A REPORT

ON

DESIGNING OF SIEVE TRAY DISTILLATION COLUMN

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CERTIFICATE

This is to certify that the Project Report on **"Designing of Sieve Tray Distillation Column"** submitted to University of Petroleum & Energy Studies, Dehradun, by **Sumit Semwal** in partial fulfillment of the requirement for the award of Degree of **Bachelor of Technology** in **Applied Petroleum Engineering** (Academic Session 2003 – 07) is a bonafide work carried out by them under my supervision and guidance. This work has not been submitted anywhere else for any other degree or diploma.

Date: 7-05-2007

D.N. Saraf

Dr.D.N. Saraf
(Distinguished Professor)

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Sumit Semwal

DESIGNING OF DISTILLATION COLUMN

Acetone is to be recovered from an aqueous waste stream by continuous distillation. The feed will contain 10 percent w/w acetone. Acetone of 98% purity is wanted and the aqueous effluent must not contain more than 50 ppm acetone. The feed will be at 20°C. Estimate the number of ideal stages required .

The column will be operated at atmosphere pressure
The data is shown below.

Mol fraction, x liquid	**0.00**	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**
Acetone y, vapour	**0.00**	**0.6381**	**0.7301**	**0.7716**	**0.7916**	**0.8034**	**0.8124**
Bubble point °C	**100.0**	**74.80**	**68.53**	**65.26**	**63.59**	**62.60**	**61.87**

x	0.35	0.40	0.45	0.50	0.55	0.60	0.65
y	0.8205	0.8269	0.8376	0.8387	0.8455	0.8532	0.8615
^{0}C	61.26	60.75	60.35	59.95	59.54	59.12	58.71

x	0.70	0.75	0.80	0.85	0.90	0.95
y	0.8712	0.8817	0.8950	0.9118	0.9335	0.9627
^{0}C	58.29	57.90	57.49	57.08	56.68	56.30

The equilibrium curve can be drawn with sufficient accuracy to determine the stage above the feed by plotting the concentrations at increment of 0.1. The diagram is plotted in Figure -11.7
Molecular weights, acetone= 58 water=18

Mole fraction of acetone feed $= \dfrac{10/58}{10/58+90/18} = 0.033$

Top product $= \dfrac{98/58}{98/58+2/18} = 0.94$

Bottom product $= 50\text{x } 10^{-6} \text{ x } \dfrac{18}{58} = 15.5 \text{ x } 10^{-6}$

feed condition (q-line)
Bubble point of feed (interpolated) = 83^{0}C
Latent heats, water 41,360, acetone 28,410 J/mol

Mean specific heats, water 75.3, acetone 128 J/mol °C
Latent heat of feed = 28410 x 0.033 + (1-0.033)41,360= 40,933 J/mol
Specific heat of feed = (0.033x128) + (1-0.033)75.3 = 77.0 J/mol °C
Heat to vaporize 1 mol of feed = (83-20)77+40,933= 45,784 J

$$q = \frac{45784}{40933} = 1.12$$

$$\text{Slope of q-line} = \frac{1.12}{1.12 - 1} = 9.32$$

for this problem the condition of minimum reflux occurs where the top of operating line just touches the equilibrium curve at the point where the q–line cuts the curve.

ϕ for the operating line at minimum reflux = 0.65 (from Fig. -11.7)
where ϕ is intercept of operating line on Y axis

using eq. $\phi = \frac{xd}{1+R}$

we get, $R_{min} = \frac{0.94}{0.65} - 1 = 0.45$

Take R = Rmin x 3

As the flows above the feed point will be a small, a high reflux ratio is justified; the condenser duty will be small

At R = 3x0.45 = 1.35

$$\Phi = \frac{0.94}{1+1.35} = 4$$

It is convenient to step the stages of starting at the intersection of operating lines. This gives 3 stages above the feed up to y =0.8. The top of section is drawn at a larger scale. Fig –11.8 to determine the stages above y= 0.8 three to four stages required total stages above the feed 7.

Below the feed, one stages is required down to x=0.04. A log-log plot is used to determine the stages below this concentration. Data for log- log plot operating line slope = 0.45/0.09 = 5.0 9 (from Fig. -11.7)

Operating line equation, $y = 4.63(x-x_b)+x_b$
$= 5.0x - 62.0x\ 10^{-6}$

Equilibrium line slope, from V-L-E data = 0.6381/0.05 = 12.8

	$x=4\times10^{-2}$	10^{-3}	10^{-4}	4×10^{-5}	2×10^{-5}
Equilibrium line	$y=0.51$	$1.3\ x1^{-2}$	1.3×10^{-3}	5.1×10^{-4}	2.6x
Operating line	$y=0.20$	4.9×10^{-3}	4.4×10^{-4}	1.4×10^{-4}	3.8x

from fig –11.9 number of stages required for this section = 8

Total number of stages below feed = 9

Total stages 7+9 =16

DESIGNING OF SIEVE TRAYS

Design the plates for the column specified previously. Take the minimum feed rate as 70 percent of the maximum (maximum feed 1000 kg/hr) .Use sieve plates.

As, the liquid and vapour flowrates and compositions will vary up the column, plate designs should be made above and below the feed point. Below, only the bottom plate will be designed in detail.

From Mc Cabe –Thiele diagram

Number of stages =16

Slope of bottom operating line =5.0

Slope of top operating line = 0.57

Top composition 94 percent mol. 98 percent w/w

Bottom composition – essentially water

Reflux ratio = 1.35

Flow rates

Mol. Weight feed=0.033x58 + (1-0.033)18=19.32

Feed=1300/19.32=67.29 kmol/hr

A mass balance on acetone gives

Top product, D = 67.29x 0.033/ (0.94)= 2.36 kmol /hr

Vapour rate, V= D (1+R) = 2.36(1+1.35) =5.55 Kmol/hr

An overall mass balance gives

Bottom product, B= 67.29 - 2.36

= 64.93 Kmol/hr

Slope of the bottom operating line L'm/V'm = 5.0

And Vm' = Lm' - B

Vapour flow below feed

Vm' = 16.23 Kmol/hr
Liquid flow below feed, Lm' = 81.16

Physical properties

Estimate base pressure, assume column efficiency of 60 percent, and take reboiler as equivalent to one stage

Number of real stages = $\frac{16-1}{0.6}$ = 25

Assume 100mm water, pressure drop per plate

Column pressure drop = 100x 10^{-3}x1000x 9.81 x25 = 24,525 pa

Top pressure, 1atm (14.7 lb/m^2) =101.4 x 10^3 Pa

Estimated bottom pressure =

101.4 x 10 3 + 24525 = 125925 Pa = 1.26 bar

from steam tables, base temp 106^{0}C

ρ_v = 0.72kg/m^3 ρ_l = 954kg/m^3

Surface tension =57 x10^{-3} N/m

Top 98% w/w acetone top temp.57^{0}C

From PPDS

ρ_v = 2.05kg/m^3 ρ_l = 753kg/m^3

Molecular weight = 55.6

Surface tension = 23 x10^{-3} N/m

Column diameter

$$Flv = \frac{Lw}{Vw}\sqrt{\frac{\rho_v}{\rho_L}}$$

$$Flx = bottom = 5\sqrt{\frac{0.72}{954}} = 0.14$$

$$Flv\ top = 0.57\sqrt{\frac{2.05}{753}} = 0.03$$

Take tray spacing as 0.30 m

from Fig. – 11.27

Base K1 =4.95 x 10^{-2}

Top K1= 7.58 x 10^{-2}

Correction for surface tensions

Base K1 $= \left(\frac{57}{20}\right)^{0.2} \times 4.95 \times 10^{-2} = 6.1 \times 10^{-2}$

Top K1 $= \left(\frac{23}{20}\right)^{0.2} \times 7.6 \times 10^{-2} = 7.8 \times 10^{-2}$

base uf $= 6.1 \times 10^{-2} \times \sqrt{\frac{954-0.72}{0.72}}$ ($uf = k \times \sqrt{\rho_L - \rho_v / \rho_v}$)

$= 2.22$ m/s

Top u$f = 7.8 \times 10^{-2} \sqrt{\frac{753-2.05}{2.05}} = 1.5$ m/s

Design for 85% flooding at max flow rate

Base $\hat{u}v = 2.22 \times 0.85 = 1.89$ m/s

Top $\hat{u}v = 1.5 \times 0.85 = 1.27$ m/s

Max volumetric flow rate

Base $= \frac{16.23 \times 18}{0.72 \times 3600} = 0.113$ m^3/sec

Top $= \frac{5.55 \times 55.6}{2.05 \times 360} = 0.042$ m^3/ sec

Net area required,

Bottom $= \frac{0.113}{1.89} = 0.06$ m^2

top $= \frac{0.042}{1.27} = 0.033$ m^2

Taking down comer area as 12% of total Column Cross sectional area

Base $= \frac{0.06}{0.88} = 0.07$

Top $= \frac{0.033}{0.88} = 0.0375$

Column diameter

Base = $\sqrt{\frac{0.7x4}{\pi}}$ = 0.298 m

Top = $\sqrt{\frac{0.0375x4}{\pi}}$ = 0.22 m

Take inside diameter 0.30m

Liquid flow pattern

Maximum volumetric liquid rate = $\frac{81.16 \times 18}{3600 \times 954}$ = $4.3x10^{-4}$ m^3/ sec

Provisional plate design

Column diameter, D_C = 0.3 m

Column area, Ac =0.071m^2

Down comer area, Ad = 0.12x 0.071

= 8.52x 10^{-3}

Net area, An = Ac- Ad

= 0.071- 8.52 $x10^{-3}$

= 0.0625 m^2

Active area, Aa = Ac- 2d

0.071 – 2(8.52$x10^{-3}$) = 0.054m^2

Take hole area, as 10 percent of Aa = 0.0054 m^2

Weir length (from fig. – 11.31) = 0.75 x0.3 = 0.225 m

$\left(\text{As } \frac{lw}{Dc} = 0.75\right)$

Take weir height = 30mm

Hole diameter = 3 mm

Plate thickness = 3mm

Check weeping

Maximum liquid rate = $\left(\frac{81.16x18}{3600}\right)$ = 0.406 Kg/sec

Minimum liq.rate at 70% turndown = 0.7x.406 = 0.2842kg/sec

Height of liquid crest over down comer weir ,

$$how = 750\left(\frac{Lw}{\rho_L\ lw}\right)^{2/3}$$

where

Lw = liquid mass flow rate

lw = weir length

ρ_L = Density of liquid

maximum how = 750 $\left(\frac{0.406}{954x0.0225}\right)^{2/3}$

= 53.242

minimum how = 750$\left(\frac{0.2842}{954x\ 0.225}\right)^{2/3}$

=9.043

At minimum rate hw + how = 30+ 9.043 = 39.043 mm

From fig – 11.30

K2 =29.6

The minimum design vapour velocity is given by

$$\breve{u}_h = \frac{[\ k2 - 0.90\ (25.4 - dh)]}{(\rho_v)^{1/2}}$$

where,

$\breve{u}_h$ = minimum vapour velocity through the holes chased on hole area, m/s

d_h = hole diameter, mm

K2 = a constant, dependent on the depth of clear liquid on the plate obtained

$\breve{u}_h$ min = $\dfrac{29.6 - 0.90\,(25.4-3)}{\square\, 0.72}$

=11.125 m/s

Actual minimum vapour velocity = $\dfrac{\text{minimum vapour rate}}{\text{Ah}}$

= $\dfrac{0.7 \times 0.113}{0.0054}$ = 14.65m/s

Plate Pressure drop

Dry Plate drop

Max vapour velocity through holes, ûh = $\dfrac{0.113}{0.0054}$ = 20.9 m/s

for plate thickness/hole dia = 1

Ah/Ap = 0.1

Dry plate pressure drop = $51 \left(\dfrac{uh}{Co}\right)^2 \dfrac{\rho_v}{\rho_L}$

$hd = 51 \left(\dfrac{20.9}{0.84}\right)^2 \dfrac{0.72}{954}$ = 23.83 mm liq.

Residual head, hr = $\dfrac{12.5 \times 10^3}{\rho_L}$

$\dfrac{12.5 \times 10^3}{954}$ = 13.103 mm

Total plate pressure drop, ht = hd + (hw+how)+hr

23.83 + (30+53.242)+ 13.103 = 120.175 mm liquid

Down comer Liquid backup

Down comer pressure loss

As hap = hw- (5 to 10 mm)

hap = 30-10 = 20 mm

Area under apron, Aap = weir length x hap

Aap = 10^3 x 0.225x 30 = 6.75×10^{-3} m^2

As this is less than Ad = 8.52×10^{-3} m^2, use Aap in eq. shown below

$$hdc = 166 \left(\frac{Lwd}{Am \times \rho_L} \right)^2$$

Where

hdi = head loss in downcomer

Lwd=liquid flow rate in downcomer , kg/sec

Am= either the downcomer area or clearance area under downcomer

$$hdc = 166 \left(\frac{0.406}{954 \times 6.75 \times 10^{-3}} \right) = 0.66$$

Back up in downcomer, hb= (hw + how)+ ht + hdc

ht = Total plate pressure drop, head of liquid

how= height of liq. crest over downcomer weir

hb= (30+53.242) + 120.175 +0.66

= 204.1 mm = 0.2041 m

$0\text{-}2041 < \frac{1}{2}$ (trayspacing+weir height)

Check Residence time

$$tr = \frac{Ad \times hbc \times \rho_L}{Lwd}$$

$$tr = \left(\frac{8.52 \times 10^{-3} \times 0.204 \times 954}{0.406} \right) = 4.01s$$

tr> 3s, satisfactory

Check entrainment

$$uv = \frac{0.113}{0.0625} = 1.81 \text{ m/s}$$

$$\text{Percent flooding} = \frac{1.81}{2.22} = 81.5$$

Flv = 0.14 from fig - ψ = 0.018 well below 0.1

ψ = entrainment factor

Number of holes

Area of one hole $= 7.1\text{x } 10^{-6}\text{ m}^2$

Number of holes $= \frac{0.0054}{7.1\text{x}10\text{-}6} = 760.56$

Number of holes = 761

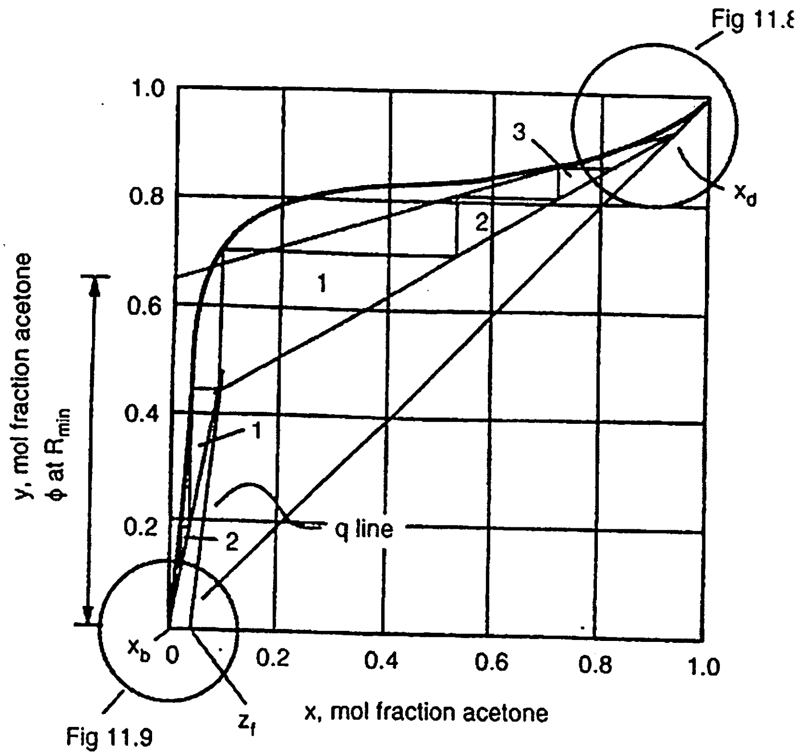


Figure 11.7. McCabe-Thiele plo

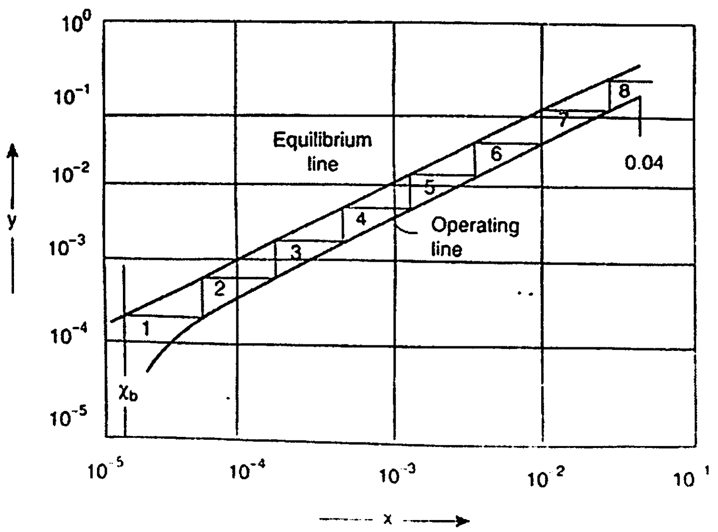


Figure 11.9. Log-log plot of McCabe-Thiele diagram

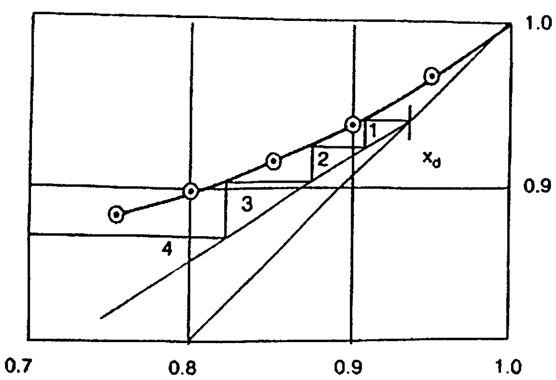


Figure 11.8. Top section enlarged

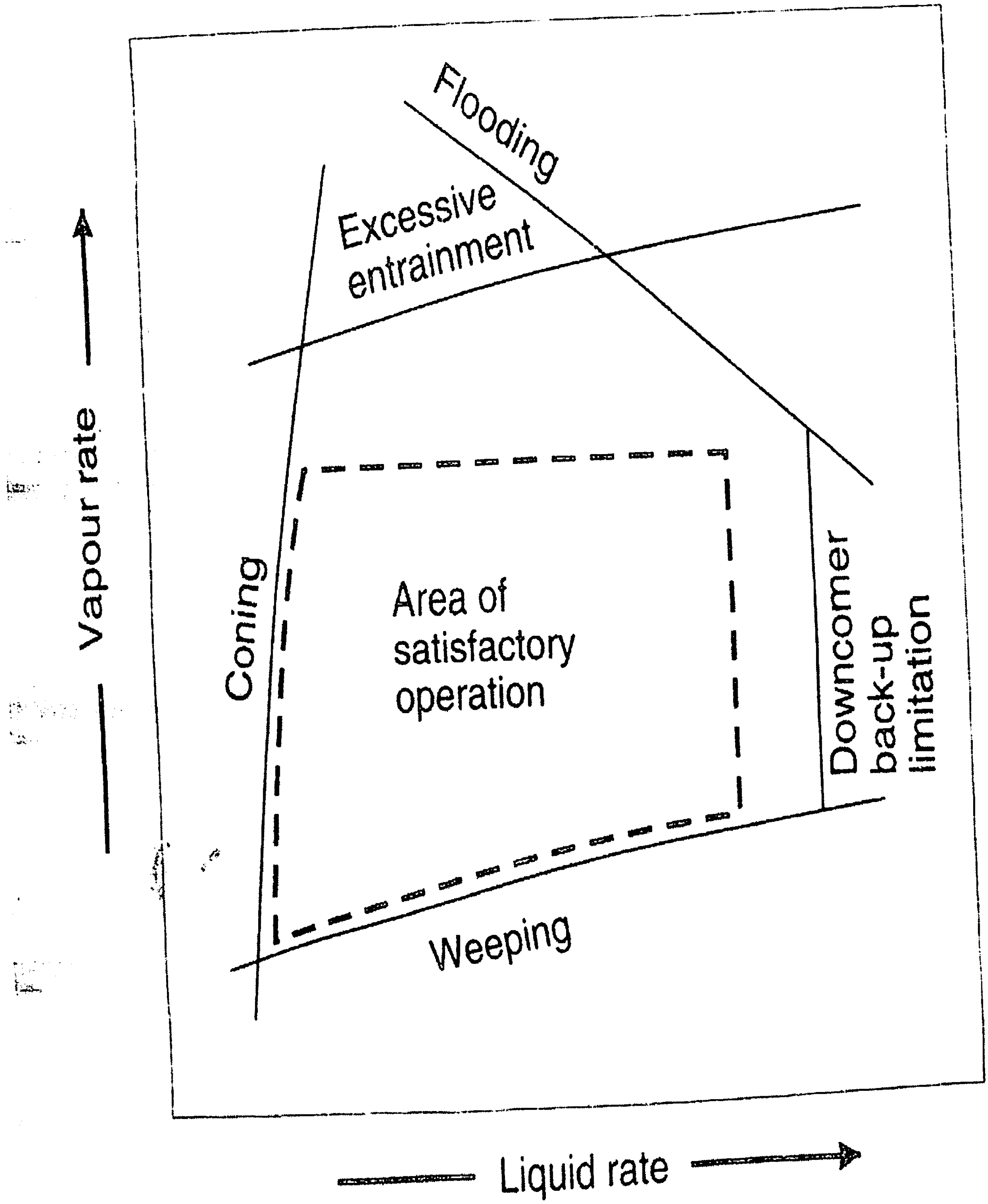


Figure 11.26. Sieve plate performance diagram

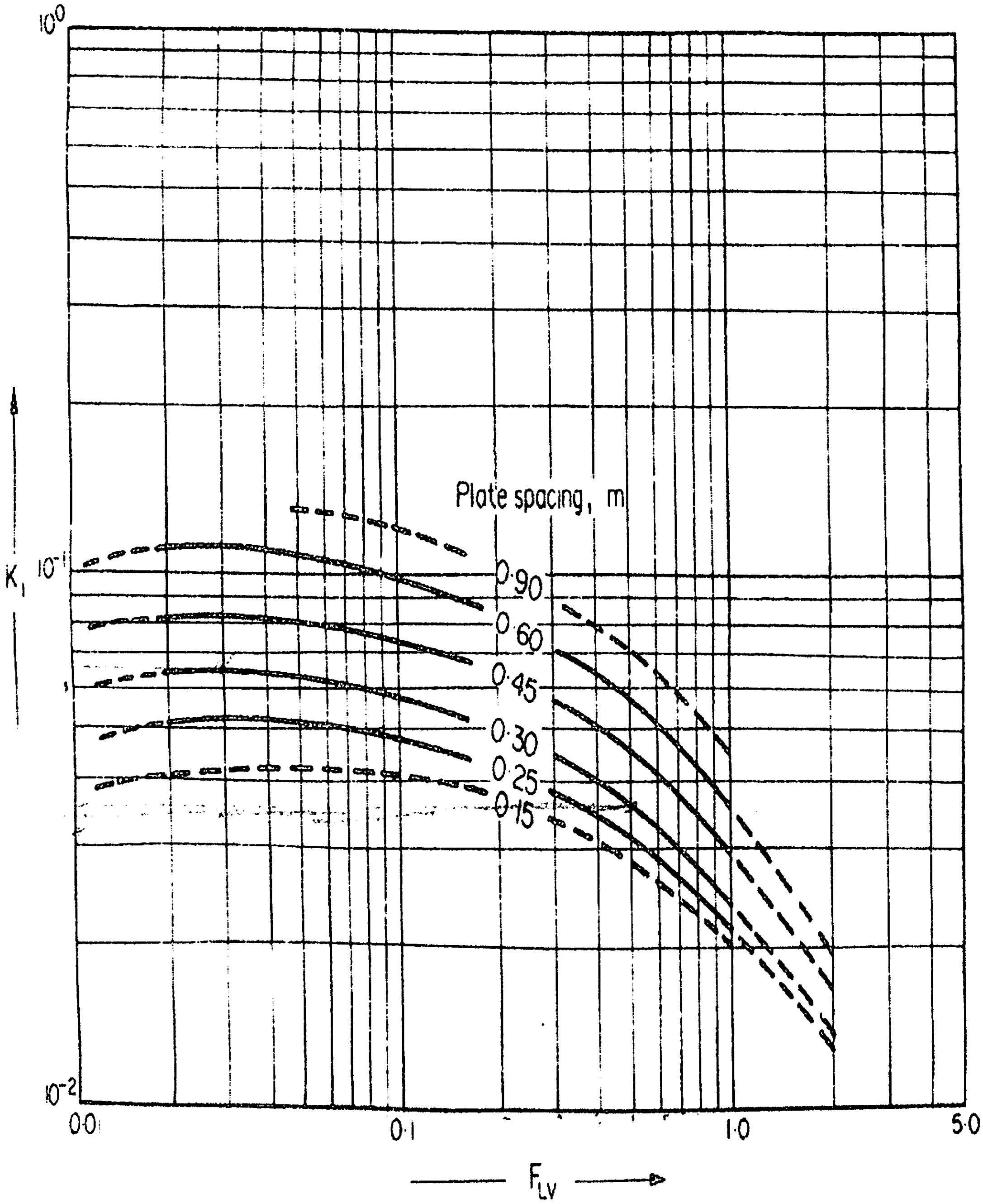


Figure 11.27. Flooding velocity, sieve plates

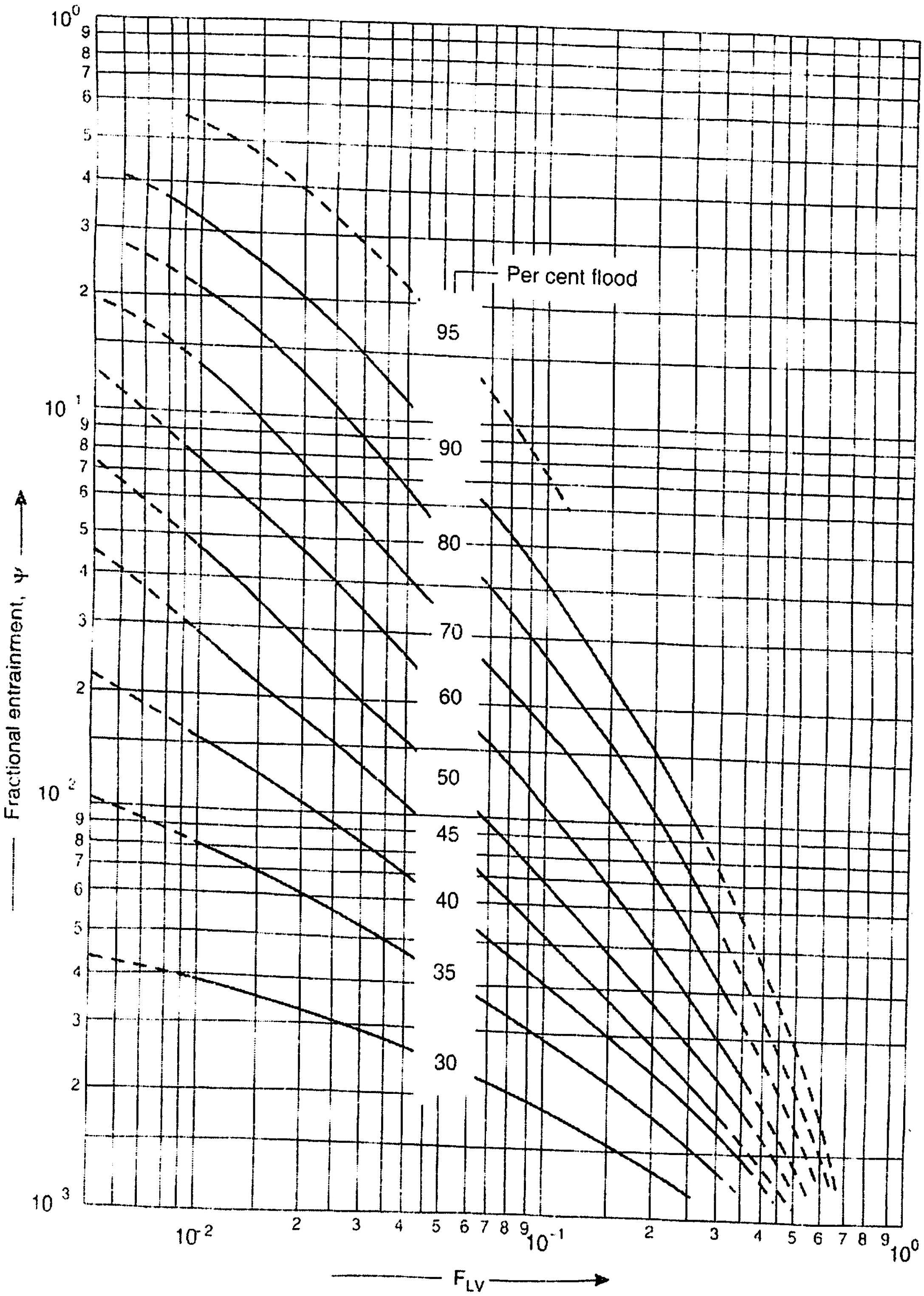


Figure 11.29. Entrainment correlation for sieve plates (Fair, 1961)

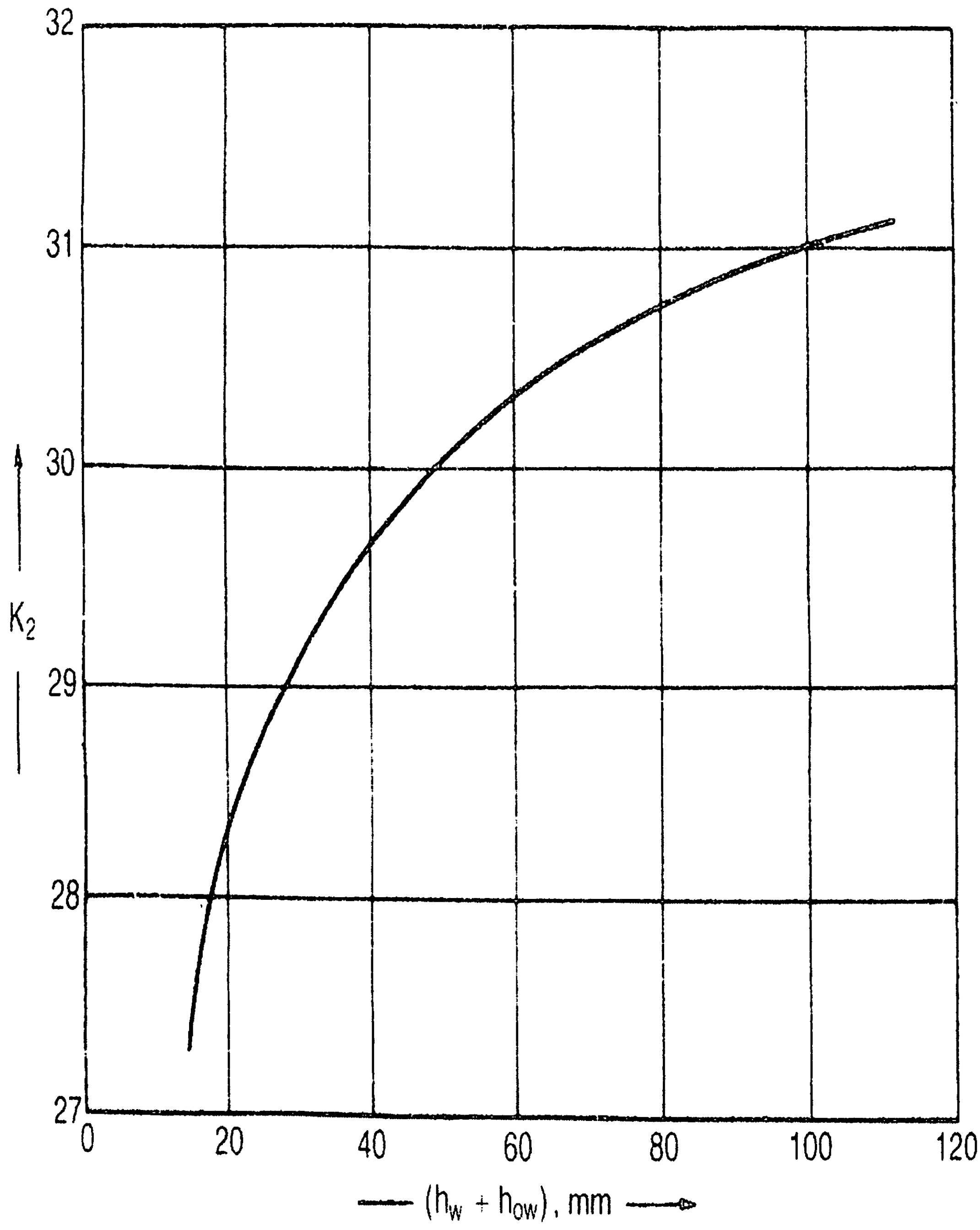
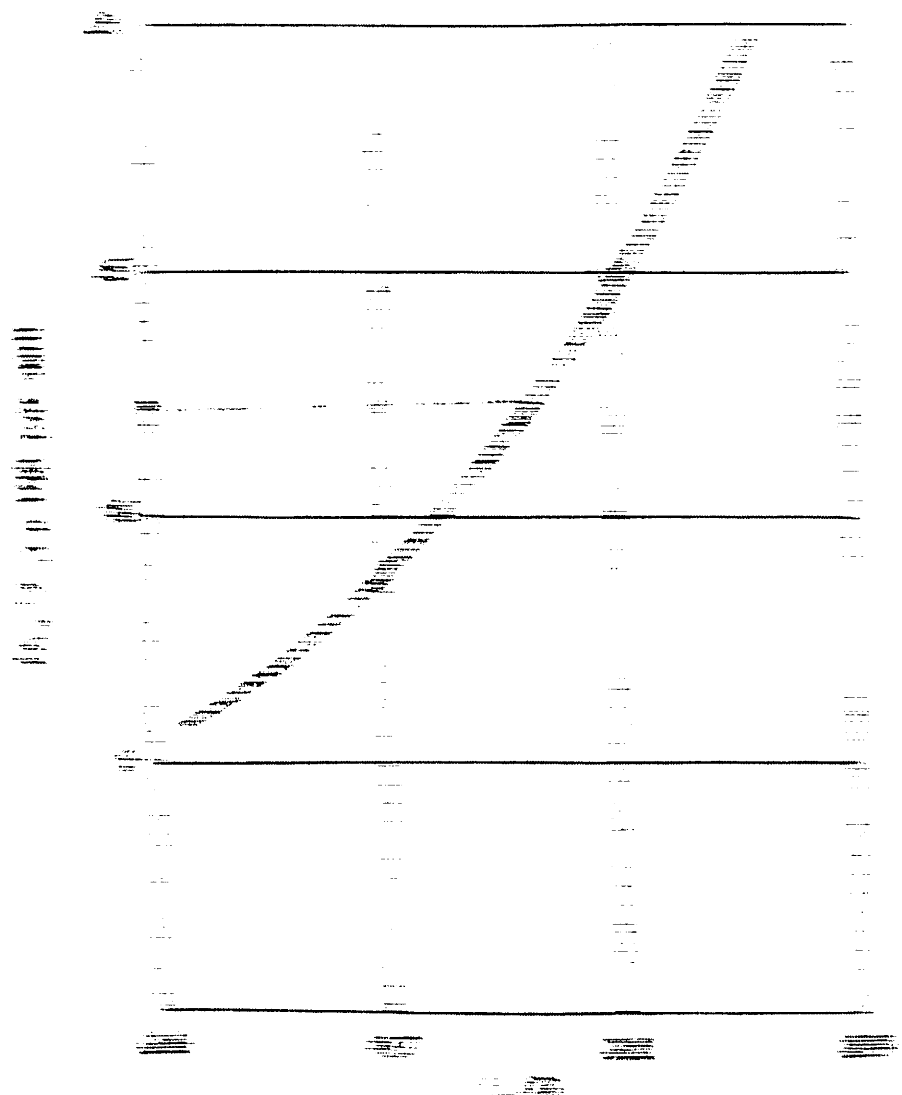


Figure 11.30. Weep-point correlation (Eduljee, 1959)



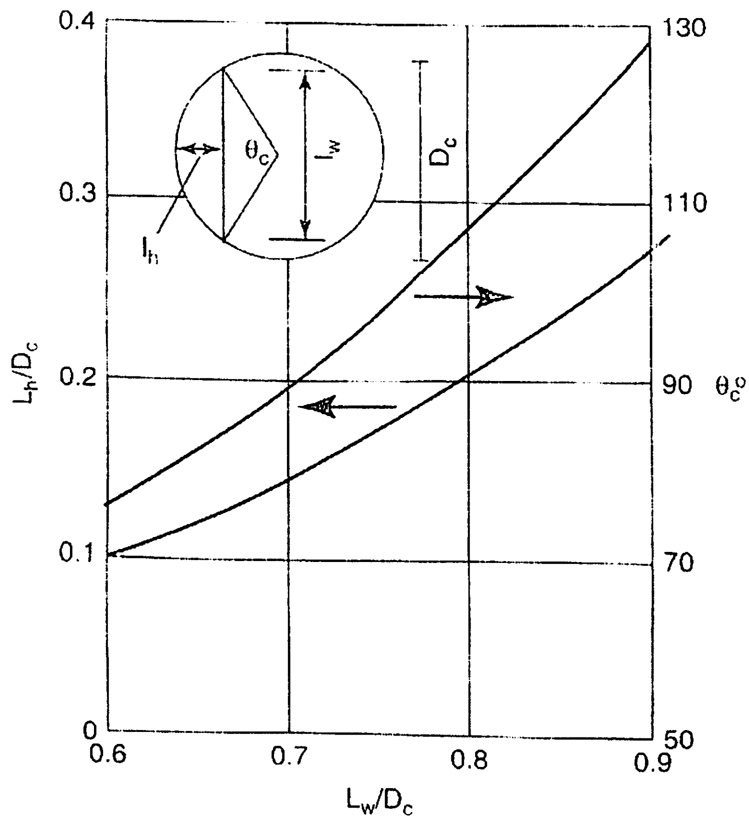


Figure 11.32. Relation between angle subtended by chord, chord height and chord length

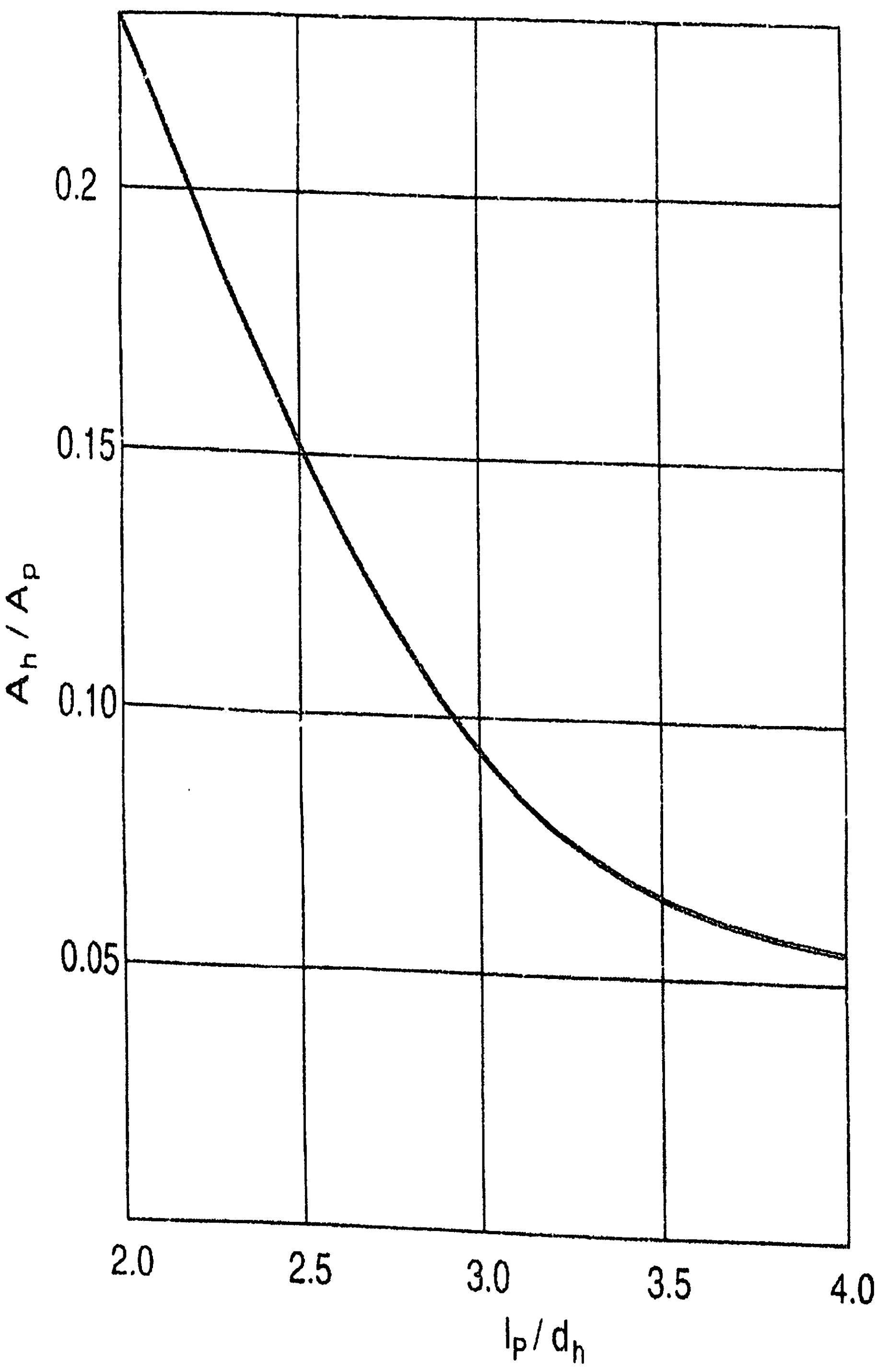


Figure 11.33. Relation between hole area and pitch

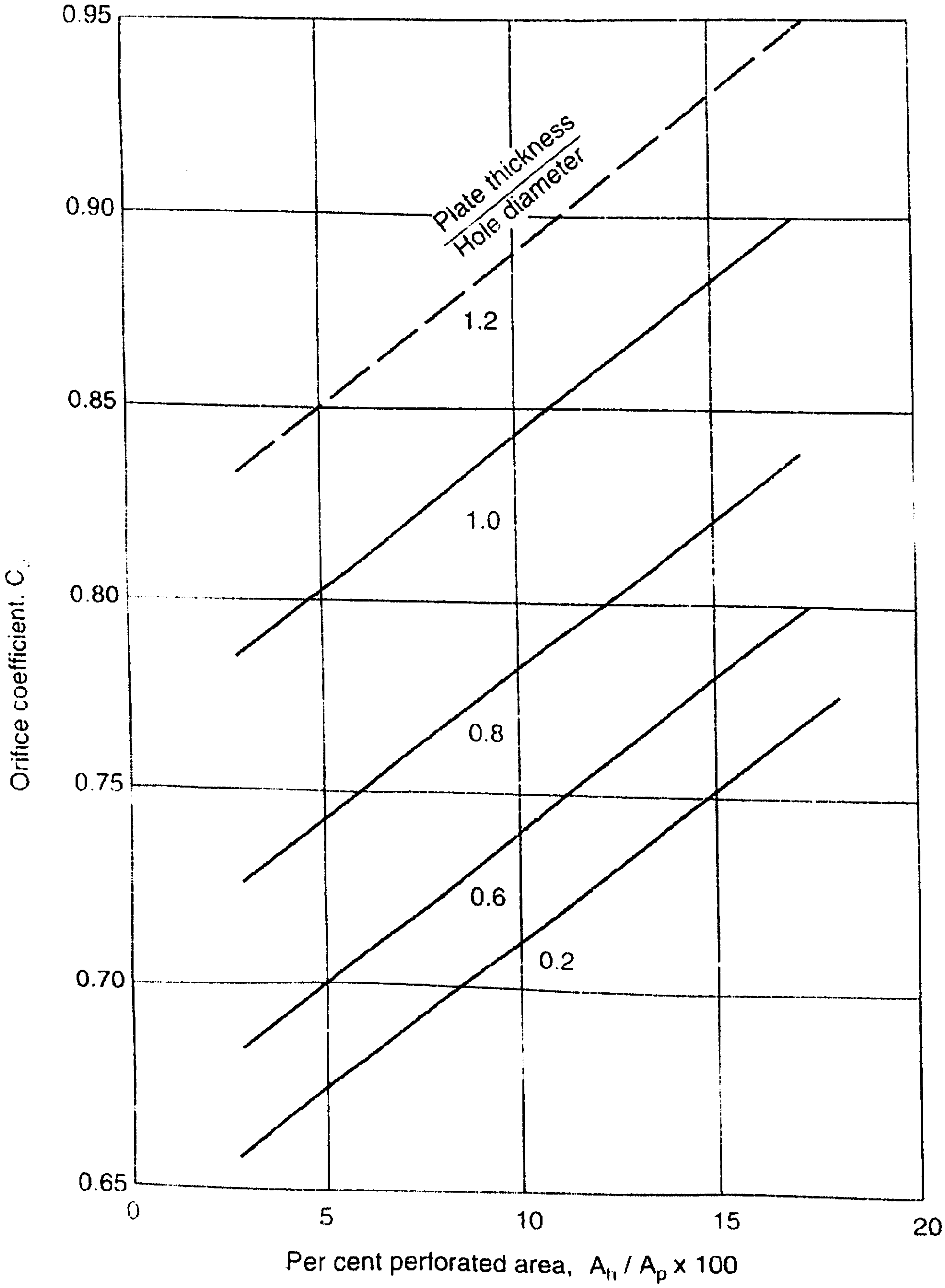


Figure 11.34. Discharge coefficient, sieve plates (Liebson *et al.*, 1957)

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