# PED Lab Report

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**Given**

| | | |
|---|---|---|
| Feed_Composition (x_f) | 0.18 | w/w% |
| | 0.205663189 | %mole |
| x_d | 0.9 | %mole |
| x_b | 0.05 | %mole |
| Density of feed | 0.866279581 | g/cc |
| Density of Top | 0.876923385 | g/cc |
| Density of Bottom | 0.864234398 | g/cc |
| Average Density | 0.869145788 | g/cc |
| M_wf | 89.12071535 | g |
| Feed | 34 | tonnes/hr |
| | 381.5050167 | Kmole/hr |
| Distillate | 69.86622074 | Kmole/hr |
| Bottom | 311.638796 | Kmole/hr |

Given Antoines Parameter

log_10(P_sat) = a - b/(t + C) Where P_sat in kPa and t in C

| | Benzene | Toluene | |
|---|---|---|---|
| a | 6.01905 | 6.08436 | |
| b | 1204.637 | 1347.62 | |
| c | 220.089 | 219.787 | |
| Density | 0.8787 | 0.8636 | g/cc |
| Boiling Point | 80.05 | 110.6 | C |

| | | | |
|---|---|---|---|
| mole fraction Distillate | 0.9 | 0.1 | |
| mole fraction Botton | 0.05 | 0.95 | |
| P_sat in kPa_82 | 107.4882374 | 41.5807802 | Kpa |
| P_sat in kPa_dew | 138.6547304 | 55.31399965 | Kpa |

| | | |
|---|---|---|
| T in C in Reflux Drum (Bubble point) | 82 | C |
| Top Col Temperature(Dew point of D) | 90.61545523 | C |

| | | |
|---|---|---|
| Bubble pressure reflux drum | 100.8974917 | Kpa |

Considering 0.3 kg/cm^2 positive gauge pressure therefore it operate a 101.325 Kpa + 0.3 kg/cm^2

| | | |
|---|---|---|
| P_Top_col | 130.3182234 | 130.3206574 |

| | | |
|---|---|---|
| P_sat in kPa | 300.0514161 | 131.3977763 |

| | | | |
|---|---|---|---|
| T in C for Boiler | 120.0257793 | C | |
| Bubble pressure for bottom colm | | 139.8304583 | Kpa |

| Temperature © | | Pure Component Vapour Pressure(Kpa) | |
|---|---|---|---|
| | | Benzene | Toluene |
| Col Top | 90.61545523 | 138.6547304 | 55.31399965 |
| Col Bot | 120.0257793 | 300.0514161 | 131.3977763 |

| | |
|---|---|
| alpha_top | 2.506684226 |
| alpha_bot | 2.283534962 |
| | |
| alpha | 2.392509367 |

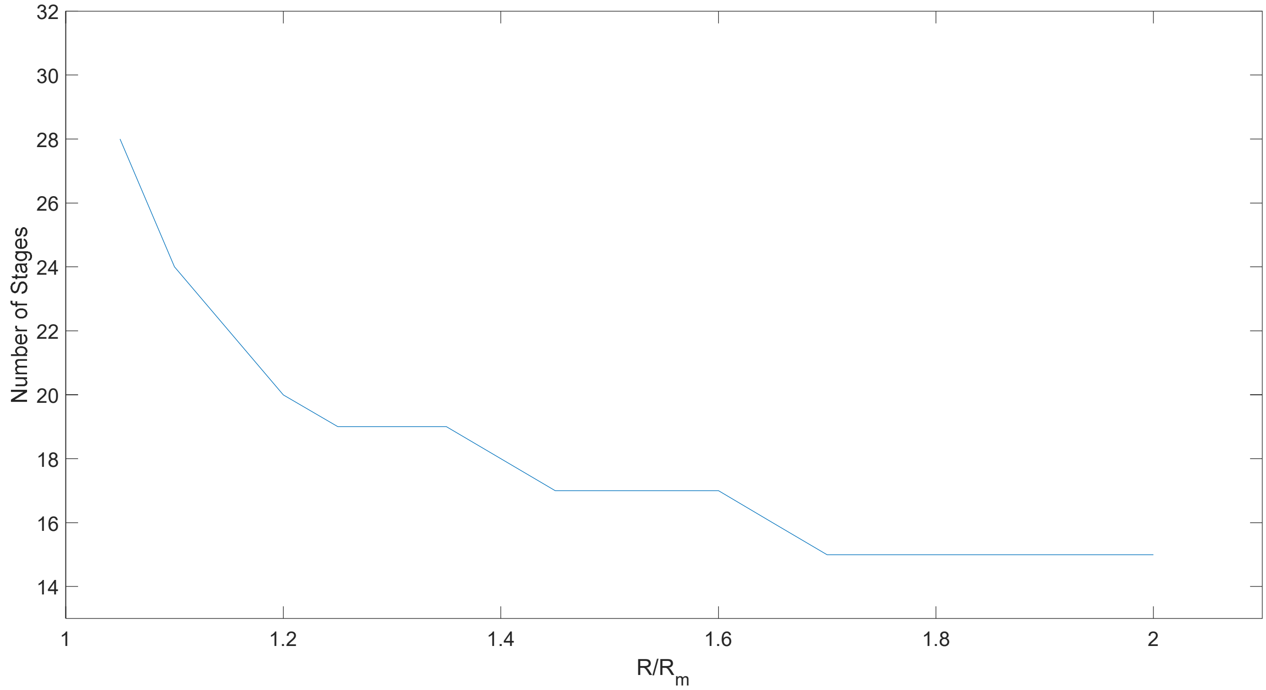
## MATLAB Code for the Calculations Using McCabe's Thiele Method:

```
warning off;
% Using McCabe Thiele Method

% Given Variable
x_f = 0.205663189;
x_d = 0.9;
x_w = 0.05;
q = 1;
alpha = 2.392509367;
efficiency = 0.7;
options = optimset('display' , 'off');

% plotting the 45 degree line for the equilibrium plot
%plot([0 1], [0 1],'k');
%grid on;
%hold on;
xlabel('Reflux Ratio');ylabel('Stages');

% The equilibrium curve and plotting it
y_eq = @(x) alpha * x / (1 - (1 - alpha) * x);
x_eq = @(y) y / (alpha + (1 - alpha) * y);
%fplot(y_eq, [0 1],'r',LineWidth=0.20);
%set(gca, 'xlim', [0 1]);
%set(gca, 'ylim', [0 1]);

% feed line or q line
q_slope = q / (q - 1);
q_intersept = -x_f / (q - 1);
q_eqn = @(x) q_slope * x + q_intersept;
if q > 1
    %fplot(q_eqn,[x_f y_eq(x_f)])
elseif q == 1
    %plot([x_f x_f],[x_f y_eq(x_f)],'b')
elseif q == 0
    %plot([x_eq(x_f) x_f],[x_f x_f],'b')
elseif q > 0 && q < 1
    %x_lim = fsolve(@(x) q_eqn(x) - y_eq(x),x_f,options);
    %fplot(q_eqn,[x_lim x_f])
end


% R_min and R calculation
if q == 1
    x_pinch = x_f;
else
    x_pinch = fsolve(@(x) q_eqn(x) - y_eq(x),x_f,options);
end
y_pinch = y_eq(x_pinch);

R_min_slope = (x_d - y_pinch)/(x_d - x_pinch);
R_min_intersept = x_d * (1 - R_min_slope);
R_min = x_d / R_min_intersept - 1;

Actual_Stages = zeros(1,size(1.05: 0.05 : 2.0,2));
Ideal_Stages = zeros(1,size(1.05: 0.05 : 2.0,2));
Rect_Stages = zeros(1,size(1.05: 0.05 : 2.0,2));
Strip_Stages = zeros(1,size(1.05: 0.05 : 2.0,2));
```

```
Ac_Rect_Stages = zeros(1,size(1.05: 0.05 : 2.0,2));
Ac_Strip_Stages = zeros(1,size(1.05: 0.05 : 2.0,2));
i = 1;
for Ratio = 1.05:0.05:2.0

    R_pinch_line = @(x) R_min/(R_min+1) * x + x_d / (R_min + 1);
    %fplot(R_pinch_line, [0 x_d])
    R = Ratio*R_min;
    % Rectifying Section operating line
    Rec_op_line = @(x) R/(R+1) * x + x_d / (R + 1);

    % Stripping Section operating line
    % Finding the intersection of the q and rec_op_line
    if q == 1
        x_intr_point = x_f;
    else
        x_intr_point = fsolve(@(x) Rec_op_line(x) - q_eqn(x), x_f, options);
    end
    y_intr_point = Rec_op_line(x_intr_point);
    % plotting the Rectifying Section operating line and stripping section
operating line
    %plot([x_d x_intr_point], [x_d y_intr_point]);
    %plot([x_intr_point x_w], [y_intr_point x_w]);

    % Rectifying Section Stages
    x_re_stage_hor_1 = x_d;
    y_re_stage_hor_1 = x_d;
    rectifying_counter = 0;
    while x_re_stage_hor_1 > x_intr_point

        y_re_stage_hor_2 = y_re_stage_hor_1;
        x_re_stage_hor_2 = x_eq(y_re_stage_hor_2);
        x_re_stage_ver = x_re_stage_hor_2;
        y_re_stage_ver = Rec_op_line(x_re_stage_ver);

        % Plotting the stage
        %plot([x_re_stage_hor_1, x_re_stage_hor_2], [y_re_stage_hor_1
y_re_stage_hor_2],'m');
        %plot([x_re_stage_hor_2, x_re_stage_ver], [y_re_stage_hor_2
y_re_stage_ver],'m');

        re_stage_x = x_re_stage_hor_1;
        x_re_stage_hor_1 = x_re_stage_ver;
        y_re_stage_hor_1 = y_re_stage_ver;

        rectifying_counter =rectifying_counter + 1;
    end

    rectifying_stages = rectifying_counter - ...
        (x_re_stage_hor_2 - x_intr_point)/(x_re_stage_hor_2 - re_stage_x);

    Rect_Stages(i) = Rect_Stages(i) + ceil(rectifying_stages);
    % Stripping Section Stages

    % stripping section equation
    strp_slope = (x_w - y_intr_point)/(x_w - x_intr_point);
    strp_intrcpt = x_w - strp_slope * x_w;
    strp_eq_x = @(y) (y - strp_intrcpt)/strp_slope;
```

```
    str_stage_x_ver_1 = x_w;
    str_stage_y_ver_1 = x_w;
    str_counter = 0;

    while str_stage_y_ver_1 < y_intr_point

        str_stage_x_ver_2 = str_stage_x_ver_1;
        str_stage_y_ver_2 = y_eq(str_stage_x_ver_2);
        str_stage_y_hor = str_stage_y_ver_2;
        str_stage_x_hor = strp_eq_x(str_stage_y_hor);

        % Plotting the stage
        %plot([str_stage_x_ver_1 str_stage_x_ver_2], [str_stage_y_ver_1
str_stage_y_ver_2],Color=[1 .2 0]);
        %plot([str_stage_x_ver_2 str_stage_x_hor], [str_stage_y_ver_2
str_stage_y_hor],Color=[1 .2 0]);

        str_stage_y = str_stage_y_ver_1;
        str_stage_x_ver_1 = str_stage_x_hor;
        str_stage_y_ver_1 = str_stage_y_hor;

        str_counter = str_counter + 1;

    end

    stripping_stages = str_counter - ...
        (y_re_stage_hor_2-y_intr_point)/(y_re_stage_hor_2 - str_stage_y);

    Strip_Stages(i) = Strip_Stages(i) + ceil(stripping_stages);
    Ideal_Stages(i) = Ideal_Stages(i) +
ceil(stripping_stages+rectifying_stages)+1;
    no_act_stages_re = ceil(rectifying_stages/efficiency);
    Ac_Rect_Stages(i) = Ac_Rect_Stages(i) + no_act_stages_re;
    no_act_stages_str = ceil(stripping_stages/efficiency);
    Ac_Strip_Stages(i) = Ac_Strip_Stages(i) + no_act_stages_str;
    %fprintf("\n The Number of Theoretical Stages in the distillation column is
%4.2f.\n",rectifying_stages+stripping_stages);
    %fprintf("\n The Number of Actual Stages in the distillation column is
%2.0f.\n",no_act_stages_str+no_act_stages_re);


    Actual_Stages(i) = Actual_Stages(i) + (no_act_stages_str+no_act_stages_re+1);
    i = i + 1;

end
rat = 1.05:0.05:2.0;
plot(rat, Actual_Stages);
set(gca, 'xlim', [1.0 2.1]);
set(gca, 'ylim', [13 32]);
ylabel("Number of Stages");xlabel("R/R_m");
set(gca,'FontSize',15);
plot_data = [rat;Rect_Stages; Strip_Stages; Ideal_Stages;Ac_Rect_Stages;
Ac_Strip_Stages;Actual_Stages]';
```

# Plot Of R/R_min VS Number of Stages:



# Tray Design Calculation

**Molecular Weight Of Feed**

| | | |
|---|---|---|
| M_f | 89.12071535 | g |
| M_d | 79.20529801 | g |
| M_b | 91.18170267 | g |

**Flow Rate**

| | | |
|---|---|---|
| mole fraction Distillate | 0.9 | 0.1 |
| mole fraction Botton | 0.05 | 0.95 |

| | | |
|---|---|---|
| Feed(Q_f) | 381.5050167 | Kmole/hr |
| | 9.444444444 | kg/sec |
| Distillate | 69.86622074 | Kmole/hr |
| Bottom | 311.638796 | Kmole/hr |

| | | |
|---|---|---|
| Distillate flow(m_D) | 5547.377926 | kg/hr |
| | 1.540938313 | kg/sec |
| Bottom Flow(m_B) | 28452.62207 | kg/hr |
| | 7.903506132 | kg/sec |
| R_min | 2.926293512 | Kg/sec |
| R/R_min | 1.2 | |

**Design of a bubble cap tray for the top tray condition specified as**

| | | |
|---|---|---|
| Vapour Flow Rate(m_V) | 6.93497614 | kg/sec |
| Liquid Flow Rate(m_L) | 5.397816464 | kg/sec |
| Density Of the Vapour(rho_V) | 3.414469017 | kg/m^3 |
| Density Of the Liquid(rho_L) | 874.7730234 | kg/m^3 |
| Flow Rate of Vapour(Q_V) | 2.031055519 | m^3/s |
| Flow Rate of Liquid(Q_L) | 0.006170534 | m^3/s |
| | 22.2139215 | m^3/hr |

**Tray Diameter (Estimation by Fair and Mathews Correlation)**

| | |
|---|---|
| F_LV | 0.048628071 |
| LN(F_LV) | -3.023554328 |

$$F_{LV} = \frac{m_L}{m_V}\sqrt{\frac{\rho_V}{\rho_L}}$$

| Tray spacing (mm) | a3 | a2 | al | a0 |
|---|---|---|---|---|
| 300 | -0.0157 | -0.1863 | -0.7713 | -2.7708 |
| 450 | -0.0178 | -0.2027 | -0.8161 | -2.5493 |
| 600 | -0.0172 | -0.2071 | -0.8609 | -2.3289 |
| 900 | -0.0182 | -0.2156 | -0.8951 | -2.1038 |

| | | |
|---|---|---|
| Tray spacing | 600 | mm |

$$\ln(C_{sb}) = a3\{\ln(F_{LV})\}^3 + a2\{\ln(F_{LV})\}^2 + a1\{\ln(F_{LV})\} + a0 - 1.1880$$

| | |
|---|---|
| LN(C_sb) | -2.331780849 |
| C_sb | 0.097122632 |

**Assuming 75% flooding**

| | | |
|---|---|---|
| j | 0.85 | |
| Surface tension(sigma) | 20 | dyne/cm |

$$U_{V,n} = \left(\frac{j}{100}\right)(\sigma/20)^{0.2} C_{sb}\sqrt{\frac{(\rho_L - \rho_V)}{\rho_V}}$$

| | | |
|---|---|---|
| U_V,n | 1.31879178 | m/s |

**Typically, as a first trial, the weir length can be considered to be 0.77D equivalent to Adc = 0.12A, i.e., k is 12%.**

| | | |
|---|---|---|
| downcomer area fraction (k) | 0.12 | % |

$$D = \left\{\frac{4(m_V/\rho_V)}{\pi(1 - k/100)}\left(\frac{1}{U_{V,n}}\right)\right\}^{1/2}$$

| | | |
|---|---|---|
| tower diameter(D) | 1.49 | m |
| | 1490 | mm |

| **Table 17.8 Increment criteria for vessels fabricated from plates.** | | | | |
|---|---|---|---|---|
| D (mm) | 450 | 1000 | 3000 | 5000 |
| Increment (mm) | 50 | 100 | 200 | 300 |

| | | | | |
|---|---|---|---|---|
| Therefore, Tower Diameter (D) | 1600 | mm | 62.99216 | inches |
| Area | 2.01 | m^2 | | |

**Actual Number of Trays**

| | |
|---|---|
| Rectification Section Tray | 10 |
| Stripping Section Tray | 8 |
| Feed Tray | 1 |

| | | |
|---|---|---|
| Column_rec+Strp Height | 9600 | mm |
| Feed tray Spacing(1.5 TS) | 900 | mm |

**Additional 150 mm over the normal tray spacing whenever the downcomer is provided with a separate seal pan.**

| | | |
|---|---|---|
| TS + 150 | 750 | mm |

**Minimum TS is 1200 mm where manholes are provided. One manhole is to be provided after 8 to 10 trays.**

| | | |
|---|---|---|
| Manhole Spacing (2 number) | 2400 | mm |

**Tower top dome height up to TTL (tangent length) may be twice the regular spacing of the tray or minimum 1200 mm from the top tray deck.**

| | | |
|---|---|---|
| 2 TS | 1200 | mm |
| Tower Height | 14900 | mm |
| | 14.9 | m |

| | | |
|---|---|---|
| Thickness of the Column(pd/2fj+p) | 1.393228435 | mm |

**Therefore, Thickness is around 1.5 mm and this thickeness is not availabe so we take thockness as 5 mm**

| | | |
|---|---|---|
| t | 5 | mm |
| Carbon Steel Cost | 70 | rs/kg |
| Density of Carbon Steel | 7840 | kg/m^3 |
| Cost Of the Column | 205513.441 | Rs |

| Diameter (inches) | Cost/Plate (Rs) |
|---|---|
| 60 | 55000 |
| 70 | 65000 |
| 80 | 85000 |
| 90 | 110000 |
| 100 | 120000 |

| | | |
|---|---|---|
| Total Cost Of the tray | 1087489.32 | Rs |
| Tatal Cost of Column and Tray | 1293002.761 | Rs |

**Heat Load of the Reboiler and Condenser**

| | Benzene | Toluene |
|---|---|---|
| Cpl (kJ/kmol K), average | 134.8 | 155.96 |
| Cpv (kJ/kmol K), average | 82.44 | 103.7 |
| Heat of vaporisation at NBP, l (kJ/kmol) | 30.77 | 38.06 |

| | | |
|---|---|---|
| C_p_L_mix | 136.916 | (kJ/kmol K) |
| C_p_V_mix | 84.566 | (kJ/kmol K) |
| Heat of Vap_mix | 31.499 | kJ/kmol |
| Q_v | -239579.0731 | W |
| Q_l | -289400.1919 | W |
| Duty of Condenser | 528979.2651 | W |

| | | |
|---|---|---|
| OverAll Heat Transfer Coefficient_condense | 65 | Btu/ft^2.F.h |
| | 369.0895 | W/m^2.K |
| LMTD | 46.25550541 | |
| Area of Condenser | 30.9844312 | m^2 |
| | 333.513319 | ft^2 |

Reboiler load,

$$Q_{reb} = Q_c + Enthalpy\ leaving\ with\ D + Enthalpy\ leaving\ with\ B - Enthalpy\ entering\ with\ F$$

| | Benzene | Toluene | |
|---|---|---|---|
| Enthalpy of Formation | 82745.39026 | 50088.5 | J/mol |
| Enthalpy of Saturated Feed | 56804.83303 | J/Kg | |

| | | |
|---|---|---|
| Enathalpy Of Distillate | 79479.70285 | J/Kg |
| Enathalpy Of Bottom | 51721.35985 | J/Kg |

| | | |
|---|---|---|
| Duty of Reboiler | 522912.5984 | W |
| LMTD for Reboiler | 8.400273952 | |
| OverAll Heat Transfer Coefficient | 567.5 | W/m^2.K |
| Area Of the Reboiler | 109.6906954 | m^2 |
| | 1180.699676 | ft^2 |

Cost Table for Condenser

| Heat transfer Area(ft^2) | Cost( Rs) |
|---|---|
| 0 | 0 |
| 1000 | 780000 |
| 1200 | 950000 |
| 1400 | 1220000 |
| 1600 | 1450000 |

| | | |
|---|---|---|
| Cost Of Condenser | 255451.2072 | RS |

Cost Table forReboiler

| Heat transfer Area(ft^2) | Cost( Rs) |
|---|---|
| 0 | 0 |
| 1000 | 400000 |
| 1400 | 500000 |
| 1800 | 620000 |
| 2200 | 800000 |
| 2600 | 1000000 |

| | | |
|---|---|---|
| Cost Of Reboiler | 434820.9341 | RS |
| Total Cost | 4759859.765 | Rs |
| Salvage | 1903943.906 | |
| life | 10 | |
| Total Annual Cost | ₹ 9,51,971.95 | Rs/Year |
| **Operating Cost** | | |
| Flow Rate of Water Condenser | 8.996246004 | kg/s |
| Cost of cooling water | 0.25 | rs/1000 kg |
| Cost of cooling water for Operating 8000 hrs | 64772.97123 | Rs/Year |
| Flow Rate of Steam | 0.193671333 | Kg/s |
| Steam Price | 0.2 | Rs/kg |
| Cost of the steam for Operating 8000 hrs | 1115546.876 | Rs/Year |
| Total Cost per Annum incluing operating co | 2132291.801 | Rs/Year |

# Tray Hydraulics

**Flow Rate of Liquid**

| | | |
|---|---|---|
| Q_L | 22.21392 | m^3/hr |
| Q_V | 2.031056 | m^3/s |

**Number of passes**

| | | |
|---|---|---|
| Diameter of Tray(D) | 1.6 | m |
| Length of Calming Zone | 0.1 | m |
| Length of Weir(l_w) = 0.76D | 1.216 | m |
| Liquid loading (Q_l/l_w) | 18.26803 | m^3/hr (m l_w) |

**Since Liquid Loading is less than 62 m^3/hr (m l_w), So single pass is OK**

## Area of Distribution over Tray

| | |
|---|---|
| For X = l_dc/D | 0.76 |

$$\frac{\tilde{A}_{dc}}{A} = (50/\pi) \times \{2\sin^{-1}\chi - \sin(2\sin^{-1}\chi)\}$$

| | |
|---|---|
| A_dc/A | 0.12 |

**Downcomer Width**

$$w_{dc} = \frac{50 \times \{1-\cos\{\sin^{-1}(\chi)\}\}}{100} \times D$$

| | | |
|---|---|---|
| w_dc | 0.280062 | m |
| Area of Tray (A) | 2.01 | m^2 |
| Area of Downcomer (A_dc) | 0.2412 | m^2 |
| Area of Calming( A_cal) | 0.1216 | m^2 |

**Taking End Wastage Around 5% we get**

| | | |
|---|---|---|
| Area of End Wastage(A_w) | 0.0201 | m^2 |

From Fig. 14.12, net tray perforated area $A_{o,tray} = A - (2A_{dc} + 2A_{\text{calming}} + A_{\text{end wastage}} + A_{\text{backing strips}})$.

Considering 10% loss of total area due to backing strips, from geometry

| | | |
|---|---|---|
| net tray perforated Area(Ao,tray) | 1.201085 | m^2 |

## Tray Layout

**Since D > 1.2 m, cap nominal size, d_cap = 100 mm**

| | | |
|---|---|---|
| d_cap | 100 | mm |

**From Table 14.6, we select carbon steel caps of 100 mm nominal size for which**

| | | |
|---|---|---|
| Cap OD | 104 | mm |
| ID | 98.44 | mm |
| height | 76 | mm |
| Cap Area(A_cap) | 0.008495 | m^2 |
| Height of Shroud ring | 6 | mm |
| skirt height | 25 | mm |
| Trapezoidal slot with no. of slots | 26 | |
| R_s | 0.5 | mm |

slot dimensions 8.5 mm * 4.2 mm

| | | |
|---|---|---|
| C_s | 0.74 | |
| h_s | 32 | mm |

**Area Ratios**

| | | |
|---|---|---|
| reversal/riser | 1.52 | |
| slot/riser | 1.69 | |
| annular/riser (r) | 1.25 | |
| slot/cap | 0.62 | |

| | | |
|---|---|---|
| Pitch (P = 1.25 * OD) | 130 | |

**Considering triangular pitch, number of caps per m2 of net perforated area of tray A_o,tray**

| | | |
|---|---|---|
| number of Caps per m^2 | 69 | |
| Total Number of Caps | 84 | |

## Weir height

h_w = cap skirt clearance (25 mm) + shroud ring height (6 mm) + slot height (32 mm) + static seal (10 mm)

| | | |
|---|---|---|
| h_w | 73 | mm |
| h_w/TS | 12.16667 | % (OK) |

## Height over weir

| | | |
|---|---|---|
| h_ow | 22.1473 | mm |

22.15mm( > 10 mm specified as minimum in text)

$$h_{ow} = 750\left(\frac{m_L}{\rho_L l_w}\right)^{2/3}$$

## Tray pressure drop

| | | |
|---|---|---|
| A_riser/A_cap | 0.366864 | |
| A_riser/cap | 0.003116 | m^2 |
| Total riser area per tray in m2 , Ar | 0.261783 | m^2 |
| Dry cap coefficient( Kc) | 0.502931 | mm/m.s |

$$\frac{A_{slot}/A_{cap}}{A_{slot}/A_{riser}} = \frac{A_{riser}}{A_{cap}}$$

$$K_c = 0.6373 \times r^2 - 2.0386 \times r + 2.0554$$

| | | |
|---|---|---|
| Rho_V/Rho_L | 0.003903 | |
| h_dry | 32.30702 | mm |

$$h_{dry} = 273.4 K_c \frac{\rho_V}{\rho_L}\left(\frac{Q_V}{A_r}\right)^2$$

## Head loss through wet slots

| | | |
|---|---|---|
| Slot area per tray (A_s) | 0.442413 | m^2 |
| Q_V,max | 1.88924 | m^3/s |
| Q_V/Q_V,max | 1.075065 | |

Maximum slot capacity formula

$$Q_{max} = C_s A_s \sqrt{h_{sh}\left(\frac{\rho_L - \rho_V}{\rho_V}\right)}$$

**The above Ratio is in the Range to operate**

| | | |
|---|---|---|
| h_so (h_s + h_shroud) | 38 | mm |
| Mean Tray Diameter | 1.408 | m |
| Q_L/Mean Tray Diameter | 0.004382 | m^3/s/m ok |

## Tray Layout

| | | |
|---|---|---|
| Distance of weir from Tray Center | 0.519938 | m |
| Width of Calming Zone | 1.361839 | m |
| Average tray width where caps are placed | 1.48092 | m |
| average no of caps per row | 11.39169 | |
| No. of rows to accommodate 84 Caps | 7.373796 | |
| Gap between rows | 112.5833 | mm |
| Maximum number of rows that can be accommodated | 7.460049 | >7.37 (Hence, OK) |

**Actual layout needs to be done to finalise number of rows but**
**7 rows can be accommodated and further calculations consider 7 rows**

| | | | |
|---|---|---|---|
| Gamma = (gap between caps/cap OD) | | 0.25 | |
| s = Cap skirt clearance | 25.4 | mm | |
| h_lo = h_w + h_ow | 95.1473 | mm | |

**Considering square pitch, number of caps per m2 of net perforated area of tray A_o,tray**

| | | |
|---|---|---|
| number of Caps per m^2 | 60 | |
| Total Number of Caps | 72 | |
| Total riser area per tray in m2 , Ar | 0.224385 | m^2 |
| h_dry | 43.97344 | mm |
| C_s | 0.74 | |
| Slot area per tray (A_s) | 0.379211 | m^2 |
| Q_V,max | 1.533634 | m^3/s |
| Q_V/Q_V,max | 1.324342 | |

**The above suugest overloaded Slots**

## Liquid gradient

$$V_o\sqrt{\rho_v} = 0.8197 \times \frac{(Q_V \text{ in m}^3/\text{s})}{(A \text{ in m}^2)} \sqrt{\rho_v \text{ in kg/m}^3}$$

| | | |
|---|---|---|
| V_o√$\rho\_v$ | 1.530531 | ft/s |
| liquid load per ft mean tray width, f | 21.17251 | gpm |

**C_v can be found from fig.14.13 using the f and V_o√$\rho\_v$**

| | |
|---|---|
| C_v | 1.14 |

$$\left\{\frac{(Q_L/l_w)}{C_d}\right\} = \exp\{0.0899 \times \{\ln(f)\}^2 - 0.0238 \times \ln(f) + 2.4146\}$$

| | |
|---|---|
| {(Q_L/l_w)/C_d} | 24.04011 |

$$\Delta = C_v \times No.\ of\ rows \times \delta$$

Δ = 1.14*7*$\delta$

$$\left\{\frac{(Q/L_w)}{C_d}\right\} = 0.2015 \times \left(\frac{\gamma}{1+\gamma}\right) \times \delta^{0.5} \times \left\{1.6 \times \delta + 3 \times \left(h_w + h_{ow} + \Delta/2 + \frac{0.3 \times s}{\gamma}\right)\right\}$$

**Putting {(Q_L/l_w)/C_d} and Δ = 1.14*7*$\delta$ in the above expression and solving for del**

| | | | |
|---|---|---|---|
| {(Q_L/l_w)/C_d} | 24.0401 | (Using the Equation Above) | |
| $\delta$ | 2.157149 | mm/row | |
| Δ | 17.21405 | 17 | mm (say) |

## Drop through aerated liquid(h_al)

| | | |
|---|---|---|
| Riser slot seal, h_ss | 13 | mm |
| dynamic slot seal,h_ds | 43.6473 | mm |
| F_Va | 2.456822 | $F_{Va} = U_{Va}\rho_V^{1/2}$ |

$$\beta = -0.0255 \times (F_{Va})^3 + 0.1744 \times (F_{Va})^2 - 0.4282 \times F_{Va} + 0.9979$$

| | | |
|---|---|---|
| Beta | 0.620415 | |
| h_al = Beta * h_ds | 27.07945 | mm |
| h_tray=h_dry+h_so+h_al | 109.0529 | mm |

## Vapour distribution

| | | |
|---|---|---|
| h_cap = h_dry + h_so | 81.97344 | mm |
| r_vd | 0.209995 | |

## Corrected 'approach to flooding'

| | | |
|---|---|---|
| A_n | 1.7688 | m^2 |
| U_V,n | 1.148267 | m/s |
| U_fV,n | 1.55152 | |
| j = U_V,n/U_fV,n | 0.740092 | ≈74 % |

**approach to flooding (Ok)**

## Downcomer dynamics

| | | |
|---|---|---|
| h_dc,clearance | 25 | mm |
| A_dc,clearance = h_dc,clearance * l_w | 0.0304 | m^2 |
| h_dc,prdrop | 6.807905 | mm |

$$h_{dc,prdrop} = 0.1275\left(\frac{Q_L}{100A_{da}}\right)^2$$

$$h'_{L,dc} = h_w + h_{ow} + h'_{dc,prdrop} + h_{tray} + \Delta$$

| | | |
|---|---|---|
| downcomer backup,h_L,dc | 228.0081 | mm |

**Considering check of h_L,dc < TS/2 = 300 (OK)**

$$t_{dc} = \frac{A_{dc}h_{L.dc}}{Q_L}$$

| | | |
|---|---|---|
| residence time in downcomer, t_dc | 8.912608 | s (Sufficient) |
| Downcomer Velocity | 0.025583 | m/s |

**Therefore, Downcomer Velocity is sufficiently below choking limit**
**Throw of liquid over weir into downcomer is not important**
**in case of segmental downcomers and hence omitted.**

## Weep holes

| | | |
|---|---|---|
| A_n,L = A - (A_dc + A_o,tray) | 0.567715 | m^2 |
| A_n,L summed over all trays | 10.78659 | m^2 |

**As per the general recommendation (275 - 280 mm^2 of weep hole area per m2**
**of net open liquid tray area summed over all trays),**
**We consider total area occupied by weep holes as 277.75 mm^2 per m^2 A_n,L**

| | | |
|---|---|---|
| Total weep hole area, A_wh | 2995.974 | mm^2 |
| Area A_wh on each tray | 157.6828 | mm^2 |
| Assuming d_wh | 3 | mm |
| number of weep holes per tray, N_wh | 22.30756 | 23 |

# Distillation Column (Benzene recovery column) Summary:

Customer ID: IIT Kharagpur, India Designer: PED GROUP – 8

Date: March, 03, 2023

| | | |
|---|---|---|
| **D, Tray/Tower diameter (m)** | **1.6** | |
| **A, tower area ($m^2$)** | **2.01** | |
| **A, active area ($m^2$)** | **1.201085** | |
| **Adc, downcomer area ($m^2$)** | **0.2412** | |
| **NP, number of passes** | **1** | |
| **W_dc(m)** | **0.280061542** | |
| **lw, weir length (m)** | **1.216** | |
| **hw, weir height (mm)** | **73** | |
| **Downcomer type** | **Segmental** | |
| **A_dc(% of A)** | **12** | |
| **Loadings @ Tray** | **8** | |
| **TS, mm** | **600** | |
| **Vapour** | **kg/s** | **6.93497614** |
| | **m3/s** | **2.031055519** |
| | **P_v, kg/m3** | **3.414469017** |
| **Liquid** | **kg/s** | **5.397816464** |
| | **m3/s** | **22.2139215** |
| | **P_l kg/$m^3$** | **874.7730234** |
| **Pressure Drop** | **QL/lw, m3/s per m** | **0.004382481** |
| | **hw, mm** | **73** |
| | **h_tray, mm liq.** | **109.0528855** |
| **A_dc,clearance ($m^2$)** | **0.0304** | |
| **h_dc,pr_drop, mm liq.** | **6.807904943** | |
| **hL,dc, mm liq.** | **228.008086** | |
| **Residence time, sec** | **8.912608306** | |