# Upstream LNG Technology
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## Lecture – 29
## Equilibrium vapour-liquid separation

Welcome, today we are going to learn about the fundamentals of Equilibrium vapour liquid separation.

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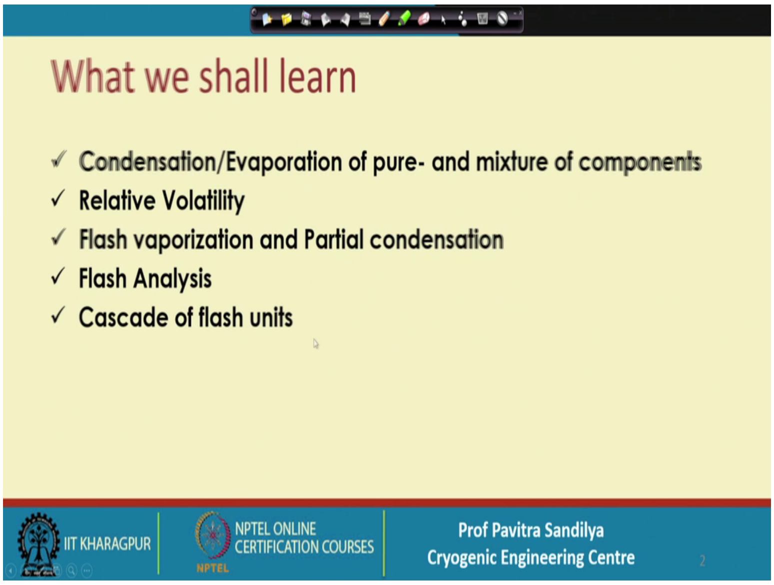

What we shall learn

- ✓ Condensation/Evaporation of pure- and mixture of components
- ✓ Relative Volatility
- ✓ Flash vaporization and Partial condensation
- ✓ Flash Analysis
- ✓ Cascade of flash units

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So, in this today's lecture, we shall be looking into the following topics. First is the condensation evaporation in pure and mixture of components about relative volatility, then flash vaporization and partial condensation which are the basis of any kind of vapor liquid separation processes, then flash analysis and we shall see that what is the cascade of flash units.

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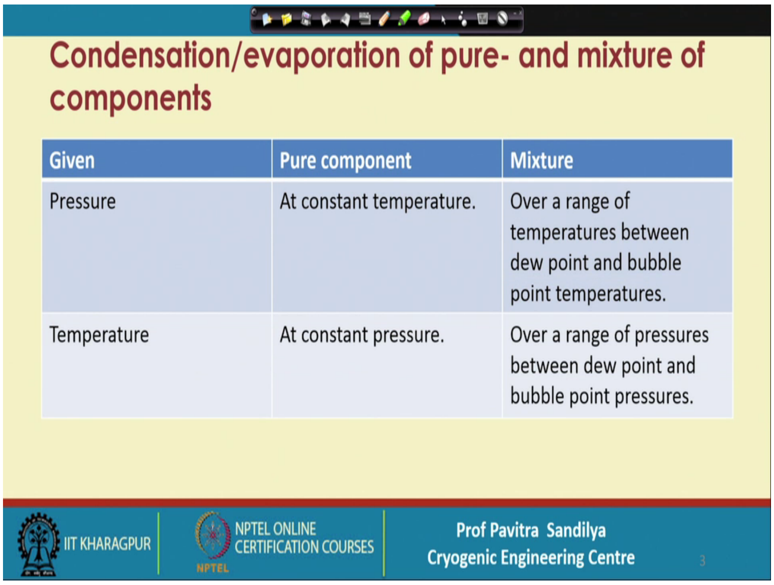

## Condensation/evaporation of pure- and mixture of components

| Given | Pure component | Mixture |
|---|---|---|
| Pressure | At constant temperature. | Over a range of temperatures between dew point and bubble point temperatures. |
| Temperature | At constant pressure. | Over a range of pressures between dew point and bubble point pressures. |

So, first let us look into the condensation and evaporation characteristics in pure and mixture of components, here, we shall see that for pure component and the mixture of components the behaviors are different. Now at a constant pressure for a pure component evaporation or condensation takes place at constant temperature while for a mixture, it takes place over a range of temperatures that is that are bounded by the dew point and the bubble point temperatures as we learned earlier.

Similarly, for a given temperature for a pure component, the phase change occurs at a constant pressure while for a mixture of component it happens over a range of pressures bounded by the dew point and the bubble point pressures.

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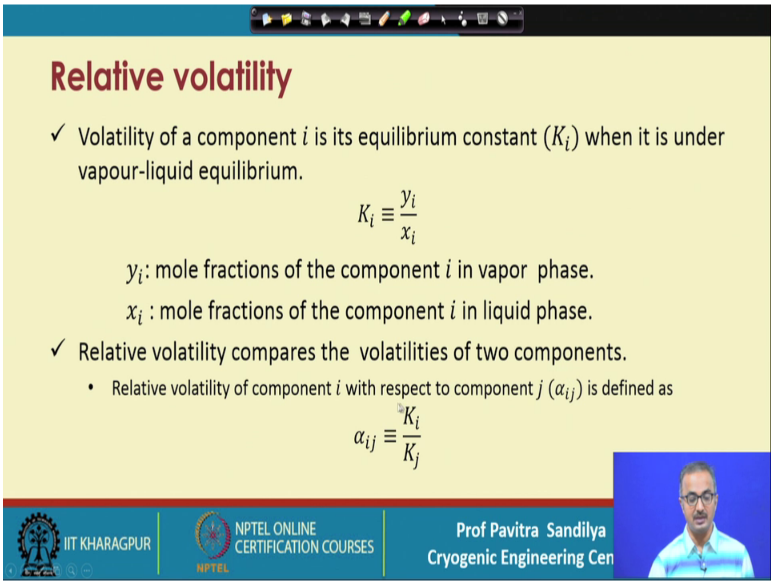

## Relative volatility

- ✓ Volatility of a component $i$ is its equilibrium constant ($K_i$) when it is under vapour-liquid equilibrium.

$$K_i \equiv \frac{y_i}{x_i}$$

$y_i$: mole fractions of the component $i$ in vapor phase.

$x_i$ : mole fractions of the component $i$ in liquid phase.

- ✓ Relative volatility compares the volatilities of two components.
  - Relative volatility of component $i$ with respect to component $j$ ($\alpha_{ij}$) is defined as

$$\alpha_{ij} \equiv \frac{K_i}{K_j}$$

Next, we come to a parameter which is important for the analysis of the vapour liquid separation systems. Now, this is relative volatility to understand this. First let us see, what is volatility? Volatility as we know that it is a tendency of a liquid component to go to the vapor phase.

So, it is defined like this that it is the for a given component i at equilibrium, it is under vapour liquid equilibrium, we write like this that K i is the equilibrium constant is defined as the ratio of the mole fraction of the ith component in the vapor phase to the mole fraction of the ith component in the liquid phase. So, this is the equilibrium constant or the volatility the more the value of K i the more the tendency of the component to go to the vapor phase.

Now, relative volatility compares the volatilities of 2 components, we define it with respect to 2 components like relative volatility of component i with respect to component j and is given by alpha ij is defined like the ratio of the K i to K j.

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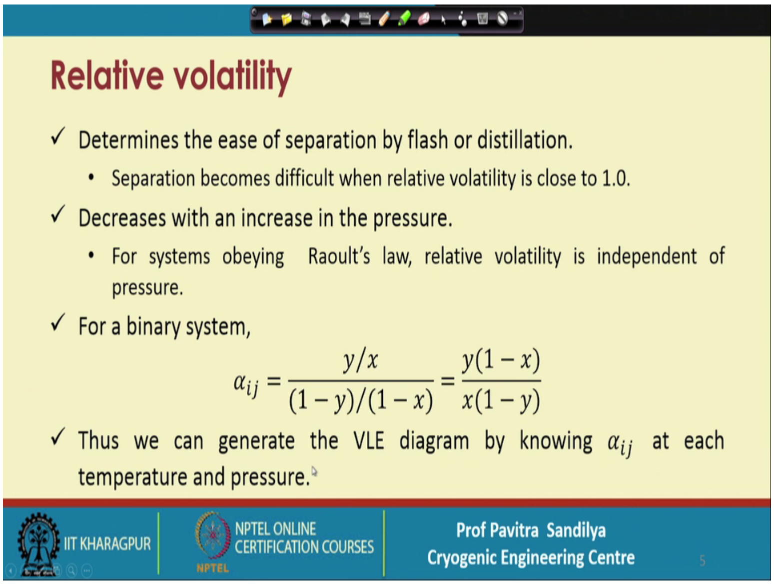

## Relative volatility

- ✓ Determines the ease of separation by flash or distillation.
    - Separation becomes difficult when relative volatility is close to 1.0.
- ✓ Decreases with an increase in the pressure.
    - For systems obeying Raoult's law, relative volatility is independent of pressure.
- ✓ For a binary system,

$$\alpha_{ij} = \frac{y/x}{(1-y)/(1-x)} = \frac{y(1-x)}{x(1-y)}$$

- ✓ Thus we can generate the VLE diagram by knowing $\alpha_{ij}$ at each temperature and pressure.

Now, if we see that this if the relative volatility is equal to 1 that is K i is equal to k j; that means, the 2 components will have the same tendency to go to the vapor phase, then we will not be getting any kind of separation.

So, what we want for separation is that the relative volatility should be as away from unity as possible, if it is equal to or near unity, then it becomes very difficult or sometimes impossible to separate the components by this flash or the condensation methods, then we have to adopt some other means of separation. Now this relative volatility decreases with an increase in the pressure.

And, but when the a system follows Raoult's law that is ideal liquid and ideal vapor in that case, relative volatility is independent of the pressure for a binary mixture, the relative volatility is defined like this that for a component with y as the vapor phase mole fraction x as the liquid phase mole fraction; that means, for the other component 1 minus y will be the vapor phase composition and 1 minus x will be the liquid phase composition in that respect we find that we are able to define the relative volatility for a binary mixture like in terms of only y and x.

Now, this particular thing may be used to generate the vapor liquid equilibrium curve which we saw in our earlier lecture for different temperatures and pressures.

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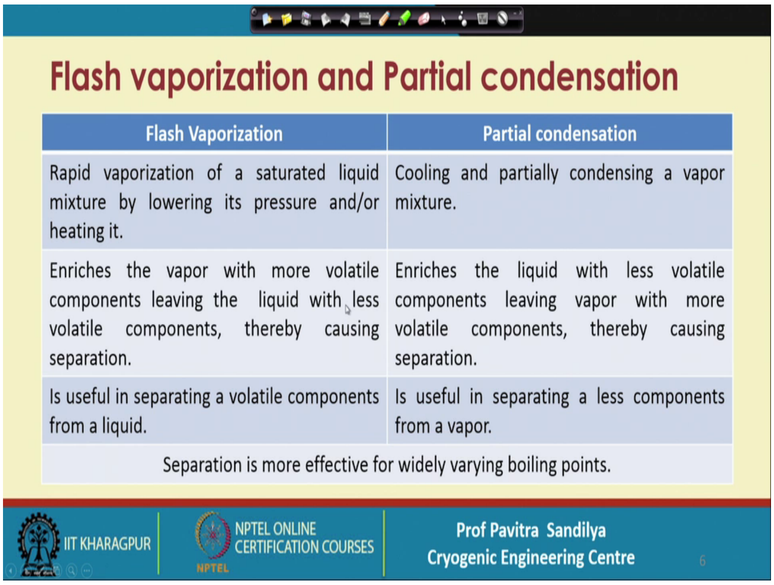

## Flash vaporization and Partial condensation

| Flash Vaporization | Partial condensation |
|---|---|
| Rapid vaporization of a saturated liquid mixture by lowering its pressure and/or heating it. | Cooling and partially condensing a vapor mixture. |
| Enriches the vapor with more volatile components leaving the liquid with less volatile components, thereby causing separation. | Enriches the liquid with less volatile components leaving vapor with more volatile components, thereby causing separation. |
| Is useful in separating a volatile components from a liquid. | Is useful in separating a less components from a vapor. |
| Separation is more effective for widely varying boiling points. | |

Now, here we come to the flash vaporization and the partial condensation which are used for separation now flash vaporization is the rapid vaporization of some liquid which is saturated by either loading its pressure or by increasing its temperature from the other hand, partial condensation means that we are cooling the vapor mixture and then partially condensing it to get a liquid phase.

Now, when we are doing; so, what happens that the in the flash vaporization the vapor gets enriched with the more volatile component leaving behind the less volatile component more in the liquid phase, on the other hand for the partial condensation, the less volatile components more go into the liquid phase leaving behind the more volatile component in the vapor phase and that is how we are able to get separation this flash vaporization is used for separating volatile components from a liquid while for the partial condensation we use it to separate the less volatile component from a vapor.

And both these separations are more effective for widely varying boiling points because the boiling points, if they come closer; that means, the relative volatility comes closer to 1 and these components will be difficult to separate by vapor liquid system.

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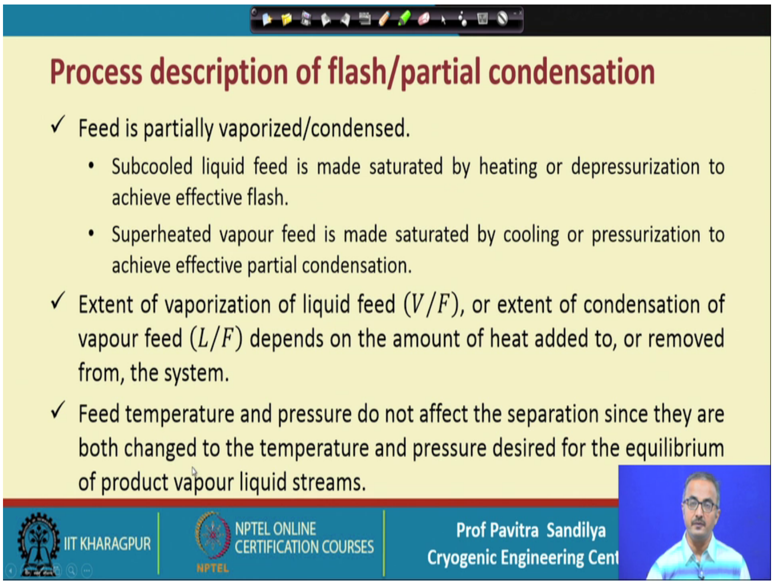

## Process description of flash/partial condensation

- ✓ Feed is partially vaporized/condensed.
  - Subcooled liquid feed is made saturated by heating or depressurization to achieve effective flash.
  - Superheated vapour feed is made saturated by cooling or pressurization to achieve effective partial condensation.
- ✓ Extent of vaporization of liquid feed $(V/F)$, or extent of condensation of vapour feed $(L/F)$ depends on the amount of heat added to, or removed from, the system.
- ✓ Feed temperature and pressure do not affect the separation since they are both changed to the temperature and pressure desired for the equilibrium of product vapour liquid streams.

Now, let us see how with describe the process both for the partial condensation and flash vaporization the feed is either partially vaporized or condensed.

Now, sub cooled liquid feed if we have then it has to be first brought to the saturated condition then only we do the flash vaporization and if we have superheated vapor first, it has to be cooled to make it saturated and then we do the partial condensation in both the cases. Now, there will be generation of some vapor or some liquid and the extent of the vaporization of the feed or the extent of the condensation of the feed these are given by some ratio V by F that is the vapor to feed ratio or L by F the liquid to feed ratio that depend on the amount of heat added or removed from the system.

Now, feed temperature and pressure do not affect these conditions, they are more dependent on the equilibrium temperature and pressure of the product vapor and liquid streams.

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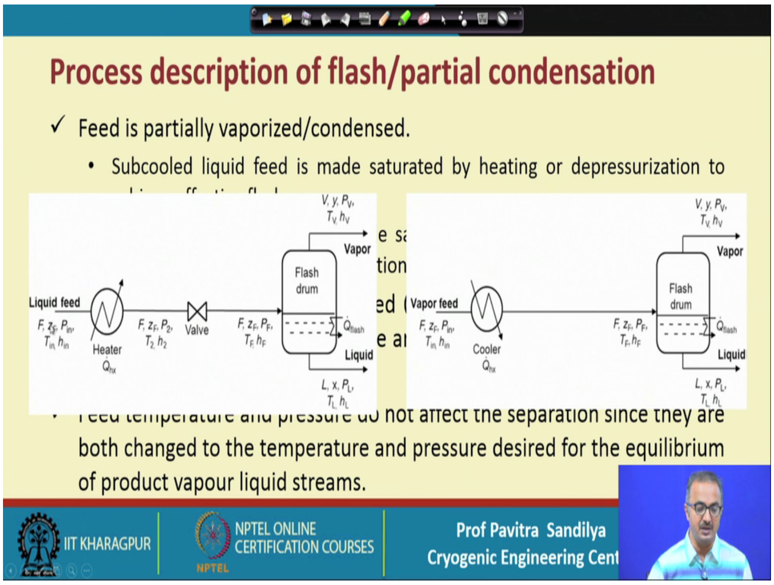

## Process description of flash/partial condensation

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Now, here the pictorial depiction of these two processes here we find for the partial vapor a flash vaporization we have a liquid feed with these conditions that F is represents the flow rate Z f is the feed composition P in t in H in, they are the pressure temperature and the enthalpy and these are passed through the heater, it is brought to some higher temperature.

And there is a valve this valve ensures that we are able to decrease the pressure or throttle it and we when we do it this liquid flashes that is goes into a vapor phase partially and then this is a flash drum in which we are separating out the 2 phases and we assume that these vapor and liquid streams are getting sufficient time for exchange of the various component and come to equilibrium and ultimately, we get the vapor product from the top and liquid from the bottom and if need be we may have to add or take out some amount of and the heat of this flash.

This depends on whether we are doing isothermally or whether we are doing adiabatically similarly for the partial condensation, we have a vapor feed in this is passed through a cooler and by passing through cooler, again, we generate the 2 streams that liquid is generated from the vapor and again this particular phase separator gives us a vapor and liquid stream and it could be carried out either isothermally or adiabatically if it is adiabatic in the both the Qs will be 0.

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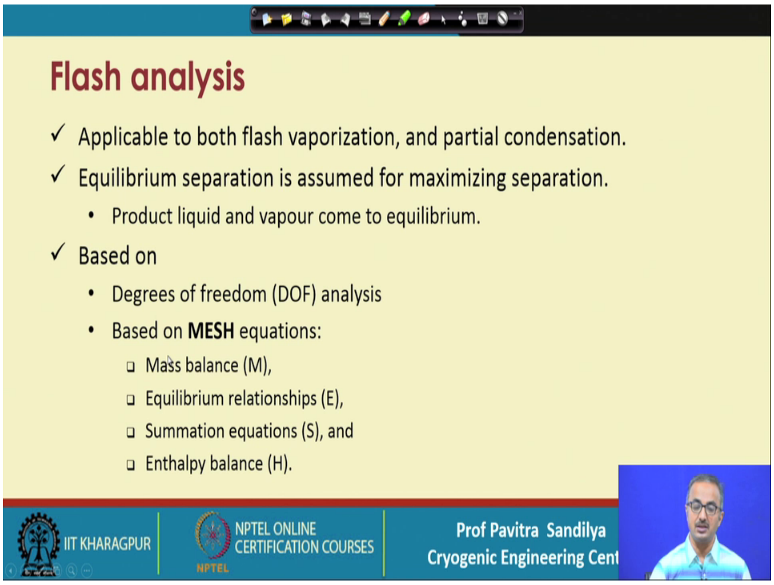

## Flash analysis

- ✓ Applicable to both flash vaporization, and partial condensation.
- ✓ Equilibrium separation is assumed for maximizing separation.
  - Product liquid and vapour come to equilibrium.
- ✓ Based on
  - Degrees of freedom (DOF) analysis
  - Based on **MESH** equations:
    - ☐ Mass balance (M),
    - ☐ Equilibrium relationships (E),
    - ☐ Summation equations (S), and
    - ☐ Enthalpy balance (H).

Now, let us go to the analysis of these 2 processes whatever we are going to learn now is applicable both 2 flash vaporization as well as to partial condensation here we are assuming that there is equilibrium after separation because equilibrium will tells us about the maximum possible separation so; that means, the vapor and liquid streams are coming to equilibrium now this analysis is based on the following. First, we do a degrees of freedom analysis in which we find out the minimum number of properties to be specified to completely describe the system and next, we come to a set of equations what we in short call mesh this mesh stands for m stands for mass balance E stands for equilibrium relationship S stands for summation equation and H stands for the enthalpy balance equation.

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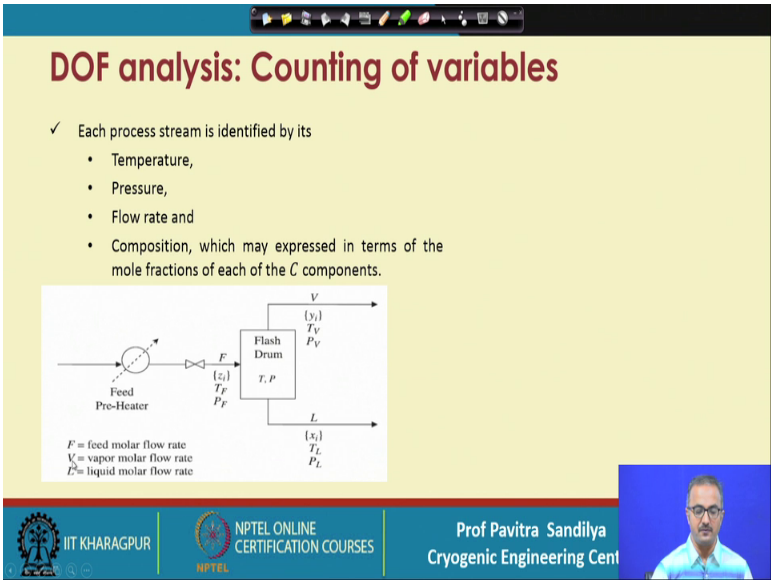

## DOF analysis: Counting of variables

✓ Each process stream is identified by its

- Temperature,
- Pressure,
- Flow rate and
- Composition, which may expressed in terms of the mole fractions of each of the $C$ components.

Before, now we come to the degrees of freedom analysis or DOF analysis in this, before we go to do that we first see that each stream is identified by temperature pressure flow rate and its composition and composition means we are assuming that there are C number of components in any stream. Now here we are going to refer to this particular system, here we have a feed which with flow rate of F and vi vapor and liquid which loaded V and L as a product and then we have use some few notations here.

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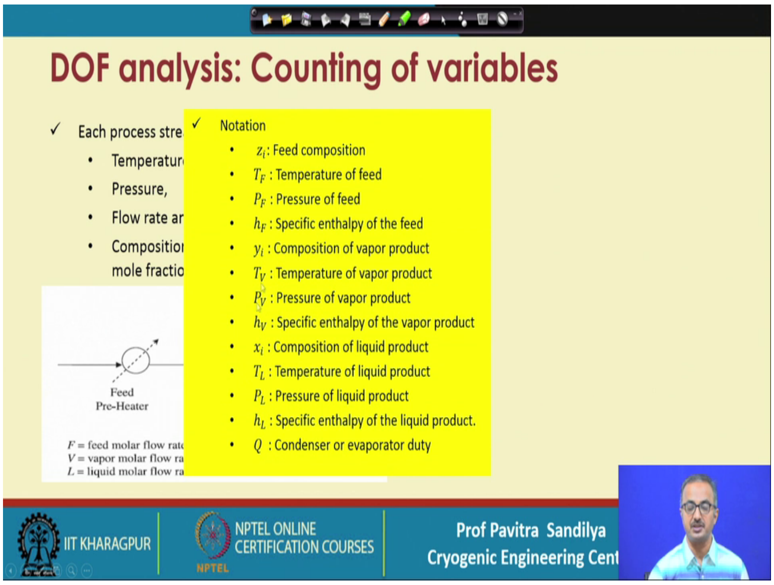

## DOF analysis: Counting of variables

✓ Each process stre

- Temperatur
- Pressure,
- Flow rate ar
- Compositio mole fractio

✓ Notation

- $z_i$: Feed composition
- $T_F$ : Temperature of feed
- $P_F$ : Pressure of feed
- $h_F$ : Specific enthalpy of the feed
- $y_i$ : Composition of vapor product
- $T_V$ : Temperature of vapor product
- $P_V$ : Pressure of vapor product
- $h_V$ : Specific enthalpy of the vapor product
- $x_i$ : Composition of liquid product
- $T_L$ : Temperature of liquid product
- $P_L$ : Pressure of liquid product
- $h_L$ : Specific enthalpy of the liquid product.
- $Q$ : Condenser or evaporator duty

The notations are that by Zi represent the feed composition of the ith component TF, PF are the temperature pressure of the feed respectively the HF is the specific enthalpy of the feed Yi is the composition of the vapor product TV, PV are the vapor temperature pressure respectively, HV is the enthalpy of the vapor Xi is the composition of the liquid TL, PL, HL are the temperature pressure enthalpy of the liquid stream respectively and Q is any kind of condenser or evaporator duty.

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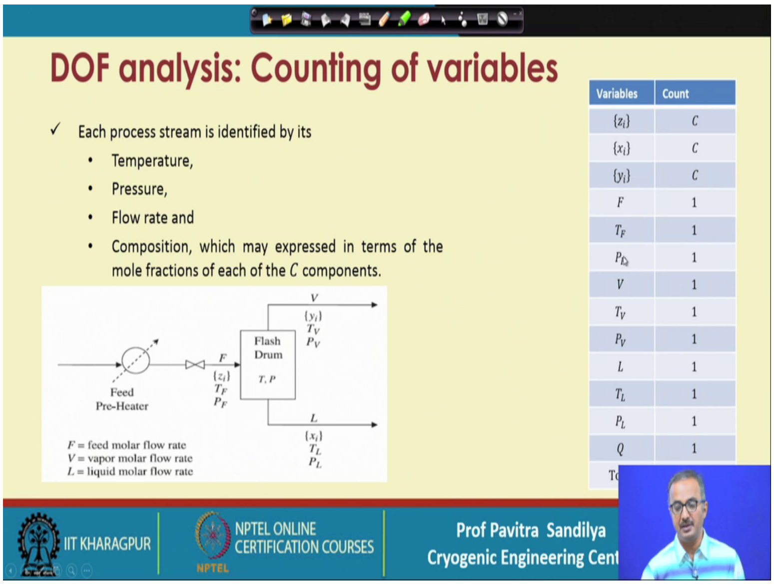

## DOF analysis: Counting of variables

✓ Each process stream is identified by its

- Temperature,
- Pressure,
- Flow rate and
- Composition, which may expressed in terms of the mole fractions of each of the $C$ components.

$F$ = feed molar flow rate
$V$ = vapor molar flow rate
$L$ = liquid molar flow rate

| Variables | Count |
|---|---|
| $\{z_i\}$ | $C$ |
| $\{x_i\}$ | $C$ |
| $\{y_i\}$ | $C$ |
| $F$ | 1 |
| $T_F$ | 1 |
| $P_F$ | 1 |
| $V$ | 1 |
| $T_V$ | 1 |
| $P_V$ | 1 |
| $L$ | 1 |
| $T_L$ | 1 |
| $P_L$ | 1 |
| $Q$ | 1 |
| To | |

Now we first understand that how to count the variables. Now here we have C number of components in each of the feed vapor and liquid. So, Zi represents basically a vector of the compositions. So, we have put this curly bracket and here we see that there are C number of components. So, C number of mole fractions.

Similarly, we have Xi we have C number for the liquid for the vapor again we have C number of components; that means, C number of mole fractions, then the flow rate of the feed represents only 1 variable the TF PF V TV, PV, L, TL, PLP all of them represent only one quantity. So, we find that for all of them we count only one variables.

Now, now we see the total number of variables are 3 C plus 10.

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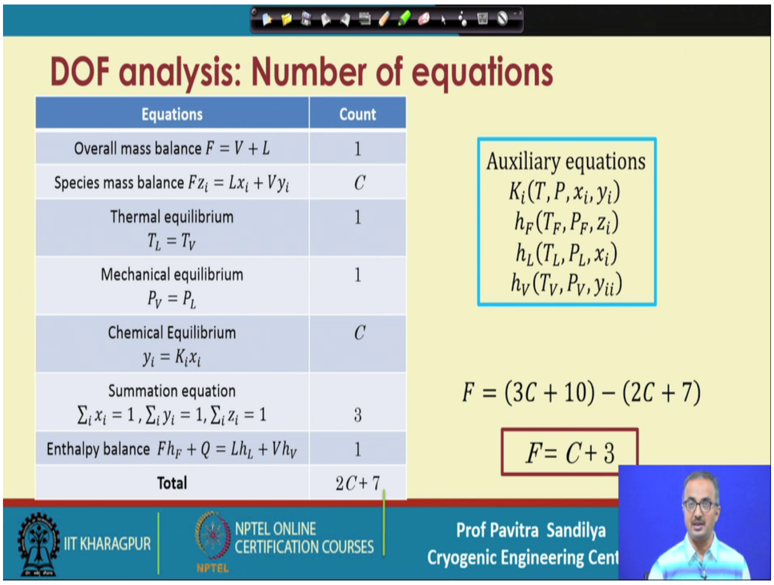

## DOF analysis: Number of equations

| Equations | Count |
|---|---|
| Overall mass balance $F = V + L$ | 1 |
| Species mass balance $Fz_i = Lx_i + Vy_i$ | $C$ |
| Thermal equilibrium<br>$T_L = T_V$ | 1 |
| Mechanical equilibrium<br>$P_V = P_L$ | 1 |
| Chemical Equilibrium<br>$y_i = K_i x_i$ | $C$ |
| Summation equation<br>$\sum_i x_i = 1, \sum_i y_i = 1, \sum_i z_i = 1$ | 3 |
| Enthalpy balance $Fh_F + Q = Lh_L + Vh_V$ | 1 |
| **Total** | $2C+7$ |

Auxiliary equations
$K_i(T, P, x_i, y_i)$
$h_F(T_F, P_F, z_i)$
$h_L(T_L, P_L, x_i)$
$h_V(T_V, P_V, y_{ii})$

$$F = (3C + 10) - (2C + 7)$$

$$\boxed{F = C + 3}$$

Now, let us see that how many equations are there which correlate these variables first we come to the overall mass balance that is F equal to V plus L that is only 1 equation, then we write the component material balances for each of the species then here we find for ith species we are writing that whatever is going with the system, this is where like is and coming out is Lxi into V by i, these are the component flow rates. So, we are we have C number of equations, then we have thermal equilibrium Ts equal to TV that represents 1 then mechanical equilibrium PV equal to PL that is 1 then chemical equilibrium Yi equal to K i xi and it goes for each of the components.

So, we have C number of equilibrium relationships then we have summation equation which tells us that the summation of the mole fractions always equal to one. So, we have three equations for the three streams and that is three number of equations here and for enthalpy balance we write it for the overall system.

So, here we have only one equation and in this equation, we have the enthalpy going with the feed and some amount of a Q, this Q may be positive or negative depending on whether we are heating it or cooling it and then we have the enthalpies going out with the liquid and vapor streams. So, this is 1 and then we count these equations this comes to 2 C plus 7.

Now, please understand that in these equations we have many variables like this K i, then Hi, HF, HL, HV, all these things have to be found out by the knowledge of temperature pressure and the compositions. So, we are not counting them as the number of the variables. So, now we have the degrees of freedom F as equal to total number of variables minus the number of equations correlating these variables and this comes out to C plus three; that means, we have to specify C plus 3 number of properties to completely describe the system and analyze it.

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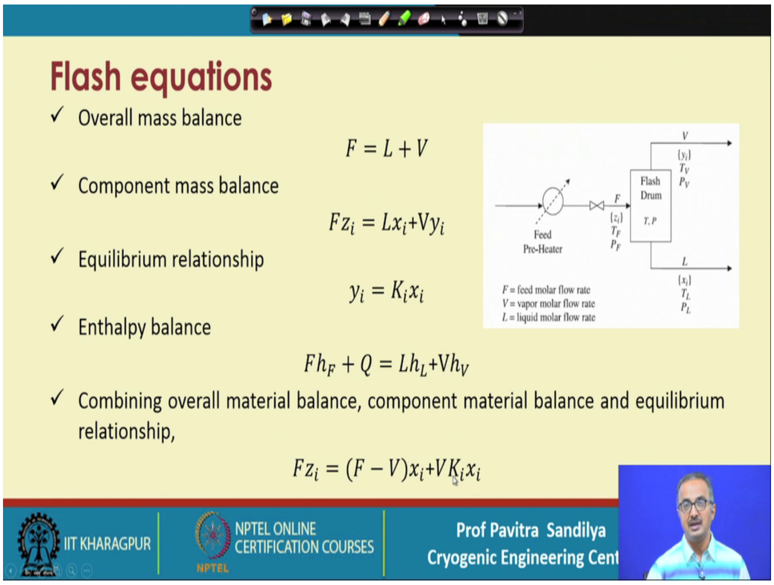

## Flash equations

- ✓ Overall mass balance

$$F = L + V$$

- ✓ Component mass balance

$$Fz_i = Lx_i + Vy_i$$

- ✓ Equilibrium relationship

$$y_i = K_i x_i$$

- ✓ Enthalpy balance

$$Fh_F + Q = Lh_L + Vh_V$$

- ✓ Combining overall material balance, component material balance and equilibrium relationship,

$$Fz_i = (F - V)x_i + VK_i x_i$$

F = feed molar flow rate
V = vapor molar flow rate
L = liquid molar flow rate

Now, we write the flash equation says as I told you that this referring to this particular figure will get the overall material balance as F is equal to L plus, then we have the component material balance as molar flow rate into the mole fraction that is the component molar flow rate equal to the Lxi plus Vyi and then we have the equilibrium relationship that is Yi equal to K i xi enthalpy balance as this and then we have the after writing these equations what we do we simply combine the various equations.

So, here we are combining the overall material balance the component material balance and the equilibrium relationship by combining this we get this equation and in this equation we have taken out the L by replacing it by F minus V and also taken out yi by replacing it with K i into xi.

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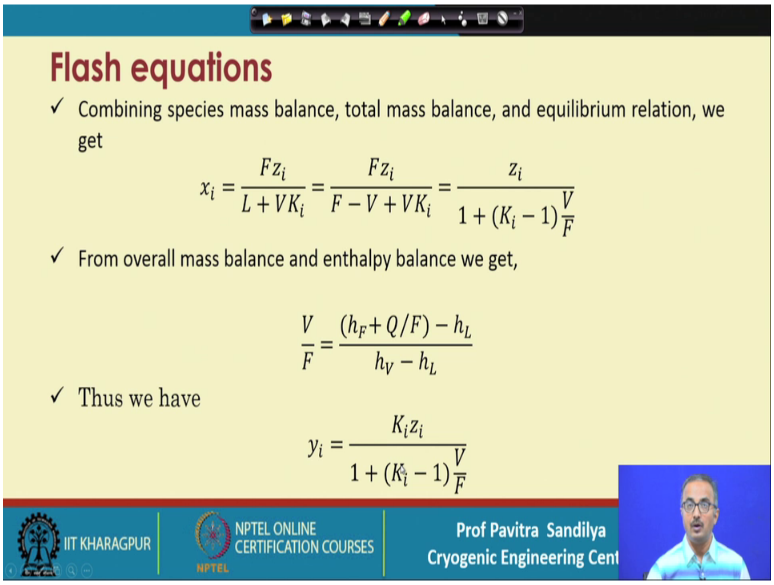

## Flash equations

- ✓ Combining species mass balance, total mass balance, and equilibrium relation, we get

$$x_i = \frac{Fz_i}{L + VK_i} = \frac{Fz_i}{F - V + VK_i} = \frac{z_i}{1 + (K_i - 1)\frac{V}{F}}$$

- ✓ From overall mass balance and enthalpy balance we get,

$$\frac{V}{F} = \frac{(h_F + Q/F) - h_L}{h_V - h_L}$$

- ✓ Thus we have

$$y_i = \frac{K_i z_i}{1 + (K_i - 1)\frac{V}{F}}$$

Now, when we rearrange this equation, we get this particular equation and in this particular equation we find the mole fraction of any component i in the liquid phase is given in terms of the mole fraction in the feed and this V by F ratio that is the how much fraction of the feed has been vaporized and in terms of the K I, similarly when we combine the overall mass balance with the enthalpy balance we get this particular equation for this V by f; that means, this V by F is given in terms of the enthalpies.

Now, we have the yi equal to K i xi that is we multiplied simply this equation with K i we get the value of yi now.

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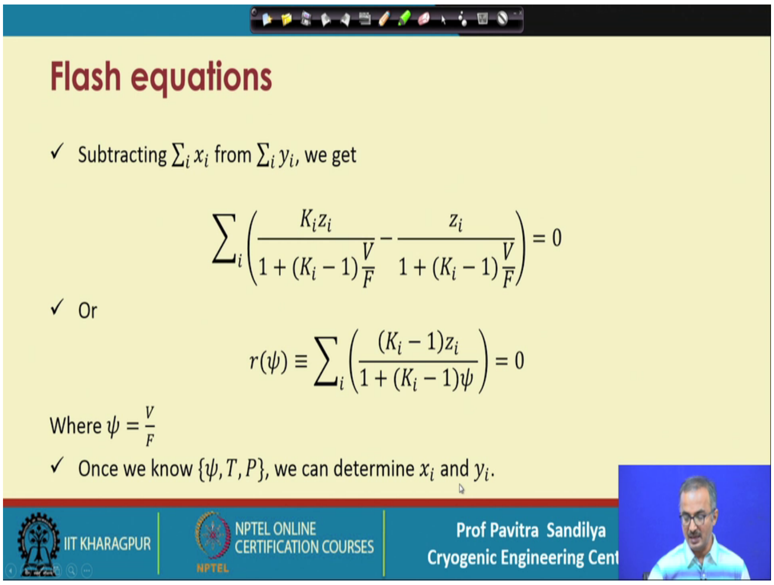

## Flash equations

- ✓ Subtracting $\sum_i x_i$ from $\sum_i y_i$, we get

$$\sum_i\left(\frac{K_i z_i}{1+(K_i-1)\frac{V}{F}}-\frac{z_i}{1+(K_i-1)\frac{V}{F}}\right)=0$$

- ✓ Or

$$r(\psi)\equiv\sum_i\left(\frac{(K_i-1)z_i}{1+(K_i-1)\psi}\right)=0$$

Where $\psi=\frac{V}{F}$

- ✓ Once we know $\{\psi, T, P\}$, we can determine $x_i$ and $y_i$.

Now, we are going to use a summation equation that summation of xi is equal to 1 summation of yi is also equal to 1. So, when we subtract this summation of xi and summation of yi we get 0. So, that is how we are able to get this particular equation in this equation can be solved if we know the value of the V by F and the value of the ki.

So, here we define this equation in terms of some ah factor psi which is nothing, but the V by F and here, we have put this thing in tough psi and ki. So, this is a non-linear equation. So, we need to use some kind of numerical technique to solve this equations please mind this equation stands for all the i components and this once we know this side temperature pressure we can determine xi and yi.

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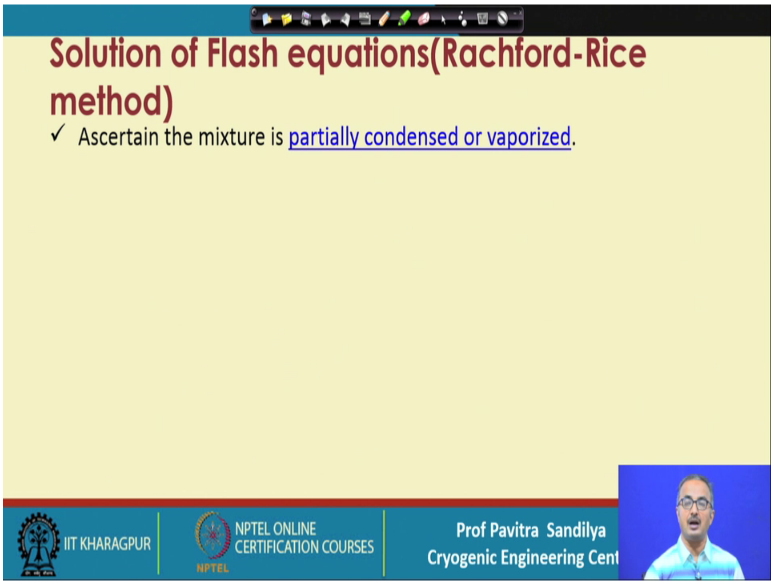

## Solution of Flash equations(Rachford-Rice method)

- ✓ Ascertain the mixture is partially condensed or vaporized.

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Now, let us go to solution of these equations, before we go to solve it, we have to first make sure that we have a partially condensed vapor or a partially vaporized liquid because if it is pure liquid or pure vapor then we are not going to get any kind of separation.

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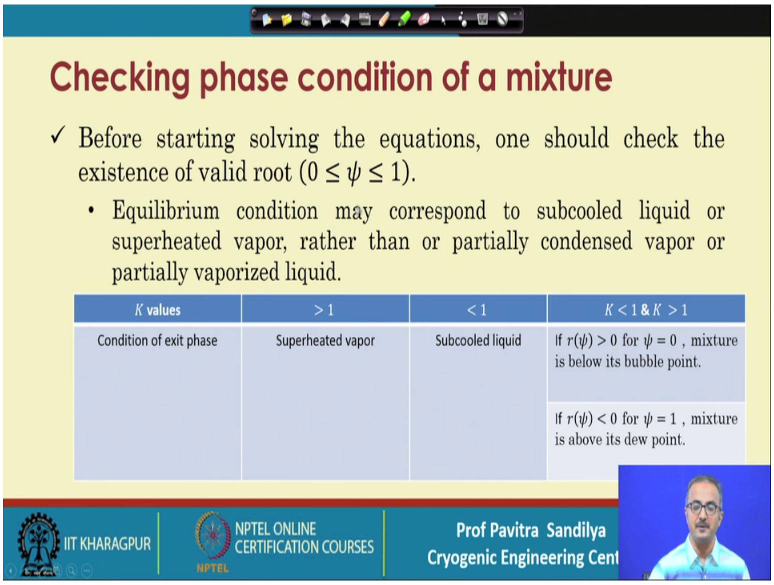

## Checking phase condition of a mixture

- ✓ Before starting solving the equations, one should check the existence of valid root ($0 \le \psi \le 1$).
  - Equilibrium condition may correspond to subcooled liquid or superheated vapor, rather than or partially condensed vapor or partially vaporized liquid.

| $K$ values | $> 1$ | $< 1$ | $K < 1$ & $K > 1$ |
|---|---|---|---|
| Condition of exit phase | Superheated vapor | Subcooled liquid | If $r(\psi) > 0$ for $\psi = 0$ , mixture is below its bubble point.<br>If $r(\psi) < 0$ for $\psi = 1$ , mixture is above its dew point. |

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So, to know this, again we have some kind of rules that first we shall see that if there is a partial condensed or partially vaporized then psi i must be lying between 0 and 1. So, here, we have that if all the k values are more than 1 that means we have superheated vapor. So, we will not be solving it again if you find that all the k values are less than 1 then we have sub cooled liquid, then also we will not be performing any kind of separation analysis.

Now, if we have some k k less than 1 and some k more than 1, then what you need to do, we shall be putting psi equal to 0 and check whether we are getting r psi more than 1 0 or not if it is more than 0, then we have a mixture which is below its bubble point that it is sub-cooled and if we put psi equal to 1 and we find that r psi is coming less than 0, then it its above its dew point; that means, it is a superheated vapor.

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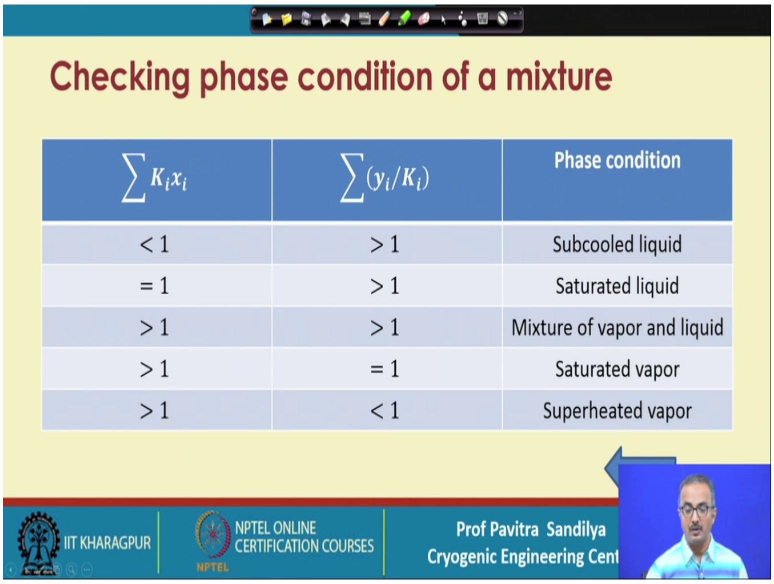

### Checking phase condition of a mixture

| $\sum K_i x_i$ | $\sum (y_i/K_i)$ | Phase condition |
|---|---|---|
| $< 1$ | $> 1$ | Subcooled liquid |
| $= 1$ | $> 1$ | Saturated liquid |
| $> 1$ | $> 1$ | Mixture of vapor and liquid |
| $> 1$ | $= 1$ | Saturated vapor |
| $> 1$ | $< 1$ | Superheated vapor |

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Now, the another way of doing and checking that whether we have a partially vaporized liquid or partially condensed vapor or not we what we do we take this summation K i xi and this summation of yi by K i and we check their values and we find that various combinations have been given by looking at these various combinations, we can make out that whether we have sub-cooled liquid saturated liquid mixture of liquid vapor saturated vapor or superheated vapour and naturally for our separation we would like to have mixture of vapor and liquid.

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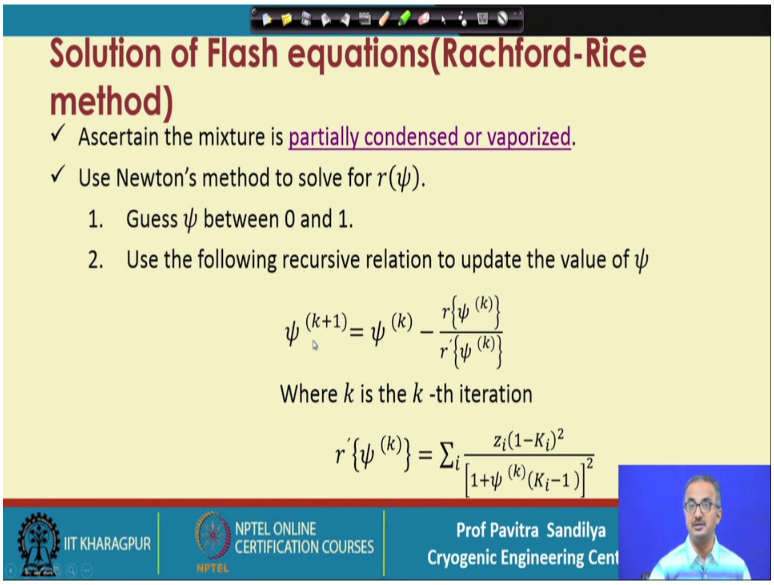

Solution of Flash equations(Rachford-Rice method)

- ✓ Ascertain the mixture is partially condensed or vaporized.
- ✓ Use Newton's method to solve for $r(\psi)$.
  1. Guess $\psi$ between 0 and 1.
  2. Use the following recursive relation to update the value of $\psi$

$$\psi^{(k+1)} = \psi^{(k)} - \frac{r\{\psi^{(k)}\}}{r'\{\psi^{(k)}\}}$$

Where $k$ is the $k$ -th iteration

$$r'\{\psi^{(k)}\} = \sum_i \frac{z_i(1-K_i)^2}{\left[1+\psi^{(k)}(K_i-1)\right]^2}$$

Now, once we have made sure that we have a partially condensed vapor or partially vaporized liquid. Now we go for it a solution and here we use a Newton's method and we know that psi has to lie between 0 and 1 and by Newton's method we know that a these are recurring relationship we find for finding the root in Newton Newton's method or Newton Raphson method for multiple variables he find that psi this K i represent this k small k represents the number of iterations.

So, we update the psi value from the previous value of the psi by this relationship this is r psi k and this is r prime that is dr by d psi this derivative. So, with this particular relationship we can update the value of psi and this; this is the expression for i prime psi k.

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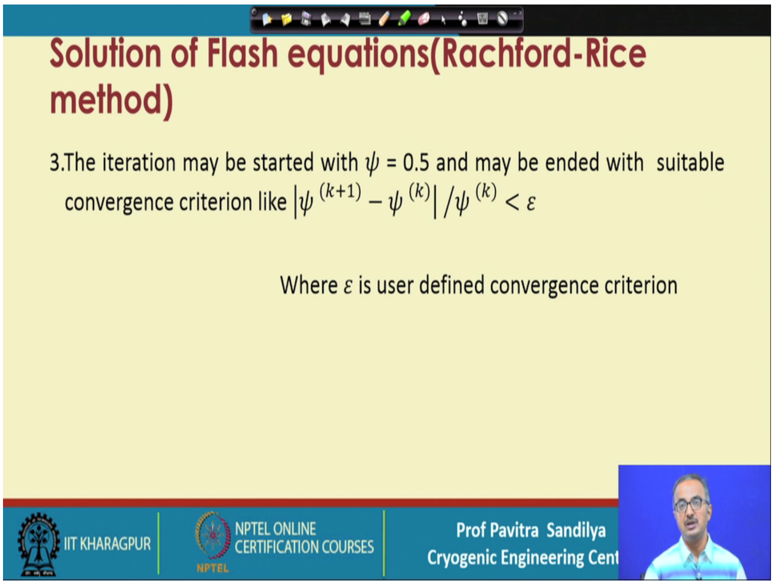

## Solution of Flash equations(Rachford-Rice method)

3.The iteration may be started with $\psi$ = 0.5 and may be ended with suitable convergence criterion like $\left|\psi^{(k+1)} - \psi^{(k)}\right| / \psi^{(k)} < \varepsilon$

Where $\varepsilon$ is user defined convergence criterion

And what we do that after each iteration we may check that how the value of psi between two consecutive iterations are changing and there are many ways of finding this, but doing this comparison one way is this way that we take the absolute value of the difference between the psi in 2 consecutive iterations divided by the psi value of the present iteration and check whether it is coming less than some user defined convergence factor.

Now, if it is less than that all equal to then, we can say that we are converging to the solution otherwise we have to keep repeating this exercise.

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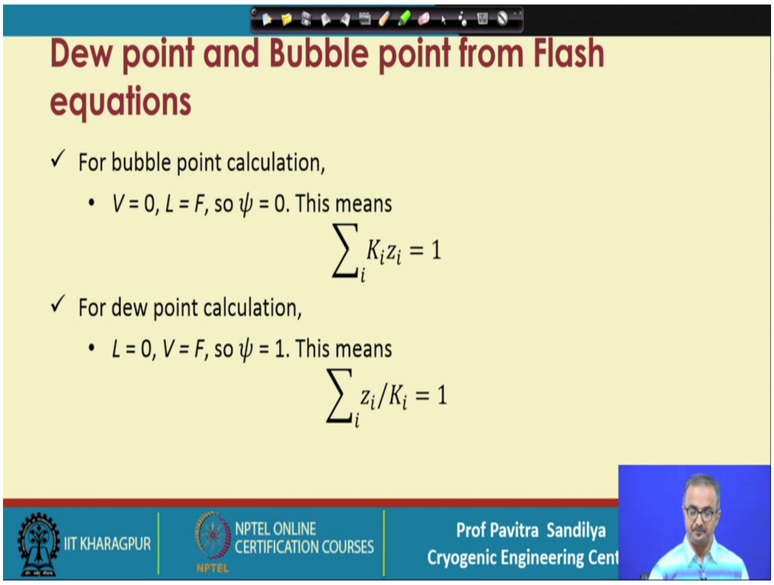

## Dew point and Bubble point from Flash equations

- ✓ For bubble point calculation,
  - $V = 0, L = F$, so $\psi = 0$. This means

$$\sum_i K_i z_i = 1$$

- ✓ For dew point calculation,
  - $L = 0, V = F$, so $\psi = 1$. This means

$$\sum_i z_i / K_i = 1$$

Now, after doing this flash analysis we also find that this analysis may also be used to find out the dew point and bubble point calculations for the bubble point calculations we find that we have there is no vapor and. So, there is bubble point means what as you recall the bubble point means when first time the liquid is going to produce the first bubble.

So, in that situation, we have only the liquid present with us and there is no vapor. So, that is why the vapor has been taken to be 0 and if I put that with a feed is equal to the l. So, we find the psi is equal to 0 and if you put psi equal to 0 in the previous equation, we find we will end up with this particular equation which is same as the one we learnt earlier in the lecture on due point and bubble point calculations.

Similarly, if we want to find the dew point then what we do we simply take the L to be 0 because due point means a vapor is going to condense and give the first droplet of liquid. So, in that case we still are going to have the liquid is not present. So, we put L equal to 0 and then feed is same as the vapor and then; that means, psi equal to 1 and when we put psi equal to 1, we find that this is the equation we get and this you see is the same equation we had earlier for the dew point calculation; that means, this particular formulation of flash is not only going to give us the solution for the liquid and vapor streams we obtain after flash vaporization or partial condensation, but they may also be used to find out the dew point and bubble point pressure or temperature.

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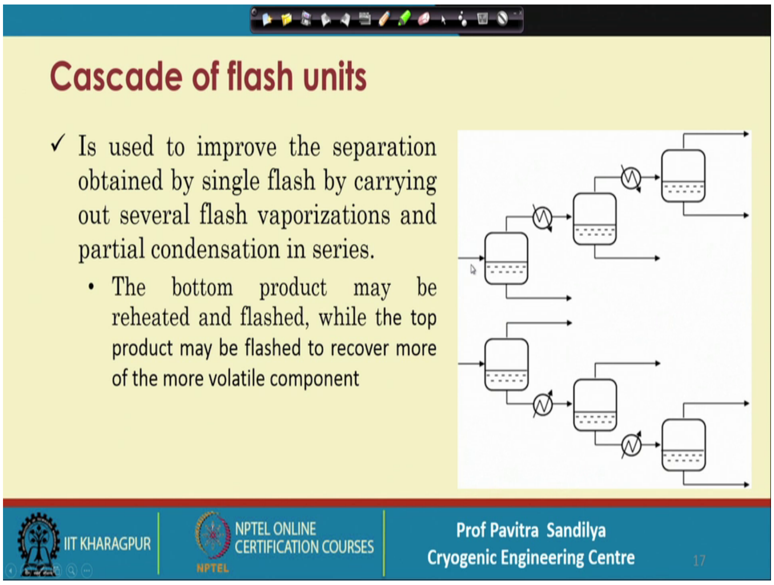

## Cascade of flash units

- ✓ Is used to improve the separation obtained by single flash by carrying out several flash vaporizations and partial condensation in series.
  - The bottom product may be reheated and flashed, while the top product may be flashed to recover more of the more volatile component

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Now, this particular flash is useful for separation, but we find that the vapor and liquid streams may not meet the desired purification or desired separation. So, to make the desired separation what we need to do that we need to make them multiple flashes may be carried out. So, by doing multiple flashes we can achieve the desired separation.

So, here we have shown a typical one thing that here if we want to enrich the vapor then what we do that we take the feed here and then after first flash we take this vapor out and this vapor is again going for partial condensation and it is again in the second after second element then again we take the vapor out and go for another partial condensation and in this way by consecutive partial condensation, we are able to enrich the vapor; that means, we are making the vapor more and more enriched with the more volatile component.

So, here we are not doing anything with the liquid because our desired product is the vapor on the other hand if we want to have a enriched liquid, then what we do we take this feed and we again flash it now we are dealing with only liquid this liquid is taken and taken for such vaporization consecutively until and unless we get the desired separation in the liquid. So, when we combine these two things then we find that we can get both enriched vapor as well as enriched liquid. So, that is how we are doing the cascade of flash units to get the separation of a of components and this is true not only for just binary components this may be used for multi components also.

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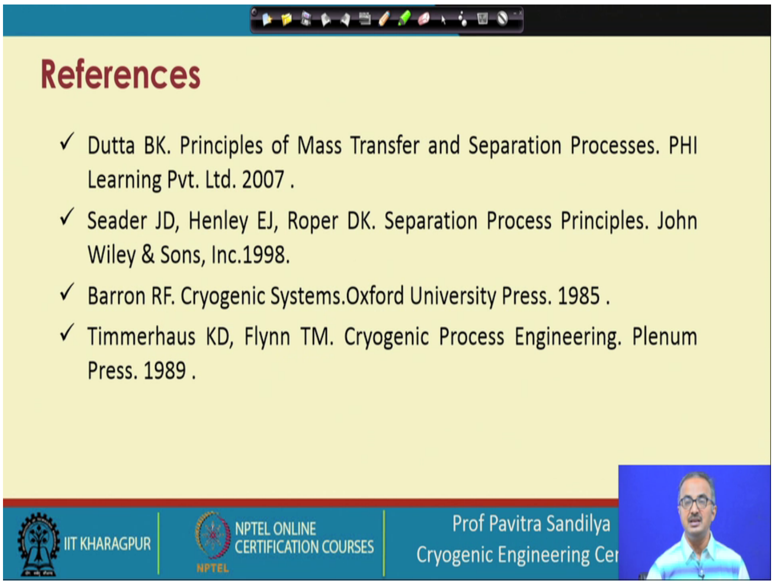

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Now, these are the references which you may refer to for more detailed studies on these processes.

Thank you.