Designing a suitable distillation column for ethyl alcohol recovery from a pharmaceutical plant effluent wastewater

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Abstract

The pharmaceutical plant is processing different types of drugs, antibiotics, tablets, syrups, and other medical-related products. In most of these industries, ethyl alcohol (ethanol) is used as a chemical solvent in many processing steps. The excess ethanol along with water is generated as an effluent stream and discharged as waste. Since ethanol is a valuable solvent, there are many processes used to design for the recovery of the solvent from effluent wastewater. The principle focused here is the fractional distillation method, since, distillation is one of the best methods to get the purest form of the desired product from the mixture of ethanol and water. The major purpose of this review is to recover the excess ethanol from the effluent stream to be recovered in a solvent recovery plant using a suitable distillation column design. The study has been conducted for two types of distillation namely tray type (plate) and packed type column. Moreover, it is very important to note that, the system ethanol-water is a non-ideal system, so a suitable empirical model is used to solve for the equilibrium data. The distillation column has been designed for 50000 kg/h of wastewater feed rate to calculate various design parameters for both the distillation columns and based on these calculated values, the suitable column type for the recovery of ethanol has been identified.

Keywords: Distillation column, ethyl alcohol recovery, pharmaceutical plant, effluent treatment, wastewater treatment.

1. Introduction

1.1. Background

It is important to know the types of pharmaceutical waste so we can ensure safe handling and disposal. It's also essential to have a dependable disposal plan that will keep your facility compliant with the law. What is pharmaceutical waste? This waste includes discarded pharmaceutical products like prescription and over-the-counter medications, as well as the chemical sludges and wastewater produced during pharmaceutical manufacturing. Because of the health hazards and ecological risks this waste poses, it requires specialized disposal processes that ensure safety. Pharmaceutical waste may come from various sources, from manufacturing plants to facilities that provide medical or veterinary services. Mostly in all pharmaceutical plants, a large amount of ethanol is used as a solvent. In a plant that uses water as a solvent, no steps will be taken to recover and reuse the solvent. Whereas in the case of ethanol, it must be recovered to reuse.

Distillation is a unit operation in which constituents of liquid mixtures (solution) are separated using thermal energy. The difference in vapor pressure (volatility) of different constituents at the same temperature is responsible for such separation. With this technique, it is possible to separate liquid mixtures into its component in almost pure form and this fact has made distillation perhaps the most important of all mass transfer operations [1].

In distillation the phases involved are liquid and vapor or gas (the vapor phase is created by supplying heat to liquid) and mass is transferred from both phases to one another, by vaporization from the liquid phase and by condensation from the vapor phase. The vapor is always richer in more volatile components than the liquid from which it is formed. If the vapor composition is the same as the liquid composition distillation technique will not affect a separation [1]. Distillation [2] is commonly encountered in chemical and petroleum industries as a means of separating liquid mixtures into parts. Separation of ethanol and water mixture, production of absolute alcohol from 95% ethanol using

benzene, and separation of petroleum crude into gasoline, kerosene, fuel oil, etc. are typical examples of distillation.

1.2. Boiling point

For any given pressure, a pure liquid when heated will boil or vaporize at a certain single temperature known as the boiling point of the liquid, it increases with an increase in pressure and vice versa. The boiling point at a given pressure varies greatly for different liquids. For example, the boiling point of water is 373 K, toluene is 383.6 K and ethanol is 351 K at one atmospheric pressure. In binary mixtures, the component with a low boiling point (high vapor pressure) is known as a more volatile component or lighter component, and a component having a higher boiling point (low vapor pressure) is known as a low volatile component or heavier component [2].

1.3. Vapor-Liquid Equilibrium

The basic data for distillation calculation is the equilibrium existing between the liquid and vapor phases of the particular system. This VLE data can be derived from the phase rule. For the two-component mixture (Ethyl alcohol-water system), the number of components and phases are two and two respectively, so as per the phase rule ($F = C - P + 2$), the degree of freedom (F) will be two which is the number of intensive variables that can be varied independently and are also two. Different variables are involved in the distillation which includes pressure, temperature, and vapor and liquid compositions. Thus, if the pressure of the solution is fixed, then only one variable can be changed independently [3].

2. Types of Distillation Column

There are many types of distillation columns available and can be designed for a particular liquid mixture. Below are the two types of distillation columns that are under consideration.

- Plate (Tray) type distillation column
- Packed bed distillation column.

2.1. Plate (Tray) distillation columns

The plate distillation column is a vertical cylindrical column that consists of many numbers trays (plates) fixed with equal plate spacing. Trays may be of any type depending on the requirements, namely bubble column trays, sieve trays or valve trays, etc. The feed liquid may enter in or more places in the column. Liquid flowing down to the column, the vapor comes in contact with the liquid several times due to the many plates. This is the critical process in the distillation column [7].

The column itself is divided into two sections called rectifying section and the stripping section. The feed enters a particular number of plates according to the calculation, somewhere in the middle of the column. The section below the feed plate is known as rectifying section, where the vapor is washed to remove the less volatile component with the liquid returning to the column from the top is known as reflux [8].
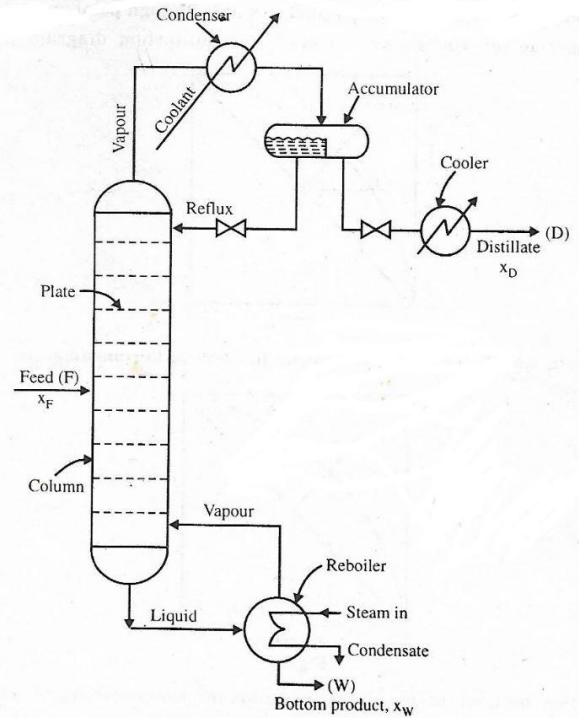

Figure 1: Typical plate distillation column. [9]

The section below the feed plate is known as the stripping section, where the liquid is stripped off more volatile components by raising vapor. The column is connected with the reboiler generally steam heated, where the initial feed supplied is collected. The vapors of more volatile components are generated in the reboiler and are fed to the bottom of the column [9]. The liquid removed from the fractionator rich in the less volatile component is called the bottom product.

2.2. Packed distillation column

The packed distillation columns are normally used whenever we need to carry out the distillation at low pressure and in very heat-sensitive materials. Usually packed columns are cheaper when compared to plate columns. The packed column consists of a cylindrical column filled with some sort of inert packing materials usually rings or saddles type which gives a larger interfacial area for the mass transfer [10]. The typically packed distillation column has been given in figure 2. In a packed column vapor flows upward and refluxed liquid flows downward to give continuous contact. The term Height Equivalent to Theoretical Plate is usually expressed in terms of an empirical form.

In the n case of a packed column, the same enrichment of vapor will occur at a certain height of the packing materials which is termed as a height equivalent to one theoretical plate. Thus, in packed distillation columns, one equilibrium step is represented by a particular height of the packed bed and the required height can be calculated by HETP with the number of theoretical plates required [11].
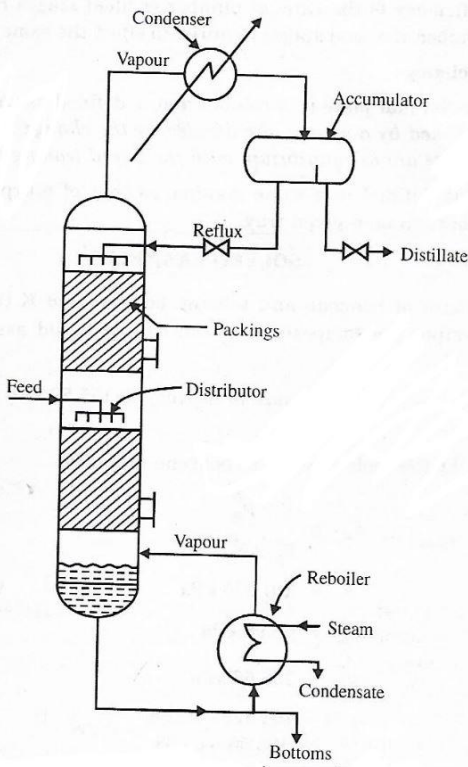
Figure 2: Typical packed distillation column. [9]

3. Design Consideration

3.1. Choice between the plate and packed column

The selection of a column is not determined by a single parameter. Various factors are to be considered on the column variables such as liquid and vapor flow rates, product quality, and the physical properties of liquid and vapor. In a few instances, it can be determined using the simulation software as well but not always. The final decision of selecting the column type for a particular separation is based on the design values, efficiency, and cost, and based on a qualitative analysis of relative advantages and disadvantages, eliminating the need for a detailed cost comparison [10].

3.2. Designing steps for a typical distillation column
- Calculation of minimum number of stages, N_{min}
- Calculation of minimum Reflux Ratio R_m.
- Calculation of actual Reflux Ratio.
- Calculation of a theoretical number of stages.
- Calculation of an actual number of stages.
- Calculation of diameter of the column.
- Check for weeping.
- Check for entrainment.
- Calculation of pressure drop.
- Calculation of height of the column.
- Calculation of column efficiency.
- Calculation of heat (Energy) requirement.

The distillation column is designed for a particular flow rate of the wastewater stream using the standard design equation and different charts for various parameters [6].

4. Results and Discussion

In a pharmaceutical plant, ethanol is used as a solvent for the basic processing step. Excess ethanol along with water is generated as an effluent stream. Ethanol from the effluent stream is to be recovered in a solvent recovery plant. The distillation column is designed for the following effluent stream condition. The design conditions can be modified for any other scale-up/scale-down requirements. For the below feed condition, the two types of distillation columns are designed using standard design procedures and suitable assumptions.

The flow rate of the waste stream generated,

F		= 50000 kg/h
Pressure (P)		= 2 kg/cm^{2}g
Temperature (T)		= 40°C
Composition is	x_F	= Ethanol in the waste stream 40 mole%
		= Water in the waste stream is 60 mole %
	x_D	= Ethanol in distillate (required composition)

The objective of the recovery is to have a minimum 80 mole % concentration (x_D) of ethanol in the n distillate. The ethanol concentration in the wastewater shall be as minimum as possible.

Physical properties

Table 1: Physical properties of ethanol and water [12].

Property	Ethanol	Water
Molecular weight, kg/kmol	46.07	18.016
Latent heat, kJ/kmol	90523	39718
Specific heat, kJ/kg°K	2.59	4.179
Boiling point, °C (K)	78.4 (351.4)	100 (373)

4.1. Design calculation

4.1.1. Molar flow rate of the feed to the column

Average molecular weight,

$$M_{avg} = (0.4 \times 46.07) + (0.6 \times 18.016)$$
$$M_{avg} = 29.2376 \text{ kg/kmol}$$

Feed molar flow rate,

$$F = 50000 / M_{avg}$$
$$F = 50000/29.2376$$
$$F = 1710.126 \text{ kmol/h}$$

4.1.2. Material balance of the distillation column

Overall material balance

$$F = D + W$$
$$1710.126 = D + W$$

Component material balance for ethanol,

$$F \times x_F \quad = (D \times x_D) + (W \times x_W)$$
$$1710.126 \times 0.4 = (D \times 0.8) + (1710.126 - D)\, x_W$$
$$684.0504 \quad = 0.8\ D + x_W\ (1710.126 - D)$$

Consider the mole% of ethanol in the residue as 2 mole%
$$x_W \qquad\qquad = 0.02$$
Solve the material balance equation for D
$$D \qquad\qquad = 833.138 \text{ kmol/h}$$
Solve for W,
$$W \qquad\qquad = 1710.126 - 833.138$$
$$W \qquad\qquad = 876.988 \text{ kmol/h}$$

4.1.3. Calculate the feed line 'q' value using the feed temperature.

The boiling point of Ethanol	$= 78.4°C = 351.4°K$
The boiling point of Water	$= 100°C = 373°K$

The average boiling point of feed, $T_b = 364.36$ K
Feed temperature, T_f $\qquad = 313$ K
Molar latent heat of feed, $\qquad = 60040$ kJ/kmol
Molar-specific heat of feed $\qquad = 3.5434$ kJ/kmol K

$$q = [Cp\,(T_b - T_f) + \lambda\,] / \lambda \quad [9]$$
$$q = [3.5434(364.36 - 313) + 60040] / 60040$$

$q = 1$, so the feed is a saturated liquid, which is at the bubble point.

4.1.4. Equilibrium Data

An empirical model for the non-ideal solution, [13]
$$y = [ax / (1+ (a - 1)\, x)] + bx\,(1 - x)$$

Table 2: Values for the Empirical Equation [12].

More Volatile Component	Less Volatile Component	a	b
Ethanol (78.4°C)	Water (100.0°C)	9.50	-1.00

Table 3: Relative volatility [12].

x_1	y_1	K_1	K_2	$\alpha = K_1 / K_2$
0	0	0	1	0
0.1	0.4235	4.235	0.6406	6.612
0.2	0.5437	2.7185	0.5704	4.766
0.3	0.5928	1.976	0.5817	3.397
0.4	0.6236	1.559	0.6273	2.485
0.5	0.6548	1.3096	0.6904	1.897
0.6	0.6944	1.1573	0.764	1.515
0.7	0.7468	1.0669	0.844	1.264
0.8	0.8144	1.018	0.928	1.097
0.9	0.8984	0.9982	1.016	0.983
1.0	1.0	1.0	-	-

Average relative volatility, $\alpha_{avg} = 2.67$
The equilibrium x-y data using the relative volatility,
$$y = \alpha x / (1 + (\alpha-1)\, x) \quad [9].$$

Table 4: Vapor Liquid equilibrium (x-y) data.

x	y
0.1	0.230
0.2	0.430
0.3	0.536
0.4	0.643
0.5	0.730
0.6	0.802
0.7	0.863
0.8	0.915
0.9	0.960
1.0	1.0

4.1.5. Reflux ratio

R_{min} is found to be 0.66 with c = 0.48. Thus, the three different R values are taken as follows,

Table 5: Different reflux ratio (R) values.

S. No	c intercept	Reflux ratio
1	0.26	2.07
2	0.162	3.94
3	0.36	1.22

Assuming the three different reflux ratios, we have taken R = 3.94 as the suitable reflux ratio for design. Since we get a minimum number of stages with suitable efficiency. The intercept of the operating line of the rectifying section on the y-axis,

$$R = 3.94$$
$$c = x_D / (R + 1)$$
$$c = 0.162$$

4.2. Plate type distillation column calculation

4.2.1. Number of theoretical plates

The minimum number of theoretical plates required was determined using the McCabe-Thiele graphical method and found to be 6.
$$N_{m + 1} = 7$$
$$N_m = 6$$

4.2.2. Vapor flow rate

$$V = V' + (1 - q)\ F$$
Where,
$\qquad$ V = vapor flow in rectifying section
$\qquad$ V' = vapor flow in stripping section
$\quad$ Since q = 1,
$$V \qquad = \qquad V'$$
At the top of the column, we have
$$V \qquad = L + D$$
$$V/D \qquad = L/D + 1$$
$$V \qquad = (R + 1)\ D$$
Substitute R = 3.94 and D = 833.138 kmol/h

Thus,

V	= 4115.42 kmol/h	
V	= 4115.42 kmol/h	= V'

4.2.3. Heat balance of the distillation column

$Q_B + H_F = Q_C + H_D + H_W$
Where,
H_W = Enthalpy of bottom product in kcal/h
Q_B = Heat supplied by steam in kcal/h
H_F = Enthalpy of feed in kcal/h
H_D = Enthalpy of distillate in kcal/h
Q_C = Heat removed by cooling water in kcal/h
H_D & H_F can be neglected since both are at base temperature.
H_W = m × C_P × ΔT
     = 4115.42 × 4.179 × 373
     = 6414980.887 × 18.58
     = 119.16 x 10^6 kJ/h
H_W = 28.48 x 10^6 kcal/h
Q_C = (m × C_P × ΔT) + (m × λ)
     = (4115.42 × 2.59 × 351.4 × 40.46) + (4115.42 × 80362)
     = 482.26 kJ/h
Q_C = 115.26 x 10^6 kcal/h
Q_B = Q_C + H_W
Q_B = 143.75 x 10^6 kcal/h

4.2.4. Overall tray efficiency

E = 51 – 32.5 [log (α x μ)] [9]
The average temperature of the column = 40°C
Viscosity values from [12]
$μ_{avg}$ = (0.6 × 0.6529) + (0.4 × 0.834)
     = 0.72534 cP
     = 0.72534 mN/m^2
E = 51 – 32.5 [log (0.72534 × 2.67)]
E = 41.67 %

4.2.5. Actual number of trays

Actual trays = $\frac{\text{no of theoritical trays}}{\text{plate efficiency}}$ x 100
           = $\frac{6}{41.67}$ x 100
           = 14. 398
Actual trays = 14 trays

4.2.6. Value of L and V

To find the L, we can use the following relation,
R = $\frac{L}{D}$
As assumed, R = 3.94
L = 3.94 × 833.138
  = 3282.56 kmol/h
  = 3282.56 × 29.2376
  = 95974.28 kg/h
V = 4115.42 × 29.2376
  = 120325.00 kg/h

4.2.7. Flow parameter

$F_{LV} = \frac{L_{mass}}{V_{mass}} \sqrt{\frac{\rho_V}{\rho_L}}$

= 0.0682
Assuming tray spacing to be 0.6 m

$V_{nf} = C_{Fair} [\frac{\sigma}{20}] \sqrt{\frac{\rho_L - \rho_V}{\rho_V}}$

Use the below chart to find the C_{Fair} or K_1

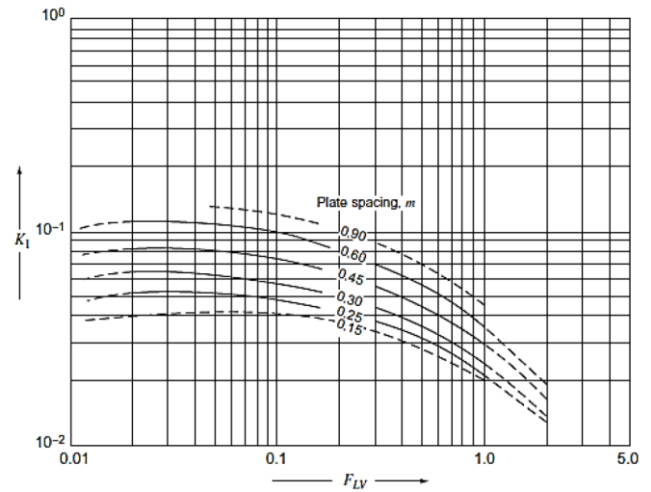**Figure 3:** K_1 vs F_{LV} chart [9].

K_1 = C_{Fair} = 0.11 from the chart.
Thus,
V_{nf} = 1.60 m/s

4.2.8. Actual velocity

Assumptions
Flooding velocity = 60 % - 80 % (Assumed as 80%)
Down comer area = 12 % (usually)

V_n = 0.8 × V_{nf}
     = 1.28 m/s
A_n = m_v / V_n
     = 0.935 m^2
A_c = A_n + A_d
Taking the down comer area value as 12 %
A_d = 12 % of A_c
     = 0.12 A_c

4.2.9. Column Diameter

A_c = A_n + 0.12 A_c
A_c = 1.0625 m^2
D = $\sqrt{\frac{A \times 4}{\pi}}$

= $\sqrt{\frac{1.0625 \times 4}{\pi}}$

D = 1.163 m

4.2.10. Column height

H = [(N – 1) + 2] × plate spacing [9]
For spacing = 0.6 m,
  = [(14 – 1) + 2] × 0.6
H = 9 m

4.2.11. Other design parameters

Liquid flow rate in m^3/s = 0.0411 m^3/s

A_d	= $0.12 \times A_C$	= 0.1275 m^2
A_a	= $A_C - 2 A_d$	= 0.8075 m^2
A_n	= $A_C - A_d$	= 0.9350 m^2

- **Weir length (l_w)**

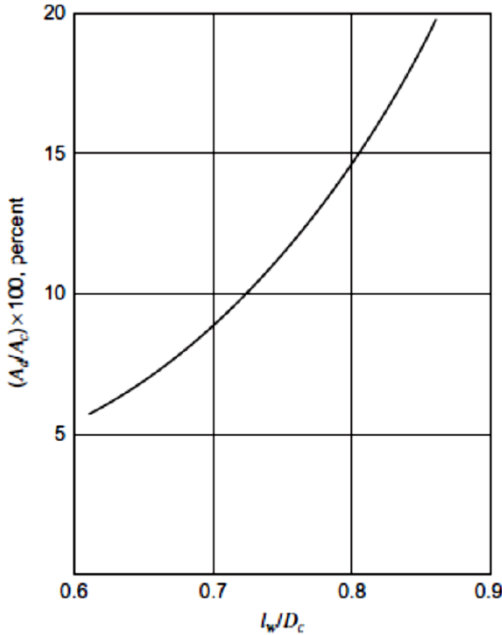$(A_d / A_C) \times 100 = 12\%$, using the below chart, find $l_w/D_c = 0.76$

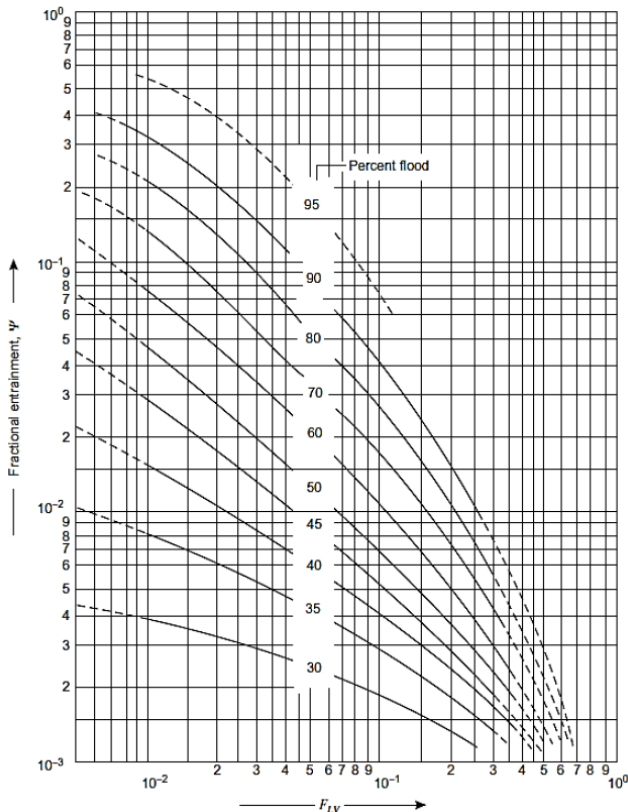**Figure 4:** Relation between downcomer area and weir length [9].

Figure 5: Entrainment correlation [9].

l_W = 0.88388 m
F_{LV} = 0.0682,

the fractional entrainment (Ψ) can be read from the below chart and found to be

Ψ = 0.04 < 0.1

So, there is **NO entrainment** in the distillation column which is a satisfactory design.

- **Hole diameter** = plate spacing / 100
   = 6 mm
- **Area of one hole** = $(\pi \times D^2) / 4$
   = 2.827 x 10^{-5} m^2
- **Active area** = $A_C - 2A_d$
   = 0.8075 m^2
- **Area of hole** = 10 % of A_a
   = 0.08075 m^2
- **No. of holes** = Total hole area / single hole area
   = 2856
- **Check for weeping:** The distillation column has to be checked for weeping, which is very critical in the operation.

The vapor volumetric flow rate = 4115.42 kmol/h
The vapor flow rate in m^3/s = 1.239 m^3/s
Assume the turndown ratio = 90%
Actual minimum vapor velocity $= \dfrac{1.239 \times 0.9}{0.08075(Ah)}$
= 13.80 m/s
Assume height of weir (h_w) = 50 mm
Height over weir (h_{ow}) $= 750[\dfrac{L_w}{\rho_v \times l_w}]^{2/3}$
= 9.604 mm
Minimum Height over weir (h_{ow}) = 9.604 x 0.9
= 8.64 mm
$h_w + h_{ow}$ = 58.64 mm
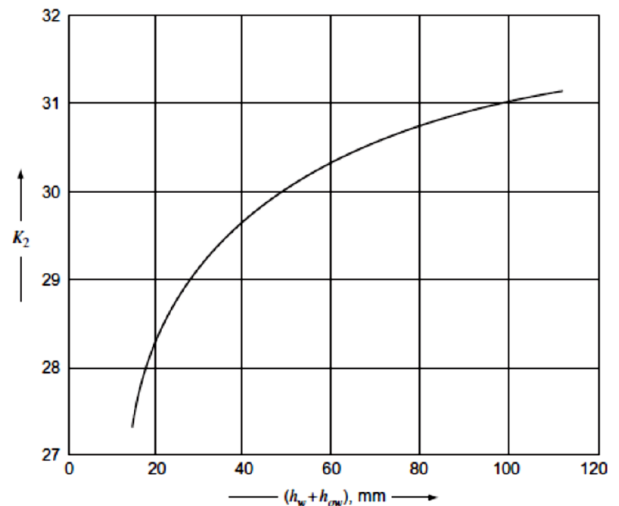K_2 from the below chart = 30.3

Figure 6: Weep point correlation [9].

Minimum design vapor velocity u_h
$= \dfrac{[k2 - 0.9(25.4 - dh)]}{\rho 1/2} = \dfrac{[30.3 - 0.9(25.4 - 6)]}{3.1^{1/2}}$ = 7.29 m/s
Actual minimum vapor velocity > Minimum design vapor velocity (u_h)
So, **NO weeping** in the distillation column is very desirable.

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4.3. Packed bed distillation calculation

4.3.1. Basic data

Table 6: Type of packing material [12]

Type	Material	Size	Packing factor
Rasching rings	Ceramic	2-inch	65

Moderate to high-pressure distillation,

$\Delta P/L$ = 32 to 63 mm of water/m packing
= 0.7 to 1.5 in water/ft packing

So, we choose, 125 mm of water/m packing as our packing size is 2 inch

C = 10.764
F = Packing factor = 65
V = Kinematic viscosity = 0.658 cS
ρ_V = Vapor density = 3.1 Kg/m^3
ρ_L = Liquid density = 958.38 Kg/m^3
R = Reflux ratio = 3.94

4.3.2. Flow rates

Liquid flow rate, G_L = $R \times D$
= 3.94×833.138
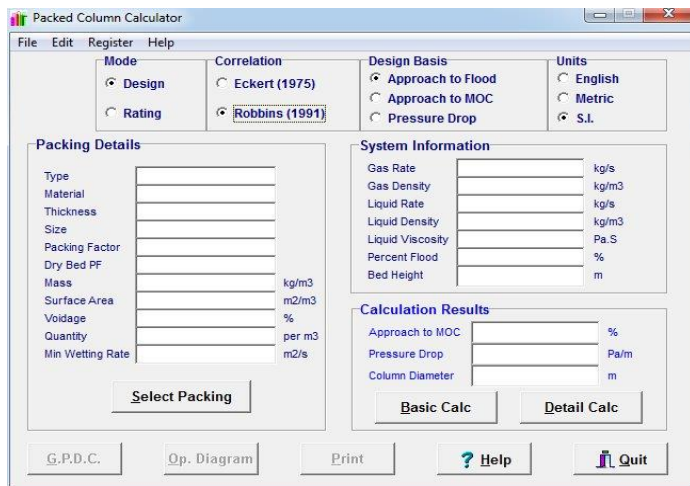= 3282.56 kmol/h
= 60989.96 kg/h

Vapor flow rate, G_V = $G_L + D$
= 4115.42 kmol/h
= 166468.7 kg/h

q = 1

4.3.3. Column diameter

Choose any simulation software to find the column diameter by entering different operational variables. The sample calculation is shown in the below software screen shots.
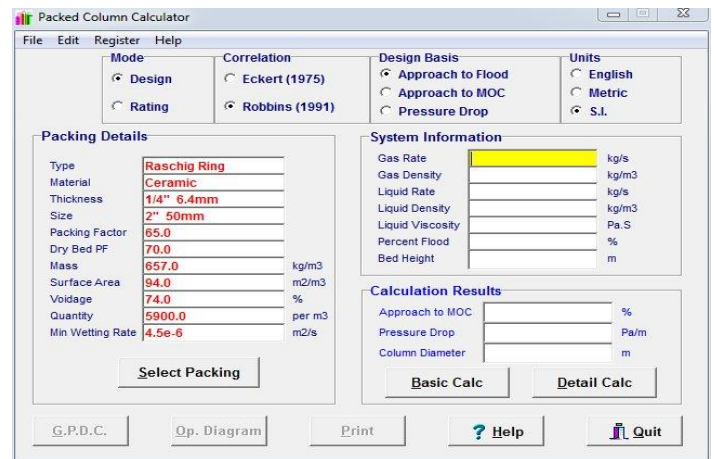
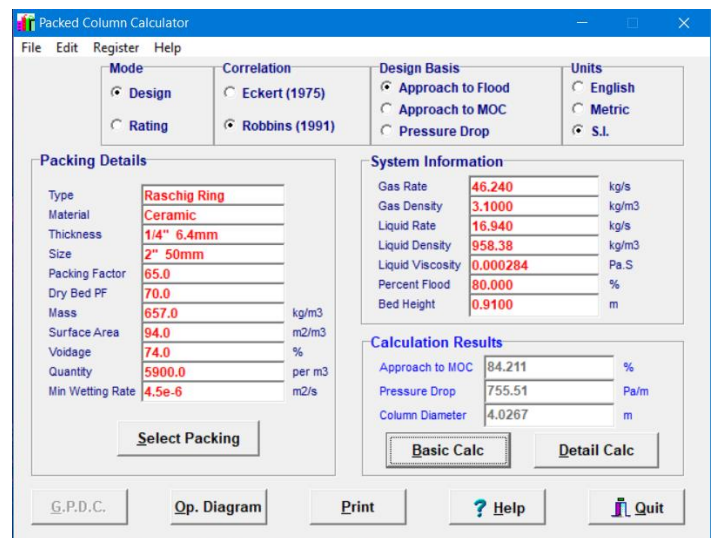Step 1: Select the mode, correlations, design basis, and units.

Step 2: Enter the packing details.

Step 3: The values for selected packing material are automatically uploaded.

Step 4: Enter the values of system information from the above calculations to obtain the pressure drop and column diameter.

Step 5: Other design calculations are listed below.

Detailed Calculations

Minimum Liquid Rate for Wetting	5.16	kg/s
Actual Liquid Flow as % of Minimum	328.1	%
Column Cross Sectional Area	12.73	m2
Gas Superficial Velocity	1.171	m/s
Liquid Superficial Velocity	0.00139	m/s
Flooding Pressure Drop	1746.5	Pa/m
Total Pressure Drop	687.5	Pa
Bed Volume	11.59	m3
Bed Mass - Dry	7613.7	kg
Bed Mass - Full of Liquid	15832.3	kg
Bed Mass - Full of Water	16189.2	kg
Total Bed Surface Area	1089.3	m2
Total Number of Packing Pieces	68373	#

Close

4.3.4. Column height

Table 7: HETP values based on packing size [9].

SETUP		HETP expressed as ft (meters)
Method	Packing Size (in)	
Distillation	1.0	1.5 (0.46)
	1.5	2.2 (0.67)
	2.0	3.0 (0.91)
Vacuum Distillation	1.5	2.7 (0.82)
	2.0	3.5 (1.06)

From the above table,
For 2-inch packing, HETP is $= 0.91$ m
Number of ideal stages for plate column $= 14$
Tower height $= \text{HETP} \times \text{No. of ideal stages}$

$$= 12.74 \text{ m}$$

4.3.5. Maximum design vapor velocity
$U_V = 0.035 \, (\rho_L / \rho_V)^{0.5}$
$= 0.61$ m/s

4.3.6. Vapor volumetric flow rate
Q_V = vapor flow rate / $(\rho_V \times 3600)$
$= 14.91$ m^3/s

4.3.7. Vessel area
$A_V = Q_V / U_V$
$= 24.4$ m^2

4.3.8. Liquid Volumetric Flow rate
Q_L = liquid flow rate / $(3600 \times \rho_L)$
$= 0.0176$ m^3/s

4.3.9. Volume for 10 minutes liquid hold up
$V_{10} = Q_L \times 600$
$= 10.60$ m^3

4.3.10. Liquid depth
$L_d = V_{10} / A_V$
$= 0.4344$ m

4.3.11. Condenser Heat duty

Overhead product contains 80 % ethanol and 20 % water (molar basis)
Mean latent heat of condensation of overhead product vapor
$= \Sigma \, x_i \lambda_i$
$= (0.2 \times 39718) + (0.8 \times 90523)$
$\lambda_D = 80362$ kJ/kmol

Since q = 1, the overhead product is a saturated liquid, so only the latent heat is removed in the condenser.
Heat load in condenser $= V \times \lambda_D$
Where,
V = vapor flow to condenser
= 4115.42 kmol/h
λ_D = mean latent heat of the overhead vapor
= 80362 kJ / kmol
Heat load in the condenser = Heat removed in the condenser
$= V \times \lambda_D$
$= 4115.42 \times 80362$
$= 330.7 \times 10^6$ kJ/h
Heat load in the condenser is to be expressed as kJ per kmol of overhead product
Heat load in condenser per kmol of overhead product
$= 330723382 / 833.138$
$= 396961.1061$ kJ/kmol

4.3.12. Reboiler heat duty

The bottom product contains 2 mole % of ethanol and 98 mole % water.
Mean latent heat of vaporization of the bottom liquid
$= \Sigma \, x_i \lambda_i$
$= (0.02 \times 90523) + (0.98 \times 39718)$
$\lambda_B = 40734.1$ kJ/kmol
V' = vapor flow from Reboiler
= 4115.42 kmol/h
The heat load of the Reboiler
$= V' \times \lambda_B$
$= 4115.42 \times 40734.1$
$= 167.6 \times 10^6$ kJ/h
Heat load of Reboiler per kmol of bottom product
$= 167637929.8 / 876.988$
$= 191151.9$ kJ/kmol

4.4. Design summary

All the above-found values for the column dimensions and various other parameters in the design calculation are being summarized in a tabulated form for better understanding as follows.

Table 8: Summary of Material Balance and Heat Loads.

Specification	Values	Unit
Distillate	833.138	kmol/h
Residue	876.988	kmol/h
Heat load in the condenser, Q_C	115.26×10^6	kcal/h
Heat load in reboiler, Q_B	143.75×10^6	kcal/h

Table 9: Design summary of the plate distillation column.

Specification	Values	Unit
Number of theoretical plates, N_m	6	No unit
Overall tray efficiency, E	41.67	%
Vapor flow rate, V	4115.42	kmol/h
Flow Parameter, F_{LV}	0.0682	No unit
Flooding velocity, V_{nf}	1.60	m/s
Actual velocity, V_n	1.28	m/s
Net area, A_n	0.935	m^2
Column area, A_c	1.0625	m^2
Diameter of the column., D	1.163	m
Column height, H	9	m
Plate spacing, l_t	0.6	m
Liquid flow rate, L	0.0411	m^3/s
Weir Length, l_W	0.88388	m
Hole Diameter, d_h	6	mm
Area of one Hole, A_{h1}	2.827×10^{-5}	m^2
Area of Hole, A_h	0.08075	m^2
No. of Holes, n_h	2856	No unit
Minimum design vapor velocity, u_h	7.29	m/s

Table 10: Design summary of the packed distillation column.

Specification	Values	Unit
Number of ideal stages, N	14	No unit
Liquid flow rate, G_L	60989.96	kg/h
Vapor flow rate, G_V	166468.7	kg/h
Diameter of the column, D	4.02	m
Column height, H	12.74	m
Maximum design vapor velocity, U_V	0.61	m/s
Vapor Volumetric flow rate, Q_V	14.91	m^3/s
Vessel area, A_V	24.4	m^2
Liquid Volumetric Flow rate, Q_L	0.0176	m^3/s
Volume for 10 minutes hold up, V_{10}	10.60	m^3
Liquid depth, L_d	0.4344	m

5. Conclusion

The basic operations of the two types of distillation columns namely plate type and packed type have been studied briefly. The pharmaceutical plant is processing different types of drugs, antibiotics, tablets, syrups, and other medical-related products. Ethyl alcohol (ethanol) is one of the common chemical solvents in a pharmaceutical plant. The major objective of this study is to recover the ethanol from the ethanol-water effluent wastewater stream. For 50000 kg/h of the effluent discharge, both types of distillations were designed. The plate column efficiency is very low (< 45%), so a very large number of trays are required to increase the efficiency, which is highly expensive in terms of fabrication cost. The design values are compared between the two columns and seem almost similar or better for the packed column. The Packed column is less expensive when compared to the plate type column as we have chosen the Ceramic Rasching rings of 2-inch (50 mm) size which do not cost much and could even be recycled after use. The packed column does not require many column internals when compared to the plate column. In order to recover the ethanol from the pharmaceutical plant, using the packed column is recommended.

Conflict of interest

The authors declare that they have no conflicts of interest.

References

[1]   K.A. Gavhane. (2004). Unit operations – II (Heat & Mass Transfer), 18th ed, Nirali Prakashan publisher, Pune, India.

[2]   R. Kumar, and Y.C. Tripathi. (2011). Getting fragrance from plants, Training Manual on Extraction Technology of Natural Dyes & Aroma Therapy and Cultivation Value Addition of Medicinal Plants.

[3]   W.L. McCabe, J.C. Smith, and P. Harriott. (2004). Unit Operations of Chemical Engineering, 5th Edition, McGraw-Hill publisher, USA.

[4]   A.S. Foust et al. (2008). Principles of Unit Operations. 2nd Edition, John Wiley & Sons publications, USA. pp. 13-14.

[5]   P.P. Panja. https://whatispiping.com/plate-tower-vs-packed-tower/.

[6]   N. Anantharaman and K.M. Meera. (2011). Mass Transfer Theory and Practice, 1st ed, PHI learning private limited.

[7]   R.E. Treybal. (1980). Mass Transfer Operations, 3rd Ed, McGraw Hill Book Company, USA.

[8]   P.C. Wanket. (2011). Separation Process Engineering, 3rd Ed, Prentice Hall, USA.

[9]   J.M. Coulson and J.F. Richardson. (2005). Chemical Engineering Design Volume 6, New Ed of 5 Revised Ed, Butterworth-Heinemann Ltd, UK.

[10]   Boardman Inc. (2011). Column internals, Volume 32, ASME Pressure vessel.

[11]   J. Seader, and E. Henley. (2010). Separation Process Principles, 3rd Ed, Chapter 7, John Wiley & Sons, USA.

[12]   R.H. Perry. (2007). Perry's Chemical Engineering Handbook, 8th Ed, McGraw Hill professional, USA.

[13]   M.F. Doherty & M.F. Malone. (2001). Conceptual Design of Distillation Systems, 1st Ed, pp.41, McGraw Hill professional, USA.

[14]   NEA, National Environmental Agency. (2008). Environmental Protection and Management (Trade Effluent) Regulations, Environmental Protection and Management Act, Chapter 94A, Section 77.

[15]   Metcalf & Eddy. (2013). Wastewater Engineering: Treatment and resource recovery, 5th Ed, McGraw-Hill publisher, USA.

[16]   A.D. Patwardhan. (2009). Industrial waste water treatment, 1st Ed, Prentice Hall of India.