft³.

d_l = liquid density, lbs./ft³.

3. Calculate the vapor loading factor,

$$\text{ACFS} \sqrt{\frac{d_v}{d_l - d_v}}$$

4. Correct the vapor loading factor and liquid rate by dividing by the tray space factor and system factor found on page 6.

$$\text{Corrected vapor load factor} = \frac{\text{ACFS} \sqrt{\frac{d_v}{d_l - d_v}}}{(\text{Tray space factor}) (\text{System factor})}$$

$$\text{Corrected liquid rate} = \frac{\text{GPM}}{(\text{Tray space factor}) (\text{System factor})}$$

5. Plot the corrected vapor loading factor and corrected liquid rate on Chart A.
6. Read the minimum diameter from Chart A, noting that in many cases the minimum diameter will depend on the number of liquid flow passes per tray.

After preliminary diameter, number of liquid passes and tray spacing have been established, a detailed tray design is made and then checked against the capacity correlation.

C. Detailed Sizing

1. Establish vapor and liquid rates as in Steps 1, 2 & 3 of Preliminary Sizing.
2. Size the downcomers. The following sizing method is based on an assumed design loading equivalent to 85% of calculated capacity. If some other design loading is used, the downcomer area should be adjusted accordingly. For most hydrocarbon columns using 24" tray spacing, sizing of the effective area at the top of the downcomer is based on a hot liquid rate of 175 GPM/ft². This is equivalent to a residence time of 5.13 seconds with a downcomer of constant size from top to bottom.
 - (a) To calculate the minimum downcomer area, use the following formula:

$$\left(\frac{\text{GPM}}{175}\right)\left(\frac{24}{\text{TS}}\right)\left(\frac{1}{\text{SF}}\right) = \text{Downcomer area, ft}^2 \quad (\text{eq.1})$$

SF is system factor if required, from page 6. TS is tray spacing in inches. Extrapolation for tray spacing greater than 30" is not recommended.

- (b) When the value of $d_l - d_v$ is less than 30 lbs./cu. ft., determine the design GPM/ft² from Chart B which compensates for the difficulties of settling froth as the density difference decreases.

$$\left(\frac{\text{GPM}}{\text{GPM/ft}^2, \text{ from Cht. B}}\right)\left(\frac{24}{\text{TS}}\right) = \text{Downcomer area, ft}^2 \quad (\text{eq.2})$$

Use the larger value calculated from eq. (1) or (2) for the minimum downcomer area.

3. Charts D and D.1 are provided for rapid determination of segmented downcomer areas. Choose a chord that will provide at least the minimum downcomer area previously determined.
4. For a one-pass tray design the bubbling area is determined by the following formula:

$$A_b = A_t - A_{dt} - A_{db} - A_e$$

$$A_b = \text{bubbling area}$$

$$A_t = \text{tower cross-sectional area}$$

$$A_{dt} = \text{downcomer area at top}$$

$$A_{db} = \text{downcomer area at bottom}$$

$$A_e = \text{edge loss for 3' - 6" diameter and smaller*}$$

$$A_e = \frac{(\text{FPL})(\text{SRW})}{66}$$

Where: FPL = flow path length, inches

SRW = support ring width, inches

*Do not use the edge loss term for tower diameters greater than 3' - 6".

5. By using Charts E and E.1, determine the weir length corresponding to the chord height chosen in paragraph 3 above.

6. Calculated Tray Capacity -- determine the percent of calculated tray capacity by using Chart C or the following formula:

Percent calculated tray capacity =

$$\frac{100}{(\text{TSF}) (\text{SF}) (0.51)} \left[C_{\text{sf (net)}} + (0.001327) \frac{\text{GPM}}{L_w} \right] \quad (\text{eq.3})$$

TSF = tray space factor

SF = system factor

$$C_{\text{sf (net)}} = \left(\frac{\text{actual CFS}}{A_b} \right) \sqrt{\frac{d_v}{d_l - d_v}}$$

A_b = bubbling area, sq. ft.

L_w = weir length, ft.

$$\text{If } \left(\frac{C_{\text{sf (net)}}}{\text{GPM}/L_w} \right) > 0.0102$$

$$\text{Percent calculated tray capacity} = \frac{100 C_{\text{sf (net)}}}{(0.46) (\text{TSF}) (\text{SF})}$$

7. Downcomer Capacity -- check the percent downcomer capacity by using the following formula:

$$\text{Percent downcomer capacity} = \left(\frac{\text{GPM}}{A_d} \right) \left(\frac{85}{175^*} \right) \left(\frac{1}{\text{SF}} \right) \left(\frac{24}{\text{TS}} \right) \quad (\text{eq.4})$$

*or Chart B value as discussed on page 8.

If Chart B value used, SF = 1.

A_d = downcomer area, ft²

SF = system factor

TS = tray spacing, inches

8. Compare eq.3 and eq.4 calculated values. If the percent calculated tray capacity from eq.3 is less than 85%, the downcomer area should be increased and steps 3 - 7 repeated until the values for eq.3 and eq.4 are very close. This constitutes a balanced design. If the values for eq.3 and eq.4 are much lower than 85%, a smaller column diameter should be tried. Columns should be designed so that calculated tray capacity does not exceed 85%.

9. If sloped downcomers are used, the area at the bottom should not be less than 50% of the area at the top.
10. Set weir height. For pressure fractionators, the usual weir height is 3" at 24" and larger tray spacing, 2½" at 18" spacing, and 2" at 12" spacing. For vacuum fractionators, the usual weir height is 1" to 1½".
11. Set downcomer clearance. With the downcomer clearance set at ½" less than the weir height, check the pressure drop under the downcomer using Chart F. If the pressure drop exceeds 1.5 inches of hot liquid, the downcomer clearance should be increased. Ordinarily, the weir height is also raised to retain the ½" seal. However, where liquid rates will always be high, a zero seal is permissible. When the liquid rate is extremely low, a ¾" to 1" clearance is preferred.

D. Pressure Drop

1. Convert the vapor rate to CFM air equivalent

$$\text{CFM (air equivalent)} = 60 \text{ ACFS} \sqrt{\frac{d_v}{0.0735}}$$

2. Estimate the number of valves on the tray by multiplying the bubbling area by the approximate valves per-square-foot from the table below.

TOWER DIAMETER	APPROXIMATE VALVES PER-SQUARE-FOOT
2'-6" to 4'-0"	10
4'-6" to 7'-6"	11.5
8'-0" to 11'-6"	12.5
12'-0" and larger	13.5

3. Calculate CFM (air equivalent) per valve = CFM/No. valves.
4. Read dry tray pressure drop from Chart G using the appropriate curve for the type of valve chosen.
5. Read the effective depth of liquid from Charts H through L for the appropriate weir height.
6. Convert the effective liquid depth to inches of water pressure drop.

$$\text{liquid pressure drop} = \text{effective liquid depth} \left(\frac{d_l}{62.4} \right)$$

7. Add the dry tray pressure drop to the liquid pressure drop to give total tray pressure drop in inches of water. Convert inches of water pressure drop to mmHg by multiplying by 1.865.

EXAMPLE PROBLEM NO. 1: HYDROCARBON FRACTIONATOR

GIVEN: Vapor Rate = 21150 lbs./hr.
 Vapor Density = 1.7 lbs./cu. ft.
 Liquid Rate = 143855 lbs./hr.
 Liquid Density = 42.7 lbs./cu. ft.
 Tray Spacing = 24"

DETERMINE: Safety Factor = 1.0 because non-foaming and $d_v < 1.8$ (pg. 6)

CALCULATE: Vapor ACFS = $\frac{211500}{*(3600)(1.7)} = 34.56$

Vapor Load = $34.56 \sqrt{\frac{1.7}{42.7 \cdot 1.7}} = 7.037$ (para. B.3.)

GPM = $\frac{143855}{*(8.021)(42.7)} = 420$

From Cht. A, Trial Diameter 6'-0" I.D., S.F. (para B.)

Min. DNC area = $\frac{420}{175} = 2.4$ sq. ft. (para C.2.)

From Cht. D, 10" chord height = 2.4 sq. ft. (para C.3)

Bubbling area = $28.27 - 2(2.4) = 23.47$ sq. ft. (para C.4)

From Cht. E, Weir Length = 4.17 ft.

% Tray Capacity = $\frac{100}{0.51} \left[\frac{7.037}{23.47} + 0.001327 \left(\frac{420}{4.17} \right) \right] = 85\%$ (para C.6.)

% DNC Capacity = $\left(\frac{420}{2.4} \right) \left(\frac{85}{175} \right) = 85\%$ (para C.7.)

CFM (air) = $(60)(34.56) \sqrt{\frac{1.7}{0.0735}} = 9973$ (para D.1.)

Estimated No. Valves = $23.47(11.5) = 270$ (para D.2.)

$\frac{\text{CFM (air)}}{\text{valve}} = \frac{9973}{270} = 36.94$ (para D.3.)

GPM/ft. of weir = $\frac{420}{4.17} = 100.72$

For 24" TS, use 3" weir height (para C.10.)

Using Type A valves: (pg. 1.)

Dry Pressure Drop, Cht. G = 2.25" water (para D.4.)

Liq. Pressure Drop, Cht. L = $2.8 \left(\frac{42.7}{62.4} \right) = 1.92$ (para D.6.)

Total Pressure Drop/Tray = $2.25 + 1.92 = 4.17$ " water (para D.7.)
 = 7.78 mmHg

*conversion factor
 DNC = Downcomer

EXAMPLE PROBLEM NO. 2: HYDROGEN FRACTIONATOR

GIVEN: Vapor Rate = 497079 lbs./hr.
Vapor Density = 1.7 lbs./cu. ft.
Liquid Rate = 513770 lbs./hr.
Liquid Density = 42.7 lbs./cu. ft.
Tray Spacing = 24"

DETERMINE: Safety Factor = 1.0 because non-foaming and $d_v < 1.8$ (pg. 6)

CALCULATE: Vapor ACFS = $\frac{497079}{*(3600)(1.7)} = 81.22$

Vapor Load = $81.22 \sqrt{\frac{1.7}{42.7 \cdot 1.7}} = 16.539$ (para. B.3.)

GPM = $\frac{513770}{*(8.021)(42.7)} = 1500$

From Cht. A, Trial Diameter 10'-0" I.D., D.F. (para B.)

Min. DNC area = $\frac{1500}{175} = 8.57$ sq. ft. (para C.2.)

From Cht. D, 12.5" chord height = 4.35 sq. ft. (para C.3)
Total side DNC area = $2(4.35) = 8.7$ sq. ft.
Select center DNC width - 10.5"

Center DNC area = $\frac{10.5}{12} (10.0) = 8.75$ sq. ft.

Bubbling area = Tower Area - Total side DNC area
- Center DNC area at bottom
= $78.54 - 8.7 - 8.75$
= 61.09

From Cht. E, Side DNC weir length = 6.1 ft.
 $L_w = 2(6.1) = 12.2$ ft.

% Tray Capacity = $\frac{100}{0.51} \left[\frac{16.539}{61.09} + 0.001327 \left(\frac{1500}{12.2} \right) \right] = 85\%$ (para C.6.)

% DNC Capacity = $\left(\frac{1500}{8.7} \right) \left(\frac{85}{175} \right) = 84\%$ (para C.7.)

CFM (air) = $(60)(81.22) \sqrt{\frac{1.7}{0.0735}} = 23437$ (para D.1.)

Estimated No. Valves = $61.09 (12.5) = 764$ (para D.2.)

$\frac{\text{CFM (air)}}{\text{valve}} = \frac{23437}{764} = 30.68$ (para D.3.)

For 24" TS, use 3" weir height (para C.10.)

Using Type A valves: (pg. 1.)

Dry Pressure Drop, Cht. G = 2.8" water (para D.4.)

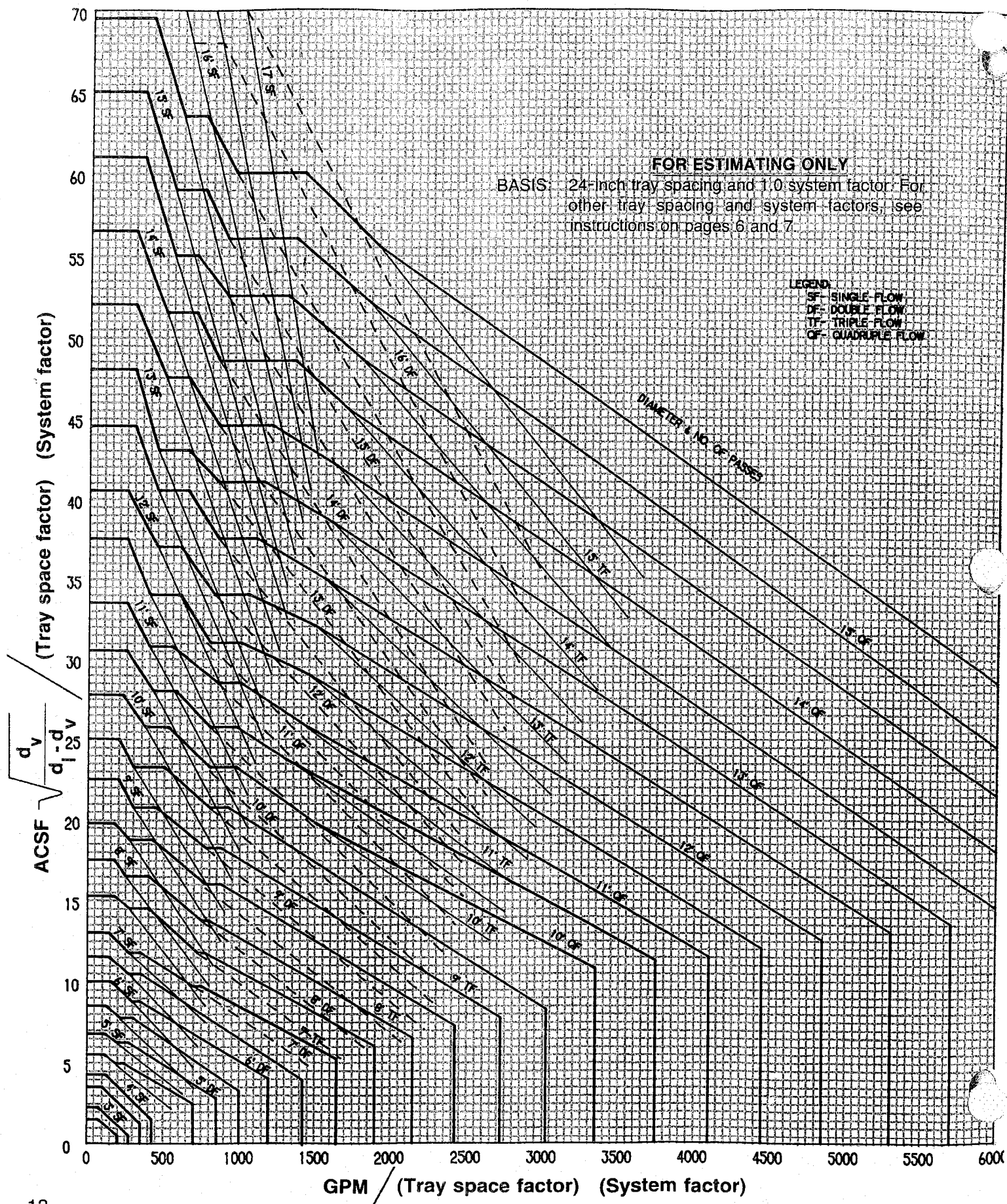
Liq. Pressure Drop, Cht. L = $2.6 \left(\frac{42.7}{62.4} \right) = 1.78$ (para D.6.)

Total Pressure Drop/Tray = $2.8 + 1.78 = 4.58$ " water (para D.7.)
= 8.54 mmHg

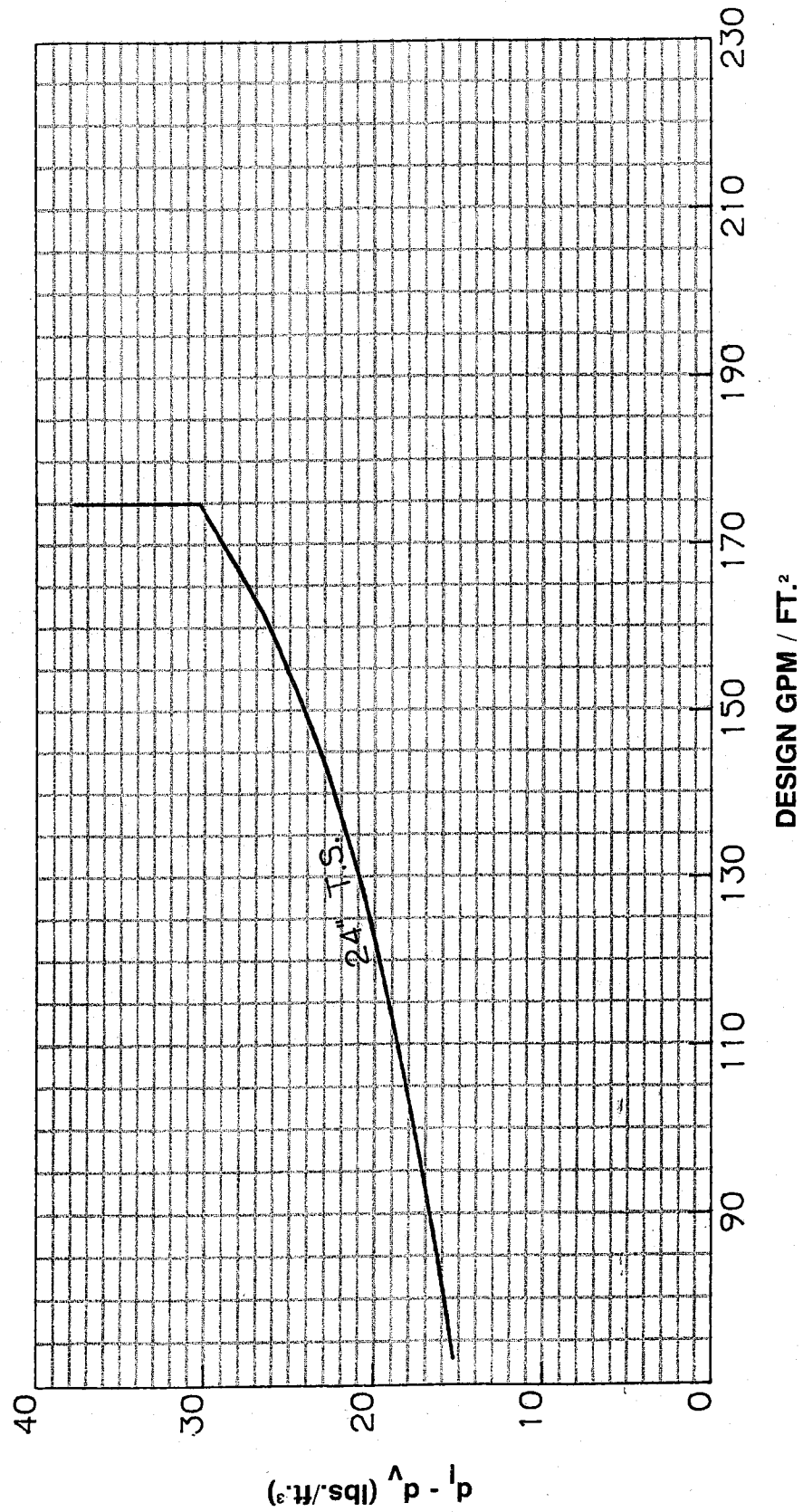
*conversion factor
DNC = Downcomer

Chart A

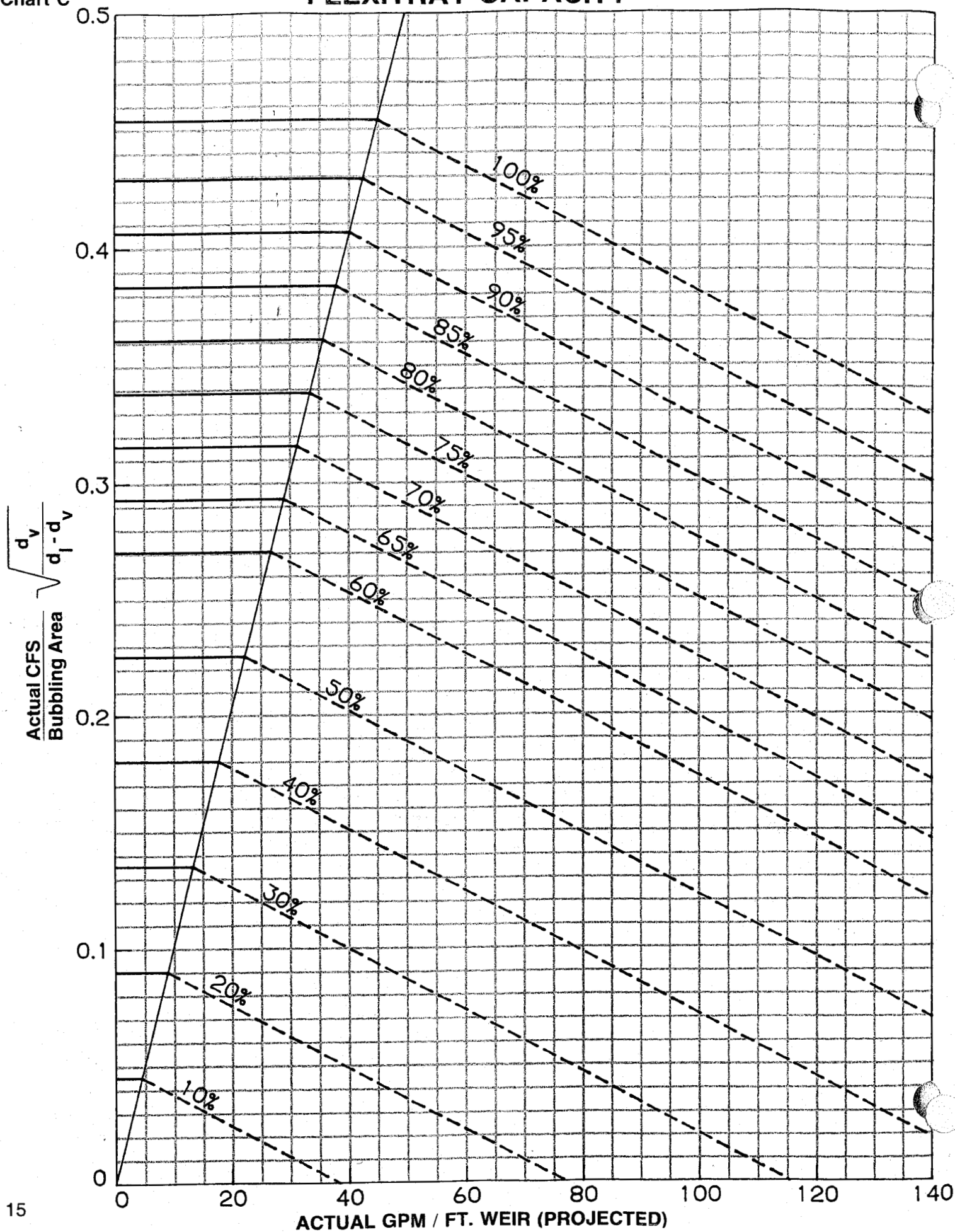
KOCH FLEXITRAY TOWER SIZING



DOWNCOMER SIZING



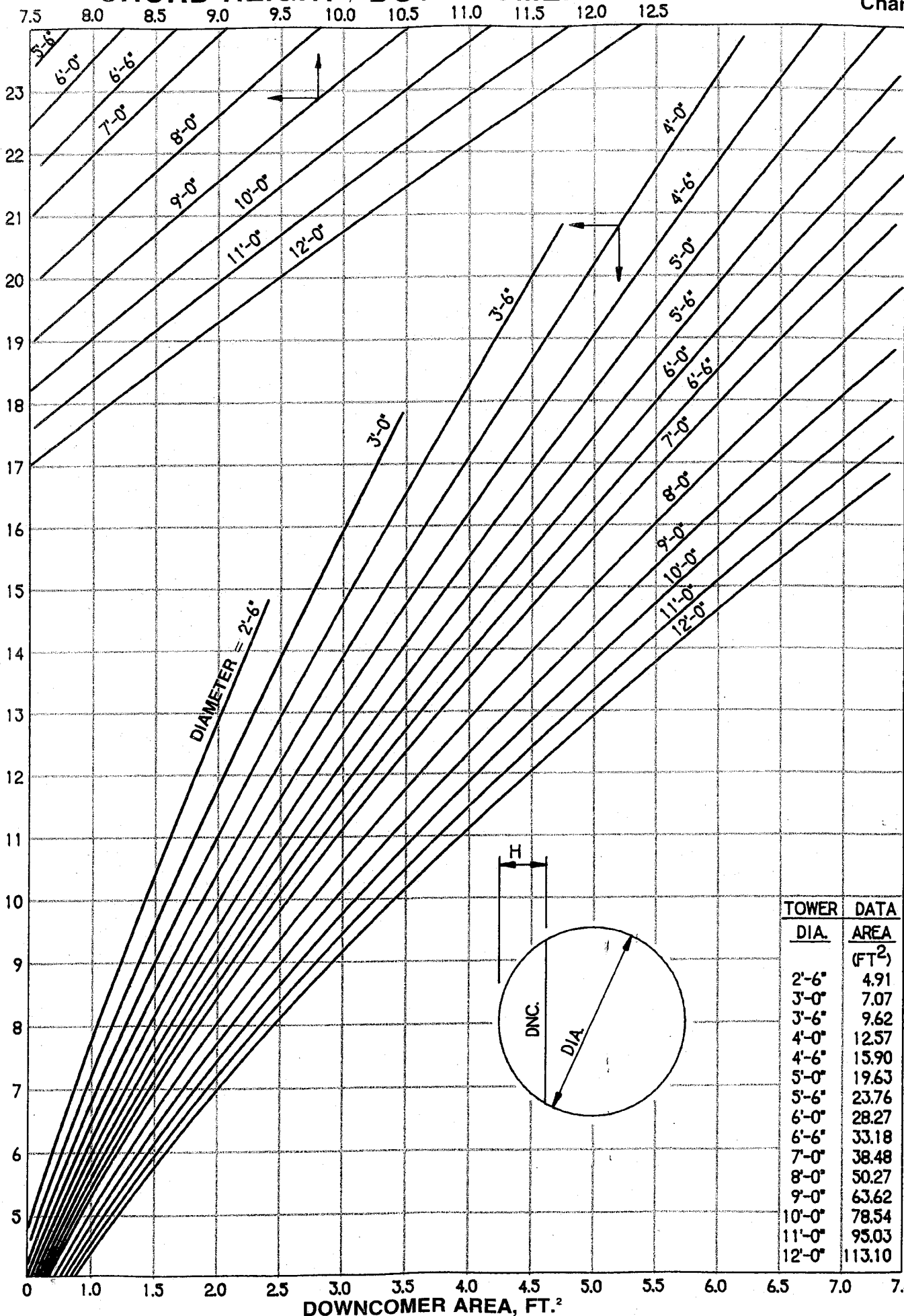
FLEXITRAY CAPACITY



CHORD HEIGHT / DOWNCOMER AREA DATA

Chart D

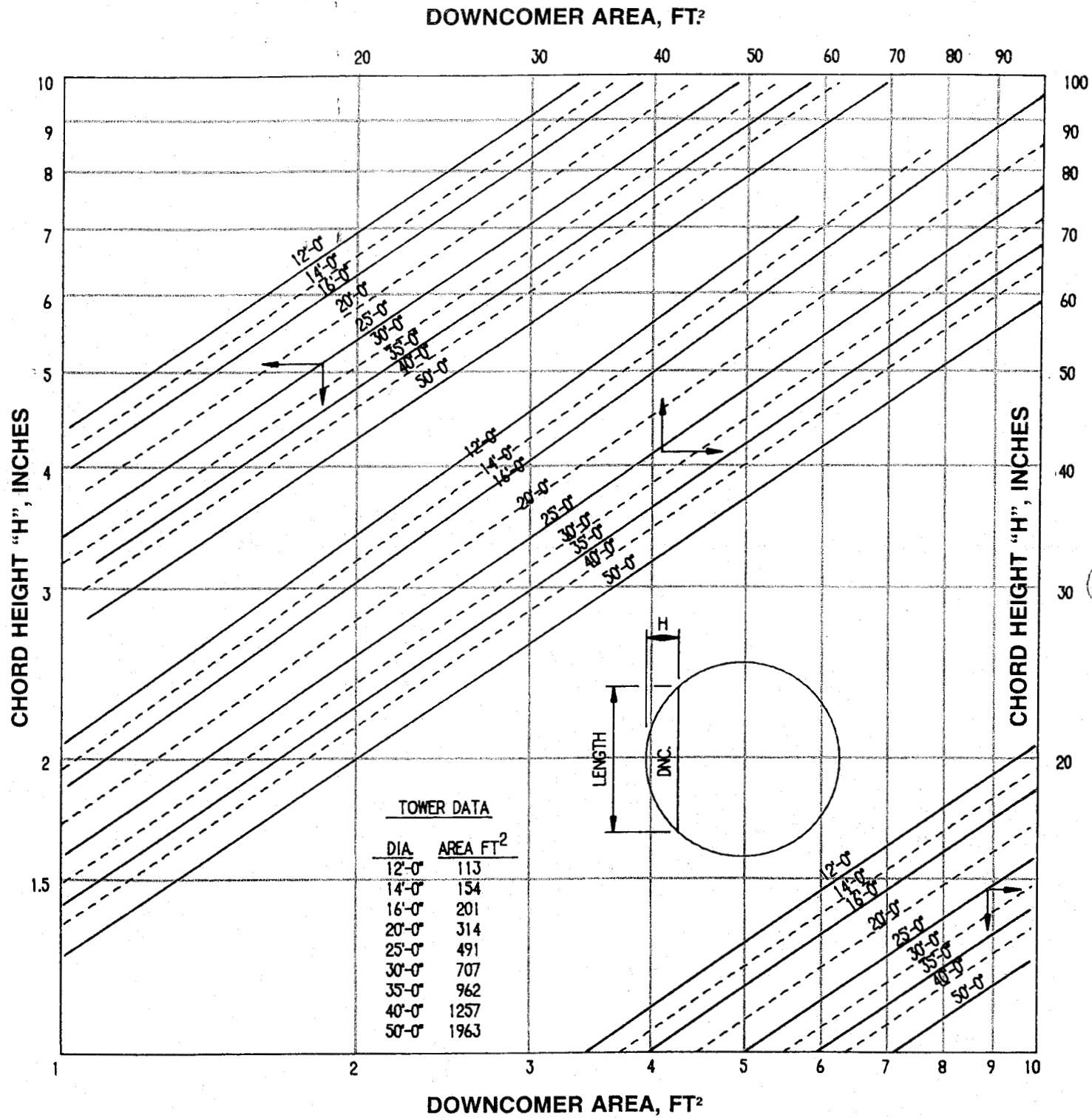
CHORD HEIGHT "H", INCHES



TOWER DIA.	DATA AREA (FT ²)
2'-6"	4.91
3'-0"	7.07
3'-6"	9.62
4'-0"	12.57
4'-6"	15.90
5'-0"	19.63
5'-6"	23.76
6'-0"	28.27
6'-6"	33.18
7'-0"	38.48
8'-0"	50.27
9'-0"	63.62
10'-0"	78.54
11'-0"	95.03
12'-0"	113.10

DOWNCOMER AREA, FT.²

CHORD HEIGHT / DOWNCOMER AREA DATA



CHORD HEIGHT / CHORD LENGTH DATA

Chart E

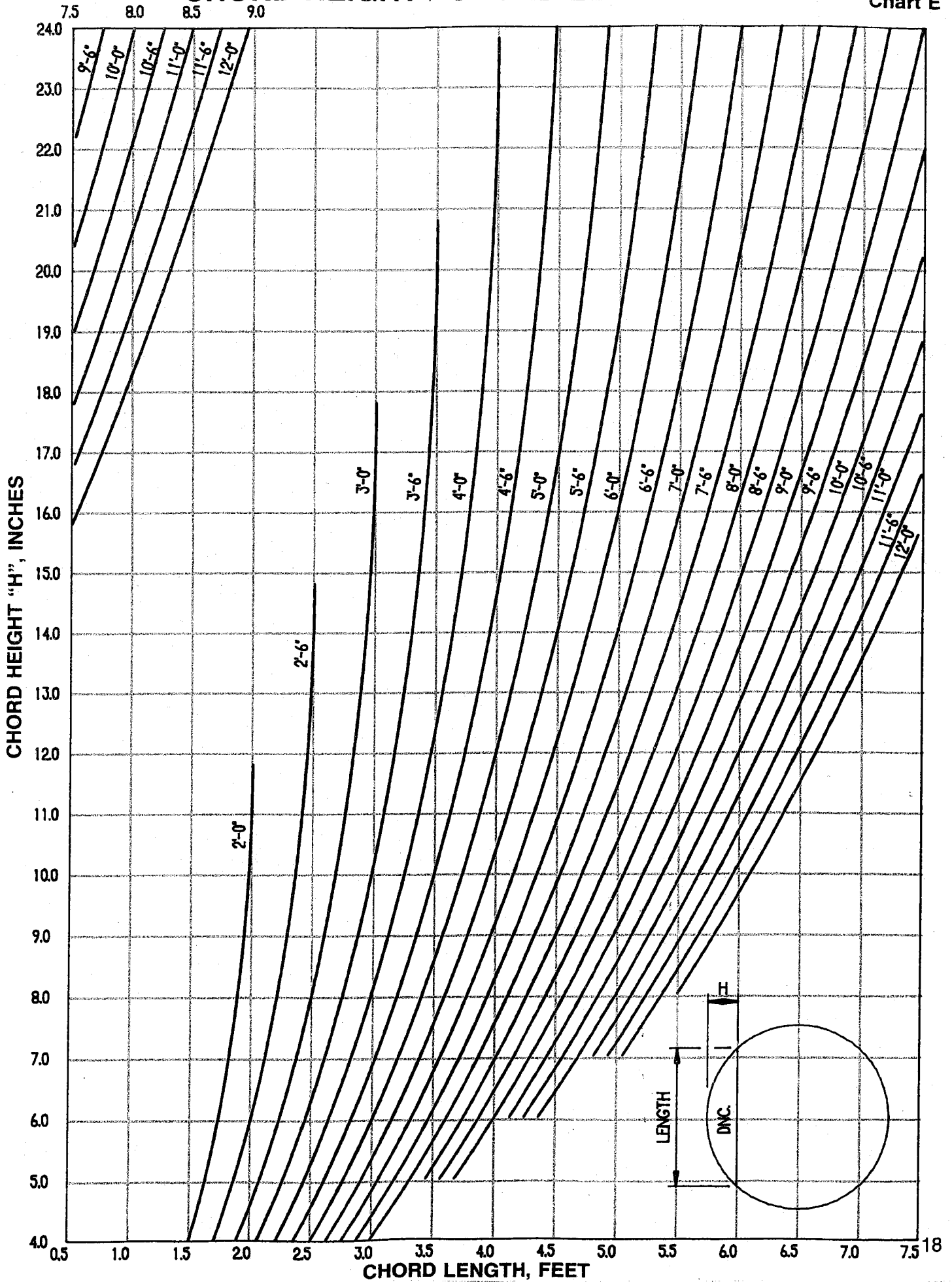
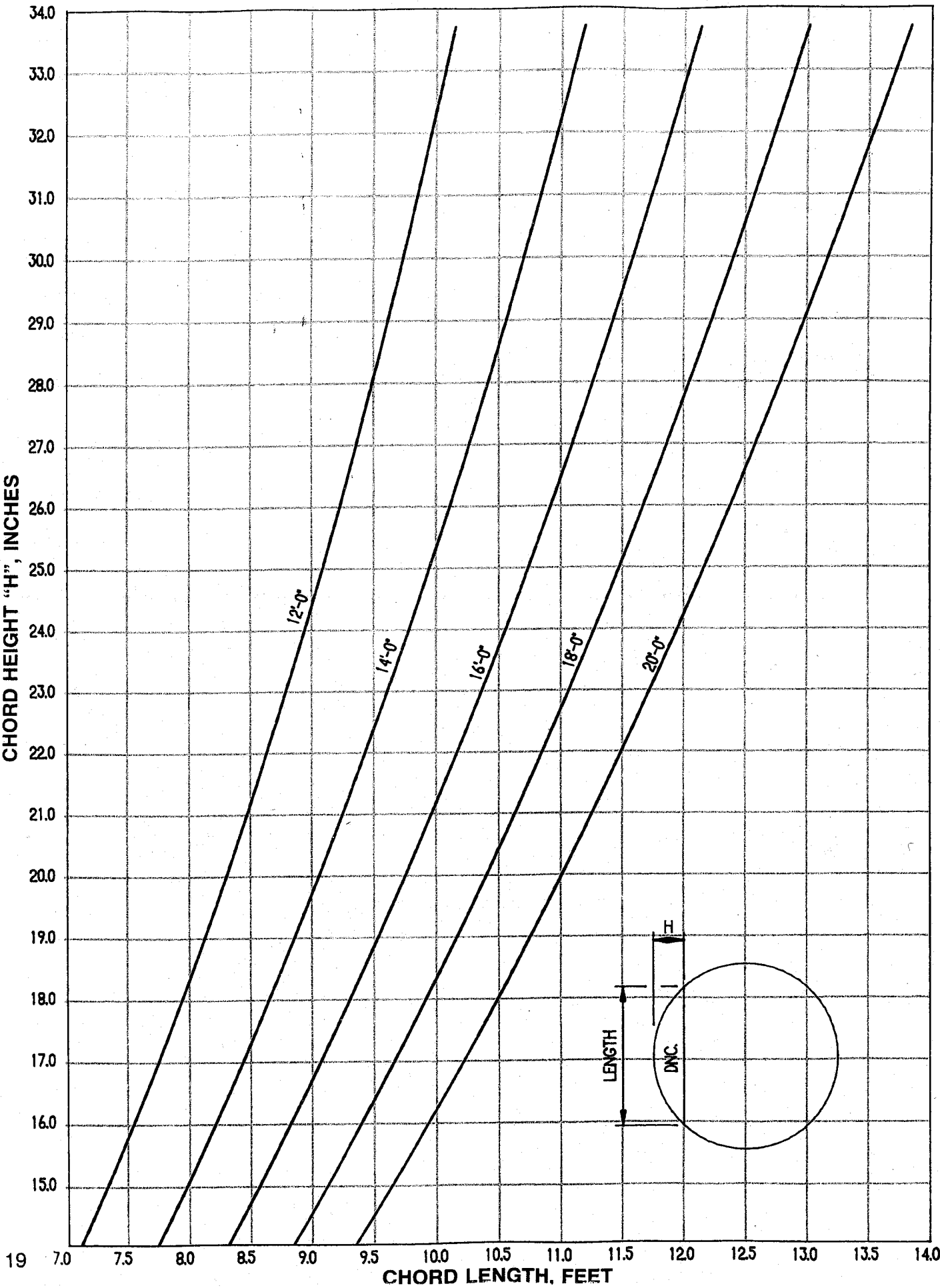


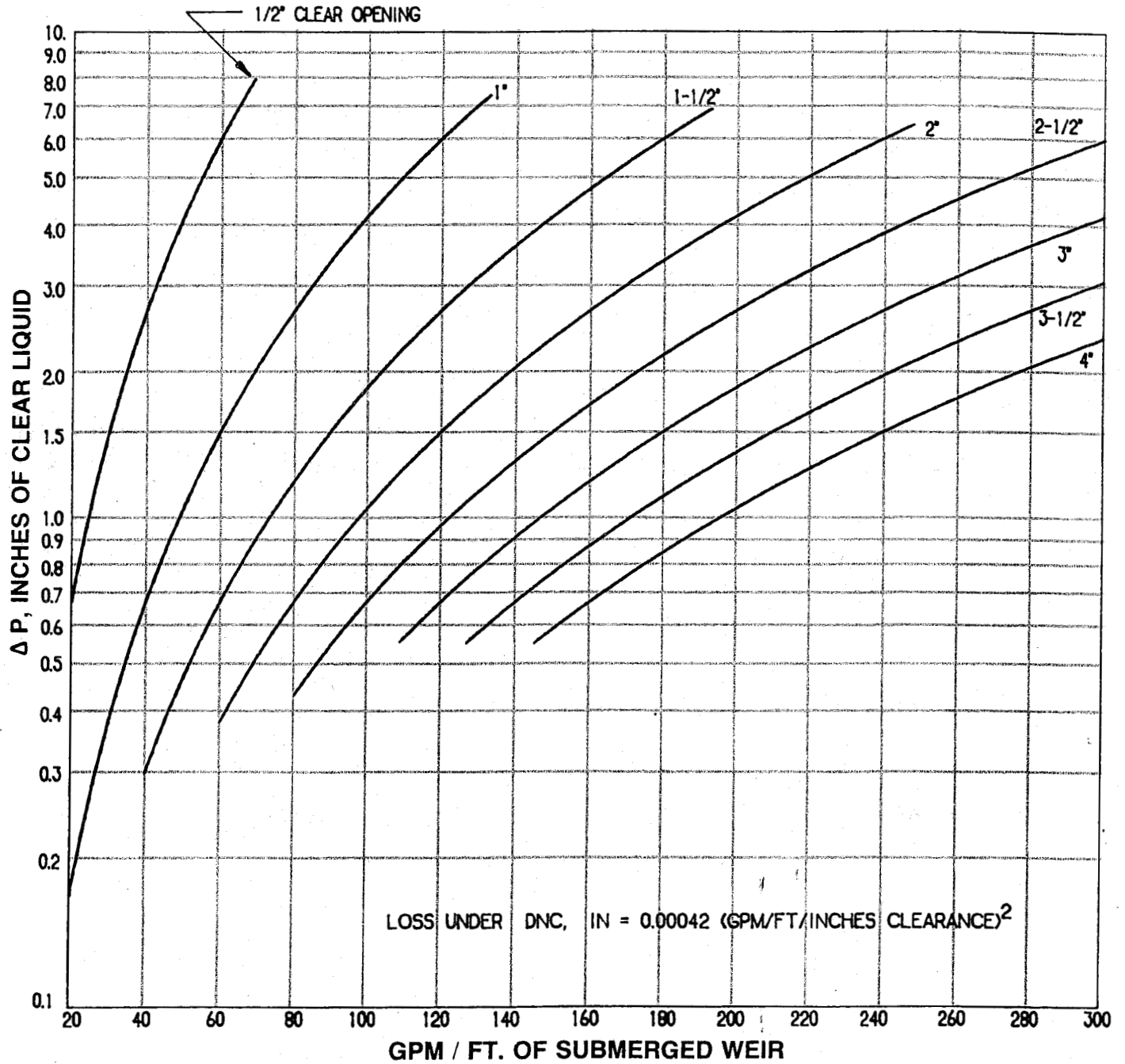
Chart E.1

CHORD HEIGHT / CHORD LENGTH DATA

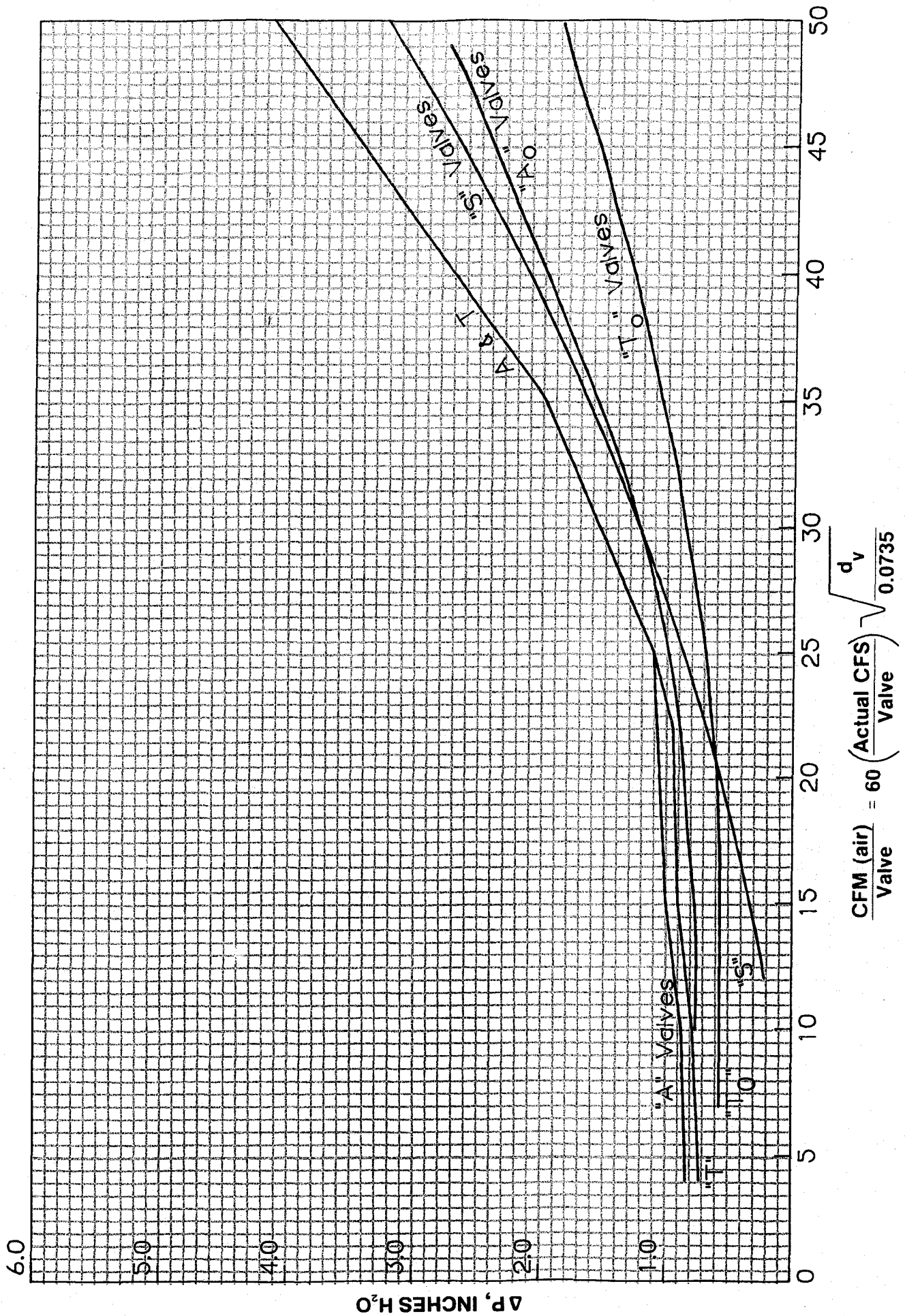


DOWNCOMER HYDRAULIC CHART

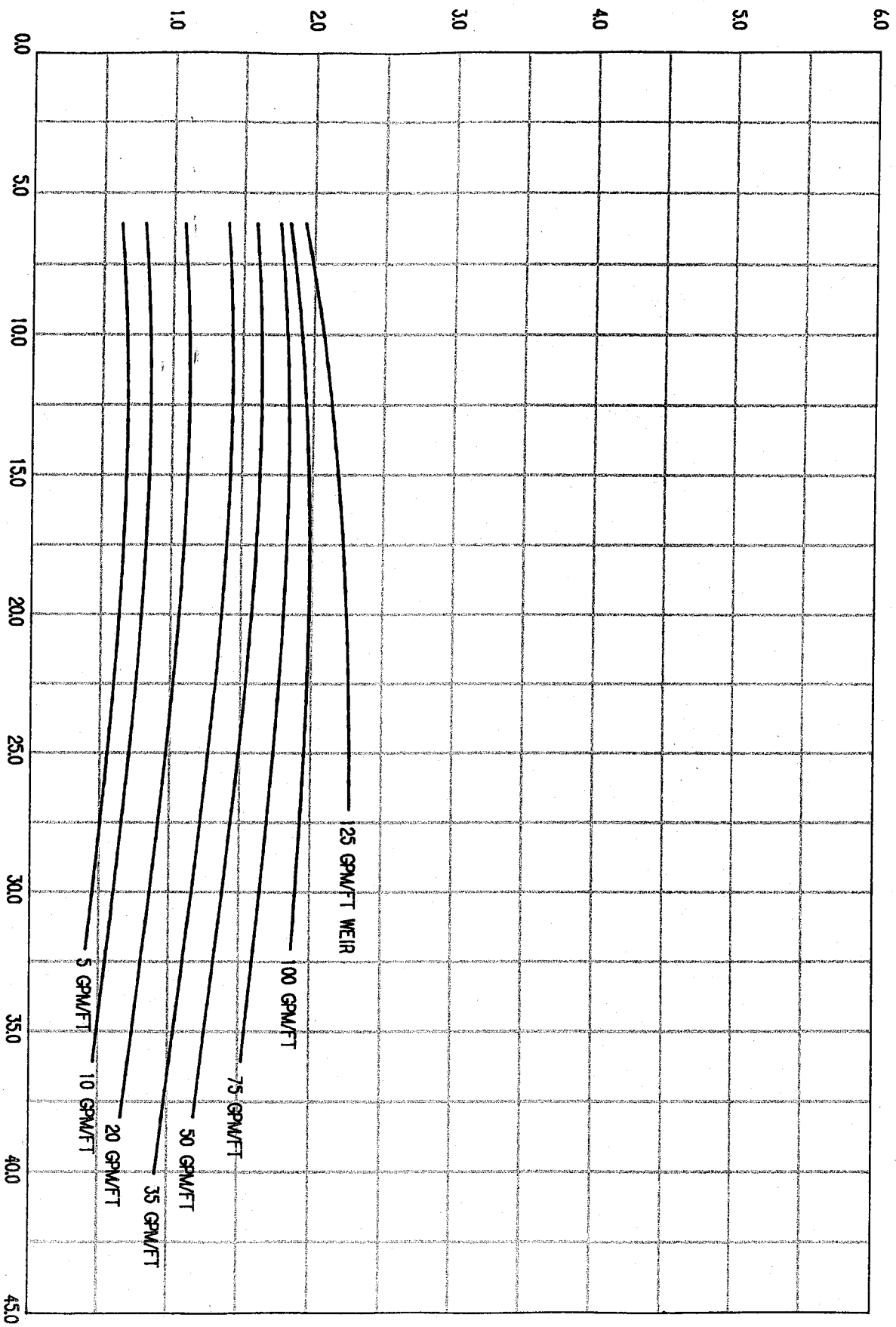
PRESSURE DROP
THROUGH DOWNCOMER CLEARANCE



DRY TRAY PRESSURE DROP



EFFECTIVE DEPTH OF LIQUID 1" WEIR HEIGHT



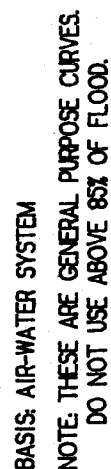
LIQUID DEPTH, INCHES CLEAR LIQUID

BASIS: AIR-WATER SYSTEM

NOTE: THESE ARE GENERAL PURPOSE CURVES
DO NOT USE ABOVE 85% OF FLOOD.

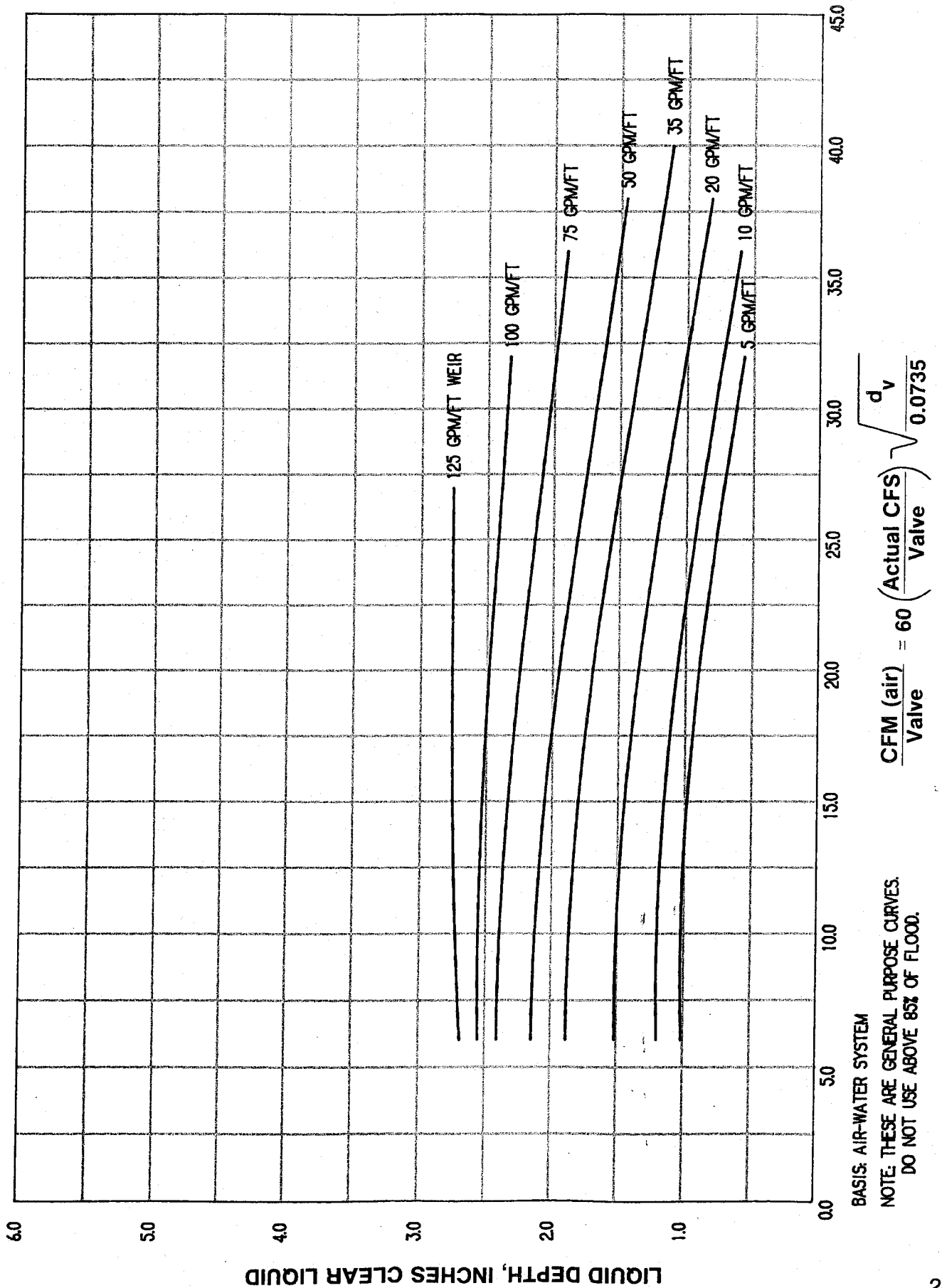
$$\frac{\text{CFM (air)}}{\text{Valve}} = 60 \left(\frac{\text{Actual CFS}}{\text{Valve}} \right) \sqrt{\frac{d_v}{0.0735}}$$

LIQUID DEPTH, INCHES CLEAR LIQUID

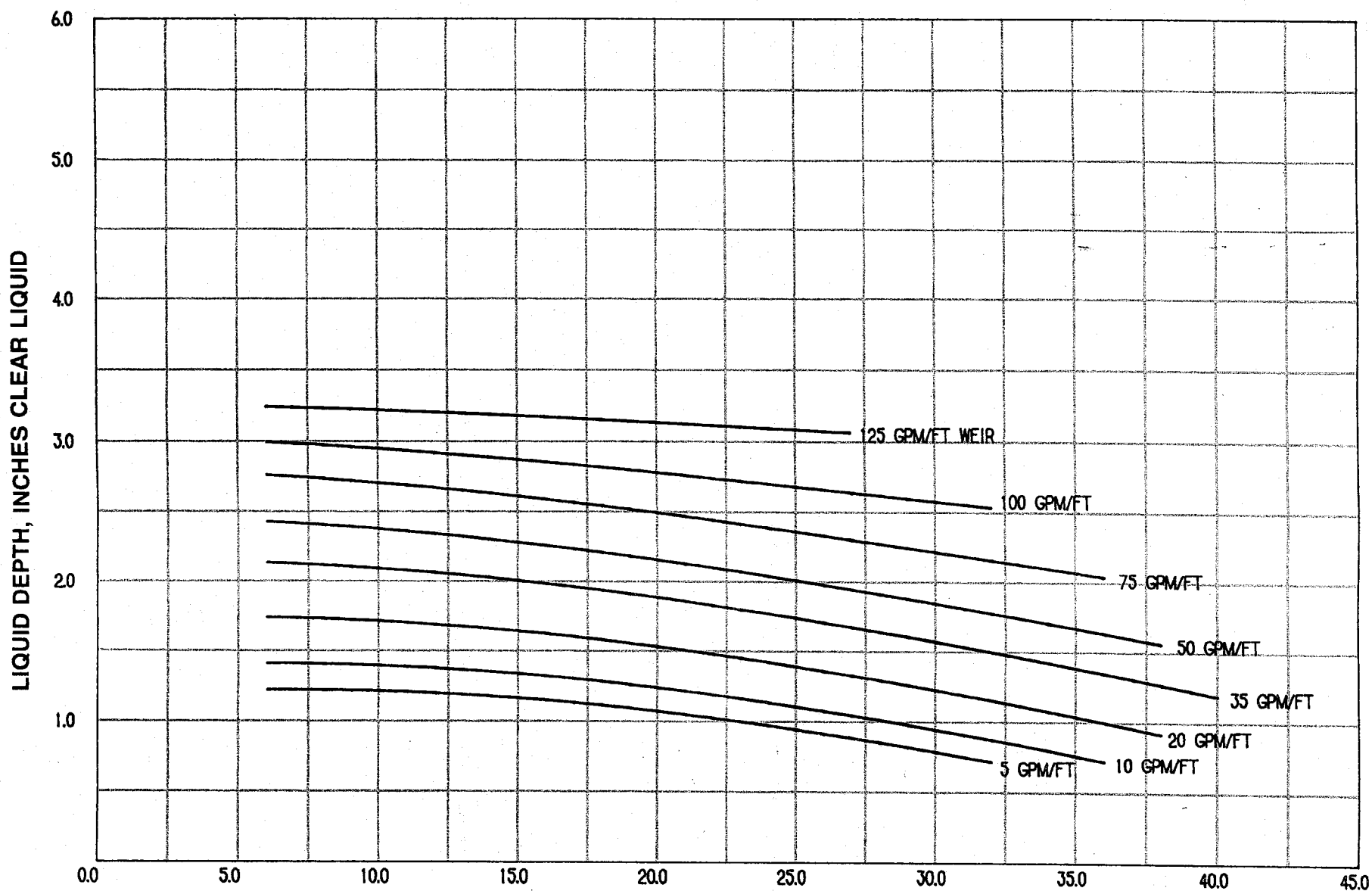


EFFECTIVE DEPTH OF LIQUID 2" WEIR HEIGHT

Chart J



EFFECTIVE DEPTH OF LIQUID 2 1/2" WEIR HEIGHT

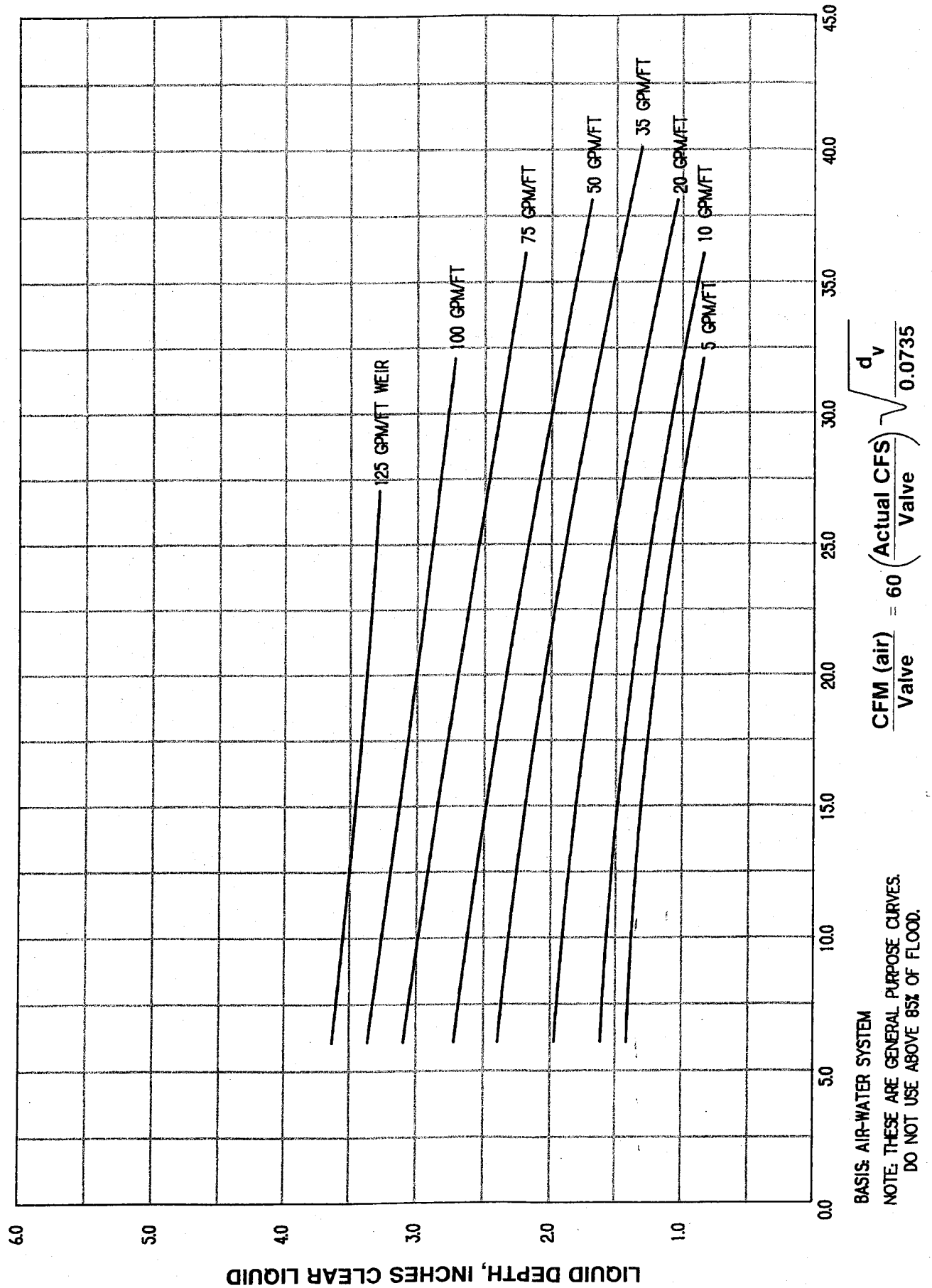


BASIS: AIR-WATER SYSTEM

NOTE: THESE ARE GENERAL PURPOSE CURVES.
DO NOT USE ABOVE 85% OF FLOOD.

$$\frac{\text{CFM (air)}}{\text{Valve}} = 60 \left(\frac{\text{Actual CFS}}{\text{Valve}} \right) \sqrt{\frac{d_v}{0.0735}}$$

EFFECTIVE DEPTH OF LIQUID 3" WEIR HEIGHT



ARRANGEMENT OF TRAYS AND NOZZLES

The maximum capacity of a trayed column can only be obtained with the proper arrangement of the nozzles with respect to the trays.

SEAL PANS: Figure 1 shows recommended seal pan dimensions. Seal pans are required to seal the bottom tray and are also used when a transition is required between two sections with a different number of passes.

REBOILER NOZZLES: Thermosyphon reboiler return nozzles should be arranged as shown in Figure 2 so that the mixed phase from the reboiler enters parallel to the seal pan. The recommended spacing below the tray is a minimum distance to allow disengagement space.

FEED NOZZLES: The recommended procedure for feeding between two trays is shown in Figure 3. Note that the nozzle is located outside the downcomer. Internal piping is not necessary. A similar procedure should be followed for two, three and four pass trays.

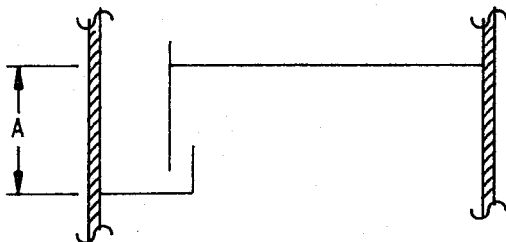
SEGMENTAL DRAWOFFS: Recommended sump dimensions are shown in Figure 4. When large diameter drawoff nozzles are required, the tray space between the drawoff tray and the tray below may need to be increased so that the distance between the bottom of the sump and the tray below is at least 80 percent of the normal tray spacing.

CENTER DRAWOFFS: Recommended sump dimensions are shown in Figure 5. The minimum width at the bottom of the center downcomer and the width of the sump is usually made equal to the nozzle diameter plus 2 inches.

NON-OVERFLOWING TRAPS: Recommended dimensions are shown in Figure 6. This procedure is recommended, for example, for a total drawoff to the reboiler. The drawoff should never be attempted from the downcomer by raising the seal pan weir.

OVERFLOWING TRAPS: A partial liquid drawoff can be made below a seal pan as shown in Figure 7. This procedure is also useful in making a transition to the tray below having a different number of passes. The drawoff should never be attempted from the seal pan alone.

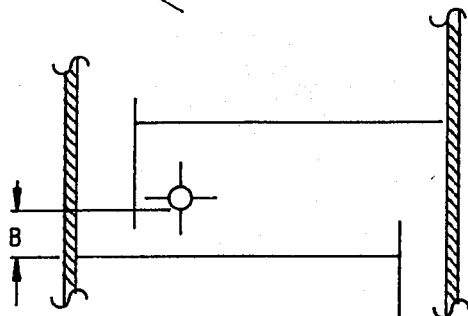
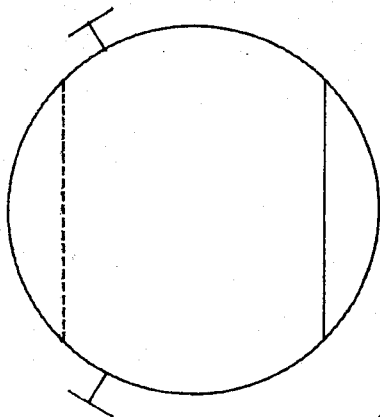
SEAL PANS



"A" = (NORMALLY) TRAY SPACE + 6".
FOR STEAM STRIPPERS NOMINAL
TRAY SPACE IS SATISFACTORY

FIG. 1

FEED NOZZLES



B = 6" ABOVE TRAY FOR LIQUID FEED
TO 1/2 TRAY SPACE FOR
MIXED FEED.

FIG. 3

THERMOSYPHON REBOILER VAPOR RETURN

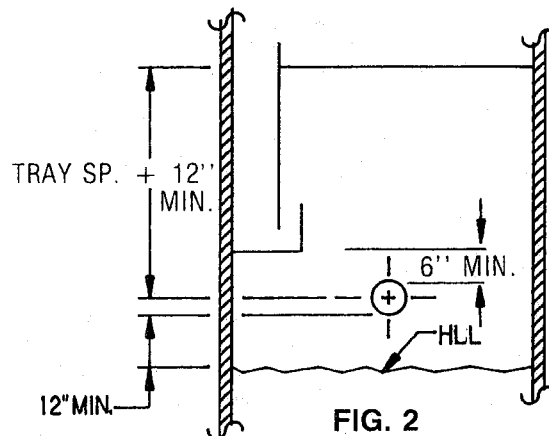
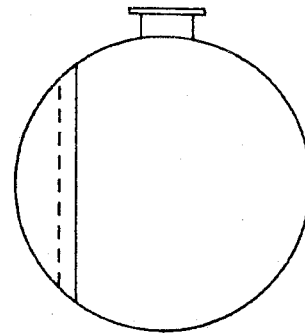


FIG. 2

DRAWOFFS-SEGMENTAL

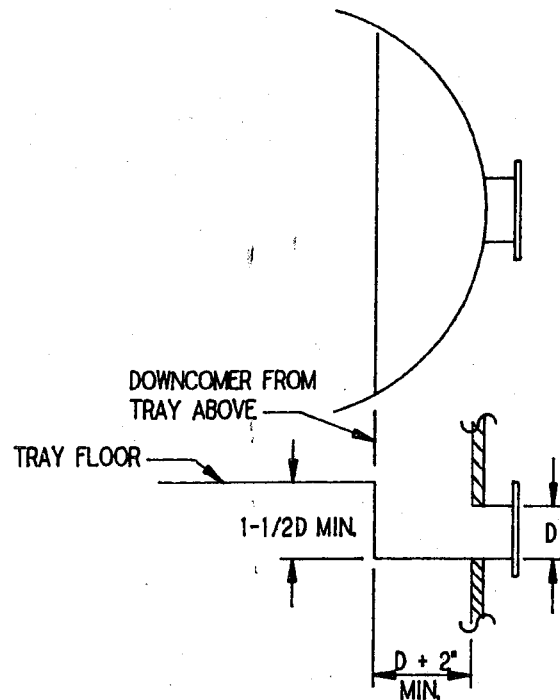


FIG. 4

NON-OVERFLOWING TRAPS

DRAWOFFS-CENTER

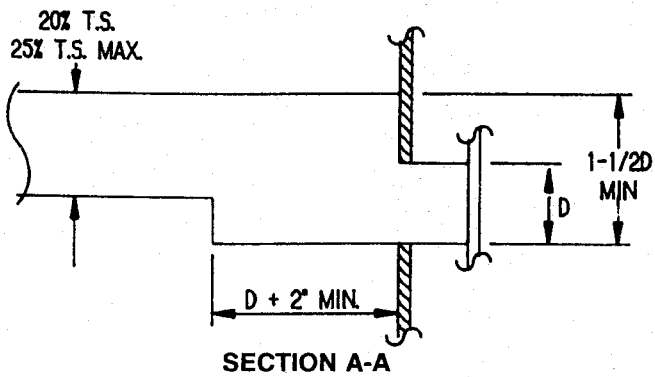
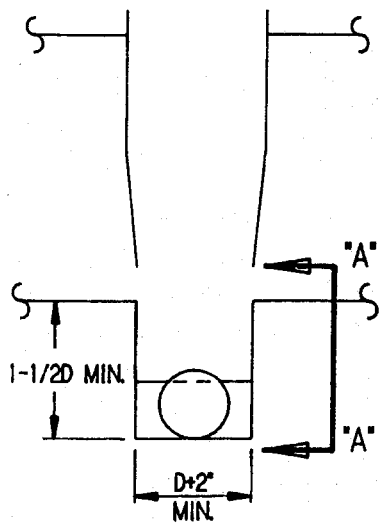


FIG. 5

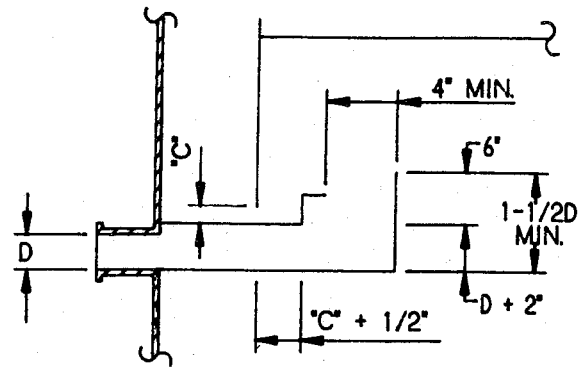


FIG. 6

OVERFLOWING TRAPS

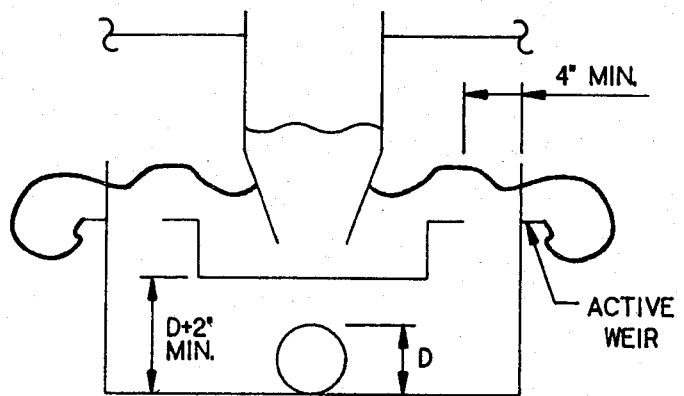


FIG. 7

MECHANICAL SPECIFICATIONS FOR VALVE TYPE TRAYS

Deflection at Operating Conditions

1/8 inch for 10'0" (diameter) and smaller.

0.001 (dia) for greater than 10'0" diameter.

Basis: 12 lbs./sq. ft. live load & 64 lbs./sq. ft. on seal pot area.

Comments: Valve type trays, with their greater minimum submergences, are less sensitive to deflection and out-of-level installation.

Tolerance — Out-of-Level, Downcomer Clearance and Weir Heights — 1/8 inch

Comments: The above tolerances should be minimized on long weirs and particularly those with low liquid traffic. There is good evidence that a series of multipass trays out of level in the same direction will suffer serious efficiency losses.

Structural Design for Erection and Maintenance

250 lbs. concentrated load on any member.

Basis: Allowable stress at atmospheric temperature.

Comments: Such loading specifications vary from 200 to 300 pounds.

Min. Thickness of Tray Parts

(Trays, Downcomers & General Const.)

Non Ferrous and Alloy 14 ga.

Carbon Steel 10 ga.

Support Ring Dimensions

Tower Diameter	Carbon Steel	Alloy
5'0" and Smaller	1 1/2" x 1/4"	1 1/2" x 1/4"
5'6" thru 7'6"	2" x 1/4"	2" x 1/4"
8'0" thru 10'0"	2 1/2" x 1/4"	2 1/2" x 1/4"
10'6" thru 11'6"	2 1/2" x 3/8"	2 1/2" x 1/4"
12'0" thru 15'0"	3" x 3/8"	3" x 1/4"
15'6" thru 20'0"	3 1/2" x 3/8"	3 1/2" x 1/4"

*Notes. Use gussets under concentrated load points.
Tower diameters larger than 20'0" to have special consideration.

Downcomer Bar Thickness

1/4" minimum for alloy.

1/4" C.S. plus corrosion allowance.

Bolting

3/8" dia. C.S. or alloy. (Larger if necessary for long major beams.)

Comments: Some users specify alloy bolting at tray manways on carbon steel trays. A few specify alloy bolting for all bolting on carbon steel trays.

Adjustable Weirs

Not required.

Comments: Adjustability should not be specified for valve type trays on any but long weirs with low liquid loads. The hazards of maladjustment overcome their potential benefits.

Tray Manways

Top and bottom removable.

Maximum weight 65 lbs.

Minimum clearance 12" x 16".

Vertically aligned where possible.

Leakage Tests

Not required for valve type tray deck areas.

Comments: The valve type tray, unlike the bubble cap tray, has no net positive head of liquid on the tray and, therefore, during operation, cannot leak to the tray below. For this reason, no gaskets are required and tray leakage tests are meaningless and unnecessary. Gasket elimination has contributed greatly toward reducing installation and maintenance costs.

FLEXITRAY RATING SHEET

The Koch Engineering Co., Inc.
Wichita, Kansas

Date _____
Sheet _____ of _____
By _____

Tower Section			
$\text{CFS} = \frac{\text{lbs./hr. Vapor}}{3600 \times d_v, \text{lbs./ft.}^3}$	$\frac{\quad}{3600 \times} =$	$\frac{\quad}{3600 \times} =$	$\frac{\quad}{3600 \times} =$
$\sqrt{\quad} = \sqrt{\frac{d_v}{d_l - d_v}}$	$\sqrt{\quad} =$	$\sqrt{\quad} =$	$\sqrt{\quad} =$
Vapor Load = CFS $\sqrt{\quad}$	CFS $\sqrt{\quad} =$	CFS $\sqrt{\quad} =$	CFS $\sqrt{\quad} =$
$\text{gPM} = \frac{\text{lbs./hr. Liq.} \times 7.48}{d_l, \text{lbs./ft.}^3 \times 60}$	$\frac{\quad}{\times 8.021} =$	$\frac{\quad}{\times 8.021} =$	$\frac{\quad}{\times 8.021} =$
$\text{CFM}_{\text{air}} = 60 (\text{ACFS}) \sqrt{\frac{d_v}{0.0735}}$	$\times \quad =$	$\times \quad =$	$\times \quad =$
CAPACITY CALCULATIONS (As % Calculated Flood)			
<u>ΔP Calculations</u>			
$\text{CFM}_{\text{air}} / \text{Valve}$	$\frac{\quad}{\quad} =$	$\frac{\quad}{\quad} =$	$\frac{\quad}{\quad} =$
GPM/ft. Weir	$\frac{\quad}{\quad} =$	$\frac{\quad}{\quad} =$	$\frac{\quad}{\quad} =$
Weir Height			
Type Valve			
Dry ΔP = in. water			
$\text{Liq. } \Delta P = \text{in. liq.} \times \frac{d_l}{62.4}$	$\times \frac{\quad}{62.4} =$	$\times \frac{\quad}{62.4} =$	$\times \frac{\quad}{62.4} =$
Total/tray, inches water			
Total/tray, mmHg.			

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We have made every effort to assure accuracy for the data published in this manual.
However, it would be necessary to review your specific requirements before a guarantee
can be made.

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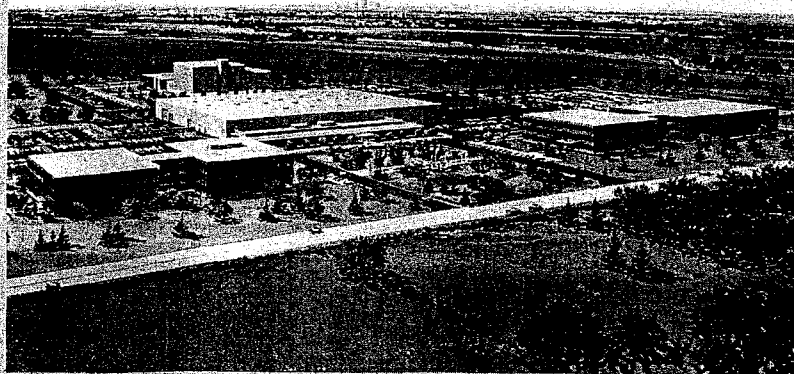
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THE PREFERRED STANDARD FOR SUPERIOR PERFORMANCE. WORLD'S MOST IMITATED FRACTIONATING TRAY.



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Maximizing Petrochemical Processing EfficiencySM

COLUMN SIZING SOLUTIONS

Use Koch Method – 75% Flood

STABILIZER - TOP SECTION

Known Data		Summer Operation	Winter Operation
Vapor Rate	ft ³ /s	16.56	12.19
Vapor Density	lb/ft ³	1.673	2.702
Liquid Rate	gpm	366.0	486.0
Liquid Density	lb/ft ³	31.1	29.39

Tray spacing is 24"

From inspection of the data, both operations look nearly the same. We will design for the winter operation and check the summer operation.

PRELIMINARY ESTIMATE

No barrel factor is available (barrel factor applies to the bottom section).

Calculate Square Root Factor:

$$Factor = \sqrt{\frac{d_v}{d_l - d_v}} = \sqrt{\frac{2.702}{29.39 - 2.702}} = 0.318$$

Calculate V_{load} :

$$V_{load} = ACFS \sqrt{\frac{d_v}{d_l - d_v}} = (12.19)(0.318) = 3.876$$

$TSF = \text{Tray Space Factor} = 1.0$ (24 inch tray spacing)

$SF = \text{System Factor} = 1.0$ (Non-foaming)

Vapor Density Derating:

$$\text{System Factor} = \frac{1.21}{(d_v)^{0.32}} = \frac{1.21}{(2.702)^{0.32}} = 0.88$$

$$\text{Corrected } V_{\text{load}} = \frac{V_{\text{load}}}{(TSF)(SF)} = \frac{3.876}{(1)(0.88)} = 4.405$$

$$\text{Corrected Liquid Rate} = \frac{\text{gpm}}{(TSF)(SF)} = \frac{486}{(1)(0.88)} = 552 \text{ gpm}$$

From Koch Chart A:

$$(V_{\text{load}} = 4.405; \text{gpm} = 552)$$

Preliminary Diameter:

5'-6" (1-Pass)

5'-0" (2-Pass)

$$\text{1-Pass: } \frac{L}{(NP)(DT)} = \frac{552}{(1)(66)} = 8.36$$

$$\text{2-Pass: } \frac{L}{(NP)(DT)} = \frac{552}{(2)(60)} = 4.60$$

Therefore, try a 2-pass tray with a 5'-0" diameter.

$$A_t = \frac{(\pi)(5)^2}{(4)} = 19.63 \text{ ft}^2$$

SIZE DOWNCOMERS

Use non-corrected loads.

$$(V_{load} = 3.876; \text{Liquid Rate} = 486 \text{ gpm})$$

Equation 1:

$$A_{dc} = \left(\frac{85}{75} \right) \left(\frac{\text{gpm}}{175} \right) \left(\frac{24}{TS} \right) \left(\frac{1}{SF} \right) = \left(\frac{85}{75} \right) \left(\frac{486}{175} \right) \left(\frac{24}{24} \right) \left(\frac{1}{0.88} \right) = 3.58 \text{ ft}^2$$

However,

$$d_l - d_v = (29.39 - 2.702) = 26.69 \text{ lb/ft}^3$$

From Koch Chart B:

$$V_{dc} = \text{Max. Downcomer Velocity} = 162 \left(\frac{75}{85} \right) = 143 \text{ gpm/ft}^2$$

Koch Equation 2:

$$A_{dc} = \left(\frac{\text{gpm}}{143} \right) \left(\frac{24}{TS} \right) = \left(\frac{486}{143} \right) \left(\frac{24}{24} \right) = 3.40 \text{ ft}^2$$

Use the larger of the two values.

$$A_{dc} = 3.58 \text{ ft}^2$$

Side Downcomers

$$\left(\frac{3.58}{2} = 1.79 \text{ ft}^2 \text{ Each} \right)$$

From UOP Charts:

$$A_D/A_T = 1.79/19.63 = 0.0912$$

$$H/D = 0.1469$$

$$H = (0.1469)(5)(12) = 8.8 \text{ in}$$

$$L/D = 0.708$$

$$L = (0.708)(5) = 3.54 \text{ ft}$$

Center Downcomer

$$(3.58 \text{ ft}^2)$$

$$L_w = \text{Weir Length} \approx 5.0 \text{ ft; (Tray Diameter)}$$

$$\text{Downcomer Width} = \frac{(3.58 \text{ ft}^2)}{(5 \text{ ft})} = 0.716 \text{ ft} = 8.6 \text{ in}$$

$$A_b = \text{Bubbling Area} = A_t - A_{dt} - A_{db} - A_e$$

$$A_e = \text{Edge Loss} \approx 0; \text{ For Diameter} > 3'6''$$

$$A_b = 19.63 - 3.58 - 3.58 = 12.47 \text{ ft}^2$$

RATING

$$pct\ Tray\ Capacity = \frac{(100)}{(TSF)(SF)(0.506)} \left[C_{sf(net)} + (0.001327) \frac{gpm}{L_w} \right]$$

$$C_{sf(net)} = \left(\frac{CFS}{A_b} \right) \sqrt{\frac{d_v}{d_l - d_v}} = \frac{V_{load}}{A_b} = \frac{3.876}{12.47} = 0.311$$

$$pct\ Tray\ Capacity = \frac{(100)}{(1)(0.88)(0.506)} \left[0.311 + (0.001012) \frac{(486)}{(3.54)(2)} \right] = 90.3\ pct; (Too\ High)$$

TRIAL 2 ESTIMATE

$$d_2 = d_1 \sqrt{\frac{90.3}{75}} = 5 \sqrt{\frac{90.3}{75}} = 5.49\ ft$$

Try 5'-6"

$$A_t = 23.76\ ft^2$$

TRIAL 2 LAYOUT

Side Downcomer

From UOP Charts:

$$A_D/A_T = 1.79/23.76 = 0.0753$$

$$H/D = 0.1288$$

$$H = (0.1288)(5.5)(12) = 8.5\ in$$

$$L/D = 0.6696$$

$$L = (0.6696)(5.5) = 3.68 \text{ ft}$$

Center Downcomer:

$$(3.58 \text{ ft}^2)$$

$$\text{Downcomer Width} = \frac{3.58 \text{ ft}^2}{5.5 \text{ ft}} = 0.651 \text{ ft} = 7.8 \text{ in}$$

Use 8 inches (minimum) for center downcomer:

$$A_{dc} = \frac{(8)}{(12)}(5.5) = 3.667 \text{ ft}^2$$

$$A_b = 23.76 - 3.58 - 3.667 = 16.51 \text{ ft}^2$$

TRIAL 2 RATING

$$C_{sf(net)} = \frac{V_{load}}{A_b} = \frac{3.876}{16.51} = 0.235$$

$$\text{pct Tray Capacity} = \frac{(100)}{(1)(0.88)(0.506)} \left[0.235 + (0.001327) \frac{(486)}{(3.68)(2)} \right] = 73.1 \text{ pct (Acceptable)}$$

$$\text{pct Downcomer Capacity} = \left(\frac{486}{3.58} \right) \left(\frac{75}{154} \right) \left(\frac{1}{0.88} \right) \left(\frac{24}{24} \right) = 75.1 \text{ pct}$$

Close enough to be balanced.

PRESSURE DROP

Convert vapor rate to air equivalent:

$$CFM = (60)(CFS) \sqrt{\frac{d_v}{0.0735}} = (60)(12.19) \sqrt{\frac{2.702}{0.0735}} = 4435$$

$$\text{Number of Valves} = \left(\text{Valves} / \text{ft}^2 \right) A_b = (13)(16.51) = 214.6 \text{ (Use 215)}$$

$$CFM / \text{valve} = \frac{4435}{215} = 20.6$$

From Koch Chart G (using "A" type valves):

$$\text{Dry Tray } \Delta P = 1.09 \text{ in } H_2O$$

Assume weir height = 2 in (typical):

$$\text{gpm} / \text{ft} = \frac{\text{gpm}}{\text{Avg. Weir Length}} = \frac{486}{(3.68) + (5.5)} = 52.9$$

From Koch Chart J:

$$(52.9 \text{ gpm} / \text{ft}, 20.6 \text{ CFM} / \text{valve})$$

$$\text{Liquid } \Delta P = 2.0 \text{ in Liquid}$$

$$\text{Liquid } \Delta P = 2.0 \left(\frac{29.39}{62.4} \right) = 0.94 \text{ in } H_2O$$

$$\text{Total Tray Pressure Drop} = (1.09) + (0.94) = 2.03 \text{ in } H_2O \text{ (3.8 mmHg)}$$

DOWNCOMER BACKUP

Look at tray with side downcomers

$$gpm/ft = \frac{486}{(3.68)(2)} = 66.0$$

Downcomer Clearance = 1.5 inches

From Chart F:

$$H_{vd} = 0.8$$

$$h_{dc} = 2(h_{wet}) + (h_{dry} + h_{vd}) \left(\frac{d_l}{d_l - d_v} \right)$$

$$h_{dc} = 2(2.03) + \left[1.09 \left(\frac{62.4}{29.39} \right) + 0.8 \right] \left(\frac{29.39}{29.39 - 2.702} \right)$$

$$h_{dc} = 7.2 \text{ in}$$

CHECK SUMMER OPERATION

$$V_{load} = 16.56 \sqrt{\frac{1.673}{31.1 - 1.673}} = 3.95$$

$$C_{sf(net)} = \frac{V_{load}}{A_b} = \frac{3.95}{16.51} = 0.239$$

$$pct \text{ Tray Capacity} = \frac{(100)}{(1)(1)(0.506)} \left[0.239 + (0.001327) \frac{(366)}{(3.68)(2)} \right] = 60.3 \text{ pct (Acceptable)}$$

$$pct \text{ Downcomer Capacity} = \left(\frac{366}{3.9} \right) \left(\frac{75}{152} \right) \left(\frac{1}{1} \right) \left(\frac{24}{24} \right) = 46.3 \text{ pct (Acceptable)}$$

PRESSURE DROP

$$CFM = (60)(CFS) \sqrt{\frac{d_v}{0.0735}} = (60)(16.56) \sqrt{\frac{1.673}{0.0735}} = 4740$$

$$CFM/\text{valve} = \frac{4740}{215} = 22.0$$

From Koch Chart G:

$$\text{Dry Tray } \Delta P = 1.1 \text{ in } H_2O$$

$$gpm/ft = \frac{gpm}{\text{Avg. Weir Length}} = \frac{366}{(3.68) + (5.5)} = 39.9$$

From Koch Chart J:

$$(39.9 \text{ gpm/ft}, 22.0 \text{ CFM/valve})$$

$$\text{Liquid } \Delta P = 1.75 \text{ in Liquid}$$

$$\text{Liquid } \Delta P = 1.75 \left(\frac{31.1}{62.4} \right) = 0.87 \text{ in } H_2O$$

$$\text{Total Tray Pressure Drop} = (1.1) + (0.87) = 1.97 \text{ in } H_2O (3.7 \text{ mmHg})$$

DOWNCOMER BACKUP

Look at tray with side downcomers

$$gpm/ft = \frac{366}{(3.68)(2)} = 50.8$$

$$\text{Downcomer Clearance} = 1.5 \text{ inches}$$

$$h_{vd} = (0.00042)(50.8/1.5)^2 = 0.48 \text{ inches liquid}$$

$$h_{dc} = 2(1.75) + \left[1.1 \left(\frac{62.4}{31.1} \right) + 0.48 \right] \left(\frac{31.1}{31.1 - 1.673} \right)$$

$$h_{dc} = 6.2 \text{ in}$$

The final solution was a 5'-6" diameter column with 2-pass trays. In the beginning of the problem, Koch Chart A gave us two initial options – 5'-6" (1-pass) and 5'-0" (2-pass). The 2-pass tray we selected became 5'-6" anyway. We should now examine a diameter of 5'-6", using 1-pass trays to find the optimal design.

Side Downcomer

$$(3.58 \text{ ft}^2)$$

From UOP Charts:

$$A_D/A_T = 3.58/23.76 = 0.1507$$

$$H/D = 0.2081$$

$$H = (0.2081)(5.5)(12) = 13.7 \text{ in}$$

$$L/D = 0.8120$$

$$L = (0.8120)(5.5) = 4.47 \text{ ft}$$

$$A_b \text{ Bubbling Area} = A_t - A_{dt} - A_{db} - A_e$$

$$A_b = 23.76 - 3.58 - 3.58 - 0 = 16.6 \text{ ft}^2$$

$$C_{sf(net)} = \left(\frac{CFS}{A_b} \right) \sqrt{\frac{d_v}{d_l - d_v}} = \frac{V_{load}}{A_b} = \frac{3.876}{16.6} = 0.233$$

$$pct \text{ Tray Capacity} = \frac{(100)}{(1)(0.88)(0.506)} \left[0.233 + (0.001327) \frac{(486)}{(4.47)} \right] = 84.7 \text{ pct}$$

The percent of flood is much higher than the 2-pass tray (73.1 percent). In this case, a 2-pass tray is the optimal design.