$A_d =$ cross-sectional area of downcomer,

$A_n =$ net area available for vapour-liquid disengagement, normally equal to $A_c - A_d$, for a single pass plate,

$A_a =$ active, or bubbling, area, equal to $A_c - 2A_d$ for single-pass plates,

$A_h =$ hole area, the total area of all the active holes,

$A_p =$ perforated area (including blanked areas),

$A_{ap} =$ the clearance area under the downcomer apron.

5.15.3 Diameter

✓ The flooding condition fixes the upper limit of vapour velocity.

✓ A high vapour velocity is needed for high plate efficiencies, and the velocity will normally be between 70 to 90 per cent of that which would cause flooding.

✓ For design, a value of 80 to 85 per cent of the flooding velocity should be used.

The flooding velocity can be estimated from the correlation given by Fair:

$$u_f = K_1 \sqrt{\frac{\rho_L - \rho_v}{\rho_v}} \tag{5.43}$$

where: u_f D flooding vapour velocity, m/s, based on the net column cross-sectional area A_n, k_1 is a constant obtained from Figure 5.15

The liquid-vapour flow factor F_{LV} in Figure 5.15 is given by:

$$F_{LV} = \frac{L_W}{V_W} \sqrt{\frac{\rho_v}{\rho_L}} \tag{5.44}$$

where L_w is liquid mass flow-rate, kg/s, and V_w is the vapour mass flow-rate, kg/s.

Note:

Restrictions must be obeyed when using Figure 5.15:

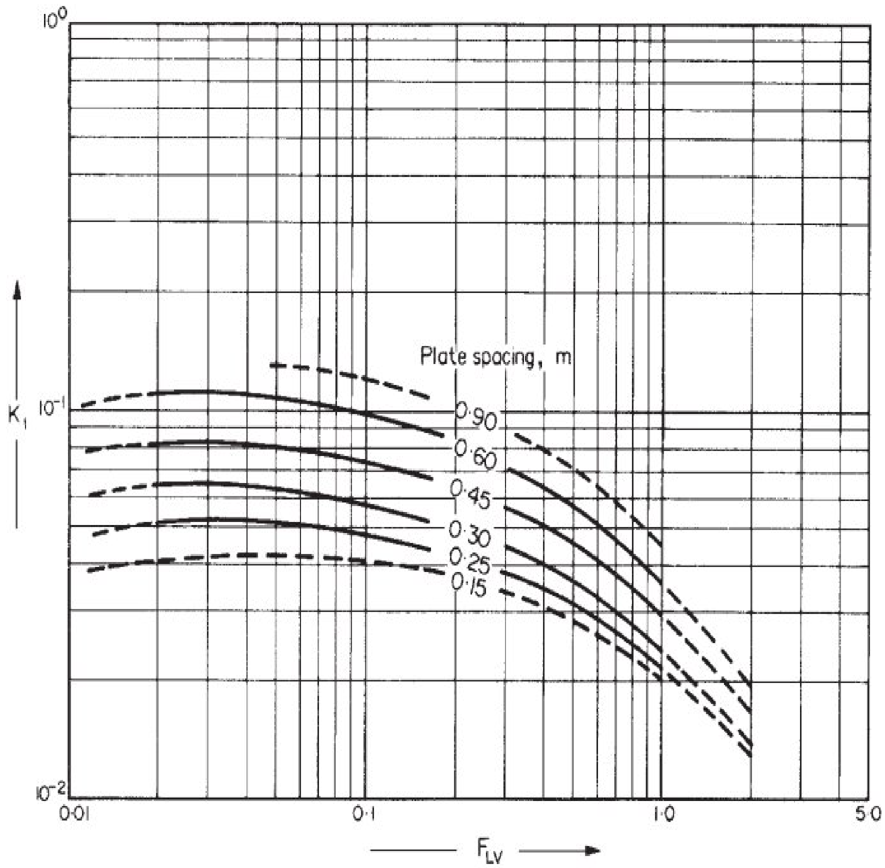

Figure 5.15: Feed and take-off nozzles

1- Hole size less than 6.5 mm. Entrainment may be greater with larger hole sizes.

2- Weir height less than 15 per cent of the plate spacing.

3- Non-foaming systems.

4- Hole: active area ratio greater than 0.10; for other ratios apply the following corrections:

5- Liquid surface tension 0.02 N/m, for other surface tensions σ multiply the value of K_1 by $[\sigma/0.02]^{0.2}$.

For the first trial:

Hole: active area	Multiply K_1 by
0.1	1
0.08	0.9
0.06	0.8

✓ To estimate diameter of the column, an estimate of A_n is required.

✓ Take the downcomers area as 12 percent of the total area and the whole active area is 10 percent.

Why For distillation will usually be sufficient to design for the conditions above and below the feed points?

Where **the vapour and liquid flow-rates, or physical properties,** vary significantly throughout the column a plate design should be made for several points up the column.

How we can accommodate the changes the vapor flow rate inside the column diameter?

Changes in the vapour flow-rate will normally be accommodated by adjusting the hole area; often by blanking off some rows of holes.

Different column diameters would only be used where there is a considerable change in flow-rate.

Changes in liquid rate can be allowed for by adjusting the liquid downcomer areas.

5.15.4 Liquid-flow arrangement

The choice of plate type (reverse, single pass or multiple pass) will depend on the liquid flow-rate and column diameter. An initial selection can be made using Figure 5.16,

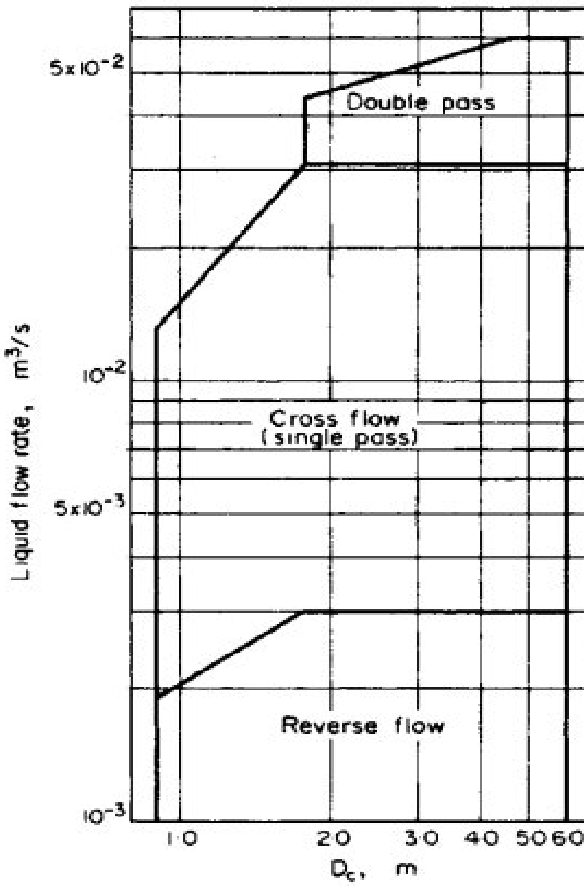

Figure 5.16: Selection of liquid-flow arrangement

5.15.5 Entrainment

It is operation when a fluid picks up and drags another fluid or a solid. Entrainment can be estimated from the correlation given by Fair (1961), Figure 5.17, which gives the fractional entrainment (kg/kg gross liquid flow) as a function of the liquid-vapour factor F LV , with the percentage approach to flooding as a parameter.

The percentage flooding is given by:

$$\text{Percentage flooding} = = \frac{u_n(\text{actual velocity based on net area})}{u_f \text{from equation 5.43}} \tag{5.45}$$

As a rough guide the upper limit of ψ can be taken as 0.1; below this figure the effect on efficiency will be small.

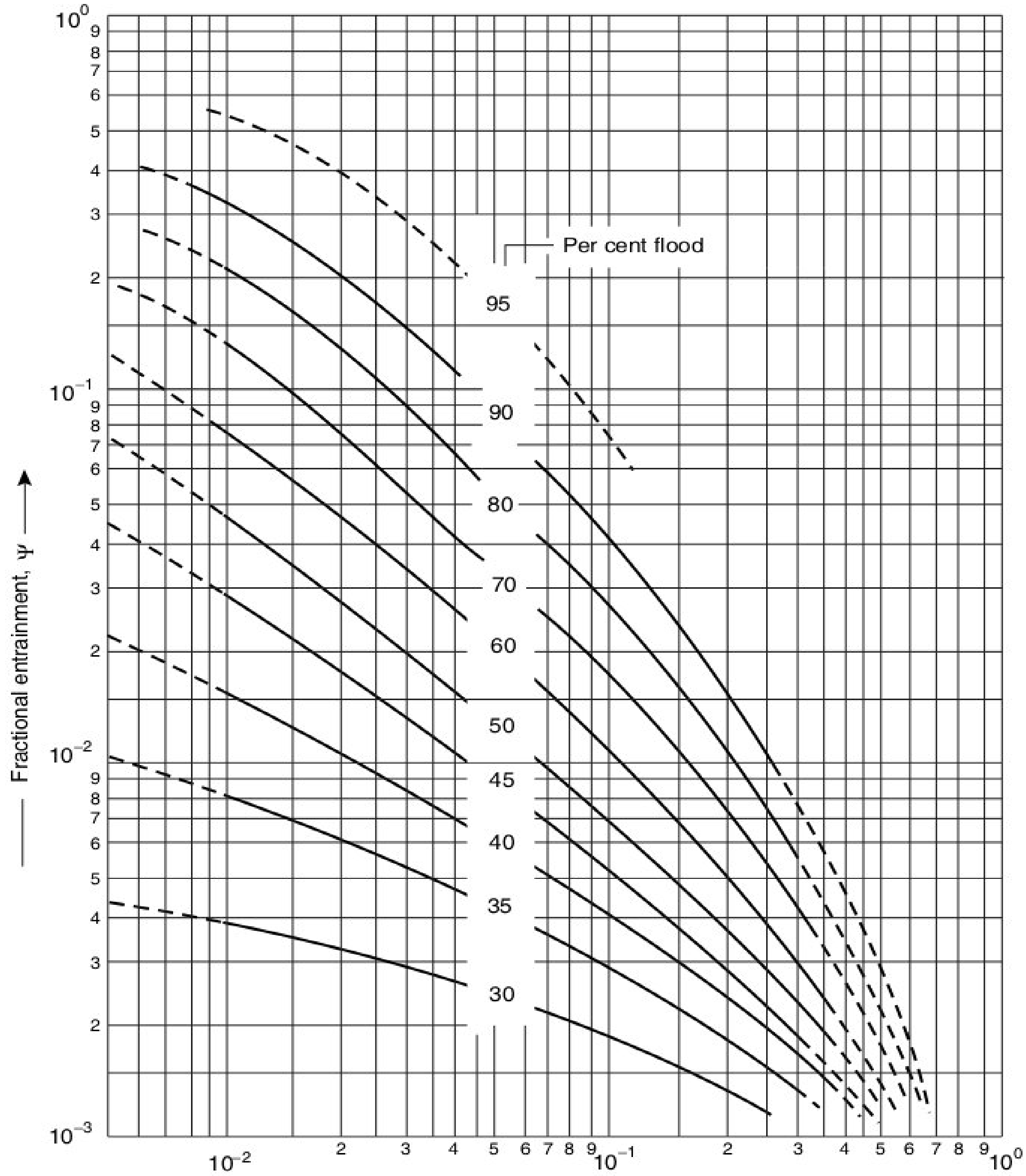

Figure 5.17: Entrainment correlation for sieve plates

5.15.6 Weep point

When the lower limit of operating range occurs in distillation tower?

It occurs when liquid leakage through the plate becomes excessive.

Note:

The vapour velocity at the weep point is the minimum value for stable operation. The hole area must be chosen so that at the lowest operating rate the vapour flow velocity is still well above the weep point.

The minimum design vapour velocity is given by:

$$u_h = \frac{[K_2 - 0.9(2.54 - d_h)]}{(\rho_v)^{1/2}} \tag{5.46}$$

where:

$u_h =$ minimum vapour velocity through the holes(based on the hole area), m/s,

$d_h =$ hole diameter, mm,

$K_2 =$ a constant, dependent on the depth of clear liquid on the plate, obtained from Figure 5.18.

Note:-

The clear liquid depth is equal to the height of the weir h_w plus the depth of the crest of liquid over the weir h_{ow}.

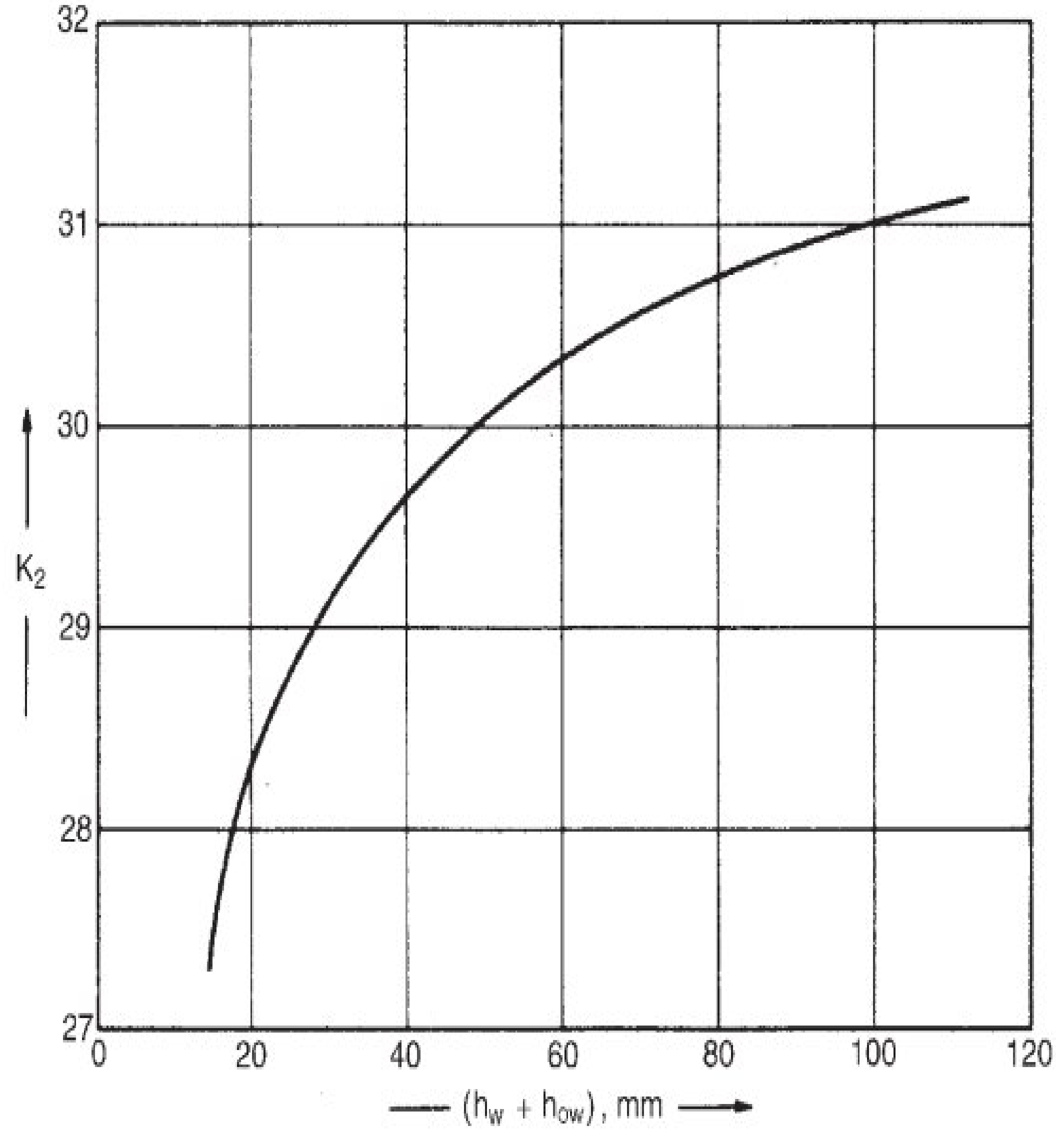

Figure 5.18: Selection of liquid-flow arrangement

5.15.7 Weir liquid crest

The height of the liquid crest over the weir can be estimated using the Francis weir formula. For a segmental downcomer this can be written as:

$$h_{ow} = 750[\frac{L_w}{\rho_l l_w}]^{\frac{2}{3}} \tag{5.47}$$

where:

l_w= weir length (m)

h_{ow}= weir crest (mm) of liquid

L_w= liquid flow rate (kg/s)

Note:

To ensure an even flow of liquid along the weir, the crest should be at least 10 mm at the lowest liquid rate. Serrated weirs are sometimes used for very low liquid rates. A high weir will increase the plate efficiency but at the expense of a higher plate pressure drop.

For columns operating above atmospheric pressure the weir heights will normally be between 40 mm to 90 mm (1.5 to 3.5 in.); 40 to 50 mm is recommended.

For vacuum operation lower weir heights are used to reduce the pressure drop; (6 to 12 mm) (1/4 to 1/2) inch is recommended.

5.15.8 Weir dimension

5.15.8.1 Weir height

For columns operating above atmospheric pressure the weir heights will normally be between 40 mm to 90 mm (1.5 to 3.5 in.); 40 to 50 mm is recommended.

For vacuum operation lower weir heights are used to reduce the pressure drop; (6 to 12 mm) (1/4 to 1/2) inch is recommended.

5.15.9 Inlet weirs

Inlet weirs, or recessed pans, are sometimes used to improve the distribution of liquid across the plate; but are seldom needed with segmental downcomers.

5.15.10 Weir length

With segmental downcomers the length of the weir fixes the area of the downcomer.

Note:

The chord length will normally be between 0.6 to 0.85 of the column diameter. A good initial value to use is 0.77, equivalent to a downcomer area of 12 per cent

The relationship between weir length and downcomer area is given in Figure 5.19. For double-pass plates the width of the central downcomer is normally (200-250) mm (8-10 in.).

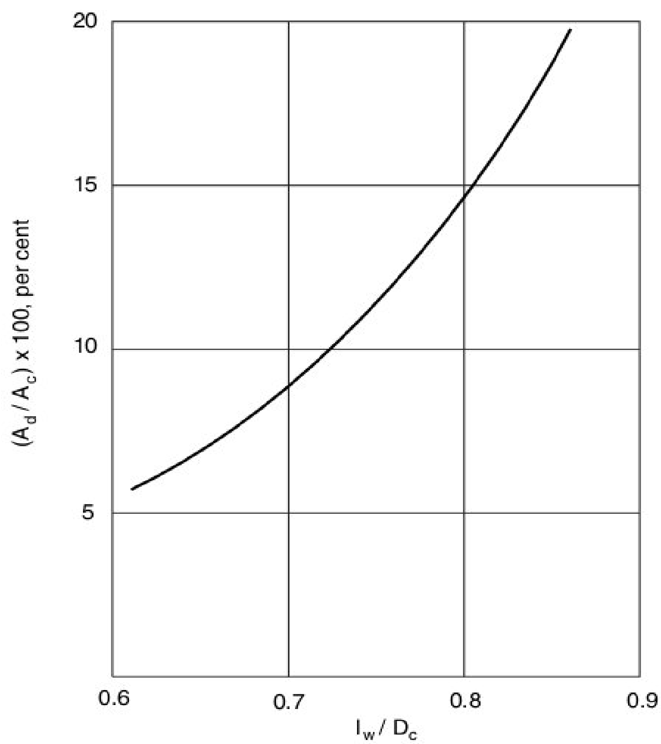

Figure 5.19: Relation between downcomer area and weir length

5.15.11 Perforated area

The area available for perforation will be reduced: 1- by the obstruction caused by structural members (the support rings and beams) 2- by the use of calming zones.

What are the calming zones on plate?

Calming zones are unperforated strips of plate at the inlet and outlet sides of the plate. The width of each zone is usually made the same; recommended values are: below 1.5 m diameter, 75 mm; above, 100 mm.

Note:

The unperforated area can be calculated from the plate geometry. The relationship between the weir chord length, chord height and the angle subtended by the chord is given in Figure 5.20.

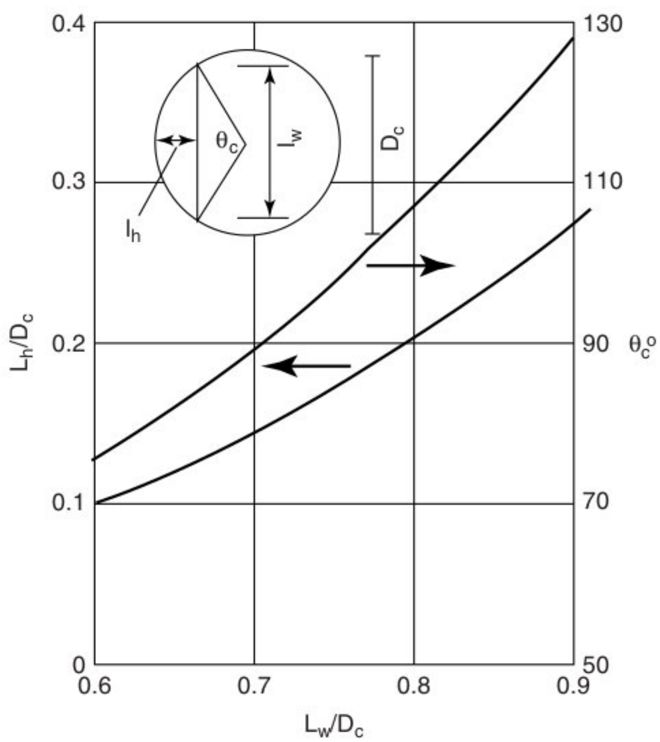

Figure 5.20: Relation between angle subtended by chord, chord height and chord length

5.15.12 Hole pitch

What is the hole pitch?How can the hole pitch be taken?

The hole pitch (distance between the hole centres) l_p should not be less than 2.0 hole diameters, and the normal range will be 2.5 to 4.0 diameters. Within this range the pitch can be selected to give the number of active holes required for the total hole area specified.

What are the patterns of hole pitch used, and which pattern is preferred?

Square and equilateral triangular patterns are used; triangular is preferred.

The total hole area as a fraction of the perforated area A_p is given by the following expression, for an equilateral triangular pitch:

$$\frac{A_h}{A_p} = 0.9\,[\frac{d_h}{l_p}]^2 \tag{5.48}$$

This equation is plotted in Figure 5.21.

5.15.13 Hydraulic gradient

What is the meaning of hydraulic gradient? The hydraulic gradient is the difference in liquid level needed to drive the liquid flow across the plate.

Clarify the hydraulic gradient on sieve plate and bubble cap plate?

When the hydraulic gradient is significant? it can be significant in vacuum operation, as with the low weir heights used the hydraulic gradient can be a significant fraction of the total liquid depth.

5.15.14 Liquid throw

Define the liquid throw in distillation and when it is important? The liquid throw is the horizontal distance travelled by the liquid stream flowing over the downcomer weir. It is only an important consideration in the design of multiple-pass plates.

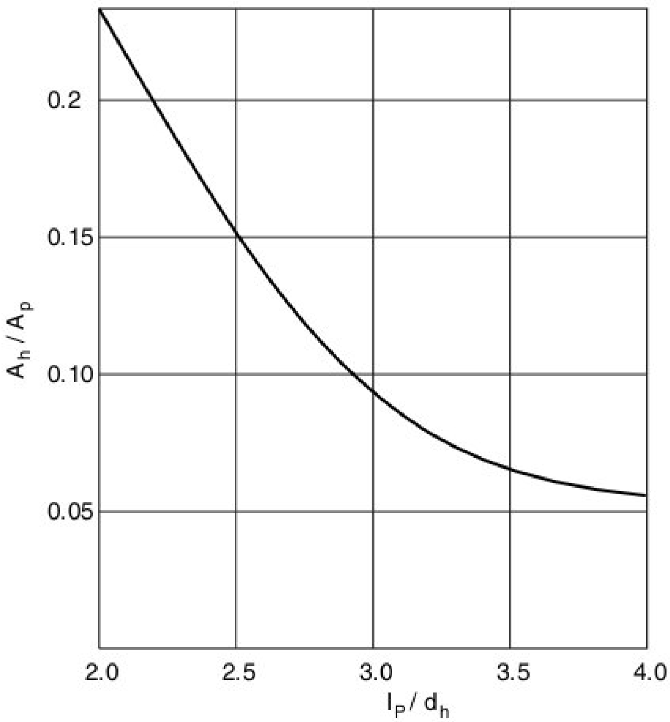

Figure 5.21: Relation between hole area and pitch

5.15.15 Plate pressure drop

What are the two main reasons for pressure drop inside the distillation column?

1- Due to vapour flow through the holes (an orifice loss)

2- Due to the static head of liquid on the plate

How we can estimate the pressure drop? A simple additive model is normally used to predict the total pressure drop. The total is taken as the sum of the pressure drop calculated for the flow of vapour through the dry plate (the dry plate drop h_d); the head of clear liquid on the plate ($h_w + h_{ow}$); and a term to account for other, minor, sources of pressure loss, the so-called residual loss h_r.

<u>**What is the residual loss in distillation?**</u>

The residual loss is the difference between the observed experimental pressure drop and the simple sum of the dry-plate drop and the clear-liquid height.

What are the effects that cause residual loss in distillation column?

The residual loss accounts to the two effects:

1- The energy to form the vapour bubbles

2- The fact that on an operating plate the liquid head will not be clear liquid but a head of aerated liquid froth, and the froth density and height will be different from that of the clear liquid.

To express the pressure drops in terms of millimetres of liquid is given as follows:

$$\Delta P_t = 9.81 \times 10^{-3} h_t \rho_L \tag{5.49}$$

where:

ΔP_t= Total pressure drop in Pa (N/m^2)

h_t= Total pressure drop, (mm) liquid

Dry plate drop:

$$h_d = 51[\frac{U_h}{C_o}]^2 \frac{\rho_v}{\rho_L} \tag{5.50}$$

where the orifice coefficient C_0 is a function of the plate thickness, hole diameter, and the hole to perforated area ratio. C_0 can be obtained from Figure 5.22, u_h is the velocity through the holes, m/s.

Residual head:

$$h_r = \frac{12.5 \times 10^3}{\rho_L} \tag{5.51}$$

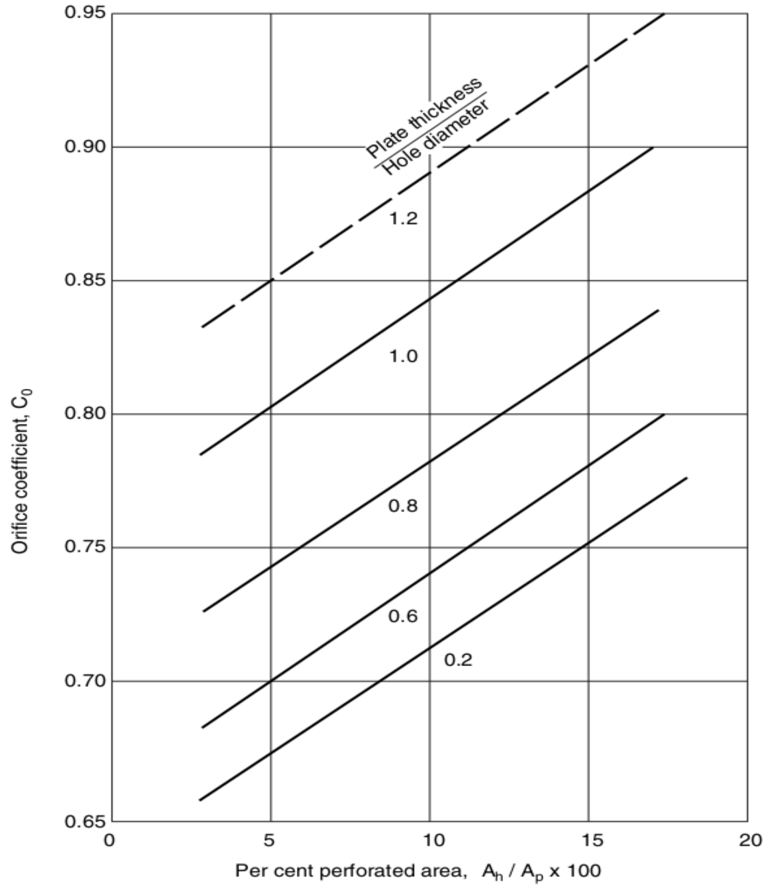

Figure 5.22: Discharge coefficient, sieve plates

Total drop:

The total pressure drop is given as follows:

$$h_t = h_d + (h_w + h_{ow} + h_r) \tag{5.52}$$

Note:

If the hydraulic gradient is significant, half its value is added to the clear liquid height.