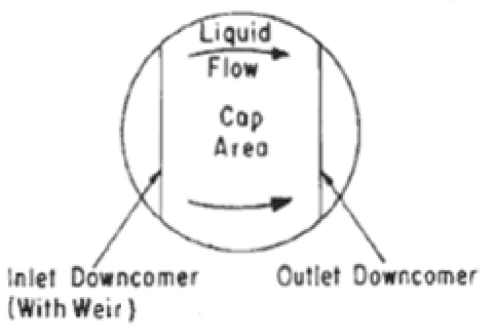
Ex-4 Bubble cap Distillation Column

Acetone is to be recovered from an aqueous waste steam by continuous distillation. The feed contains 3.3 mole % of acetone. Acetone of at least 94 mole % in the product is required, and the aqueous effluent must not contain more than 0.016 mole % of acetone. The ideal number of stages based on 100% tray efficiency is estimated to be 16. The average tray efficiency is assumed to be 80%. Reflux ratio is maintained at 1.35. Saturated liquid feed is used.

Properties of fluid at the operating temperature are:
Density of acetone vapor = 2.05 kg/m^3; Density of liquid acetone = 753 kg/m^3.
Density of water vapor = 0.72 kg/m^3; Density of liquid water = 954 kg/m^3.
Molecular weight of acetone is 55.6; and that of water is 18.

Surface tension of acetone-water feed liquid against its vapor at the feed composition is 25 dyne/cm.

A distillation column of the following configuration is available:
Distillation Column is 3 feet in inner diameter, 10 mm thickness shell, 20 bubble cap trays with a tray spacing of 0.6 m. Feed is introduced in 10th tray from top. The column is supported on the ground with a skirt support. Man-holes of
ϕ500 mm are available in between (a) 5th and 6th tray from top, and (b) 15th and 16th tray from top. And a sight glass of ϕ300 mm is available over the feed tray. Other dimensions of tray (as shown in the following sketch) are given below:



Details of cap
Nominal diameter = 4inch
Number of caps = 27
Pitch = 5.25inch, triangular

Details of tray
Cross flow tray (as shown in schematic) with weir on the inlet and outlet down-comers
Weir length = 24.75inch; weir height = 3.5inch
Max distance between down-comer plate and column

at the outlet of down-comer = 2.5inch
No of weep hole of 3/8 inch dia = 4
Cross sectional area of down-comer is about 15% of the total column cross sectional area.

Man-way details:
Hexagonal man-way plate attached with the tray by bolting arrangement
Width of man-way plate = 13.75 inch
Maximum length of man-way plate = 26inch

(a) Check whether the following design is satisfactory for a feed flow rate of 300 kmol/h, and the operating velocity of vapor is 65% of the flooding velocity.

(b) And draw:
(i) Line diagram of distillation column assembly indicating the feed tray, sight-glass, man-holes location.
(ii) Details of a typical tray (plan and elevation)

Design Calculations

Mass balance:

Feed (F) = Distillate (D) + Bottom product (B)

F = D + B --- (1)
F x_F = D x_D + B x_B --- (2)

300 = D + B --- (3)

300 x 0.033 = 0.94 D + 0.00016 B --- (4)

(3) x 0.94 ➔

282 = 0.94 D + 0.94 B --- (5)

(5) – (4) ➔

272.1 = 0.93984 B

B = 289.5 kmol/h

D = F – B = 300 – 289.5 = **10.5 kmol/h**

Flow rates of vapor and liquid in various sections of column:

Vapor (V) in the enriching section is returning back to the column as refluxed liquid (L) and leaving the column as distillate (D).

i.e.,

V = L + D

By definition, reflux ratio (R) is:

R = L/D

L = RD

L = 1.35 x 10.5 = **14.175 kmol/h**

Therefore,
V = RD + D
i.e.,
V = (R+1)D = (1.35 + 1) x 10.5 = **24.675 kmol/h**

Liquid flow rate in stripping section (L_B) =

liquid flow rate in enriching section + flow rate of saturated liquid feed

= 14.175 + 300 = **314.175 kmol/h**

For saturated liquid feed, vapor flow rate in stripping section is equal to the vapor flow rate in enriching section. Hence the molar flow rate of vapor is constant throughout the column (24.675 kmol/h)

Molecular weight of acetone = 58.0

Since the enriching section is having more of acetone,

Mass flow rate of vapor in enriching section = 24.675 x 58
= 1431.15 kg/h = 0.398 kg/s

Mass flow rate of liquid in enriching section = 14.175 x 58
= 822.15 kg/h = 0.228 kg/s

Molecular weight of water = 18

Since the stripping section is having more of water,

Mass flow rate of vapor in stripping section = 24.675 x 18
= 449.55 kg/h = 0.125 kg/s

Mass flow rate of liquid in stripping section = 314.175 x 18
= 5655.15 kg/h = 1.571 kg/s

The following areas terms are used in the plate design procedure:

A_c = total column cross-sectional area,

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,

C = 675 (from Figure 8.82)

(Source: Ludwig, Applied Process Design, 2nd Volume, 3rd Edition)

Density of acetone vapor = 2.05 kg/m^3; Density of liquid acetone = 753 kg/m^3.

Density of water vapor = 0.72 kg/m^3; Density of liquid water = 954 kg/m^3.

Top section:

Column is more of acetone in the top

ρ_v = 2.05 kg/m^3; ρ_l = 753 kg/m^3

ρ_v = 2.05 kg/m^3 = 0.13 lb/ft^3
ρ_l = 753 kg/m^3 = 47 lb/ft^3

From chart, maximum mass flux of vapor Gv = 1300 lb/ft^2.hr = 1.77 kg/m^2.s

Operating at 65% of the maximum, Gv = 0.65 x 1.77 = 1.15 m^2

Area required = mass flow rate / mass flux = 0.398 / 1.15 = 0.346 m^2

Bottom section:
Column is more of water in the bottom
ρ_v = 0.72 kg/m^3; ρ_l = 954 kg/m^3

ρ_v = 954 kg/m^3 = 0.045 lb/ft^3
ρ_l = 954 kg/m^3 = 59.5 lb/ft^3

From chart, maximum mass flux of vapor Gv = 1100 lb/ft^2.hr = 1.49 kg/m^2.s

Operating at 85% of the maximum, Gv = 0.65 x 1.49 = 0.97 m^2

Area required = mass flow rate / mass flux = 0.125 / 0.97 = 0.129 m^2

Net area required: (A = Q/v)

Top = 0.346 m^2

Bottom = 0.129 m^2

Down-comer area = 15% of total column cross sectional area. Therefore, column cross-section area required is:

Top = 0.346 / (1 – 0.15) = 0.407 m^2

Bottom = 0.129 / (1 – 0.15) = 0.152 m^2

Column diameter:

A = (π / 4) D^2

Top D = 0.72 m

Bottom D = 0.44 m

For uniformity of column diameter, throughout the height, the column diameter for satisfactory operation is fixed at 0.72 m.

Diameter of available column is 0.91 m. Therefore, the given design is satisfactory.