10 Design of distributors

Chapters 6 to 9 have shown how indispensable distributors are in packed columns – for distributing either the liquid at the head or the gas at the bottom of the column or for redistributing the phases at given heights –. Their design is governed by the principle on which they operate (cf. Fig. 10.1). It merits great importance because distributors serve to overcome maldistribution, which – according to Eqn (8-25) – may greatly impair the efficiency of large-diameter columns. Allowance must be made in design for differences in liquid load, because it is obviously more difficult to distribute small than large amounts of liquid (cf. Table 10.1).

<table>
<thead>
<tr>
<th>Distributor</th>
<th>Principle</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capillary</td>
<td>Liquid transport by capillary forces</td>
<td></td>
</tr>
<tr>
<td>Profiled slot</td>
<td>passage as liquid jets</td>
<td></td>
</tr>
<tr>
<td>Sieve or tube</td>
<td>Liquid discharge as jets</td>
<td></td>
</tr>
<tr>
<td>Slot</td>
<td>Overflow as liquid jets</td>
<td>In big columns, mainly as rough-types with liquid predistribution</td>
</tr>
<tr>
<td>Nozzle</td>
<td>Liquid distributed as droplets</td>
<td>Perforated</td>
</tr>
</tbody>
</table>

Fig. 10.1. The principles of liquid distribution
Table 10.1. Ranges of liquid loads for various distributors and the flow rates per outlet

<table>
<thead>
<tr>
<th>Liquid load $u_L$ [m$^3$/m$^2$h]</th>
<th>Type of distributor</th>
<th>Liquid per feed point</th>
</tr>
</thead>
<tbody>
<tr>
<td>5–large</td>
<td>tube or box</td>
<td>$&gt;20$</td>
</tr>
<tr>
<td>1–medium</td>
<td>perfor. plate or box</td>
<td>$&gt;10$</td>
</tr>
<tr>
<td>0.5–very large</td>
<td>profiled slot</td>
<td>$&gt;2$</td>
</tr>
<tr>
<td>0.5–10</td>
<td>capillary</td>
<td>0.05–0.5</td>
</tr>
</tbody>
</table>

10.1 Fundamental design aspects and relationships

Distributors must be accurately finished and correctly installed to avoid differences in liquid level. They should be fitted with drip edges, which prevent coalescence of the liquid on the underside and thus ensure trouble-free operation.

Capillary plates are suitable distributors for very low liquid loads, viz. $u_L \geq 0.5$ m$^3$/m$^2$h, and allow flow rates of about 0.05–0.5 l/h through each outlet. Profiled-slot distributors permit liquid loads of $u_L = 0.5$–200 m$^3$/m$^2$h, and the flow rate through each outlet is higher than 2 l/h. Perforated-plate and trough-type distributors with liquid discharge are recommended for moderate liquid loads, viz. $u_L \geq 1$ m$^3$/m$^2$h. The volumetric flow rate $l$ through an outlet in a trough-type distributor is higher than 10 l/h.

A crucial parameter in the selection or design of a distributor is the liquid load $u_L$ required for the separation process. Together with the head $h_o$ (cf. Fig. 10.2), it allows the flow velocity at an outlet $u_o$, and thus the number of outlets required, to be determined in distributors with liquid discharge or overflow. In this case, the usual equation for flow through orifices applies, i.e.

$$u_o = \sqrt{\frac{2}{g} h_o} \quad (10-1)$$

Usually, the head $h_o$ is higher than 5–10 mm.

Since the cross-sectional area $a$ of the outlet is known, the volumetric flow rate $l$ can be obtained from

$$l = a \cdot u_o \quad (10-2)$$

If the outlets are of the shapes shown in Fig. 10.2, $q$ can be easily determined. According to H. Ulrich, W. Deeke and W. Geipel, the following equations apply for outlets in trough-type distributors:

1. For filleted rectangular slots:

$$l = X \frac{2}{3} b \sqrt{2g h_o^3} \quad (10-3)$$

2. For triangular notches:

$$l = X \frac{8}{15} \sqrt{2g h_o^3 \tan \delta} \quad (10-4)$$
where $X$ is the constriction factor (for vena contracta).

According to H. Ulrich et al., allowance for the effect of surface tension $\sigma$ on the constriction factor $X$ can be made by means of a characteristic value $N_Z$ for the number of feeders, which is given by

$$N_Z = \frac{1}{4} \frac{Q_L g}{\sigma} d_h h_0$$  \hspace{1cm} (10-5)$$

where $Q_L$ is the liquid density, $\sigma$ is the surface tension, and $d_h$ is the hydraulic diameter, which depends on the outlet’s effective cross-sectional area $\bar{a}$ and wetted periphery $\bar{P}$, i.e.

$$d_h = 4 \frac{\bar{a}}{\bar{P}}$$  \hspace{1cm} (10-6)$$

Values of $N_Z$ for open box-type or trough-type distributors can be read off against the constriction factor in Fig. 10.3.

The flow rate $l$ of liquid through a circular outlet with a diameter $d$ on the lower side of a perforated-plate or trough-type distributor is given by

$$l = X \frac{\pi}{4} d^2 \sqrt{2 \left( g h_0 - \frac{\Delta p_v}{Q_L} \right)}$$  \hspace{1cm} (10-7)$$

If the outlets have been carefully rounded off, the constriction factor is $X = 0.9$–$1$. The term $\Delta p_v$ allows for the pressure drop in the vapour as it passes through the distributor; it is the amount by which the pressure at the outlet exceeds the pressure at the surface of the liquid.
Experiments have shown that all the outlets in distributors with liquid overflow will be reliably fed if the feeder characteristic, as defined by Eqn (10-5), is $N_{Z} > 2$. This figure corresponds to a liquid flow rate of $l = \text{ca. } 0.01 \text{ m}^3/\text{h}$ per slot in trough-type distributors with rectangular slots of 5-mm width; and of $l = \text{ca. } 0.005 \text{ m}^3/\text{h}$ per notch, in those with triangular notches.

Once $l$ is known, the number $Z$ of distributor outlets per square metre of column cross-section that is required to cope with a liquid load $u_L$ in m$^3$/m$^2$h can be obtained from

$$Z \leq \frac{u_L}{l}$$  \hspace{1cm} (10-8)

Liquid distributors that operate on the principles outlined in Fig. 10.2 can be quite easily designed with the aid of Eqns (10-3) to (10-8) and Fig. 10.3. Deviations from the tolerances specified in manufacture and assembly are responsible for differences in the head $h_o$ and flow rate $l$. Consequently, it would be an advantage to instal some means of adjustment in the components of a distributor. For instance, differences in head of $\Delta h_o = 1 \text{ mm}$ between the lowermost and uppermost ends of the distributor would lead to maldistribution of about 10%, i.e. $M = 0.1$, or more depending on the design. It is evident from Eqns (8-25) and (8-28) that the associated reduction in column efficiency $E_C$ represents the borderline case that can be barely disregarded. However, as can be easily proved, differences in head of $\Delta h_o = 4 \text{ mm}$ simply cannot be tolerated.

Experiments with the various types of distributors illustrated in Fig. 10.2 have verified the relationships expressed in Eqns (10-4) to (10-7) and Fig. 10.3. The breadth $b$ of the slots was varied between 4 and 6 mm, the notch angle $2\delta$ was 90°, and the head was varied between 20 and 40 mm.
10.2 Types of phase distributors

Obviously, uniform distribution can be achieved more easily at high rather than at low liquid flow rates. Thus, if the liquid load is \( u_L \approx 1 \, \text{m}^3/\text{m}^2\text{h} \) and the head is \( h_o = 1 \, \text{mm} \), the number of liquid outlets \( Z \) required per square metre of column cross-section would be \( Z = 150 \) in a plate distributor with perforations of \( d = 3 \, \text{mm} \) diameter. In the same column operating at the same load but under a head of \( h_o = 3 \, \text{mm} \), the number required would be \( Z = 80 \). If the column were fitted with a profiled-slot distributor, the number of outlets required would be \( Z = 200/\text{m}^2 \). At such low loads, capillary-plate distributors would account for the highest number of outlets.

Plates with spouts or trough-type distributors with liquid overflow that permit flow rates of 20 l/h per outlet are suitable for liquid loads ranging from \( u_L = 5 \, \text{m}^3/\text{m}^2\text{h} \) to very high values.

It is general practice to predistribute the liquid in the designs described above. By this means, perfect hydrodynamic functioning of the distributor itself and thus optimum liquid distribution over the column cross-section can be ensured.

Predistribution is unnecessary in pipe distributors, in which the liquid is discharged either through perforations or by nozzles. These distributors are suitable for liquid loads ranging from low to very high.

Distributors consisting simply of spray nozzles fitted above the bed obviously have a comparatively restricted operating range in which the sprays can be uniformly distributed over the column cross-section.

10.2 Types of phase distributors

There are numerous designs of phase distributors. The few that have been selected for discussion here are characteristic of those used in industrial-scale columns.

The trough-type distributors shown in Fig. 10.4 are suitable for average to high liquid loads in columns of 0.6 m diameter or larger. If the liquid loads are small, bolts should be installed to allow alignment of the individual troughs.

If the liquid load is less than \( 5 \, \text{m}^3/\text{m}^2\text{h} \), perforated plates (cf. Fig. 10.5) or distributors with spouts (cf. Chapter 3) are recommended.

Perforated-pipe distributors (cf. Fig. 10.6) still give satisfactory performance at liquid loads of \( 0.75 \, \text{m}^3/\text{m}^2\text{h} \) in columns of any given diameter. If they are properly designed, they also allow very low liquid loads of about \( 25 \, \text{m}^3/\text{m}^2\text{h} \) to be uniformly distributed. The same applies to distributors consisting of spray nozzles, but these are not depicted here.

Before they are installed, liquid distributors for columns of very large diameter should be subjected to experiments on a test rig in order to determine the standard deviation in liquid distribution (cf. Fig. 10.7).

Devices for liquid redistribution are advisable in many separation tasks. An integrated structure consisting of support plates, liquid collectors, and phase distributors (i.e. for the liquid and gas phases) can be used for this purpose (Fig. 10.8).

The dimensions entered in Fig. 10.9 are useful for arranging distribution within a column.

Other column fittings, e.g. support plates, packing retainers, and liquid collectors for product withdrawal are shown schematically in Fig. 10.10.
Fig. 10.4. Box-type liquid distributor

Fig. 10.5. View of a sieve plate liquid distributor, design of Raschig
Fig. 10.6. Pipe-type liquid distributor
Fig. 10.7. Montz liquid distributor of large diameter under test for measuring the distribution accuracy
Fig. 10.8. Drawing of a redistributor for both liquid and gas phases, including support tray and liquid collector.

Fig. 10.9. Characteristic dimensions for the arrangement of phase distributors.
Fig. 10.10. Schematic diagram indicating the location of internals for packed towers