

Plant Design and Economics
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Lecture No -37
Selection Criteria for Separation Processes

Welcome to lecture 37 and plant design and economics. In this week, we are talking about synthesis of separation systems, and in today's lecture we will consider selection criteria for separation methods.

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Synthesis of Separation Systems

The Synthesis of Separation Systems involves the selection of:

- Separation methods
- Energy Separating Agent (ESA) and/or Mass Separating Agent (MSA)
- Separation equipment
- Optimal arrangement or sequencing of the equipment
- Optimal operating condition (temperature and pressure) for the equipment

The slide features a background with a stylized tree of icons representing various chemical engineering concepts. In the bottom right corner, there is a video inset of Prof. Debasis Sarkar, a man with glasses wearing a light blue shirt. The bottom of the slide includes the IIT Kharagpur logo and the NPTEL logo.

Now synthesis of separation systems involve this separation methods, so you have to select separation methods along with energy separating agent and mass separating agent. We have to select separation equipment and then optimal arrangement or sequencing of these equipment and finally optimal operating conditions such as temperature pressure for the equipment. So this is what we mean by synthesis of separation systems.

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Common Industrial Separation Methods

- Flash
- Ordinary Distillation
- Gas Absorption
- Stripping
- Extractive Distillation
- Azeotropic Distillation
- Liquid-Liquid Extraction
- Crystallization
- Gas Adsorption
- Liquid Adsorption
- Membrane Based Separation
- Supercritical Extraction
- Leaching (Solid-Liquid Extraction)
- Drying
- Desublimation

How to Select a Separation Method?



Now there are several industrial separation methods, in our previous lecture we have given you a table, which involves certain basic information's about this commonly used industrial separation methods. Now, how do I select a particular separation method, so what should be criteria for selection? So this is what we are going to discuss in today's class.

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Criteria for Selection: Phase Condition of Feed

Selection of separation method based on phase condition of feed:

- Vapor Partial condensation, Distillation (cryogenic), Gas Absorption, Adsorption, Gas permeation (membranes), Desublimation
- Liquid Flash, Distillation, Stripping, Liquid-Liquid extraction, Supercritical extraction, Crystallization, Adsorption, Dialysis/Ultrafiltration/Reverse osmosis (membranes)
- Solid Slurry feed: Filtration/Centrifugation → wet cake → separate into vapour and dry solid by drying
Dry feed: Leaching with selective solvent



First, the criteria for selection of a particular separation method may be based on the phase condition of the feed the phase condition of the feed may be a vapour feed, a liquid feed or a solid. If the feed is vapour then we can select the separation methods such as partial condensation, which is opposite of flash or partial vaporization. Distillation under cryogenic condition, gas absorption, adsorption, gas permeation using membranes, desublimation.

If the feed is liquid, we can consider flash distillation, both ordinary distillation, azeotropic distillation as well as extractive distillation, stripping, liquid-liquid extraction, supercritical extraction, crystallization, adsorption, membrane base separation processes, such as dialysis, ultra filtration, reverse osmosis, par preparation etcetera. If the feed is in solid state, it can be a slurry feed or it can be dry solid feed.

If you have a slurry feed we can perform filtration or centrifugation to obtain wet cake and then the wet cake can be separated into vapour and dry solid by method of drying. On the other hand if we have dry feed, leaching can be used with a selective solvent.

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Criteria for Selection: Separation Factor: Define

The separation factor, SF, defines the degree of separation achievable between two key components of the feed.

The SF for separation of component 1 from component 2 between Phases I and II, for a single stage of contacting, is defined as:

$$SF = \frac{C_1^I / C_2^I}{C_1^{II} / C_2^{II}}$$

C_i^j = composition (concentration, mole/mass fraction of component j in phase i)

If Phase-I is to be rich in component 1 and Phase-II is to be rich in component 2, then SF must be large.

The value of SF is limited by thermodynamic equilibrium except for membrane separations.

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Now, we will define a separation factor which will guide us for selection of separation method. The separation factor defines the degree of separation that can be achieved between two key components of the feed. The separation factor for separation of component 1 from component 2 between phase 1 and phase 2 for a single stage contacting is defined as shown. Note that the separation factor has been defined as a ratio of two ratios.

So in the numerator you have concentration of species 1 divided by concentration of species 2 in the phase 1 and in the denominator you have concentration of species 1 divided by concentration of species 2 in the phase 2. So it is a ratio of two ratios, we can use concentration, we can use mole fraction or you can use mass fraction. So in general we can say that the separation factor can be defined as a ratio of two ratios which indicates the composition of two species in both numerator and denominator.

So in the numerator you have composition of species 1 by composition of species 2 in the phase 1 and in the denominator you have composition of species 1 by composition of species 2 in phase 2. If phase 1 is to be reach in component 1 and phase 2 needs to be reach in component 2 then that according to the definition of the separation factor, you can conclude that the separation factor must be large.

Note that except for the membrane by separation processes, they extend a mass transfer in other processes are limited by thermodynamic equilibrium. So the value of separation factor is limited by thermodynamic equilibrium, of course except for membrane by separation processes where the exiting phases are not in thermodynamic equilibrium.

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Criteria for Selection: Select High Separation Factor

SF is generally limited by thermodynamic equilibrium. For example, in the case of distillation, using mole fractions as the composition variable and letting Phase-I be the vapor and Phase-II be the liquid, the limiting value of SF is given in terms of vapor-liquid equilibrium ratios (K-values) as:

$$SF = \frac{y_1/y_2}{x_1/x_2} = \frac{y_1/x_1}{y_2/x_2} = \frac{K_1}{K_2} = \alpha_{1,2} \quad (\text{Relative volatility})$$

➤ Generally, components 1 and 2 are so designated such that $SF > 1.0$.

➤ Thus, the larger the value of SF, the more feasible is the particular separation operation.

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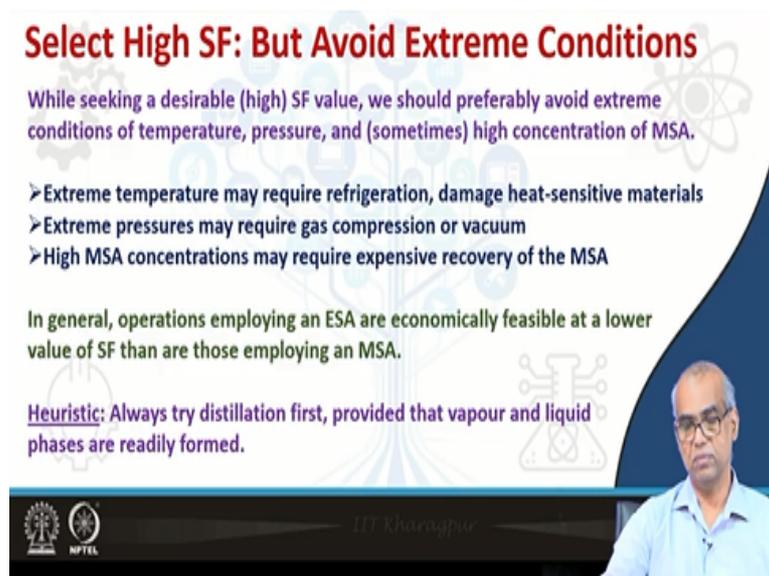
Now, once we have selected the separation factor, we have to select a separation method with high separation factor, as we discuss the separation factor is generally limited by thermodynamic equilibrium. For example, in the case of distillation let us denote phase 1 to be the vapour phase and phase 2 to be the liquid phase, the compositions can be expressed in terms of mole fractions.

In that case, the limiting value of separation factor is given in terms of vapour liquid equilibrium ratios or K values as this. So separation factor is y_1 by y_2 divided by x_1 by x_2 . So y_1 is the mole fraction of species 1 in the vapour phase, y_2 is the mole fraction of species 2 in the vapour phase. Similarly x_1 and x_2 represents mole fractions of species 1 and 2 respectively in the liquid phase.

Note that this ratio can be expressed as K_1 by K_2 which are K values and K_1 by K_2 is nothing but relative volatility. In general, the components 1 and 2 will be so designated such that the value of the separation factor is greater than 1. So the larger the value of separation factor, the more feasible is the particular separation operation. So according to the definition of our separation factor the high value of the separation factor will go in favour of that particular separation factor.

So we will tend to select separation process or separation method with high separation factor. Now, we have to take certain cautions as well.

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Select High SF: But Avoid Extreme Conditions

While seeking a desirable (high) SF value, we should preferably avoid extreme conditions of temperature, pressure, and (sometimes) high concentration of MSA.

- Extreme temperature may require refrigeration, damage heat-sensitive materials
- Extreme pressures may require gas compression or vacuum
- High MSA concentrations may require expensive recovery of the MSA

In general, operations employing an ESA are economically feasible at a lower value of SF than are those employing an MSA.

Heuristic: Always try distillation first, provided that vapour and liquid phases are readily formed.

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While we select a high value separation factor, we should keep in mind that we need to preferably avoid extreme conditions for temperature, pressure as well as sometimes we should avoid excessive use of mass separating agent, why? Because the extreme temperature may require refrigeration, which is an expensive option, destined temperature may also damage these sensitivity materials.

Extreme pressures may require gas compression or vacuum again expensive options, high mass separating agent concentration may require expensive recovery method for the mass separating agent. Note that even if you separation process can be achieved in a single piece of equipment, but whenever I use mass separating agent there has to be additional separation process for recovery of the mass separating agent so that you can recycle it.

So excessive use of mass separating agent should be avoided in those cases where the recovery is very expensive. In general operations employing an energy separating agents are economically feasible at a lower value of separation factor than are those employing a mass separating agent. So, let us follow a rule of thumb or heuristic guideline, we will always try distillation first provided vapour and liquid phases are readily formed.

So a vapour and liquid phases are readily formed will always try distillation first as the preferred method of liquid-liquid separation.

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SF: Ideal L-V Solution, Moderately Non-ideal Liquid

When a multi-component mixture forms nearly ideal L-V solutions, and the ideal gas law holds, the Relative Volatility and K-values are readily estimated from vapour pressure. Thus, the SF for V-L separation operations employing an ESA (partial evaporation, partial condensation, or ordinary distillation) is given by:

$$SF = \alpha_{1,2} = \frac{P_1^s}{P_2^s} \quad (P = \text{Vapour Pressure})$$

When the components form moderately non-ideal liquid solutions (hydrocarbon mixtures or homologous series of other organic compounds), we can use Equation of States to estimate SF using fugacity coefficient. Common EOS:

- Soave-Redlich-Kwong (SRK)
- Peng Robinson (PR), etc.

$$SF = \alpha_{1,2} = \frac{\phi_1^L / \phi_1^V}{\phi_2^L / \phi_2^V}$$

Now, let us consider separation factor for ideal liquid-vapour solution and moderately non-ideal liquid solution. When a multi-component mixture forms nearly ideal liquid-vapour solutions and the ideal gas law holds the relative volatility and K values can be readily estimated from the vapour pressures of the species involved. Thus, the separation factor for vapour-liquid separation operations employing an energy separation agent such as partial evaporation, partial condensation or ordinary distillation can be given by ratio of vapour pressures of the species involved.

For example, separation factor alpha between species 1 and 2 will be equal to vapour pressure of species 1 divided by vapour pressure of species 2. When the components of moderately non-ideal liquid solutions, such as hydrocarbon mixtures or homologous series of other organic compounds. We can use equation of states to estimate separation factor by use of fugacity coefficients.

The commonly used equation of states may be SRK equation as well as Peng Robinson equation. So for moderately non-ideal liquid solutions the separation factor $\alpha_{1,2}$ can be represented by ratios of fugacity coefficients. Note that in the denominator you have the fugacity coefficient of component 1 in the liquid phase divided by fugacity coefficient of component 1 in the vapour phase.

And in the denominator you have the fugacity coefficient of component 2 in the liquid phase divided by 2 fugacity coefficient of component 2 in the vapour phase.

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SF: L-V Separation With MSA: Non-ideal Liquid

For vapour-liquid separation operations that use an MSA that causes the formation of a non-ideal liquid solution but operate at near ambient pressure (azeotropic and extractive distillation), modified Raoult's law holds:

$$SF = \alpha_{1,2} = \frac{\gamma_1^L P_1^s}{\gamma_2^L P_2^s}$$

where γ_i is the liquid phase activity coefficient of component i , which is estimated from the Wilson, NRTL, UNIQUAC, or UNIFAC equations and is a strong function of mixture composition.

NRTL:

$$\ln \gamma_i = \sum_j x_j \tau_{ji} G_{ji} + \sum_j \left(\frac{x_j G_{ij}}{\sum_k x_k G_{kj}} \right) \left(\tau_{ij} - \frac{\sum_n x_n \tau_{ni} G_{ni}}{\sum_k x_k G_{kj}} \right) \quad G_{ij} = \exp(-\alpha_{ij} \tau_{ij}), \quad G_{ii} = 1$$

$$\tau_{ij} = a_{ij} + b_{ij}/T + c_{ij} \ln T + f_{ij} T, \quad \tau_{ii} = 0$$

$$\alpha_{ij} = c_{ij} + d_{ij}(T - 273.15)$$

(Summations are made for all n -components)

The binary parameters a_{ij} , b_{ij} , c_{ij} , d_{ij} , e_{ij} and f_{ij} can be found in literature or regressed from experimental data. Useful for generating VLE, LLE data.

Now, there are liquid-vapour separation processes where we use mass separating agents. In fact use of mass separating agents can enhance the separation factor. Now, when you use mass separating agent, it may cause the formation of non-ideal liquid solutions. For example, in case of azeotropic distillation or extractive distillation, we use mass separating agents. So when use of mass separating agent causes the formation of non-ideal solutions but we operate at near ambient pressures.

We can apply modified Raoult's law and then the separation factor given by relative volatility can be estimated by use of activity coefficients. Note that, the separation factor for non ideal liquid solutions has been expressed in terms of activity coefficients of component 1 and component 2 and the vapour pressures of component 1 and component 2. So, gamma is the liquid phase activity coefficient, gamma 1 is the liquid phase activity coefficient of component 1 gamma 2 is the liquid phase activity coefficient of component 2 and p 1 and p 2 represents the vapour pressures.

Now, how will you obtain this activity coefficients? The activity coefficient can be obtained by use of various thermodynamic models such as Wilson model, NRTL model, UNIQUAC model or UNIFAC models. Remember that, the activity coefficient is a very strong function of mixture composition. Here the NRTL equations which establishes the correlation between the liquid phase activity coefficient γ_i for component i with the liquid phase mole fraction of component in the x is shown.

Here all the summations are need to be made for all the components present in the mixture. So we consider there are n components present in the mixtures all the summations runs for 1 to n . Here x represents liquid phase mole fractions, γ_i represents liquid phase activity coefficient for component i and then there are several binary parameters. The relationships are shown here.

Now some of the binary parameters such as a , b , c , d , e , f they can be found in the literature for the particular system you are handling if it has already been reported in the literature. Otherwise, these values can also be regressed from the experimental data on thermodynamic equilibrium. NRTL thermodynamic model can be used for generation of vapour-liquid equilibrium data, as well as liquid-liquid equilibrium data.

So, similar equations are available for Wilson models, UNIQUAC work models UNIFAC models etcetera. So such a thermodynamic model can be used to estimate the liquid phase activity coefficient and then the separation factor for the non-ideal liquid solution can be obtained.

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SF: Liquid-Liquid Separation: Selectivity

If an MSA is used to create two liquid phases, such as in liquid-liquid extraction, the SF is referred to as the relative selectivity, β :

$$SF = \beta_{1,2} = \frac{\gamma_1^II / \gamma_2^II}{\gamma_1^I / \gamma_2^I}$$

Here Phase-II is usually the MSA-rich phase and component 1 is more selective for the MSA-rich phase than is component 2.

A slide from an NPTEL presentation. It features a white background with a blue wave on the right side. The text is in black and purple. There are icons of a gear, a tree, and a chemical flask. A small inset video of a man in a light blue shirt is in the bottom right corner. The NPTEL logo is in the bottom left corner.

Now when you talk about liquid-liquid separation; the separation factor is referred to as selectivity. So a mass separating agent is used to create two liquid phases. Such as in case of liquid-liquid extraction the separation factor is referred to as the relative selectivity and the relative selectivity usually denoted by beta can be defined as shown between components one and two.

So again, these are the ratios of activity coefficients of two components and in two phases. Here phase 2 is usually the MSA rich phase and component 1 is more selective for the MSA rich phase than is component 2.

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Criteria for Selection: ESA and MSA

In general, operations employing an ESA are economically feasible at a lower value of SF than are those employing an MSA.

Usually, MSAs for extractive distillation and liquid-liquid extraction are selected according to their ease of recovery for recycle and to achieve relatively large values of SF. Such MSAs are often polar organic compounds.

Example: Furfural is used to separate n-butane from 2-butenes.

Sometimes, the MSA is selected in such a way that it forms one or more homogeneous or heterogeneous azeotropes with the components in feed.

Example: n-butyl acetate is added to (acetic acid + water). Heterogeneous minimum-boiling azeotrope (acetate + water) is formed. Take Azeotrope overhead, separate acetate and water layers, and recirculate acetate.

A slide from an NPTEL presentation. It features a white background with a blue wave on the right side. The text is in black and purple. There are icons of a gear, a tree, and a chemical flask. A small inset video of a man in a light blue shirt is in the bottom right corner. The NPTEL logo is in the bottom left corner.

In general, operations employing an energy separating agent are economically feasible at a lower value of separating factor than those employing a mass separating agent. Usually, mass

separating agents for extractive distillation and liquid-liquid extraction are selected according to their ease of recovery for recycle and to achieve relatively large values of separation factor. So, the selection of mass separating agent should be based on mainly two consideration one is ease of recovery, second is enhancement of the separation factor.

Such mass separating agents are often polar organic compound, for example; Furfural is used for separation of n butane from 2-butene. This is what we have seen in the separation that we discussed multi component separation, we discussed in our previous lecture. Sometimes the mass separating agent is selected in such a way that it forms one or more homogeneous or heterogeneous azeotropes with the components in the feed.

For example; consider the separation of acetic acid and water mixture here we add n-butyl acetate as mass separating agent. Upon addition of n-butyl acetate a heterogeneous minimum boiling azeotrope of acetate and water is formed, we can take the azeotrope overhead and then separate acetate and water layers and then recirculate the acetate.

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Criteria for Selection: Multistage Operations

The value of SF is generally much lower than that required for achieving sharp separation and necessary product purities.
But the application of efficient counter-current flow cascades of many contacting stages (distillation operations) can frequently achieve sharp separations.

Task: $P = 290 \text{ psia}$

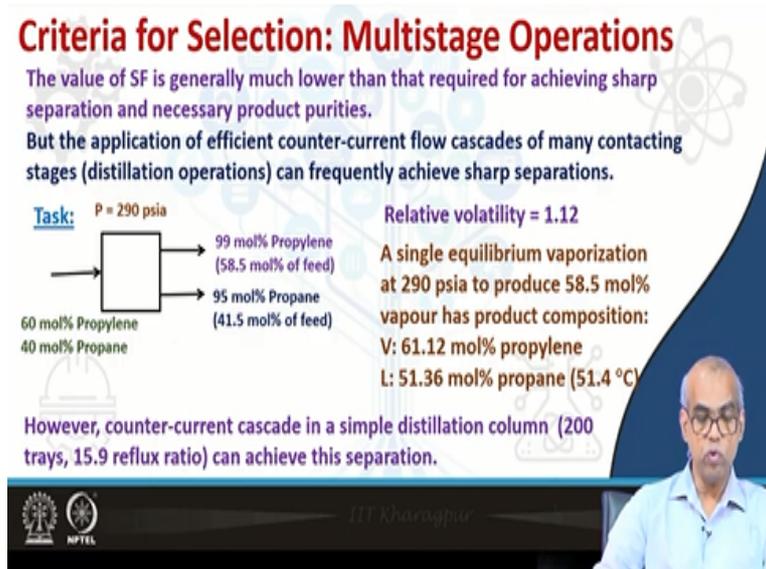
60 mol% Propylene
40 mol% Propane

99 mol% Propylene (58.5 mol% of feed)
95 mol% Propane (41.5 mol% of feed)

Relative volatility = 1.12

A single equilibrium vaporization at 290 psia to produce 58.5 mol% vapour has product composition:
V: 61.12 mol% propylene
L: 51.36 mol% propane (51.4 °C)

However, counter-current cascade in a simple distillation column (200 trays, 15.9 reflux ratio) can achieve this separation.



Now, let us look at the importance of multi stage operations. Generally speaking the value of the separation factor is much lower than that required for achieving very sharp separation and for achieving the specified product purity. But the application of efficient counter current flow cascades of many contacting stages such as distillation operation can frequently achieve specified sharp separations.

Note that, the separation factor that we define was based on single contacting stage. So the value of the separation factor that we have obtained will generally be much lower than that required for achieving sharp separation and than that required for achieving the desired specification on product purity. However when you perform efficient counter current cascades of several contacting stages we can frequently achieve sharp separations.

For example; we generally obtain sharp separation in distillation operations, unless they are very close boiling-mixtures. Let us say you have this given task, we have a mixture of 60 mol percent propylene and 40 mol percent propane. We want to separate it into 99 mol percent propylene and 95 mol percent of propane. We have to perform this separation at 290 psi absolute. A mass balance will tell you that 99 mol percent of propylene in the product stream is equivalent of 58.5 mol percent of feed.

Similarly, 95 mol percent of propane in the product stream is equivalent to 41.5 mol percent of feed. Now if I want to perform this separation, we first see that relative volatility is 1.12. A single equilibrium vaporization at 290 psi absolute to produce 58.5 mol percent vapour will have the product composition which is as follows. In the vapour phase you will have 61.12 mol percent propylene and in the liquid phase here 51.36 mol percent propane at 51.4 degree Celsius.

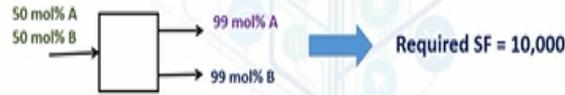
Note that, the product that we obtain is using a single equilibrium vaporization is much less than the separation task that was specified which is 99 mol percent propylene and 95 mol percent propane. So single equilibrium vaporization cannot achieve this, however we can perform counter current cascade of contacting stages in a simple distillation column and we can achieve this separation it will require 200 trays and high reflux ratio of 16, but we can achieve this sharp separation.

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Criteria for Selection: Single-Stage Operations

Single-stage operations (e.g., partial vaporization or partial condensation with the use of an ESA) are employed:

- > If SF between the two key components is very large
- > If a rough or partial separation is needed



Single Stage Partial Vaporization

At low values of SF (1.05 to 1.10), ordinary distillation may still be the most economical choice.

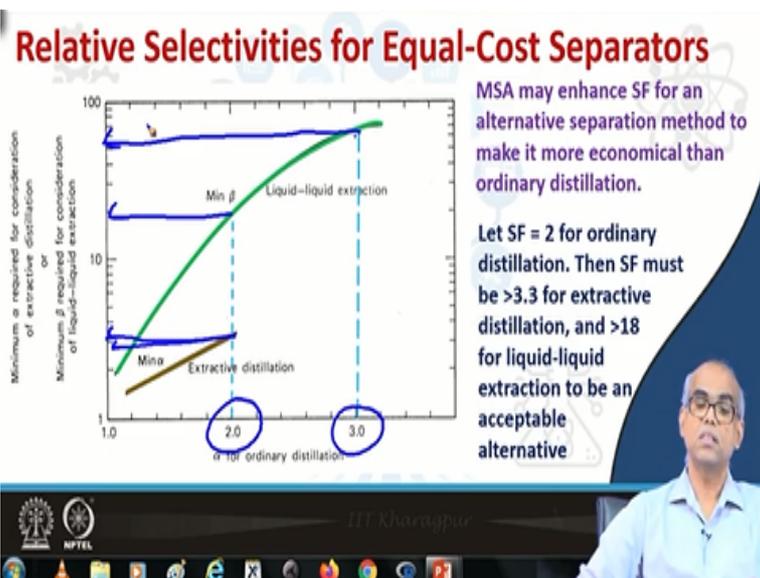


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So when we perform single stage operation? Single stage operation such as partial vaporization or partial condensation with use of an energy separating agents are employed only if separation factor between the two key components is very large or if a rough or partial separation is needed, then we can think of performing single stage operation. Again consider the separation of an equimolar mixture A and B, so 50 mol percent A, 50 mol percent B.

And, if you want to separate it into 99 mol percent A and 99 mol percent B, the required separation factor for a single stage partial vaporization would be 10,000 which is very large.

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At low values of separation factor said the range of 1.05 to 1.10 the ordinary distillation method may still be the most economic choice for separation process, the use of mass separating agent may enhance separation factor. For example, extractive distillation the

separation factor can be enhanced by use of a mass separating agent and your enhancement be to the extent that this process will be more economical than ordinary distillation, it is possible.

Now, the plot shows you on the X axis, we have plotted the relative volatility for ordinary distillation, so separation factor for ordinary distillation and in the vertical axis, we have minimum relative volatility required for consideration of extractive distillation or minimum selectivity required for consideration of liquid-liquid extraction. This plot has been obtained on the basis of equal cost consideration.

This plot will guide us to consider whether extractive distillation or liquid-liquid extraction will be more attractive or when it will be more attractive compared to ordinary distillation process. So, when you can perform a particular separation using ordinary distillation, extractive distillation, as well as liquid-liquid extraction such plot will be helpful to figure out what should be the chosen process.

For example let us consider the separation factor equal 2 for ordinary distillation. Then if I want to use extractive distillation the separation factor obtained by extractive distillation must be say as I has 3.3 or so and if I want to use liquid-liquid extraction in place of ordinary distillation the selectivity for the liquid-liquid extraction process should be as I has 18 or above.

Then only the extractive distillation or liquid-liquid extraction will be more attractive or acceptable alternative compared to ordinary distillation. Similarly, when the separation factor for ordinary distillation is 3, note that the separation selectivity which is separation factor for liquid extraction has to be very high thing in the range of 70 or so. So such figure based on equal cost consideration will guide us to select appropriate method.

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Separation Factor: Absorption, Stripping

Unless values of SF are about 10 or above, absorption and stripping operations cannot achieve sharp separation between two components.

Nevertheless, these operations are used widely for preliminary or partial separations where the separation of one key component is sharp, but only a partial separation of the other key component is adequate.

The degree of sharpness of separation is given by the Recovery Factor (RF):

$$RF = \frac{n_i^{\text{Product}}}{n_i^{\text{Feed}}}$$

where n is moles or mass of component i



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Separation factor for absorption, stripping: Unless values of separation factor are about 10 or above absorption and stripping operations cannot achieve sharp separation between two components. Nevertheless, these operations are used widely for preliminary or partial separations where the separation of one key component is served, but only a partial separation of the other key component is adequate.

So, when you are happy with sharp separation of only one key component then this can be used. The degree of sharpness of separation is given by the recovery factor, where the recovery factor is defined as moles or mass of component i in the product phase divided by moles or mass of component i in the feed phase.

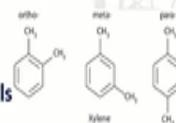
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Separation Factor: Crystallization: High Purity

Consider: Separation of metaxylene from paraxylene.

p-xylene: Used for PET plastic bottles and polyester fiber

m-xylene: Used for production of isophthalic acid, pharmaceuticals



Difference in normal boiling points: $< 1^\circ\text{C}$

Difference in melting points: $> 60^\circ\text{C}$

Ordinary distillation: SF = 1.02

To produce relatively pure products from an equimolar mixture of the two isomers would require about 1,000 stages and a reflux ratio of more than 100.

Crystallization: SF is nearly infinity because essentially pure p-xylene is crystallized. However, the mother liquor contains at least 13 mol % p-xylene in m-xylene, corresponding to the limiting eutectic composition.

	BP ($^\circ\text{C}$)	MP ($^\circ\text{C}$)
m-xylene	139	-48
p-xylene	138.3	13.2



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Crystallization when performed carefully can achieve very, very high purity. Consider the separation of a mixture of metaxylene and paraxylene. Paraxylene is used for polyethylene terephthalate, PET plastic bottles and polyester fiber, Metaxylene is used for production of isophthalic acid is an important ingredient in polymer industries, metaxylene is also used in pharmaceutical industries, so this is metaxylene and this is paraxylene.

Now, if you look at the physical properties particularly boiling point and melting point of this metaxylene and paraxylene we see that the difference in normal boiling point is less than 1 degree Celsius, whereas difference in melting point is more than 60 degrees Celsius. So ordinary distillation is definitely not a suitable choice the separation vector is only 1.02 and to produce relatively pure products from an equimolar mixture of the two isomers of paraxylene and metaxylene we may require a distillation column with more than 1,000 stages and reflux ratio as about 100.

However, if you use crystallization the separation factor is almost infinity because nearly pure paraxylene can be crystallized. However the mother liquor contains at least 13 mol% of paraxylene in metaxylene because this corresponds to the limiting eutectic composition.

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Separation Factor: Adsorption

The separation factor for adsorption depends on either differences in the rate of adsorption or adsorption equilibrium.

For equilibrium adsorption, the same definition for Separation Factor applies:

$$SF = \frac{C_1^I / C_2^I}{C_1^{II} / C_2^{II}}$$

Here the concentrations that are at equilibrium (compare I and II) are:

- Concentrations on the adsorbed layer within the pores of the adsorbent
- Concentrations in the bulk fluid external to the adsorbent particles

The slide also features a video inset of a man in a light blue shirt and glasses, and logos for IIT Kharagpur and NPTEL at the bottom.

The separation factor for adsorption depends on either differences in the rate of adsorption or adsorption equilibrium. For equilibrium adsorption the same definition of separation factor applies that is the ratio of two ratios which is composition of component 1 by component 2 in the phase 1 divided by composition of component 1 divided by composition of component 2 in the phase 2.

Now in case of adsorption the concentrations that are at equilibrium are; concentration on the adsorbed layer within the pores of the adsorbent and concentrations in the bulk fluid external to the adsorbent particles. So these two concentrations correspond to those places one and two in the definition of the separation factor.

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Separation Factor: Very Dilute Mixture

If only a small amount of one component is present in a mixture, changing the phase of the components in high concentrations should be avoided.

In such a case, absorption, stripping, or selective adsorption is more appropriate to remove the minor component.

Adsorption is particularly effective because of the high selectivity of adsorbents. It is widely used for purification, where small amounts of a solute are to be removed from a liquid or vapour feed.

The slide features a blue background with white text and icons of a gear, a molecular structure, and a chemical flask. A small inset video shows a man in a light blue shirt speaking. Logos for IIT Kharagpur and NPTEL are visible at the bottom left.

When you have a very dilute mixture you have only a small amount of one component present in the mixture. In such a case changing the phase of the components in high concentration should be avoided. In such a case absorption, stripping or selective adsorption is more appropriate to remove the minor component that means the component which is present in a very small amount.

Adsorption is particularly effective because of the high selectivity of the adsorbents. It is widely used for purification where small amounts of solute are to be removed from a liquid or vapour feed.

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Separation Factor: Membrane Processes

The SF is governed by relative rates of mass transfer in terms of permeabilities rather than by equilibrium considerations.

$$SF = \frac{PM_1}{PM_2} \quad PM_i = \text{Permeability of species } i$$

In most cases, the value of SF must be established experimentally.

Membrane separation operations should be considered whenever adsorption methods are considered. Typical SF for gas separation is 6. Such SF is good for partial separation.

Membranes are either porous or nonporous. If porous, the permeability is proportional to the diffusivity through the pore.

If nonporous, the permeability is the product of the solubility of the molecule in the membrane and its diffusivity for travel through the membrane.



Now, let us talk about separation factor for membrane based processes. The separation factor is governed by relative rates of mass transfer in terms of permeability's rather than by equilibrium consideration. So separation factor here we define as permeability of species 1 divided by permeability of species 2. In most cases, the value of the separation factor must be established experimentally.

Membrane separation processes should be considered wherever we consider adsorption methods as a possible separation process. Typical separation factor for gas separation using membrane is about 6. This separation factor is not very high for achieving sharp separation. However, this is good for achieving partial separation. Membranes are either porous or non-porous.

If porous, the permeability is the product is proportional to the diffusivity through the pore and if the membranes are non-porous the permeability is the product of the solubility of the molecule in the membrane and its diffusivity for travel through the membrane.

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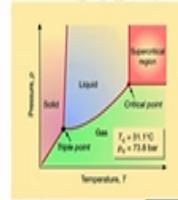
Separation Factor: Supercritical Extraction

Supercritical extraction utilizes the solvent power of a gas at near-critical conditions.

CO₂ is considered as a green solvent and at supercritical conditions, it has enhanced solubility. Its critical T, P are 31.1 °C and 73.8 bar. Near ambient T_c makes CO₂ attractive for heat sensitive materials.

Super Critical Extraction with CO₂ is the preferred method for removal of undesirable ingredients from foodstuffs, extraction of phenolic compounds from plants.

The SF is difficult to estimate from equations of state and is best determined by experiment. For leaching (solid-liquid extraction) also, the value of SF is best determined by experiment.



Supercritical extraction, supercritical extraction uses the solvent power of a gas at near critical conditions. Carbon dioxide is considered as a green solvent, at super critical condition it has very high solvent power, it has very enhanced solubility, it is critical temperature is 31.1 degree Celsius and critical pressure is 73.8 bar. So if you notice that the critical temperature is very near to ambient temperature.

And this makes carbon dioxide is a very attractive solvent under supercritical conditions for heat sensitive materials. Super critical extraction with carbon dioxide is the preferred method for removal of undesired ingredients from foodstuffs. It is also frequently used for extraction of phenolic compounds from plants. In recent years the supercritical extraction is in carbon dioxide is being increasingly used in pharmaceutical industries.

The separation factor is difficult to estimate from use of equation of state and the separation factor is based, estimated or determined rather from experimental data. Similarly for liquid-liquid extraction or leaching also the value of separation factor is based determined by experiment.

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Separation Criteria: Conclusion

The purpose of separation are:

- Purification of a species or group of species
- Removal of undesirable constituents
- Recovery of constituents for subsequent processing or removal.

In the case of purification, the use of an MSA method may avoid exposure with an ESA method to high temperatures that may cause decomposition.

In some cases, removal of undesirable species together with a modest amount of desirable species may be economically acceptable.

Likewise, in the recovery of constituents for recycle, a high degree of separation from the product(s) may not be necessary.



So to conclude separation criteria, we state that the purpose of separations are purification of species or group of species, removal of undesired constituents, recovery of constituents from subsequent processing or removal. So the broad purposes of separations are purification of a species or a group of species, removal of undesired constituents and recovery of constituents for subsequent processing or removal.

In case of purification the use of a mass separating agent may avoid exposure with an energy separating method to high temperature that may cause decomposition particularly for heat sensitive materials. In some cases, removal of undesirable species together with the modest amount of desirable species may be economically acceptable. Likewise, in the recovery of constituents for recycle a high degree of separation from the products may not always be necessary, with this we stop our discussion here.