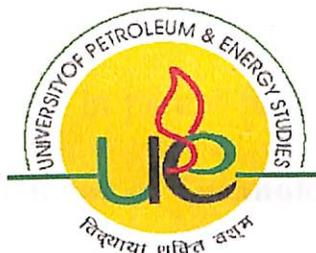


# **“DESIGNING OF SIEVE TRAY”**

**A FINAL PROJECT REPORT**

**SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR  
THE DEGREE OF BACHELOR OF TECHNOLOGY  
(APPLIED PETROLEUM ENGINEERING)**



**Submitted To  
UNIVERSITY OF PETROLEUM  
AND  
ENERGY STUDIES**

**Guided by  
Dr. D.N. Saraf**

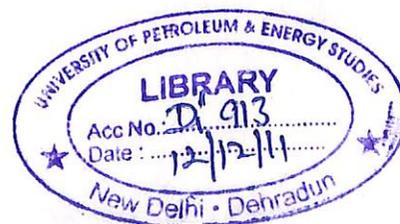
**Submitted By  
JAVED KHAN SHERVANI  
R-010103017**

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### CERTIFICATE

This is to certify that the Project Report on “**DESIGNING OF SIEVE TRAY**” submitted to University of Petroleum & Energy Studies, Dehradun, by **JAVED KHAN SHERVANI** in partial fulfillment of the requirements for the award of Degree of **Bachelor of Technology in Applied Petroleum Engineering** (Academic Session 2003 – 07) is a bonafide work carried out by ~~him~~ under my supervision and guidance. This work has not been submitted anywhere else for any other degree or diploma.

Date: *May 8, 2007*

**Dr.D.N.Saraf**  
**(Distinguished Professor)**

## Acknowledgement

With great pleasure we would like to express our sincere thanks to Dr. **Deoki.N.Saraf**, College of Engineering (COE), University of Petroleum & Energy Studies, for giving us the opportunity to carry out our training and work on the project “**Designing of Sieve Tray**” under his guidance and support.

We are deeply indebted to our college Lab staff for their timely and generous help at every stage during the progress of our project work.

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# INTRODUCTION:

## TRAY TOWERS

Tray towers are vertical cylinders in which the liquid and gas are contacted in stepwise fashion on trays or plates, as shown schematically for one type (bubble-cap trays). The liquid enters at the top and flows downward by gravity. On the way, it flows across each tray and through a downspout to the tray below. The gas passes upward through openings of one sort or another in the tray, then bubbles through the liquid to form a froth, disengages from the froth, and passes on to the next tray above. The overall effect is a multiple countercurrent contact of gas and liquid, although each tray is characterized by a cross flow of the two. Each tray of the tower is a stage, since on the tray the fluids are brought into intimate contact, interphase diffusion occurs, and the fluids are separated. The number of equilibrium stages (theoretical trays) in a column tower is dependent only upon the difficulty of the separation to be carried out and is determined solely from material balances and equilibrium considerations. The stage or tray efficiency, and therefore the number of real trays, is determined by the mechanical design used and the conditions of operation. The diameter of the tower, on the other hand, depends upon the quantities of liquid and gas flowing through the tower per unit time. Once the number of equilibrium stages, or theoretical trays, required has been determined, the principal problem in the design of the tower is to choose dimensions and arrangements which will represent the best compromise between several opposing tendencies, since it is generally found that conditions leading to high tray efficiencies will ultimately lead to operational difficulties. For stage or tray efficiencies to be high the time of contact should be long to permit it the diffusion to occur, the interfacial surface between phases must be made large, and a relatively high intensity of turbulence is required to obtain high mass-transfer coefficients. In order to provide long contact time, the liquid pool on each tray should be deep, so that bubbles of gas will require a relatively long time to rise through the liquid. When the gas bubbles only slowly through the openings on the tray, the bubbles are large, the interfacial surface per unit of gas volume is small, the liquid is relatively quiescent, and much of it may even pass over the tray without having contacted the gas. On the other hand, when the gas velocity is relatively high, it is dispersed very thoroughly into the liquid, which in turn is agitated into a froth. This provides large interfacial surface areas. For high tray efficiencies, therefore, we require deep pools of liquid and relatively high gas velocities. These conditions, however, lead to a number of difficulties. One is the mechanical entrainment of droplets of liquid in the rising gas stream. At high gas velocities, when the gas is disengaged from the froth, small droplets of liquid will be carried by the gas to the tray above. Liquid carried up the tower in this manner reduces the concentration change brought about by the mass transfer

and consequently adversely affects the tray efficiency. And so the gas velocity may be limited by the reduction in tray efficiency due to liquid entrainment. Furthermore, great liquid depths on the tray and high gas velocities both result in high pressure drop for the gas in flowing through the tray, and this in turn leads to a number of difficulties. In the case of absorbers and humidifiers, high pressure drop results in high fan power to blow or draw the gas through the tower, and consequently high operating cost. In the case of distillation, high pressure at the bottom of the tower results in high boiling temperatures, which in turn may lead to heating difficulties and possibly damage to heat-sensitive compounds. Ultimately, purely mechanical difficulties arise. High pressure drop may lead directly to a condition of *flooding*. With a large pressure difference in the space between trays, the level of liquid leaving a tray at relatively low pressure and entering one of high pressure must necessarily assume an elevated position in the downspouts, as shown in Figure 1. As the pressure difference is increased due to the increased rate of flow of either gas or liquid, the level in the downspout will rise further to permit the liquid to enter the lower tray. Ultimately the liquid level may reach that on the tray above. Further increase in either flow rate then aggravates the condition rapidly, and the liquid will fill the entire space between the trays. The tower is then flooded, the tray efficiency falls to a low value, the flow of gas is erratic, and liquid may be forced out of the exit pipe at the top of the tower. For liquid-gas combinations which tend to foam excessively, high gas velocities may lead to a condition of *priming*, which is also an inoperative situation. Here the foam persists throughout the space between trays, and a

great deal of liquid is carried by the gas from one tray to the tray above. This is an exaggerated condition of entrainment. The liquid so carried recirculates between trays, and the added liquid-handling load increases the gas pressure drop sufficiently to lead to flooding. We can summarize these opposing tendencies as follows. Great depths of liquid on the trays lead to high tray efficiencies through long contact time but also to high pressure drop per tray. High gas velocities, within limits, provide good vapor-liquid contact through excellence of dispersion but lead to excessive entrainment and high pressure drop. Several other undesirable conditions may occur. If liquid rates are too low, the gas rising through the openings of the tray may push the liquid away (*coning*), and contact of the gas and liquid is poor. If the gas rate is too low, much of the liquid may rain down through the openings of the tray (*weeping*), thus failing to obtain the benefit of complete flow over the trays; and at very low gas rates, none of the liquid reaches the downspouts (*dumping*). The relations between these conditions are shown schematically in Fig. 6.9, and all types of trays are subject to these difficulties in some form. The various arrangements, dimensions, and operating conditions chosen for design are those which experience has proved to be reasonably good compromises. The general design procedure involves a somewhat empirical application of them, followed by computational check to ensure that pressure drop and flexibility, i.e., ability of the tower to handle more or less than the immediately expected flow quantities, are satisfactory. A great variety of tray designs have been and are being used. The various forms practically all towers were fitted with bubble-cap trays, but new installations now use either sieve trays or one of the proprietary designs which have proliferated since 1950.

## General Characteristics

Certain design features common to the most frequently used tray designs will be dealt with first.

**Shell and trays** The tower may be made of any number of materials, depending upon the corrosion conditions expected. Glass, glass-lined metal, impervious carbon, plastics, even wood but most frequently metals are used. For metal towers, the shells are usually cylindrical for reasons of cost. In order to facilitate

cleaning, small-diameter towers are fitted with hand holes, large towers with manways about every tenth tray. The trays are usually made of sheet metals, of special alloys if necessary, the thickness governed by the anticipated corrosion rate. The trays must be stiffened and supported (see, for example, and must be fastened to the shell to prevent movement owing to surges of gas, with allowance for thermal expansion. This can be arranged by use of tray-support rings with slotted bolt holes to which the trays are bolted. Large trays must be fitted with manways so that a person can climb from one tray to another during repair and cleaning. Trays should be installed level to within 6 mm (~ in) to promote good liquid distribution.

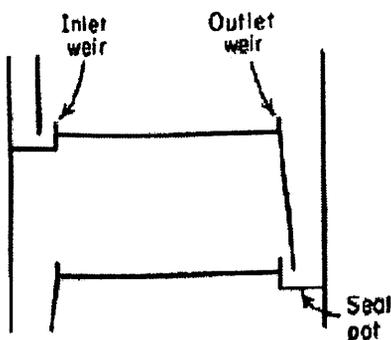
**Tray spacing** Tray spacing is usually chosen on the basis of expediency in construction, maintenance, and cost and later checked to be certain that adequate insurance against flooding and excessive entrainment is present. For special cases where tower height is an important consideration, spacings of 15 cm (6 in) have been used. For all except the smallest tower diameters, 50 cm (20 in) would seem to be a more workable minimum from the point of view of cleaning the trays.

**Tower diameter** The tower diameter and consequently its cross-sectional area must be sufficiently large to handle the gas and liquid rates within the region of satisfactory operation. For a given type of tray at flooding, the superficial velocity of the gas  $V_F$  (volumetric rate of gas flow  $Q$  per net cross-section for flow  $A_n$ ) is related to fluid densities by

$$V_F = C_F \left( \frac{\rho_L - \rho_G}{\rho_G} \right)^{1/2}$$

The net cross section  $A_n$  is the tower cross section  $A_t$  minus the area taken up by the downspouts ( $A_d$  in the case of a cross-flow tray as in CF is an empirical constant, the value of which depends on the tray design. Some appropriately smaller value of  $V$  is used for actual design; for non foaming liquid this is typically 80 to 85 percent of  $V_F$  (75 percent or less for foaming liquids), subject to check for entrainment and pressure-drop characteristics

**Downspouts** The liquid is led from one tray to the next by means of downspouts, or downcomers. These may be circular pipes or preferably portions of the tower cross section set aside for liquid flow by vertical plates. Since the liquid is agitated into a froth on the tray, adequate residence time must be allowed in the downspout to permit disengaging the gas from the liquid, so that only clear liquid enters the tray below. The downspout must be brought close enough to the tray below to seal into the liquid on that tray, thus preventing gas from rising up the downspout to short-circuit the tray above. Seal pots and seal-pot dams (inlet weirs) may be used, but they are best avoided (see below), especially if there is a tendency to accumulate sediment. If they are used, weep holes (small holes through the tray) in the seal pot should be used to facilitate draining the tower on shutdown. **Weirs** The depth of liquid on the tray required for gas contacting is maintained by an overflow (outlet) weir, which may or may not be a continuation of the downspout plate. Straight weirs are most common; multiple V-notch weirs maintain a liquid depth which is less sensitive to variations in liquid flow rate and consequently also from departure of the tray from levelness; circular weirs, which are extensions of circular pipes used as downspouts, are not recommended. Inlet weirs may result in a hydraulic jump of the liquid and are not generally recommended. In order to ensure reasonably uniform distribution of liquid flow on a single-pass tray, a weir length of from 60 to 80 percent of the tower diameter is used. lists the percentage of the tower cross section taken up by downspouts formed from such weir plates.



### Downspout

#### Sieve (perforated) trays

These trays have been known almost as long as bubble-cap trays, but they fell out of favor during the first half of this century. Their low cost, however, has now made them the most important of tray devices. The principal part of the tray is a horizontal sheet of perforated metal, across which the liquid flows, with the gas passing upward through the perforations. The gas, dispersed by the perforations, expands the liquid into a turbulent froth, characterized by a very large interfacial surface for mass transfer. The trays are subject to flooding because of backup of liquid in the downspouts or excessive entrainment (priming), as described earlier.

#### Design of Sieve Trays

The diameter of the tower must be chosen to accommodate the flow rates, the details of the tray layout must be selected, estimates must be made of the gas-pressure drop and approach to flooding & assurance against excessive weeping and entrainment must be established.

**Tower diameter** The flooding constant  $C_F$  of has been correlated for the data available on flooding. The original curves can be represented by

$$C_F = \left[ \alpha \log \frac{1}{(L'/G')(\rho_G/\rho_L)^{0.5}} + \beta \right] \left( \frac{\sigma}{0.020} \right)^{0.2}$$

**perforation and active area** Hole diameters from 3 to 12 mm (0 to 1/2 in) are commonly used, 4.5 mm (3/16 in) most frequently although holes as large as 25 mm have been successful. For installations, stainless steel or other alloy perforated sheet is used, rather than carbon steel, even though not necessarily required for corrosion resistance. Sheet thickness is usually less than one half than on the hole diameter for stainless steel, less than one diameter for carbon steel or copper alloys.

Table lists typical values.

The holes are placed in the corners of equilateral triangles at distances between centers (pitch) of from 2.5 to 5 hole diameters. For such an arrangement

$$\frac{A_p}{A_o} = \frac{\text{hole area}}{\text{active area}} = 0.907 \left( \frac{d_h}{p} \right)^2$$

Typically, the peripheral tray support, 25 to 50 mm (1 to 2 in) wide, and the beam supports will occupy up to 15 percent of the cross-sectional area of the tower; the distribution zone for liquid entering the tray and the disengagement zone for disengaging foam (which are sometimes omitted) use 5 percent or more [47, 66]; and downspouts require additional area. The remainder is available for active perforations (active area  $A_d$ ).

**Liquid depths** Liquid depths should not ordinarily be less than 50 mm (2 in), to ensure good froth formation. These limits refer to the sum of the weir height  $h_w$  plus the crest over the weir  $h_1$ , calculated as clear liquid although in the perforated area the equivalent clear-liquid depth will be smaller than this.

**Weirs** The crest of liquid over a straight rectangular weir can be estimated by the well-known Francis formula

$$\frac{q}{W_{\text{eff}}} = 1.839 h_1^{3/2}$$

where  $q$  - rate of liquid flow, m<sup>3</sup>/s

$W_{\text{eff}}$  - effective length of the weir, m

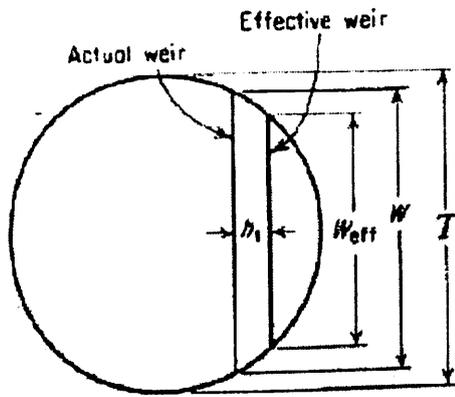
$h_1$  - liquid crest over the weir, m

Because the weir action is hampered by the curved sides of the circular tower, it is recommended that  $W_{\text{eff}}$  be represented as a chord of the circle of diameter  $T$ , a distance  $h_1$  farther from the center than the actual weir, as in can then be rearranged to

$$h_1 = 0.666 \left( \frac{q}{W} \right)^{2/3} \left( \frac{W}{W_{\text{eff}}} \right)^{2/3}$$

$$\left( \frac{W_{\text{eff}}}{W} \right)^2 = \left( \frac{T}{W} \right)^2 - \left\{ \left[ \left( \frac{T}{W} \right)^2 - 1 \right]^{0.5} + \frac{2h_1}{T} \frac{T}{W} \right\}^2$$

For  $W/T = 0.7$ , which is typical, can be used with  $W_{\text{eff}} = W$  for  $h_1/W = 0.055$  or less with a maximum error of only 2 percent in  $h_1$ , which is negligible.



### Effective Weir Length

**Pressure drop for the gas** For convenience, all gas-pressure drops will be expressed as heads of clear liquid of density  $\rho_L$  on the tray. The pressure drop for the gas  $h_G$  is the sum of the effects for flow of gas through the dry plate and those caused by the presence of liquid:

$$h_G = h_D + h_L + h_R$$

where  $h_D$  = dry-plate pressure drop

$h_L$  = pressure drop resulting from depth of liquid on tray

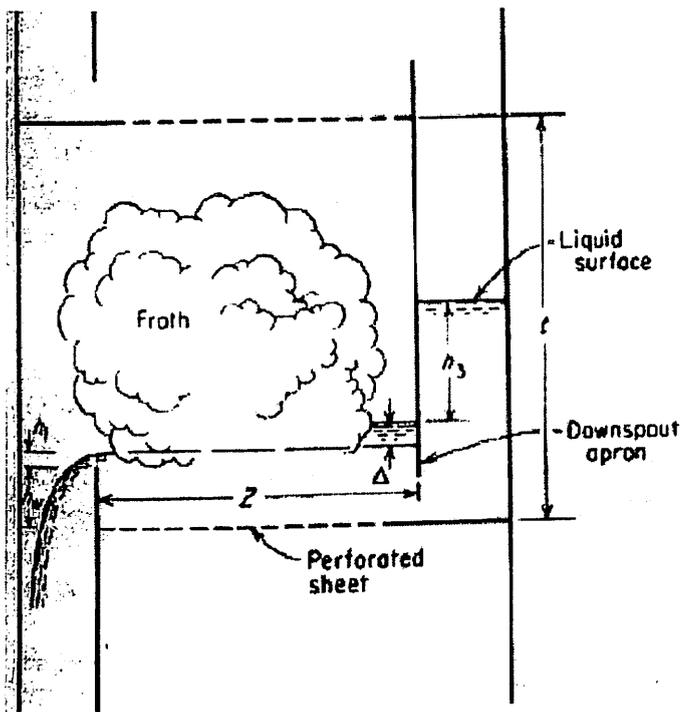
$h_R$  = residual pressure drop

**Dry pressure drop  $h_D$**  This is calculated on the basis that it is the result to a loss in pressure on entrance to the perforations, friction within the short tube formed by the perforation owing to plate thickness, and an exit loss

$$\frac{2h_D \rho_L}{V_o^2 \rho_G} = C_o \left[ 0.40 \left( 1.25 - \frac{A_o}{A_n} \right) + \frac{4f}{d_o} + \left( 1 - \frac{A_o}{A_n} \right)^2 \right]$$

The Fanning friction factor  $f$  is taken from a standard chart  $C_o$  is an orifice coefficient which depends upon the ratio of plate thickness to hole diameter. Over the range  $l/d_o - 0.2$  to  $2.0$

$$C_o = 1.09 \left( \frac{d_o}{l} \right)^{0.25}$$



**Schematic diagram of sieve tray**

**Hydraulic head  $h_L$**  In the perforated region of the tray, the liquid is in the form of a froth. The equivalent depth of clear liquid  $h_L$  is an estimate of that which would obtain if the froth collapsed. That is usually less than the height of the outlet weir, decreasing with increased gas rate. Some methods of estimating  $h_L$  use a specific *aeration factor* to describe this. In which is the recommended relationship the effect of the factor is included as a function of the variables which influence it

$$h_L = 6.10 \times 10^{-3} + 0.725h_W - 0.238h_W V_a \rho_G^{0.5} + 1.225 \frac{q}{z}$$

where  $z$  is the average flow width, which can be taken as  $(T + W)/2$ .

**Residual gas pressure drop  $h_R$**  This is believed to be largely the result of overcoming surface tension as the gas issues from a perforation. A balance of the internal force in a static bubble required to overcome surface tension is

$$\frac{\pi d_p^2}{4} \Delta p_B = \pi d_p \sigma$$

$$\Delta p_B = \frac{4\sigma}{d_p}$$

where  $\Delta p_B$  is the excess pressure in the bubble due to surface tension. But the bubble of gas grows over a finite time when the gas flows, and by averaging over time, it develops that the appropriate value is  $\Delta p_R$

$$\Delta p_R = \frac{6\sigma}{d_p}$$

Since the bubbles do not really issue singly from the perforations into relatively quiet liquid, we substitute as an approximation the diameter of the perforations  $d_a$  which leads to

$$h_R = \frac{\Delta p_R g_c}{\rho_L g} = \frac{60 g_c}{\rho_L d_a g}$$

**Pressure loss at liquid entrance  $h_2$**  The flow of liquid under the downspout apron as it enters the tray results in a pressure loss which can be estimated as equivalent to three velocity heads

$$h_2 = \frac{3}{2g} \left( \frac{q}{A_{da}} \right)^2$$

where  $A_{da}$  is the smaller of two areas, the downspout cross section or the free area between the downspout apron and the tray. Friction in the downspout is negligible.

**Backup in the downspout** The distance  $h_3$ , the difference in liquid level inside and immediately outside the downspout, will be the sum of the pressure losses resulting from liquid and gas flow for the tray above. Since the mass in the downspout will be partly froth carried over the weir from the tray above, not yet disengaged, whose average density can usually be estimated roughly as half that of the clear liquid, safe design requires that the level of equivalent clear liquid in the downspout be no more than half the tray spacing. Neglecting A, the requirement is

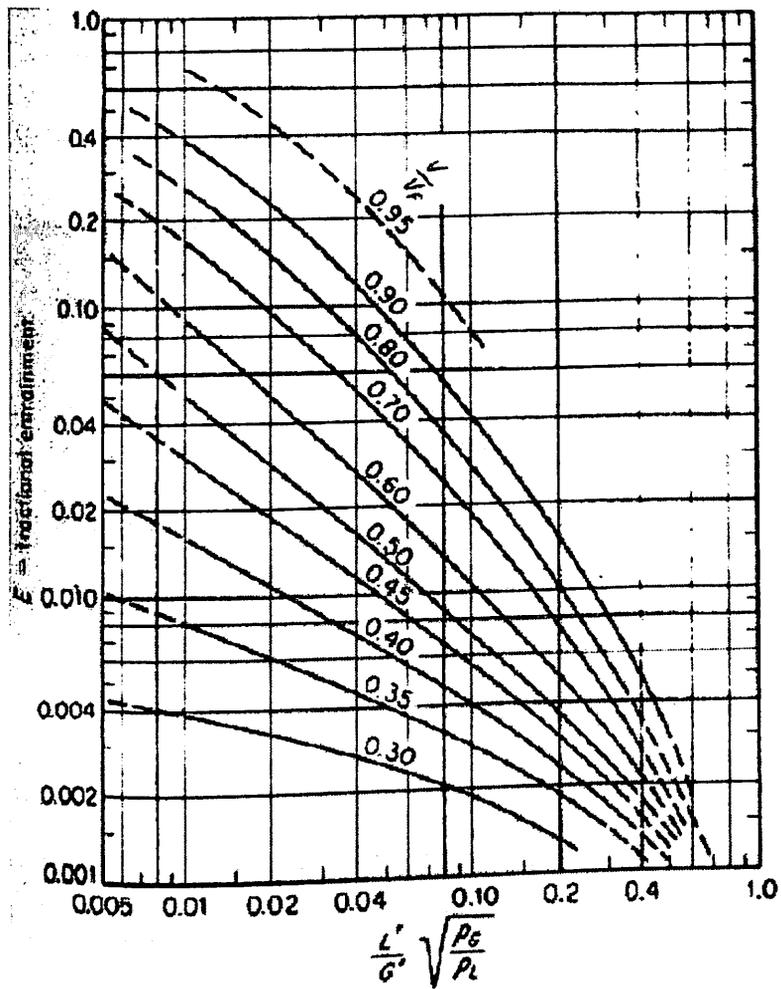
$$h_w + h_1 + h_3 < \frac{1}{2}$$

**Weeping** if the gas velocity through the holes is too small, liquid will drain through them and contact on the tray for that liquid will be lost. In addition, for cross-flow trays, such liquid does not flow the full length of the tray below. The data on incipient weeping are meager, particularly for large liquid depths, and in all likelihood there will always be some weeping.

$$\frac{V_{ow} \mu_G}{g_c} = 0.0229 \left( \frac{\mu_G^2}{g_c \rho_G d_a \rho_L} \right)^{0.379} \left( \frac{1}{d_a} \right)^{0.293} \left( \frac{2A_o d_o}{\sqrt{3} p^2} \right)^{2.8 / (Z/d_a)^{0.724}}$$

**Liquid entrainment** When liquid is carried by the gas up to the tray above, the entrained liquid is caught in the liquid on the upper tray. The effect is cumulative, and liquid loads on the upper trays of a lower can become excessive. A convenient definition of the degree of entrainment is the fraction of the liquid entering a tray which is carried to the tray above

$$\text{Fractional entrainment} = E = \frac{\text{moles liquid entrained} / (\text{area})(\text{time})}{L + \text{moles liquid entrained} / (\text{area})(\text{time})}$$



Entrainment graph

# Designing for stripping an aniline water solution with steam

Given :

At the top of the tower :

Temperature = 98.5°C  
Pressure = 745 mmHg abs

Liquid :

Composition = 7 mass% aniline  
Rate = 6.3 Kg/s  
Density = 961 Kg/m<sup>3</sup>  
Viscosity =  $3 \times 10^{-4}$  Kg/m.s  
Surface tension = 0.058 N/m  
Aniline diffusivity =  $52 \times 10^{-10}$  m<sup>2</sup>/s  
Molecular wt. of H<sub>2</sub>O = 18  
Molecular wt of aniline = 93  
Average molecular wt =  $0.07 \times 93 + (1 - 0.07) \times 18$   
= 23.25 Kg/Kmol  
Volume flow rate (q) =  $6.3 / 961 = 6.55 \times 10^{-3}$  m<sup>3</sup>/s

Vapour :

Composition = 3.6 mole% aniline  
Rate = 3.15 Kg/s  
Aniline diffusivity =  $1.261 \times 10^{-5}$  m<sup>2</sup>/s  
Average molecular wt =  $0.036 \times 93 + (1 - 0.036) \times 18$   
= 20.7 Kg/Kmol  
Gas density =  $20.7 \times 273 / 22.4 \times (273 + 98.5) = 0.679$  Kg/m<sup>3</sup>  
Gas flow rate (Q) =  $3.15 / 0.679 = 4.64$  m<sup>3</sup>/s

## 1. perforation

stainless steel

take  $d_o = 4.5$  mm

equilateral triangle pitch = 12 mm between hole centre

plate thickness/hole diameter = 0.43

plate thickness (l) =  $0.43 \times 4.5 = 2$  mm

$$\frac{A_o}{A_a} = \frac{\text{hole area}}{\text{active area}} = 0.907 \left( \frac{d_o}{p'} \right)^2$$
$$= 0.907 (4.5/12)^2$$
$$= 0.1275$$

## 2. tower diameter

take  $t = 0.50$  m tray spacing

$$\frac{L'}{G'} \left( \frac{\rho_G}{\rho_L} \right)^{0.5}$$

$$= (6.55 \times 10^{-3} * (961/0.679)^{0.5}) / 4.64$$

$$= 0.053$$

$$\alpha = 0.0744(0.50) + 0.01173 = 0.0489$$

$$\beta = 0.0304(0.50) + 0.015 = 0.0302$$

$$C_F = \left[ \alpha \log \frac{1}{(L'/G')(\rho_G/\rho_L)^{0.5}} + \beta \right] \left( \frac{\sigma}{0.020} \right)^{0.2}$$

$$= 0.1145$$

$$V_F = C_F \left( \frac{\rho_L - \rho_G}{\rho_G} \right)^{1/2}$$

$$= 4.31 \text{ m/s}$$

$$V = 0.75 * 4.31$$

$$= 3.23 \text{ m/s}$$

$$A_n = A_t - A_d$$

$$\text{Let weir length } W = 0.75T$$

$$A_d = 11.255\%$$

$$A_t = 1$$

$$A_n = 1 - (11.255/100)$$

$$= 0.88745$$

$$A_n = Q/V = 4.64/3.23 = 1.437 \text{ m}^2$$

$$0.88745 A_t = 1.437$$

$$A_t = 1.619 \text{ m}^2$$

$$T = (A_t * 4 / \pi)^{0.5}$$

$$= 1.44 \text{ m}$$

$$\text{Corrected } A_t = \pi * T^2 / 4$$

$$= 1.629 \text{ m}^2$$

$$W = 0.75(1.44) = 1.08 \text{ M}$$

$$A_d = 0.11255 * 1.629 = 0.1833 \text{ m}^2$$

Area taken by [ tray support + disengaging and distribution zone ]

40 mm wide support ring

50mm wide disengaging and distribution zone  
 $= 2 * [0.040 * 1.44] + 2 * [0.050 * 1.44]$   
 $= 0.2592 \text{ m}^2$

$A_a = A_t - 2A_d$  – area taken by [ tray support + disengaging and distribution zone ]  
 $= 1.629 - 2(0.1833) - 0.2592$   
 $= 1.0032 \text{ m}^2$

### 3. weir crest $h_1$ and weir height $h_w$

let  $h_1 = 25 \text{ mm} = 0.025 \text{ m}$   
 $h_1/T = 0.025/1.44 = 0.02$   
 $T/W = 1.44/1.08 = 1.333$   
 $q/W = 6.55 * 10^{-3}/1.08 = 6.06 * 10^{-3} \text{ m}^2/\text{s}$

$$\left( \frac{W_{\text{eff}}}{W} \right)^2 = \left( \frac{T}{W} \right)^2 - \left\{ \left[ \left( \frac{T}{W} \right)^2 - 1 \right]^{0.5} + \frac{2h_1}{T} \frac{T}{W} \right\}^2$$

$$= 0.918$$

$$h_1 = 0.666 \left( \frac{q}{W} \right)^{2/3} \left( \frac{W}{W_{\text{eff}}} \right)^{2/3}$$

$$= 0.0209 \text{ m}$$

Let  $h_2 = 0.0209 \text{ m}$

$$h_2/T = 0.0209/1.44 = 0.015$$

$$W_{\text{eff}}/W = 0.9279$$

$$h_2 = 0.02105$$

let  $h_3 = 0.02195$

$$h_3/T = 0.02105/1.44 = 0.02105/1.44 = 0.0146$$

$$W_{\text{eff}}/W = 0.9299$$

$$h_3 = 0.02109$$

let  $h_4 = 0.02109$

$$h_4/T = 0.02109/1.44 = 0.0146$$

$$W_{\text{eff}}/W = 0.929$$

Taking:

$$W_{\text{eff}}/W = 0.9299$$

$$h_1 = 0.02109 \text{ m}$$

let weir height  $h_w = 50 \text{ mm} = 0.05 \text{ m}$

#### 4. Pressure drop for the gas

a. determination of  $h_D$

$$C_o = 1.09 \left( \frac{d_o}{l} \right)^{0.25}$$

$$= 1.09(4.5/2)^{0.25}$$

$$= 1.335$$

$$A_o = 0.1275 A_a$$

$$= 0.1275(1.0032)$$

$$= 0.128 \text{ m}^2$$

$$V_o = Q/A_o = 4.64/0.128 = 36.25 \text{ m/s}$$

$$Re = 0.0045 * 36.25 * 0.679 / 1.25 * 10^{-5} = 8860$$

$$f = 0.009$$

$$\frac{2h_D 8 \rho_L}{V_o^2 \rho_G} = C_o \left[ 0.40 \left( 1.25 - \frac{A_o}{A_n} \right) + \frac{4f}{d_o} + \left( 1 - \frac{A_o}{A_n} \right)^2 \right]$$

$$h_d = 0.0828 \text{ m}$$

b. determination of  $h_L$

$$V_a = Q/A_a = 4.64/1.0032 = 4.625 \text{ m/s}$$

$$Z = T+W/2 = 1.44 + 1.08/2 = 1.26 \text{ m}$$

$$h_L = 6.10 \times 10^{-3} + 0.725 h_w - 0.238 h_w V_a \rho_G^{0.5} + 1.225 \frac{q}{z}$$

$$= 0.0033 \text{ m}$$

c. determination of  $h_R$

$$h_R = \frac{\Delta p_R 8c}{\rho_L g} = \frac{6 \sigma g c}{\rho_L d_o g}$$

$$= 6 * 0.058 / 961 * 0.0045 * 9.807$$

$$= 8.2 * 10^{-3}$$

$$h_G = h_d + h_L + h_R = 0.0828 + 0.0033 + 8.2 * 10^{-3} = 0.0943 \text{ m}$$

Pressure loss at liquid entrance :  $h_2$

The down spout approx. will be set out at  $=h_w - 0.025 = 0.025$

The area for liquid flow under approx.

$$= 0.025 * W$$

$$= 0.025 * 1.08$$

$$= 0.027 \text{ m}^2$$

$$A_{da} = 0.027 \text{ m}^2$$

$$h_2 = \frac{3}{2g} \left( \frac{q}{A_{da}} \right)^2$$
$$= 9.001 * 10^{-3} \text{ m}$$

Back up in the down spout

$$h_3 = h_G + h_2$$

$$= 9.001 * 10^{-3} + 0.0943$$

$$= 0.1033 \text{ m}$$

Check on flooding :

$$h_w + h_1 + h_3 < t/2$$

$$h_w + h_1 + h_3 = 0.05 + 0.02109 + 0.1033 = 0.17439$$

$$t/2 = 0.50/2 = 0.25$$

hence chosen  $t$  is satisfactory

#### 4. Weeping velocity :

For  $W/T = 0.75$

Distance from the centre of the tower =  $0.3296 * T$

$$= 0.3296 * 1.44$$

$$= 0.475$$

$$Z = 2 * 0.475$$

$$= 0.95$$

$$\frac{V_{ow} \mu_G}{\sigma_{Gc}} = 0.0229 \left( \frac{\mu_G^2}{\sigma_{Gc} \rho_G d_o} \frac{\rho_L}{\rho_G} \right)^{0.375} \left( \frac{l}{d_o} \right)^{0.293} \left( \frac{2A_a d_o}{\sqrt{3} p'^3} \right)^{2.8 / (Z/d_o)^{0.724}}$$

$$V_{ow} = 5.14 \text{ m/s}$$

#### 5. Entrainment :

$$V/V_F = 3.23/4.31 = 0.7$$

$$\frac{L'}{G'} \left( \frac{\rho_G}{\rho_L} \right)^{0.5}$$

$$= 0.053$$

$$E = 0.038$$

## 6. Determination efficiency of sieve tray

$$Y_{n+1} = 3.6 \text{ mole \% aniline}$$

$$\mu_{lg} = \frac{\prod \mu_{lgi} y_i M_i^{0.5}}{\prod y_i M_i^{0.5}}$$

$$= \frac{(0.82 \cdot 0.036 \cdot 93^{0.5} + 0.27 \cdot 0.964 \cdot 18^{0.5})}{(0.036 \cdot 93^{0.5} + 0.964 \cdot 18^{0.5})}$$

$$= 0.313 \text{ cp}$$

$$Sc = \frac{\mu_g}{D_G \rho_g}$$

$$= \frac{0.313 \cdot 10^{-3}}{0.679 \cdot 1.261 \cdot 10^{-5}}$$

$$= 36.55$$

$$\theta_L = \frac{\text{vol liquid on tray}}{\text{vol liquid rate}} = \frac{h_L z Z}{q}$$

$$= \frac{0.0033 \cdot 1.26 \cdot 0.95}{6.55 \cdot 10^{-3}}$$

$$= 0.603$$

$$D_E = \left( 3.93 \times 10^{-3} + 0.0171 V_a + \frac{3.67q}{Z} + 0.1800 h_w \right)^2$$

$$= 0.0137 \text{ m}^2/\text{s}$$

$$N_{iL} = 40000 D_L^{0.5} (0.213 V_a \rho_G^{0.5} + 0.15) \theta_L$$

$$= 1.67$$

$$N_{iG} = \frac{0.776 + 4.57 h_w - 0.238 V_a \rho_G^{0.5} + 104.6 q / Z}{Sc_G^{0.5}}$$

$$= 0.135$$

For 7% aniline

$$X_{\text{Local}} = (7/93)/(7/93+93/18) \\ = 0.0143$$

Plotting of equilibrium curve aniline -water

Antonie constant for aniline

$$A = 6.4450$$

$$B = 1731.50$$

$$C = -67.0500$$

$$\text{Log}_{10}P_A = A - B/(T + C) \\ = 6.4450 - 1731.50 / (371.5 - 67.0500) \\ = 0.7576$$

$$P_A = 5.72 \text{ kpas}$$

Antonie constant for water

$$A = 7.0733$$

$$B = 1686.40$$

$$C = -46.2500$$

$$\text{Log}_{10}P_w = A - B/(T + C) \\ = 1.888$$

$$P_w = 77.26 \text{ kpas}$$

Bubble point calculation :

$$P = P_w + [P_A - P_w] X_i$$

$$Y_i = X_i P_A / P$$

1.  $X_1 = 0$

$$P = 77.26$$

$$Y_1 = 0$$

2.  $X_1 = 0.1$

$$P = 70.106$$

$$Y_1 = 0.0163$$

3.  $X_1 = 0.2$

$$P = 62.952$$

$$Y_1 = 0.0181$$

4.  $X_1 = 0.3$

$$P = 55.798$$

$$Y_1 = 0.0308$$

5.  $X_1 = 0.5$

$$P = 48.64$$

$$Y_1 = 0.047$$

6.  $X_1 = 0.5$

$$P = 41.49$$

$$Y_1 = 0.0689$$

7.  $X_1 = 0.6$   
 $P = 34.336$   
 $Y_1 = 0.0689$
8.  $X_1 = 0.7$   
 $P = 27.182$   
 $Y_1 = 0.1473$
9.  $X_1 = 0.8$   
 $P = 20.028$   
 $Y_1 = 0.228$

10.  $X_1 = 0.9$   
 $P = 12.874$   
 $Y_1 = 0.399$

11.  $X_1 = 1$   
 $P = 5.72$   
 $Y_1 = 1$

Line AC is drawn with slope :

$$\begin{aligned} - N_{tL} * L / N_{tG} * G &= - 1.67 * 0.271 / 0.135 * 0.152 \\ - \Theta &= (-22.05) \tan^{-1} \\ - &= -87.40 \end{aligned}$$

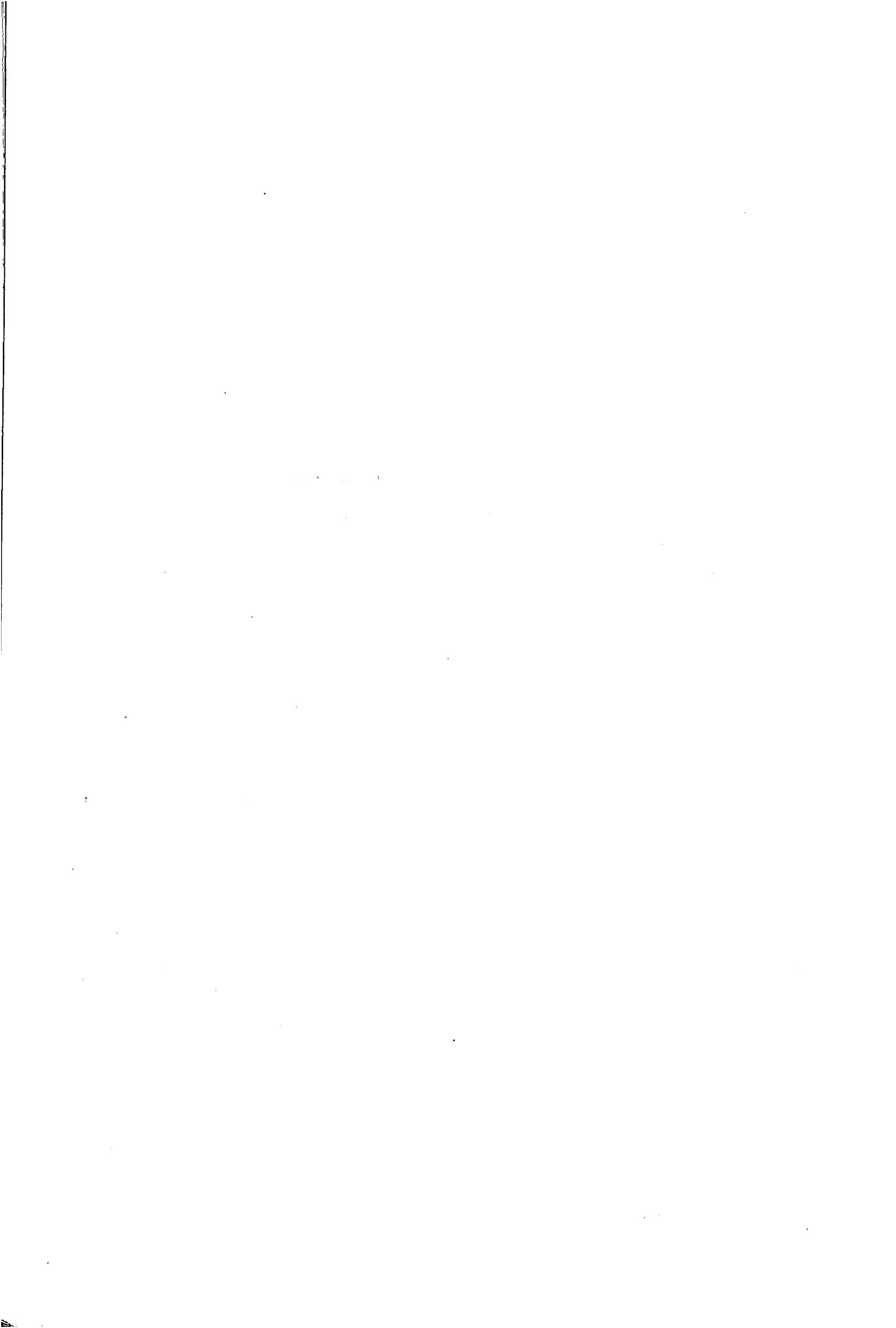
$$\begin{aligned} L &= 6.3 \text{ Kg/s} \\ &= 6.3 / 23.23 \text{ Kmole/s} \\ &= 0.271 \text{ Kmole/s} \\ G &= 3.15 / 20.7 \text{ Kmole/s} \\ &= 0.152 \text{ Kmole/s} \\ \text{Slope} &= \tan 17^\circ = 0.306 \end{aligned}$$

$$\frac{1}{N_{tOG}} = \frac{1}{N_{tG}} + \frac{mG}{L} \frac{1}{N_{tL}}$$

$$1/N_{tOG} = 0.1332$$

$$N_{tOG} = 0.1332$$

$$\begin{aligned} \text{Point efficiency } (E_{OG}) &= 1 - e^{-N_{tOG}} \\ &= 1 - e^{-0.1332} \\ &= 0.414 \end{aligned}$$



## Notation :

Q	volumetric flowrate
q	volumetric liquid flowrate
$d_o$	perforation diameter
l	plate thickness
$A_o$	area of perforation
$A_a$	active area
t	tray spacing
$L'$	superficial liquid mass velocity
$G'$	superficial gas mass velocity
$C_F$	flooding constant
$V_F$	flooding velocity
$A_n$	net tower cross-sectional area for gas flow
$A_d$	downspout cross-sectional area
$A_t$	tower cross-sectional area
T	tower diameter
W	weir length
$h_l$	weir crest
$W_{eff}$	effective weir length
$h_w$	weir height
$C_o$	orifice coefficient
$\cdot A_o$	area of perforation
$V_o$	velocity through an orifice

$Re$	reynold number
$f$	frictional factor
$h_D$	dry plate gas pressure drop as head
$h_L$	gas pressure drop due to liquid hold up
$h_R$	residual gas pressure drop
$h_G$	gas pressrure drop as head
$A_{da}$	smaller of two area
$V_{ow}$	weeping velocity
$E$	entrainment
$h_3$	back up of liquid in downspout
$h_2$	head loss owing to liquidflow under down spout
$Y_{n+1}$	mass fraction in gas phase
$Sc$	schimdt number
$\theta_L$	time of residence of liquid on tray
$D_E$	eddy diffsvivity
$X_{Local}$	mass fraction in liquid phase
$P_w$	vapour pressure of water
$P_A$	vapour pressure of aniline
$N_{iL}$	number of liquid phase transfer unit
$N_{iG}$	number of gas phase transfer unit
$N_{toG}$	number of overall gas phase transfer unit
$X_{Local}$	mass fraction in liquid phase
$A, B, C$	antonie constant

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