Design of extraction column & distillation unit: coupled with advanced separation technologies

Internship

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In

Chemical Engineering

Submitted By

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UNDER THE SUPERVISION AND GUIDANCE OF

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January – May 2025

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Place: Gwalior

This is to certify that the above statement made by the candidates is correct to the best of my knowledge and belief.

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ABSTRACT

Efficient operation in chemical and process industries relies heavily on the proper design of extraction columns and heat exchangers. Extraction columns facilitate the separation of components through liquid-liquid extraction, where effectiveness is influenced by factors such as the type of column used, flow rates of the phases, the area where the two liquids contact, and the rate of mass transfer. Selecting between packed, tray, or agitated columns depends on the fluids' properties and the required separation outcome. Heat exchangers are essential for transferring heat between fluids, with their design influenced by temperature differences, flow patterns, heat transfer efficiency, and compatibility of materials. Properly engineered heat exchangers improve energy efficiency and ensure stable temperature control within processes. Beyond traditional equipment, industries are adopting innovative separation methods to boost performance and reduce energy use. Pressure Swing Adsorption (LIKE PRESSURE SWING ADSORPTION) is a gas separation technique that uses differences in adsorption at various pressures to isolate specific gases, commonly applied in hydrogen purification, oxygen production, and carbon dioxide capture due to its precision and energy savings. Another innovative method, the Reactive Bubble Process (RBP), combines chemical reactions with gas-liquid contact inside bubbling systems, allowing simultaneous reaction and separation. Advancements in separation technologies have introduced methods like Pressure Swing Adsorption (LIKE PRESSURE SWING ADSORPTION) and Rotating Packed Beds (RPBs) to enhance efficiency and sustainability. LIKE PRESSURE SWING ADSORPTION operates on the principle that certain gases are more readily adsorbed onto solid materials at high pressures and released at lower pressures. RPBs, also known as HiGee contactors, enhance mass transfer by spinning packing material at high speeds, generating strong centrifugal forces. This creates thin liquid films and increases the contact area between phases, boosting mass transfer efficiency. RPBs are particularly effective in separating azeotropic mixtures, such as IPA and water, which are challenging for conventional distillation. By integrating RPBs with techniques like azeotropic or extractive distillation, separation efficiency is significantly improved. In azeotropic distillation, an entrainer is added to alter the boiling characteristics of the mixture, facilitating separation. The RPB intensifies mass transfer, allowing for more compact and efficient separation units. Similarly.

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Efficient operation in chemical and process industries relies heavily on the proper design of extraction columns and heat exchangers. Extraction columns facilitate the separation of components through liquid-liquid extraction, where effectiveness is influenced by factors such as the type of column used, flow rates of the phases, the area where the two liquids contact, and the rate of mass transfer. Selecting between packed, tray, or agitated columns depends on the fluids' properties and the required separation outcome. Heat exchangers are essential for transferring heat between fluids, with their design influenced by temperature differences, flow patterns, heat transfer efficiency, and compatibility of materials. Properly engineered heat exchangers improve energy efficiency and ensure stable temperature control within processes. Beyond traditional equipment, industries are adopting innovative separation methods to boost performance and reduce energy use. Pressure Swing Adsorption (LIKE PRESSURE SWING ADSORPTION) is a gas separation technique that uses differences in adsorption at various pressures to isolate specific gases, commonly applied in hydrogen purification, oxygen production, and carbon dioxide capture due to its precision and energy savings. Another innovative method, the Reactive Bubble Process (RBP), combines chemical reactions with gas-liquid contact inside bubbling systems, allowing simultaneous reaction and separation. This integration enhances mass transfer, reduces equipment size, and intensifies processes. Assessing these advanced methods involves examining separation efficiency, cost-effectiveness, scalability, and how well they can be integrated with existing technology. This work focuses on exploring the design principles of extraction columns and heat exchangers, alongside evaluating LIKE PRESSURE SWING ADSORPTION and RBP techniques, highlighting their potential to create more efficient, compact, and sustainable chemical processing solutions.

1.1 Extraction Column

Efficient operation in chemical and process industries hinges on the optimal design of extraction columns and heat exchangers. Extraction columns, pivotal in liquid-liquid extraction, separate components based on their solubility in two immiscible liquids, typically water and an organic solvent. The choice between packed, tray, or agitated columns depends on fluid properties and desired separation outcomes. Packed columns, filled with structured or random packing materials, enhance surface area for mass transfer. Tray columns utilize perforated plates to facilitate phase contact, while agitated columns employ mechanical mixing to improve dispersion. Key design considerations include flow rates, contact area, and mass transfer efficiency.

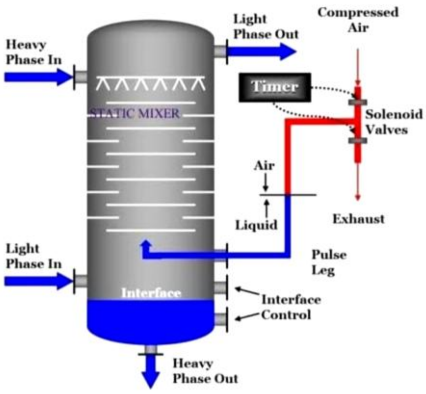

Figure 1.1: Pictorial View of Extraction Column

1.2 Advanced Separation Techniques

1.2.1 Pressure swing adsorption (LIKE PRESSURE SWING ADSORPTION)

Advancements in separation technologies have introduced methods like Pressure Swing Adsorption and Rotating Packed Beds (RPBs) to enhance efficiency and sustainability. LIKE operates on the principle that certain gases are more readily adsorbed onto solid materials at high pressures and released at lower pressures. By cycling the pressure, like systems can selectively capture and release specific gases. This technique is widely used for gas separations, including hydrogen purification and oxygen production. For instance, in separating isopropyl alcohol (IPA) from water, can selectively adsorb water using molecular sieves, producing high-purity IPA. The process involves adsorption at elevated pressures and temperatures, followed by regeneration through pressure reduction or heating. A dual-column setup allows continuous operation, with one column adsorbing while the other regenerates.

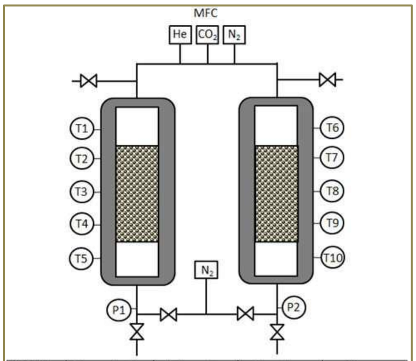

Figure 1.2.1: PSA

1.2.2. Rotating Packed Bed (RBPs)

RPBs, also known as HiGee contactors, enhance mass transfer by spinning packing material at high speeds, generating strong centrifugal forces. This creates thin liquid films and increases the contact area between phases, boosting mass transfer efficiency. RPBs are particularly effective in separating azeotropic mixtures, such as IPA and water, which are challenging for conventional distillation. By integrating RPBs with techniques like azeotropic or extractive distillation, separation efficiency is significantly improved. In azeotropic distillation, an entrainer is added to alter the boiling characteristics of the mixture, facilitating separation. The RPB intensifies mass transfer, allowing for more compact and efficient separation units. Similarly, in extractive distillation, a high-boiling solvent is introduced to change the relative volatilities of components, and the RPB enhances the separation by providing high mass transfer rates.

In conclusion, the integration of advanced separation techniques like LIKE and RPBs with traditional equipment such as extraction columns and heat exchangers offers significant improvements in efficiency, compactness, and sustainability in chemical processing. These innovations address the limitations of conventional methods, enabling more effective separation processes and energy savings.

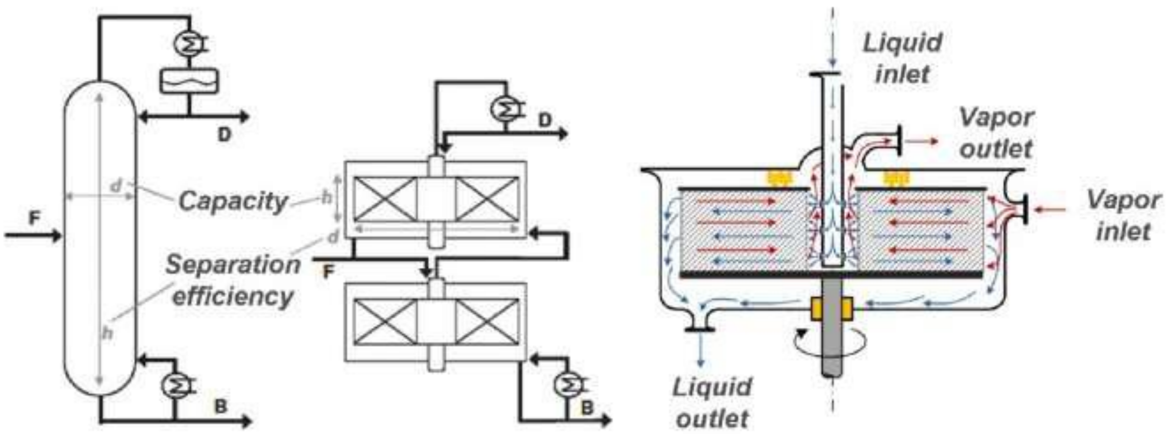

Figure 1.2.2: RBPs

CHAPTER 2: LITERATURE SURVEY

Separation processes are fundamental to chemical engineering, as they allow the isolation and purification of desired components from complex mixtures. These operations are crucial not only for improving product quality and operational efficiency but also for enhancing the sustainability of industrial processes.[1] Among the numerous separation units used in practice, extraction columns and heat exchangers are particularly significant due to their roles in mass and energy transfer. Extraction columns enable liquid-liquid separations by allowing selective solute transfer between two immiscible or partially miscible liquids.[2] The design of these columns depends on the selection of appropriate equipment types such as packed, pulsed, or centrifugal columns—and the optimization of operational factors like flow rates, residence time, and column geometry.[3] Modern improvements in extraction technologies include the use of structured packings and computational fluid dynamics (CFD) simulations. These advancements enable engineers to predict fluid behavior more accurately, leading to better efficiency before full-scale deployment.[4] However, these technologies can be computationally intensive and require skilled interpretation. For example, Pressure Swing Adsorption is a widely used technique for gas separation, leveraging pressure variation to cycle between adsorption and desorption phases.[5] While systems are energy-efficient and scalable, their performance is constrained by the quality of the adsorbent material and operational tuning. Meanwhile, membrane separation technologies offer an alternative approach, relying on selective permeability for component separation.[6] Advances in membrane materials, including mixed-matrix and nanocomposite layers, have expanded their use in processes such as solvent recovery and gas purification. A drawback of membrane systems, however, is their sensitivity to fouling and degradation over time.[7] Rotating Packed Beds (RPBs) are gaining attention for their ability to enhance mass transfer through the application of centrifugal force. This results in improved separation efficiency, especially in difficult tasks like azeotrope breaking.[8] Despite their promise, RPBs face issues related to mechanical complexity, scale-up, and material stability.[9] Reactive separation processes where chemical reactions and separations occur simultaneously are another area of interest, offering reduced equipment footprint and improved energy efficiency. However, designing such hybrid systems requires careful consideration of reaction kinetics and catalyst placement.[10]

CHAPTER 3: COMPANY PROFILE

At Myriadly Engineering & Business Solutions Pvt. Ltd., we take pride in offering highly specialized engineering and business solutions tailored for the Chemical and Pharmaceutical industries. Since our establishment, our fundamental principle has been to deliver reliable, efficient, and client-focused solutions designed to enhance operational performance and productivity in industrial environments.

We specialize in designing and manufacturing customized engineering products and systems that align with the unique requirements of our clients. Every product we deliver is crafted with precision and care, ensuring it meets both Indian and International quality benchmarks. Our approach is rooted in flexibility—enabling us to provide tailored solutions that integrate seamlessly with existing systems and deliver measurable value to our clients' operations.

Over the past four years, our organization has witnessed consistent growth, driven by the trust and positive response we've received from clients across India. Our progress is a reflection of our commitment to quality, innovation, and customer satisfaction. We remain focused on meeting and exceeding client expectations by constantly improving our products, services, and internal processes.

We follow a meticulous quality control process that encompasses every stage of production. From the selection of raw materials to the final inspection before dispatch, each product undergoes a series of rigorous tests to ensure high performance, durability, and reliability.

- **Raw Material Inspection:** The initial phase includes thorough evaluation of raw materials to verify that they meet predefined specifications. This step is critical to maintaining consistency in quality.
- **In-Process Inspection:** Throughout the manufacturing stages—be it molding, fabrication, machining, or galvanizing—continuous monitoring is carried out to minimize errors and reduce rejection rates. This ensures that the final product upholds the desired standards.
- **Pre-Dispatch Quality Check:** Before any product is shipped, a comprehensive inspection is conducted to verify proper assembly, fitment, and functionality. This step

guarantees that the end user receives a flawless product ready for immediate deployment.

Our company's mission is to offer cost-effective engineering solutions without compromising on quality or safety. We believe that excellence lies in the details, and every unit that leaves our facility reflects our dedication to craftsmanship and technological advancement.

Each product is developed with cutting-edge design principles and robust quality assurance protocols, ensuring they meet the complex demands of modern industrial applications.

At Myriadly Engineering & Business Solutions Pvt. Ltd., we are not just equipment manufacturers—we are solution providers. Our team of experts works closely with clients to understand their challenges and deliver results that not only meet expectations but often surpass them.

Our vision is to be recognized as a trusted partner in the engineering industry by consistently delivering world-class solutions with unmatched quality and value. We continue to build long-term relationships with our clients, guided by transparency, integrity, and a deep commitment to excellence.

CHAPTER 4: PROBLEM FORMULATION

Problem 1: Extraction columns are an important part of chemical process industries. Caffeine extraction is a well-known example. Design a column to obtain 99% purity of the extract for the provided parameters (Water in feed – 98.5%, Volumetric flow rate – 6m3/hr, Raffinate – 0.1% allowable, Caffeine in feed – 2.5%, equilibrium relation (Ye= 1.2* X r). Solvent flow rate is 3m3/hr. Include the following points in your design

To Calculate:

- No. of Ideal Stages.
- Height of column.
- Diameter of column.

a.) The quality of the extract cannot be compromised. b.) Would the proposed design be suitable for % x changes in parameters i.e. mention the assumptions used and limitations of the columns.

Problem 2: Distillation Design Problem:

Designing a separation system for a binary mixture of isopropyl alcohol (IPA) and water. The feed consists of 60% IPA and 40% water by weight, and is introduced at a rate of 2000 lt/hour. The target is to produce high-purity IPA containing 99.5% IPA and only 0.5% water. Consider the following separation techniques for this purpose:

Azeotropic distillation: (producing an 88% IPA + 12% water mixture)

- Pervaporation
- Pressure swing adsorption (PSA)
- Rotating bed distillation

CHAPTER 5: METHODOLOGY

5.1. Method for Extraction Column

5.1.1 Problem Identification and Representation:

- Begin by understanding the problem you need to solve.
- Draw the phase diagram to represent the components involved (solvent, extract, and raffinate).

5.1.2. Identify the Solvent and Extract Phases:

- Determine the solvent (S) and extract (E) phases.
- Read the problem carefully to identify the solute to be extracted.

5.1.3. Convert Fractions and Flow Rates to Solute-Free Basis:

- Express flow rates and fractions in terms of moles of solute per moles of other constituents.
- For example, use the ratio X = X / (1 - X), where X represents the moles of solute per moles of other constituents, and x is the mole fraction of solute.
- Define Fs as the solute-free feed rate and F as the total feed rate with solute.

5.1.4. Mode of Operation:

- Check if the mode of operation (e.g., counter-current) is specified.
- If not, use counter-current operation for maximum purity of the extract.

5.1.5. Material Balances:

- Apply general material balances across stages (F + S = E + R).
- Component balance: $F * X_r + S * Y_s = E * Y_e + R * X_r$
- For solute-free basis, F and R flow rates will be equal for each stage.

5.1.6. Equilibrium Relationship:

- Ensure that the equilibrium relationship is given between the extract and raffinate phases.

5.1.7. Pure Solvent Case:

- If the solvent is pure, the raffinate phase (Y_S) will be zero.

5.1.8. Calculate Minimum Number of Stages:

- Use the Kremser equation to regulate the minimum number of equilibrium stages required.

5.1.9. McAbe-Thiele Plot:

- Find the stages from the McCabe-Thiele plot.

.1.10. Efficiency of the Column:

- Determine the efficiency of the column for practical situations.

5.1.11. Actual Number of Stages:

- Calculate the actual number of stages using the theoretical plates and efficiency from literature.

5.1.12. Calculate Height of the Tower (Z):

- Z = HTU (Height Transfer Unit) * Number of actual stages.

5.1.13. Flooding Velocity:

- Find the flooding velocity for the given operation and select 60-65% of it.

.1.14. Then calculate net tower cross section area with the help density, mass flow rate and operating velocity.

5.1.15. Then find total tower area as An = 0.90At

5.1.16. Then further calculation will depend on the type of valve selected for the operation.

Bubble cap provides maximum pressure drop with very less weeping problem.

.1.17. Safety factor must also involved during designing.

5.2. Method for Distillation Column

5.2.1. Define Separation Targets

- Know the feed composition and flow rate.
- Set desired purities for distillate and bottom products.
- Record feed condition: temperature, pressure, and phase (e.g., saturated liquid/vapor).

5.2.2. Material Balances

- **Total balance:** F= D + B
- **Component balance:** $F*x_F=D*x_D + B*x_B$

Where:

x_F, x_D, x_B= Mole fractions in feed, distillate, and bottoms

5.2.3. Minimum Reflux Ratio (R_{min})

- Use Underwood's method or simplified formula:

$$R_{min}= (x_D - x_B) / (x_D - x_F)$$

5.2.4. Operating Reflux Ratio (RRR)

- Choose R=1.2 to 1.5 * R_{min}
- Higher R = fewer trays but more energy use

5.2.5. Theoretical Stages

- **Fenske Equation** (at total reflux):

$$N_{min}=\log \{(x_D (1-x_B) / x_B (1-x_D)\}/\log (\alpha_{avg.})$$

- Use Gilliland correlation to estimate actual stages.

5.2.6. Feed Stage Estimation

- Calculate thermal condition q:
  - q =1: saturated liquid
  - q = 0: saturated vapor

- Use McCabe-Thiele diagram for feed tray location.

5.2.7. Column Diameter

- Avoid flooding using **Souders–Brown Equation**:

$$V = K*\text{sqrt}\{a(\rho L-\rho V) / \rho V\}$$

- Calculate area and diameter:

$$A=V' / V,\ D = \text{sqrt}\{4A/\pi\}$$

5.2.8. Tray or Packing Design

- **Trays**: Determine spacing, downcomer area, weir height, and efficiency.
- **Packing**: Choose type and use HETP:

$$H=N\times HETP$$

5.2.9. Heat Duties

- **Reboiler duty**:

$$Q_R=D*\lambda_D + B*h_B - F*h_F$$

- **Condenser duty**:

$$Q_C = D_\lambda$$

5.2.10. Design Validation

- Check for:
  - Flooding, weeping, entrainment
  - Pressure drops
  - Structural aspects (material, wall thickness)

5.3. Solution 1: Given,

- Water – 97.5%
- Caffeine(feed) – 2.5%
- Volumetric flow rate – 3 m^3/hr
- Raffinate (R) – 1% (allowable)
- Molar mass of caffeine – 194.19
- Density (caffeine) – 1230 kg/m^3
- Density of water – 1000 kg/m^3
- Average density of feed – 1005.75 $kgm3$
  - Mass flow rate (m) = 3017.25 kg/hr
  - $M_{avg.}$ (feed) = 22.4047
  - Molar flow rate (M) = 134.670103 kmol/hr
  - X_f - 0.025
  - Mole of caffeine
- In feed – 3.366 kmol
- In extract – 3.33 kmol
- In raffinate – 0.0336 kmol
  - Water
- feed – 131.303 kmol
- In raffinate – 131.303 kmol
- X_r – 0.00025641
- Equilibrium relation Ye = 1.2* X_r
- Ye – 0.0003072

➢ Applying balance,

$$F + S = E + R$$

$$F*X_f + S*Y_s = E*Y_e + R*X_r$$

$$S = 10847.08 \text{ kmol/hr}$$

$$E = 10847.08 \text{ kmol/h}$$

➢ Mole fraction of caffeine

- In extract – 0.000307
- Mole fraction of $CHCL3$ – 0.9997

- ➢ Mole fraction of caffeine in raffinate – 0.00025634
- ➢ Mole fraction of water in raffinate – 0.9997

- ➢ Density(feed) = 1000 $kg/m3$
- ➢ Column design
  - No. of stages - 3 (by kremerser's equation)
  - Efficiency – 20% (given) (perforated plate column is used)
  - Actual no. of plates – 15
  - Height of Tower – 15m
  - Flooding Velocity – 0.5 m/s
  - Net area (An) – 0.5680 m^2
  - At – 0.6311 m^2
  - Diameter – 0.897 m

	A	B	C	D	E
1					
2	Parameter	Value		Unit	
3	Feed Flow Rate	6000		L/hr	
4	Feed Composition (Water)	98.55		%	
5	Feed Composition (Caffeine)	1.45		%	
6	Solvent Flow Rate	3000		L/hr	
7	Equilibrium Relationship	0			
8	2. Molecular Weight Calculations				
9	Molecular Weight (Caffeine)	194.2		g/mol	
10	Molecular Weight (Chloroform)	119.37		g/mol	
11	Molecular Weight (Water)	18.02		g/mol	
12	3. Density Values				
13	Density (Caffeine)		1230		kg/m³
14	Density (Water)		1000		kg/m³
15	Density (Chloroform)		1489		kg/m³
16	4. Average Density and Mass Flow Rate Calculation				
17	Avg. Density of Feed	1003.34		kg/m³	
18	Feed Volume	6		m³/hr	
19	Feed Mass Flow Rate	6020		kg/hr	
20	5. Moles Calculation				
21	Caffeine Mass	87.29		kg	
22	Caffeine Moles	449.45		mol/hr	
23	Water Mass	5932.71		kg	
24	Water Moles	329208.7		mol/hr	
25	Chloroform Volume	3		m³/hr	
26	Parameter	0		Unit	
27	Chloroform Mass	4467		kg/hr	
28	Chloroform Moles	37422.5		mol/hr	
29	6. Extract and Raffinate Phase				
30	Extract (E)	4554.29		kg/hr	
31	Raffinate (R)	5932.71		kg/hr	
32	7. Height of Transfer Unit (HTU)				
33	HTU		1.0		m
34	8. Number of Theoretical Stages				
35	Theoretical Stages (N)		4		stages
36	9. Plate Efficiency and Actual Number of Plates				
37	Plate Efficiency	0.7			
38	Actual Number of Plates	6		plates	
39	10. Column Height Calculation				
40	Column Height (H)	6.0		m	
41	11. Column Diameter Calculation				
42	Parameter	0		Unit	
43	Flow Rate (Q)	2.5		L/s	
44	Velocity (v)	0.3		m/s	
45	Area (A)	0.0083		m²	
46	Diameter (D)	0.103		m	
47	Design Diameter	0.15		m	
48	12. Extraction Products				
49	Product			Composition	
50	Extract Product			87.29 kg Caffeine + Chloroform	
51	Raffinate Product			Caffeine-free Water	
52					

Table 5.3.1: Excel Table

4.4. Solution 2:

Design distillation column

Density Of Water	1	kg/L
Avearge Feed Density	0.872	kg/L
Iso Propyl Alcohol	60%	1200
Water	40%	800
Assume For PSA Method		
Superficial Gar Velocity	0.3	m/s
Bed Void Fraction	0.4	
Cycle Time	5	
Absorbent capacity of water	0.25	
Bulk density of absorbent	700	kg/m^3

Given data		
Feed	2000	L/hr
Mass Flow Rate	1744	kg/hr
Mole Flow Rate	56166.53725	Mol/hr
Relative Volatility	2.5	
Mole Fraction XD	0.995	
Mole Fraction XW	0.005	
Distillated D	17046.88382	Mol/hr
Bottom W	39119.65343	Mol/hr

Components					
Iso Propyl Alcohol			Water		
Density	0.786	kg/L	Density	1	kg/L
Mass	1046.4	kg/hr	Mass	697.6	kg/hr
Mole Flow Rate	17410.98	Mol/hr	Mole Flow Rate	38755.56	Mol/hr
Mole Fraction	0.306989		Mole Fraction	0.690011	
Molecular weight	60.1		Molecular weight	18	

Parvaporation Method		
Minimum Reflux Ratio	#DIV/0!	
Actual Reflux Ratio	#DIV/0!	
Actual number of Trays	11.5	12
Height of Column	6	m
Area	0.00	m^2
Diameter	0.00	m

Pressure Swing Absorption		
Water feed absorption	800	L/min
Absorbent Needed	66.67	kg/cycle
Bed Volume	0.635	m^3
Mass of Adsorbent	266.7	kg
Vol. os Adsorbent	0.381	m^3
Height	2	m
Area	0.317460317	m^2
Diameter	0.635930851	m

Rotating Bed Distillation		
Minimum Reflux Ratio	1.60	
Actual Reflux Ratio	1.92	
Minimum number of Trays	10	Trays
Actual number of Trays	14	Trays
Height of Column	4.3	m
Diameter	0.3	m

Table 5.4.1: Excel Table

CHAPTER 6: RESULT & DISCUSSION

6.1. The caffeine extraction is an important example mass transfer operation. The problem is solved accurately without compromising the quality (strictly follow at 99%). The amount of solvent can be changed to maintain caffeine extraction up to 99% with different feed flow rates and in that case the number of stages required will be more. An equilibrium between the extract and raffinate phase must be maintained in each stage. Additionally, the solvent must be low viscous and partially miscible with the carrier, so attention must be paid to temperature variations during the process. An increase in temperature will increase the solubility of the solvent with the carrier liquid and the operation will become less economical since solvent recovery units in this case will keep more charge.

For the given problem following results obtained

- No. of stages obtained = 3
- Height of column = 15m
- Extraction of 99% of caffeine from feed

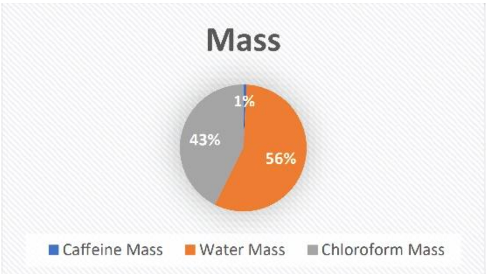

Figure 6.1.1: Extraction Mass Result

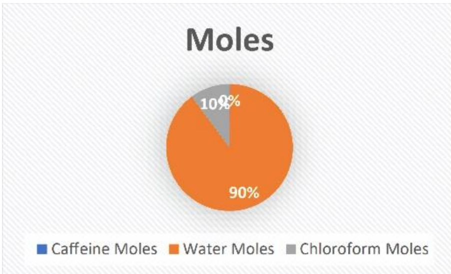

Figure 6.1.2: Extraction Moles Result

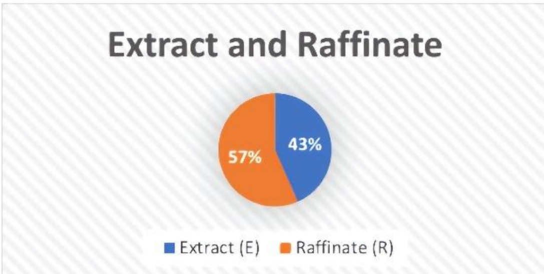

Figure 6.1.3: Extraction and Raffinate Result

6.2. Advanced separation methods such as Pressure Swing Adsorption and Rotating Packed Beds (RPBs) provide notable advantages in separating challenging azeotropic mixtures like isopropyl alcohol (IPA) and water. Conventional distillation is often inefficient for such systems due to azeotrope constraints that cap achievable purity levels. allows for the targeted removal of water by cycling pressure and utilizing selective adsorbents, thereby improving IPA recovery with lower thermal energy demands. Meanwhile, RPBs enhance vapor-liquid mass transfer by generating high centrifugal forces, resulting in faster, more compact, and energy-efficient separation. When combined, and RPBs offer a sustainable, economical, and highly efficient alternative for achieving high-purity separations in continuous operations.

Design distillation column

Density Of Water	1	kg/L
Avearge Feed Density	0.872	kg/L
Iso Propyl Alcohol	60%	1200
Water	40%	800
Assume For PSA Method		
Superficial Gar Velocity	0.3	m/s
Bed Void Fraction	0.4	
Cycle Time	5	
Absorbent capacity of water	0.25	
Bulk density of absorbent	700	kg/m^3

Given data		
Feed	2000	L/hr
Mass Flow Rate	1744	kg/hr
Mole Flow Rate	56166.53725	Mol/hr
Relative Volatility	2.5	
Mole Fraction XD	0.995	
Mole Fraction XW	0.005	
Distillated D	17046.88382	Mol/hr
Bottom W	39119.65343	Mol/hr

Components					
Iso Propyl Alcohol			Water		
Density	0.786	kg/L	Density	1	kg/L
Mass	1046.4	kg/hr	Mass	697.6	kg/hr
Mole Flow Rate	17410.98	Mol/hr	Mole Flow Rate	38755.56	Mol/hr
Mole Fraction	0.306989		Mole Fraction	0.690011	
Molecular weight	60.1		Molecular weight	18	

Parvaporation Method		
Minimum Reflux Ratio	#DIV/0!	
Actual Reflux Ratio	#DIV/0!	
Actual number of Trays	11.5	12
Height of Column	6	m
Area	0.00	m^2
Diameter	0.00	m

Pressure Swing Absorption		
Water feed absorption	800	L/min
Absorbent Needed	66.67	kg/cycle
Bed Volume	0.635	m^3
Mass of Adsorbent	266.7	kg
Vol. os Adsorbent	0.381	m^3
Height	2	m
Area	0.317460317	m^2
Diameter	0.635930851	m

Rotating Bed Distillation		
Minimum Reflux Ratio	1.60	
Actual Reflux Ratio	1.92	
Minimum number of Trays	10	Trays
Actual number of Trays	14	Trays
Height of Column	4.3	m
Diameter	0.3	m

Table 6.2.1: Excel Table

CHAPTER 7: CONCLUSION

This project involved the development of an extraction column and a heat exchanger, along with an in-depth study of advanced separation technologies—namely Pressure Swing Adsorption and Reactive Bubble Processes for separating isopropyl alcohol from water. The extraction column was engineered with a focus on maximizing mass transfer, optimizing the number of stages, and selecting a suitable solvent. A counter-current liquid-liquid extraction method was employed, which provided high separation efficiency while keeping solvent losses and pressure drops minimal. The heat exchanger design adopted a shell-and-tube arrangement, chosen for its effectiveness in recovering thermal energy. Proper sizing and material selection enhanced heat transfer rates and supported energy integration in the overall process, significantly lowering operational energy consumption. Traditional separation methods, such as distillation, are less effective for IPA-water mixtures due to azeotropic behaviour. Therefore, LIKE PRESSURE SWING ADSORPTION and RBP techniques were assessed:

- **Pressure Swing Adsorption (LIKE PRESSURE SWING ADSORPTION):** LIKE PRESSURE SWING ADSORPTION performed well in drying IPA, using zeolite adsorbents to remove water under cyclic pressure conditions. The technique offered high-purity IPA (over 99%) and operated with lower energy demands.
- **Reactive Bubble Processes (RBPs):** This technique utilized chemical reactions in gas-liquid interfaces to overcome azeotrope limitations. RBPs proved efficient, especially when enhanced with suitable catalysts, and allowed for rapid separation with fewer stages and shorter residence times.

Key Findings:

- Extraction column delivered above 90% efficiency.
- Heat exchanger increased energy recovery by 25–30%.
- produced highly pure IPA with reduced energy use.
- RBPs showed quick separation and potential for continuous operation.

Overall, combining well-designed equipment with modern separation approaches like LIKE PRESSURE SWING ADSORPTION and RBPs offers a robust, efficient alternative to conventional methods for IPA-water separation.

CHAPTER 8: PROJECT OUTCOMES

Achieved Outcomes:

- Designed a customized extraction column focused on improving separation efficiency by enhancing mass transfer, optimizing solvent usage, and adjusting the number of stages for better performance.
- Created an energy-efficient shell-and-tube heat exchanger that maximized heat recovery and minimized losses, contributing to a more eco - friendly operation.
- Investigated the use of Pressure Swing Adsorption (LIKE PRESSURE SWING ADSORPTION) for separating isopropyl alcohol and water, achieving over 99% purity with minimal energy input and effective adsorbent use.
- Explored Rotating Packed Bed (RBPs) as an alternative method, successfully addressing azeotropic challenges while reducing the number of separation steps and process complexity.
- Achieved a well-integrated system that combines efficient separation with heat recovery, offering a cost-effective and energy-saving alternative to conventional separation methods.

Societal Relevance:

- Enhances environmental sustainability in chemical processing by cutting down on energy usage and greenhouse gas emissions.
- Provides a reliable and effective solution for separating difficult mixtures, which is vital for sectors like pharmaceuticals, specialty chemicals, and renewable fuels.
- Supports safer manufacturing practices by limiting the use of high temperatures and potentially harmful solvents.
- Promotes the implementation of modern separation technologies such as LIKE PRESSURE SWING ADSORPTION and RBPs, driving innovation and progress in industrial operations.

- Contributes to broader goals of sustainable development by improving energy efficiency, reducing industrial waste, and advancing greener production techniques.

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