Principles and Practices of Process Equipment and Plant Design

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Module - 02
Lecture - 09
Flash Distillation and Design problem

Well hello everybody. So, in the last class, we had started the process of distillation and I had given you a brief introduction about the different distillation processes. I had mentioned that the first discussion will be on the Flash Distillation, then the rectification or the fractionator and then the batch distillation column.

So, today we are going to start our discussions on a brief overview of the design considerations for designing a Flash Distillation column.

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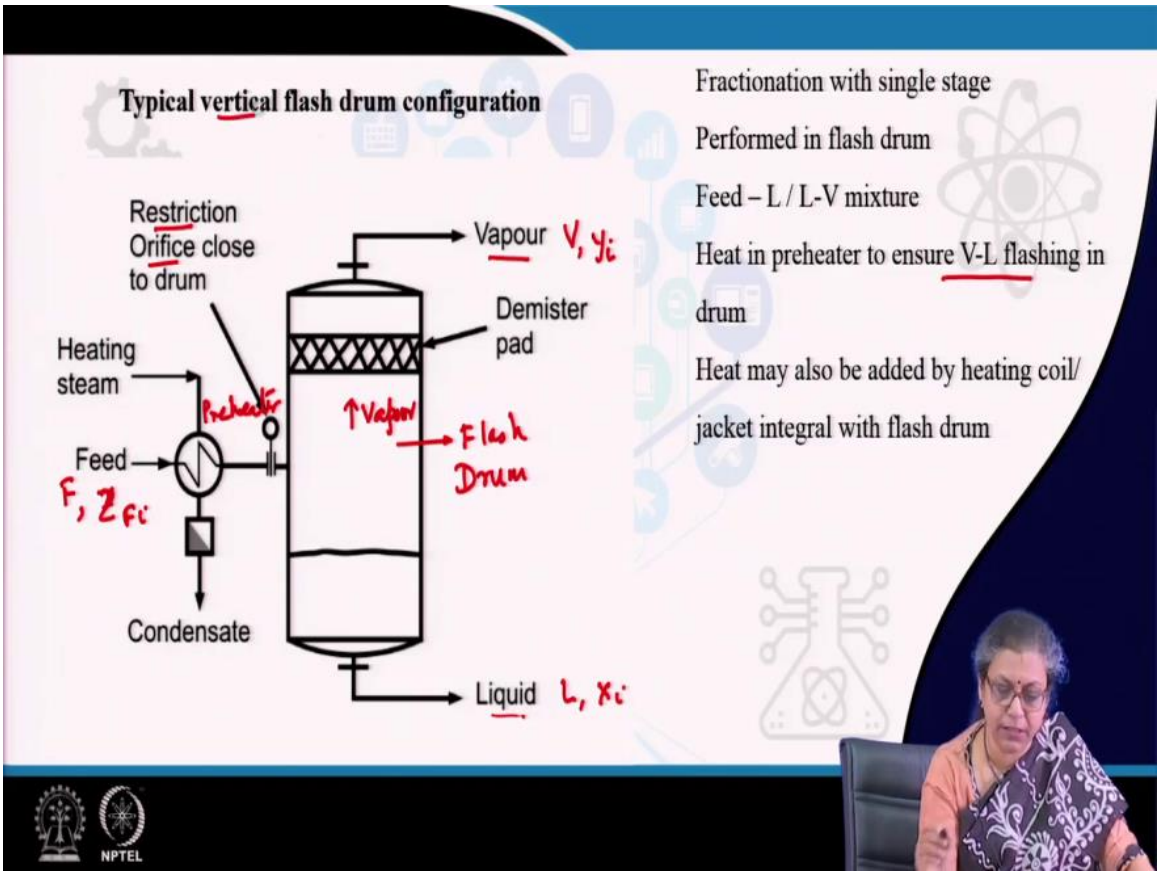

what do we have? We have a feed flow rate is F and the composition is denoted by z_{Fi} and the feed is usually heated in a preheater. This preheater heats the feed such that after it is throttled through the valve, it reaches the condition where it can flash to form the vapour and the liquid streams which meet the composition specifications which are specified. The compositions can be specified either concerning the vapour product or the liquid product.

So, therefore, the feed preheater is required to ensure that vapour liquid flashing occurs in the flash drum. The equipment used for flash distillation is usually called the flash drum.

Instead of the preheater, we can also supply heat inside the flash drum by either inserting coils at the bottom or maybe by a jacket. Usually for such cases condensing steam or a condensing fluid is used to provide the heat. But fluid heating inside the flush drum is applicable for very small units. But for such cases, the heat transfer coefficient is controlled by the liquid inside the drum. As the heat transfer coefficient is less for liquid, so the heat transfer is not so efficient in this case.

So, usually, we prefer the preheater. From the preheater, feed goes to a restriction orifice. In this restriction orifice, flashes the liquid such that the two-phase mixture forms inside the flush drum. So, it is needless to say that the restriction orifice is placed as close to the drum as possible such that the entire flashing occurs inside the drum and the vapour-liquid separator separation can happen inside the flash drum.

Once it happens, the vapour rises. The vapour flow rate is V and usually, these are multi-component mixtures. Therefore, the composition of each component is denoted by y_i and the liquid drawn is L and the composition is given by x_i.

Now, after separation, the liquid forms small droplets. These droplets can be drawn out with vapour. To arrest the liquid droplets and to ensure that almost dry vapour comes out of the flash drum, we have demister pads that arrest the liquid and prevent the liquid passage along with the vapour.

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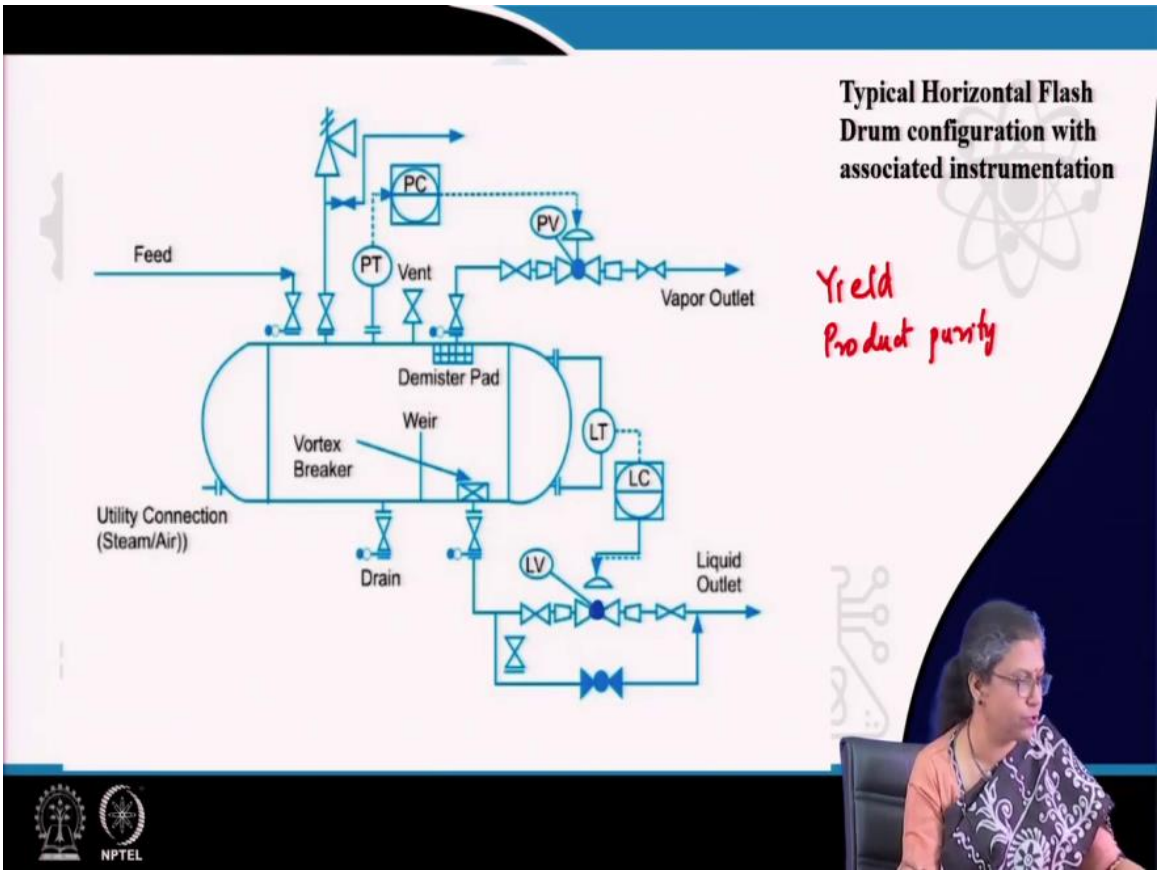

These flash drums can be vertical or horizontal. In a horizontal flash drum, the demister pad is usually located near the vapour outlet line. The choice between the horizontal and the vertical flash drum depends on certain considerations which will be discussed in detail when will be discussing the pressure vessels. For the moment it is sufficient for you to remember that usually for vertical flash drums the length to diameter (L/D) ratio is around 3 to 5.

When it exceeds 5 generally go for a horizontal flash drum. In a horizontal flash drum, the vapour has to flow through a larger path. We get a greater distance for vapour liquid separation and while it is flowing the vapour velocity decreases. Therefore, the separation is naturally better. Further, when the headspace is a limitation, we go for a horizontal vessel. When the floor space is limited, we go for a vertical vessel.

So, with all these considerations, we select whether we will take a vertical or a horizontal vessel. Now, we need to know the control parameters in a flash drum. The first thing is the pressure, how is the pressure controlled? The pressure can be controlled by using the

control valve in the vapour outlet line. So, by regulating the vapour flow, the pressure inside the drum is controlled. The other thing that we need to control is the liquid level. So, for controlling the liquid level, there is a level controller which is again regulated by regulating the flow rate of the liquid outlet. These are the two basic things that need to be controlled.

The condition in the flash drum should be such that on flashing the vapour and liquid stream generated should meet the specifications. The specifications can be specified either in terms of the yield. Yield indicates the amount of vapour fraction or in terms of product purity. Say for example, for the more volatile component we need this much amount of product separation. It can be anything of that sort.

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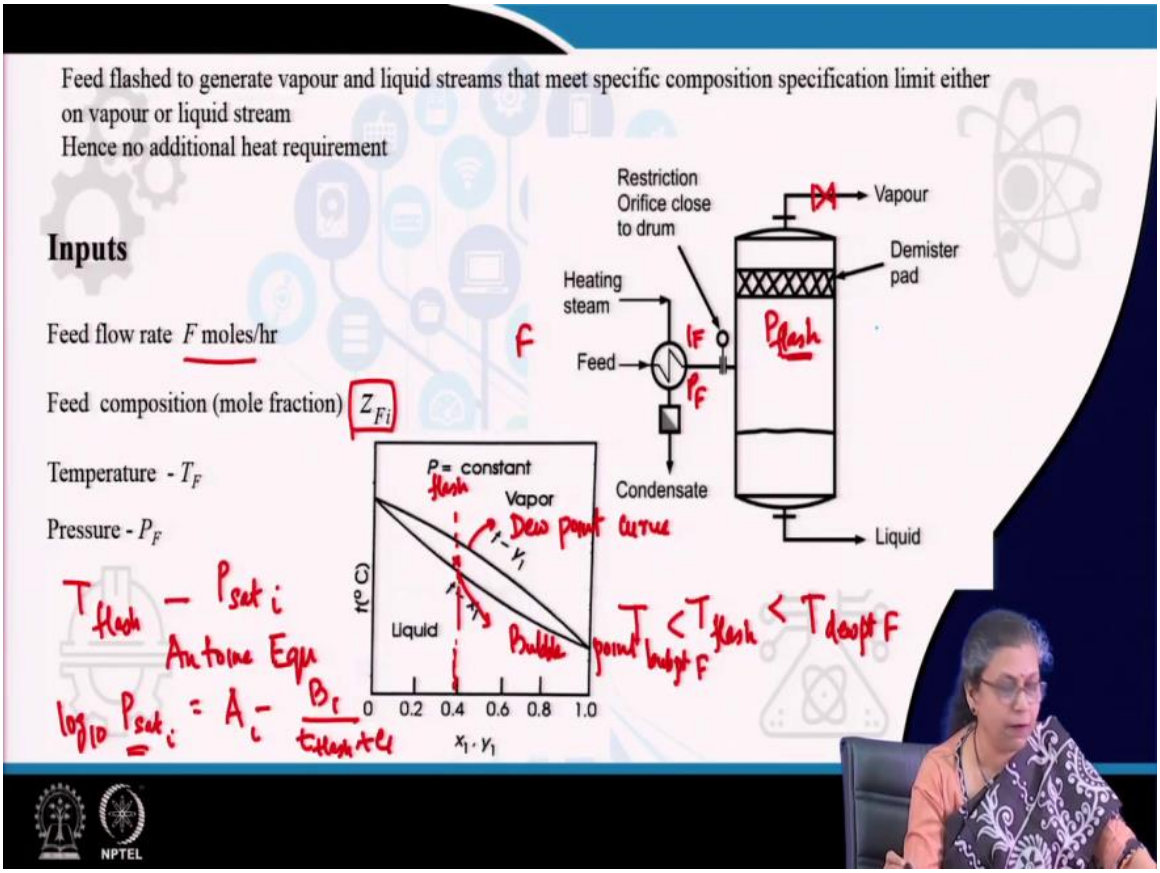

So, therefore, now if you have to design this particular flash drum tell me what are the inputs that we already know. We know the feed flow rate, F and the feed composition Z_{Fi}. Again you just recollect it is Z_{Fi} because it can be X_{Fi} or it can be Y_{Fi}. After the preheater, we know the temperature of the feed (T_F) and the pressure of the feed (P_F). Now, once the

feed enters through orifice into flash drum then it flashes. I have told you that the pressure inside the drum is regulated by a control valve which is placed in the vapour line. So, therefore, by means of the control valve we can control the pressure inside the flash drum. So, once we know the pressure inside the flash drum say P_{flash}. we have the t-x-y plot. So, therefore, now how do we proceed with the distillation over the design of the flash drum?

So, suppose we know the composition. Now, once it is flashed definitely the composition will lie on this particular line. Since it is separating into a vapour and a liquid feed. So, quite naturally, it should lie on this particular vertical line between the dew point and the bubble point.

So, therefore, the flashing should be such that the temperature lies between the dew point of the feed and the bubble point of the feed. Since P_{flash} can be regulated accordingly, we can select a T_{flash} such that the T_{flash} lies between the bubble point and the dew point say at somewhere at this particular instant.

$$T_{bubble,F} < T_{flash} < T_{dew,F}$$

So, at this particular point, we can find out corresponding to T_{flash}. we can find out the saturated vapour pressure for each component "i". How do we do it? If you recollect during my discussions on equilibrium we had told you that p_i^{sat} is obtained from Antoine's equation.

What is Antoine's equation? p_i^{sat} is equal to A_i, A_i means the Antoine constant corresponding to component "i", minus B_i plus t_{flash} plus $\log_{10} p_i^{sat}$, this is equal to t flash plus C_i. So, for each component Antoine constants are available. So, accordingly from there we can find out once we know t flash we can find out P saturated i for each of them.

Antonie's Equation: $$log_{10}P_i^{sat} = A_i - \frac{B_i}{t_{flash}+C_i}$$

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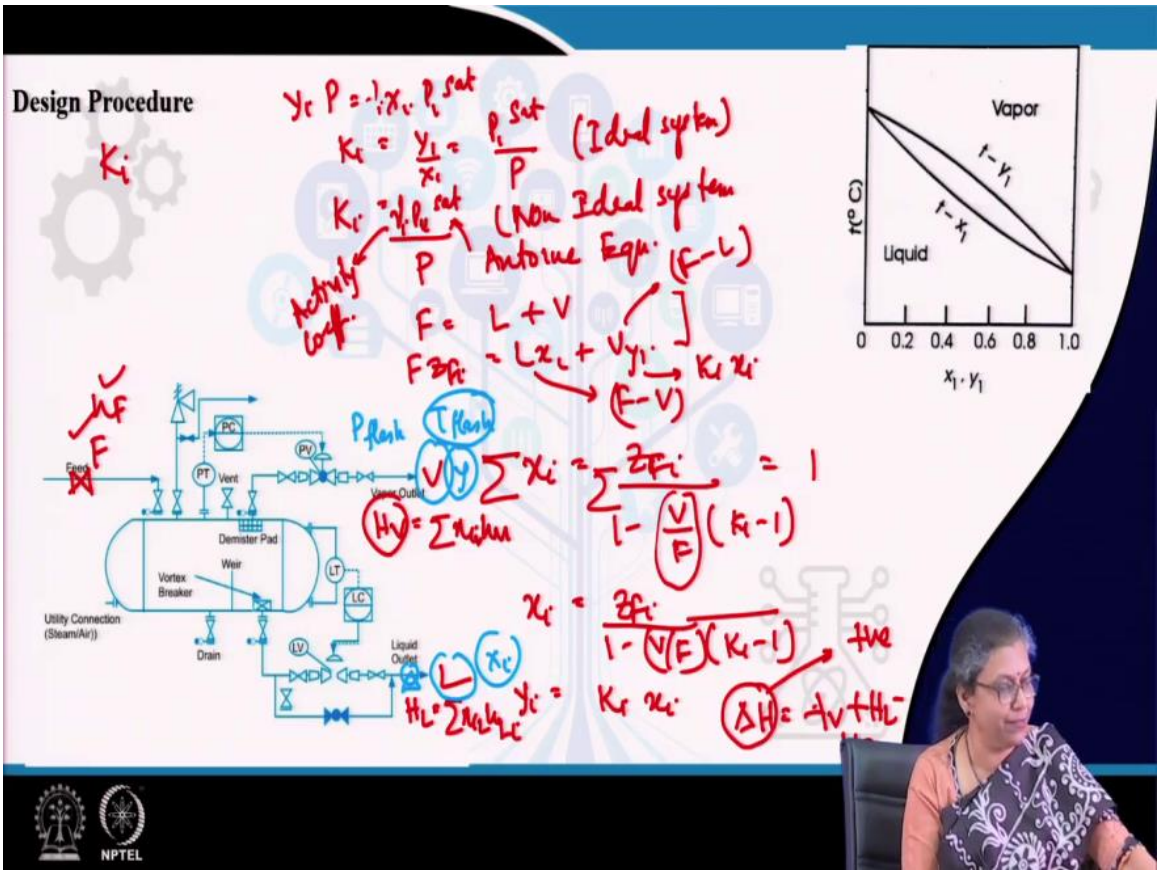

Once we can find out P_i^{sat} for each of them, then from there what we can do? We can find out K_i. If suppose we are dealing with hydrocarbon distillation that case usually we are dealing with the adjacent members of the homologous series. In this cases we can assume that the system is ideal. For an ideal system you already know Raoult's law. It gives you $y_i P$ equals to $x_i P_i^{sat}$. As a result of which K_i is nothing, but equal to P_i^{sat}/P.

$$y_i P = x_i P_i^{sat}$$

$$K_i = \frac{y_i}{x_i} = \frac{P_i^{sat}}{P}$$

If it is for a non-ideal system then quite naturally the expression of K_i will be like this:

$$K_i = \frac{y_i}{x_i} = \frac{\gamma_i P_i^{sat}}{P}$$

If a system is non-ideal then in that case along with Antoine equation to find out P_i^{sat}. We also need some particular activity coefficient models to find out the γ_i. As I had already

mentioned the activity coefficient models which are usually used are either the NRTL model or the UNIQUAC or the Wilson model etc.

I will write down the basic mass and component balance equations for flash distillation.

$$F = L + V$$

$$FZ_{Fi} = L_{xi} + V_{yi}$$

Now from these two equations, we can find out x_i for each corresponding thing we substitute y_i as $K_i x_i$ and we can also substitute L as (F-V). Then from there what we can find out each particular x_i in terms of F and we can denote the V/ F as a ratio. Therefore, from these two equations, we can find out x_i as Z_{Fi} /(1- (V/F)(K_i -1)). Instead of V/ F, you can also write it down in terms of L/ F. In that case you have to just substitute this with (F- L).

$$x_i = \frac{Z_{Fi}}{1 - \frac{V}{F}(K_i - 1)}$$

So, therefore, for each composition, if we write down the above equation and we know that $\sum x_i$ has to be equal to 1 which automatically implies that this has to be equal to 1. So, therefore, if we can write down this equation for each case then from this particular equation we know everything except V/ F. So, therefore, we can from this equation we can find out V/ F.

$$\sum x_i = \sum \frac{Z_{Fi}}{1 - \frac{V}{F}(K_i - 1)} = 1$$

Once we can find out V/ F from the second part of the equation. Then for each particular V/F, we can find out x_i just the way I had written for each particular V/F, x_i corresponds to it can be obtained from this equation.

$$x_i = \frac{Z_{Fi}}{1 - \frac{V}{F}(K_i - 1)}$$

Once we can find out x_i, we can find out y_i as K_i x_i.

$$y_i = K_i x_i$$

After that, we need to see whether the pressure and temperature which we had assumed that both have to lie between the dew point and the bubble point. For that, we need to check the "t- x-y" diagram.

So, therefore, we can just do an enthalpy matching to find out whether we have reached the correct value of V/F. How can we do it? We can find out the vapour enthalpy H_V. We can do it we can find out this H_V is nothing, but $\sum n_{iV} h_{Vi}$ for every component.

$$H_V = \sum n_{iV} h_{Vi}$$

We can find out the outlet enthalpy along with the liquid this will be H_L which is $\sum n_{iL} h_{Li}$.

$$H_L = \sum n_{iL} h_{Li}$$

We know that enthalpy of the feed which coming from orifice nozzle (throttling occur here) is increased or supplied at preheater. We know the same enthalpy is there after it is getting throttled. So, therefore, we are in a position to find out H_F.

Now under assuming that there are no heat losses etc. So, therefore, under the balanced conditions what do we expect? We expect that the enthalpy in should be equal to the enthalpy out. So, what do we do for this particular case? Suppose we define the enthalpy difference as ($H_V + H_L - H_F$) and we find out what is this ΔH.

$$\Delta H = H_V + H_L - H_F$$

If suppose this ΔH is positive, then in that case what do we have to do? We have to reduce the flash temperature and then we have to repeat the calculations from starting. In the beginning, assuming the T flash and finding out P_i^{sat}, from there we have to continue this.

So, therefore, we know F and H_F. The things which are required to find out is V. We will be finding out y, we will be finding out L. We will be finding out x_i. If we assume that we know P flash then in that case we will be finding out T flash by this particular process.

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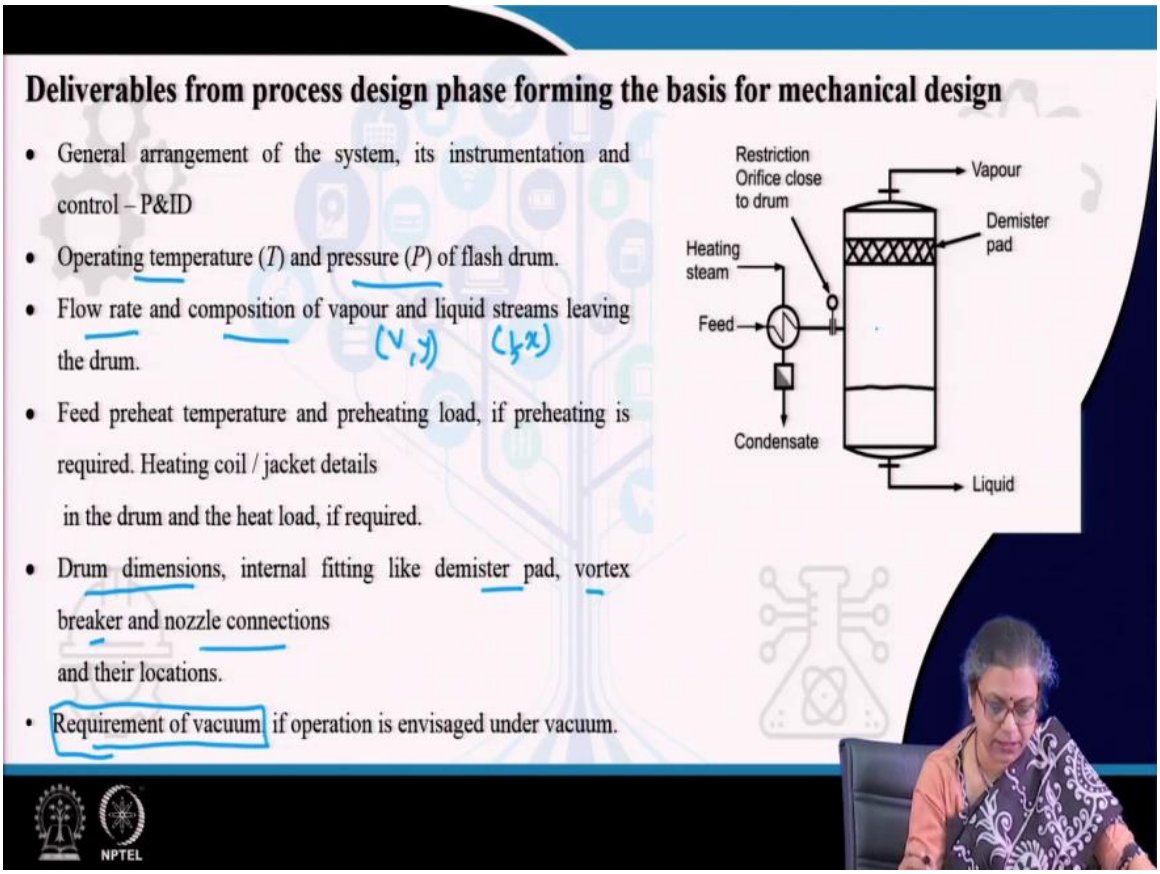

So, therefore, from the inputs that I have mentioned what are the deliverables? The deliverables are going to be the operating temperature and the operating pressure of the flash drum which I have already discussed, flow rate and composition of the vapour and the liquid streams; These indicates V, y, L, and x which I have discussed. Feed pre-heat temperature and the preheating load if the preheating is required and accordingly if the jacket details or the heating coil details if suppose the drum is heated.

Finally, after we do all these things, we need to finalize is the drum dimensions and also the internal fittings like the demister pads, the vortex breakers and the nozzle connections and their locations.

Where do we need to operate the flash drum under a vacuum condition? If we go for lower and lower pressures, the difference between the bubble point and the dew point increases and we will be getting a much better separation. So, therefore, it can happen that under conditions where you need to recover a large amount of the lighter component as per your

specifications you might have to operate under a vacuum. Under that conditions, you have to find out the vacuum requirements.

One thing I just wanted to mention just like I had told you about a demister pad in the same way we also need a vortex breaker. What does the vortex breaker do in this particular case? In this particular case here the liquid is there as the liquid goes out there is it can take up some amount of vapour along with it. So, the vortex breaker it breaks the vortex such that disengagement between liquid and vapour happens, but this has got a much more important purpose.

After that, the liquid will be going to some particular storage or something. So, therefore, the liquid will be pumped out from here and it will be taken. Now, you very well know that if a liquid-vapour mixture is introduced in a liquid pump just recollect the phenomena of cavitation which happens. So, therefore, you can understand the greater requirement of a vortex breaker in this particular case.

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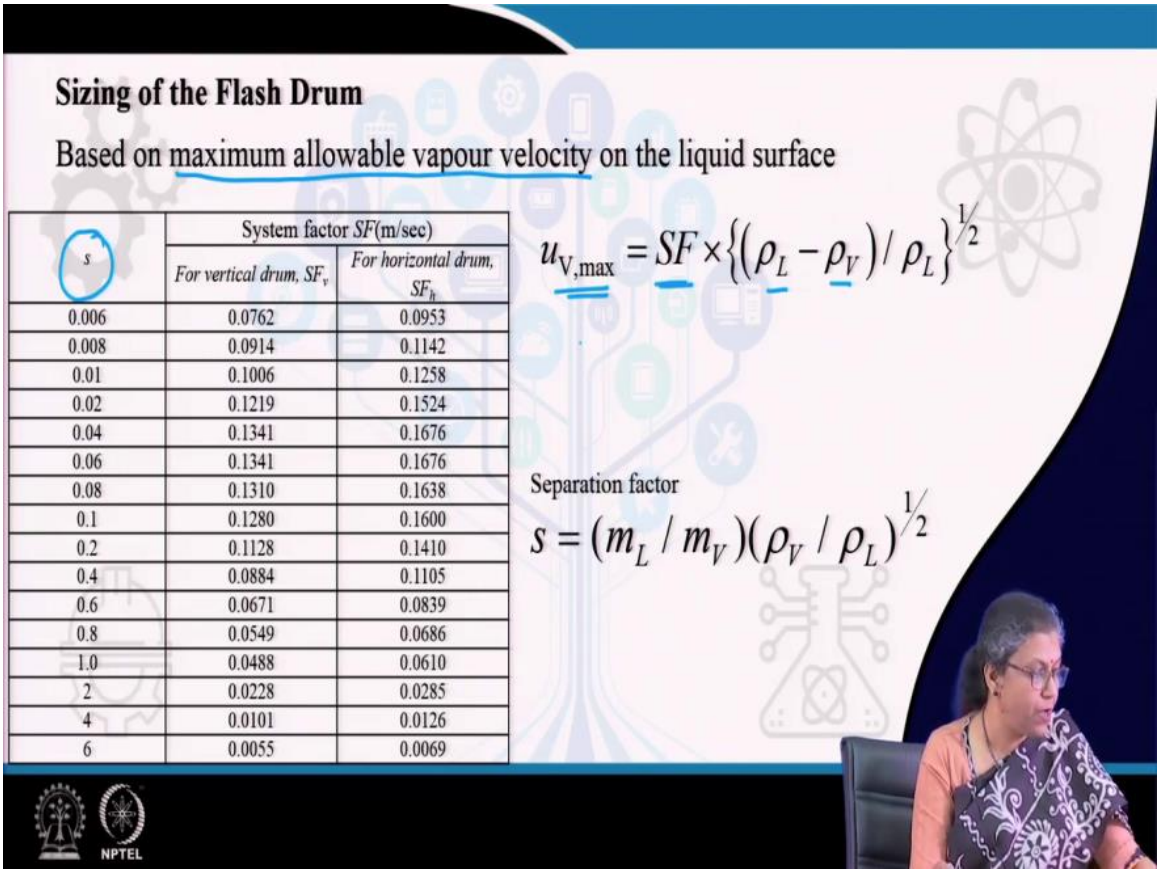

s	System factor SF(m/sec)	
	For vertical drum, SF_v	For horizontal drum, SF_h
0.006	0.0762	0.0953
0.008	0.0914	0.1142
0.01	0.1006	0.1258
0.02	0.1219	0.1524
0.04	0.1341	0.1676
0.06	0.1341	0.1676
0.08	0.1310	0.1638
0.1	0.1280	0.1600
0.2	0.1128	0.1410
0.4	0.0884	0.1105
0.6	0.0671	0.0839
0.8	0.0549	0.0686
1.0	0.0488	0.0610
2	0.0228	0.0285
4	0.0101	0.0126
6	0.0055	0.0069

But I will be discussing shortly that what should be the optimum pressure? How we should be selecting the optimum pressure and temperature?

After deciding the vapour flow rate, and other input and output parameters, then the drum has to be sized. Now, the sizing is based on the total mass flow rate of the vapour, which you can find out once you know V in moles per hour. You know the molecular weight, the composition, you can find the mass flow rate. So, based on the total mass flow rate and the maximum allowable vapour velocity on the liquid surface, you can find out the drum diameter.

Now the maximum allowable vapour velocity can be found out from a system factor and the liquid and the vapour velocities. The system factors are given as a function of the separation factor in this particular table for a horizontal drum and a vertical drum and we find that if the system factor is higher then it allows a higher $u_{v,max}$. If it allows a higher $u_{v,max}$ a lower cross-section of the drum can be obtained.

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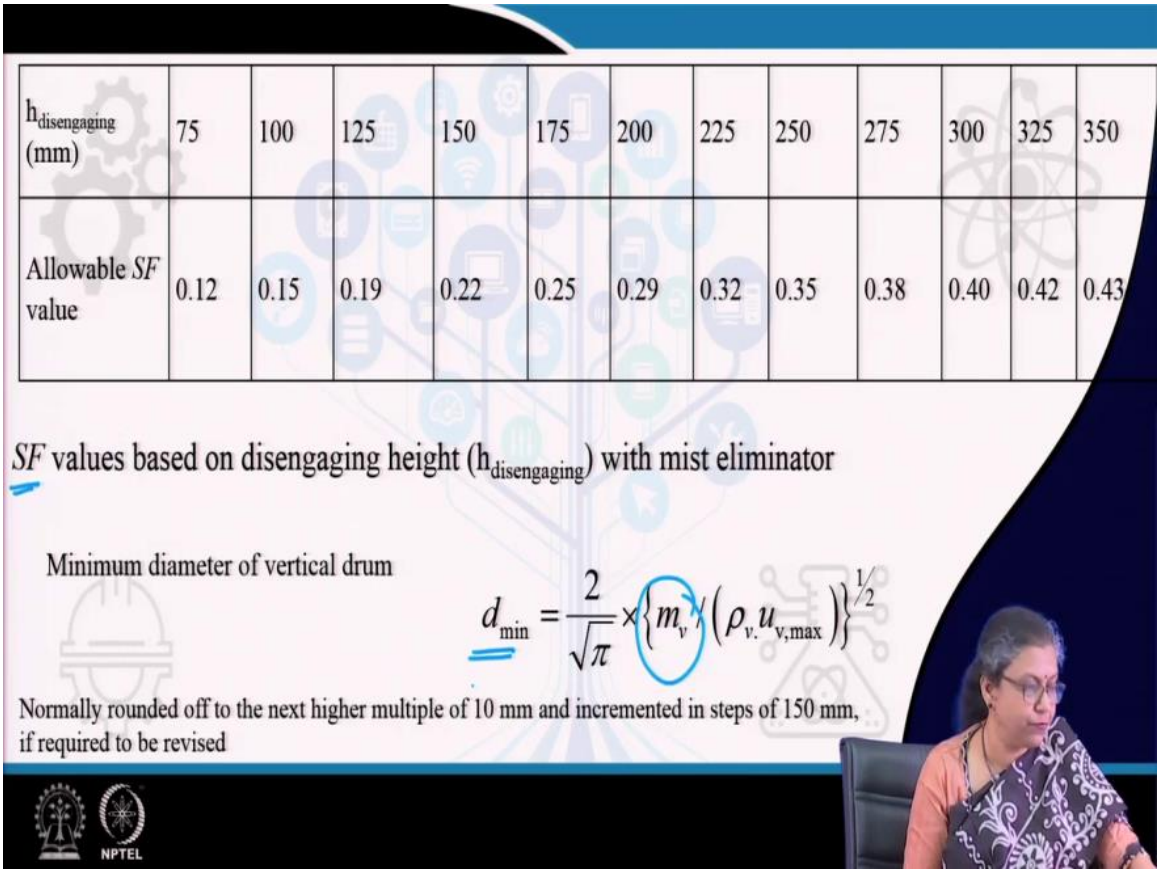

So, therefore, an alternate way of finding out the diameter is can be based on the disengagement height. A higher disengagement height reduces entrainment. When it reduces entrainment, the drum can be operated with a higher SF. So the second approach is to find out SF based on the disengagement height.

So, you can find out SF values, then you can find out $u_{v,\,max.}$ Once you have found out $u_{v,max}$,. You know the mass flow rate.

So, therefore, based on them you can find out the diameter of the flash drum. When we will be discussing the pressure vessels you will find that just to confirm two codes. So, therefore, it is usually round off to confirm two codes and those things we will be discussing later.

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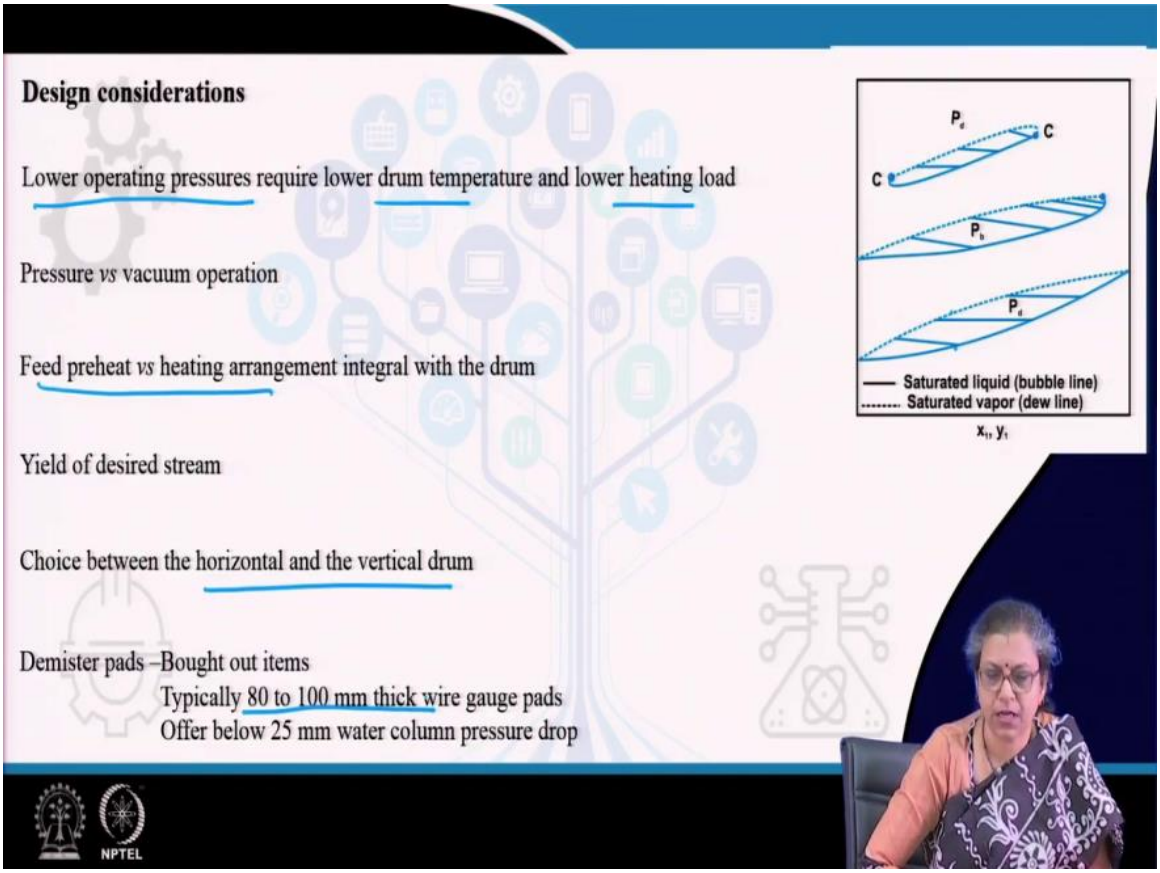

I will just mention the design considerations which you should keep in mind when you are discussing or forming up the design. The first thing is definitely as I was telling you, we would prefer a lower operating pressure.

When you go for lower operating pressure, it is quite evident that the temperature required for the line between the bubble point and the dew point is lower. The heating load will be lower. But at the same time, you have to remember that if you have to go to pressure much lower compared to the atmospheric pressure, then there will be every chance of some leakage of air into the column.

Suppose you are dealing with a hydrocarbon column. Then, in that case, due to this leakage, there is every chance that an explosive mixture will form. So, therefore, we have to keep in mind for operating in a vacuum. So, keeping everything in mind we would like to operate under a condition where it is going to be operationally safe, it is going to be feasible and most importantly it is not going to be exorbitant.

The next thing is which I have already mentioned that whether we should have a heating arrangement integral or whether we should have a preheater.

The other thing is the yield. Now to optimize the yield, we need to find out the combination of the flash pressure and the yield such that we can get the maximum yield of the desired stream.

The choice between horizontal and vertical drums I have already mentioned.

The demister pad is a very standard bought out item, I have nothing to say about it.

The whole thing will be a little clearer when we discuss a problem with flash distillation.

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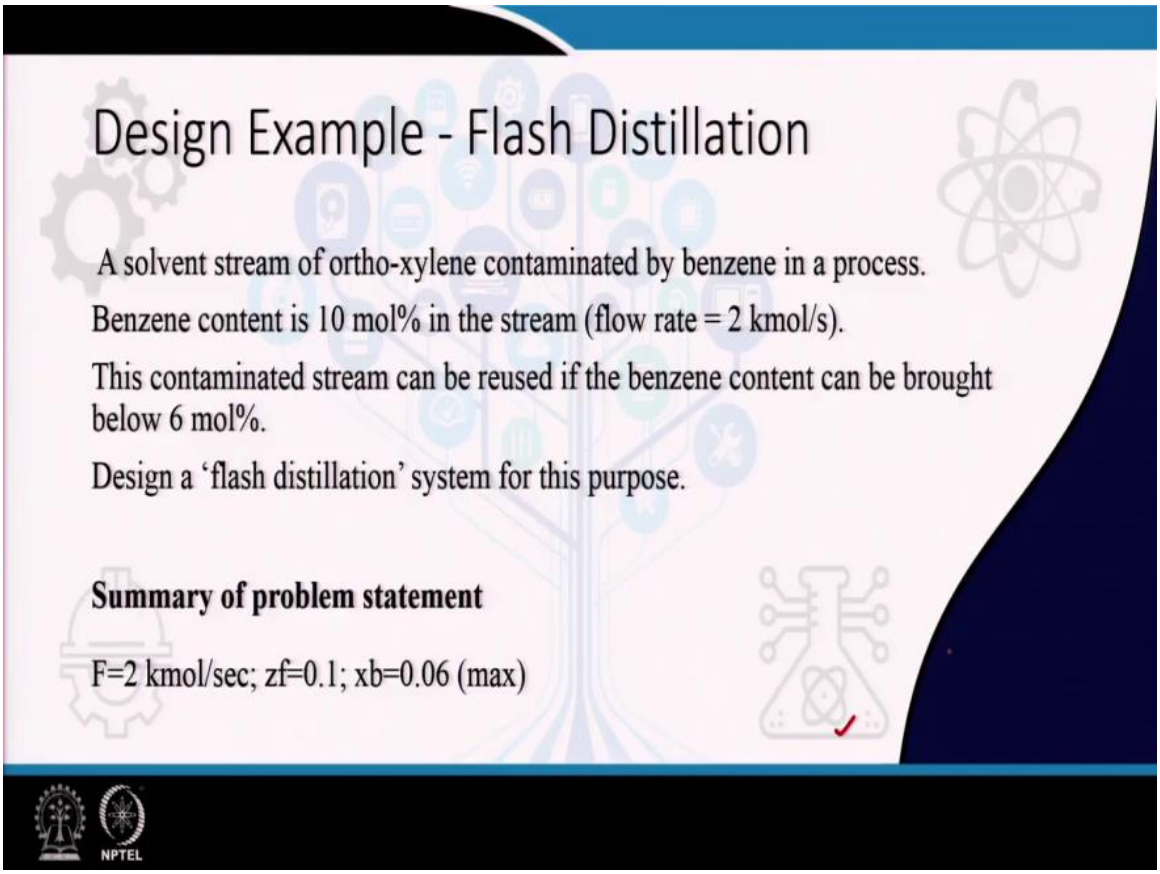

Dear students, you already have been given an introduction to flash distillation and here I am to give you an example of a design procedure for designing a flash distillation column. Well, you can call it a column, you can call it a drum, but normally it is called a drum a flash drum.

The problem at hand is that of a contaminated straight stream of ortho-xylene which is available from a plant and is contaminated by benzene. The content of benzene is 10 mole% in the stream and the flow rate of the stream is roughly 2 kmole/s. This contaminated stream can be used again if the benzene content can be brought below about 6 mole%.

We are supposed to design a flash distillation system for this purpose. To start with what we do, we will make a summary of the problem. So far, what we know is the flow rate is 2 kmol/s that is a feed rate. So, F is equal to 2. z_f is the mole fraction of benzene. The lighter component in this system is 10 mol% i.e. $z_f = 0.1$. The maximum benzene content at the bottom is 6 mole%. So, naturally, we decide for the moment that x_b is equal to 0.06.

We also know that if we can achieve something slightly lower than that it will give us a margin may be of 5.9 or something.

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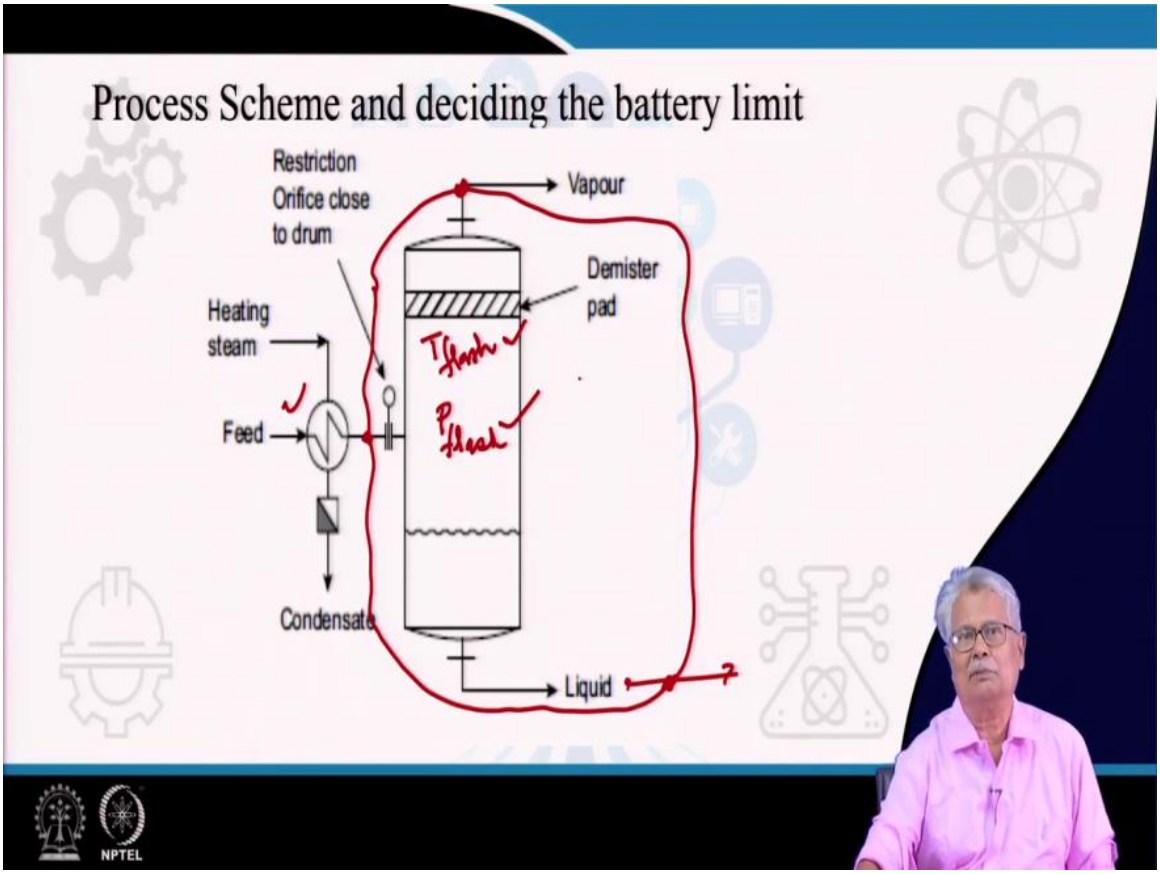

Now, we will go for the process scheme. we have a look at it. You can see here that the feed comes through some sort of heating arrangement, a preheater. Then what you have is a restriction orifice here which is close to the drum. So, basically, upstream, what you have, is at higher pressure and a higher temperature and downstream of the orifice is having the pressure of the drum, where the pressure is something like P_{flash} and the temperature is T_{flash}.

So, naturally, the phase separation occurs at a temperature of T_{flash} and P_{flash} which we do not know yet. So far, what we know are only two parameters. My feed rate is 2 kmol/s and my z_f is 0.1. The liquid maximum composition here is 6 percent which is 0.06(x_b). We do not know any other parameters at the moment.

But tentatively, we are going to go for a drum. We do not know yet and we have not confirmed, but tentatively we may have a demister pad there or we may not have it also.

Now, it is absolutely important before any design to decide on a battery limit. It indicates the number of connections to the external world to the section that you are going to design.

So, I am going to draw it here and define my battery limit like this. Naturally, the liquid goes out as well and the vapour goes out as shown here. So, we are supposed to have the conditions at the feed inlet (which come after the preheater) point, at the vapour outlet point and the liquid outlet point. The process conditions within will be the temperature of flash (T_{flash}) and the pressure of flash (P_{flash}).

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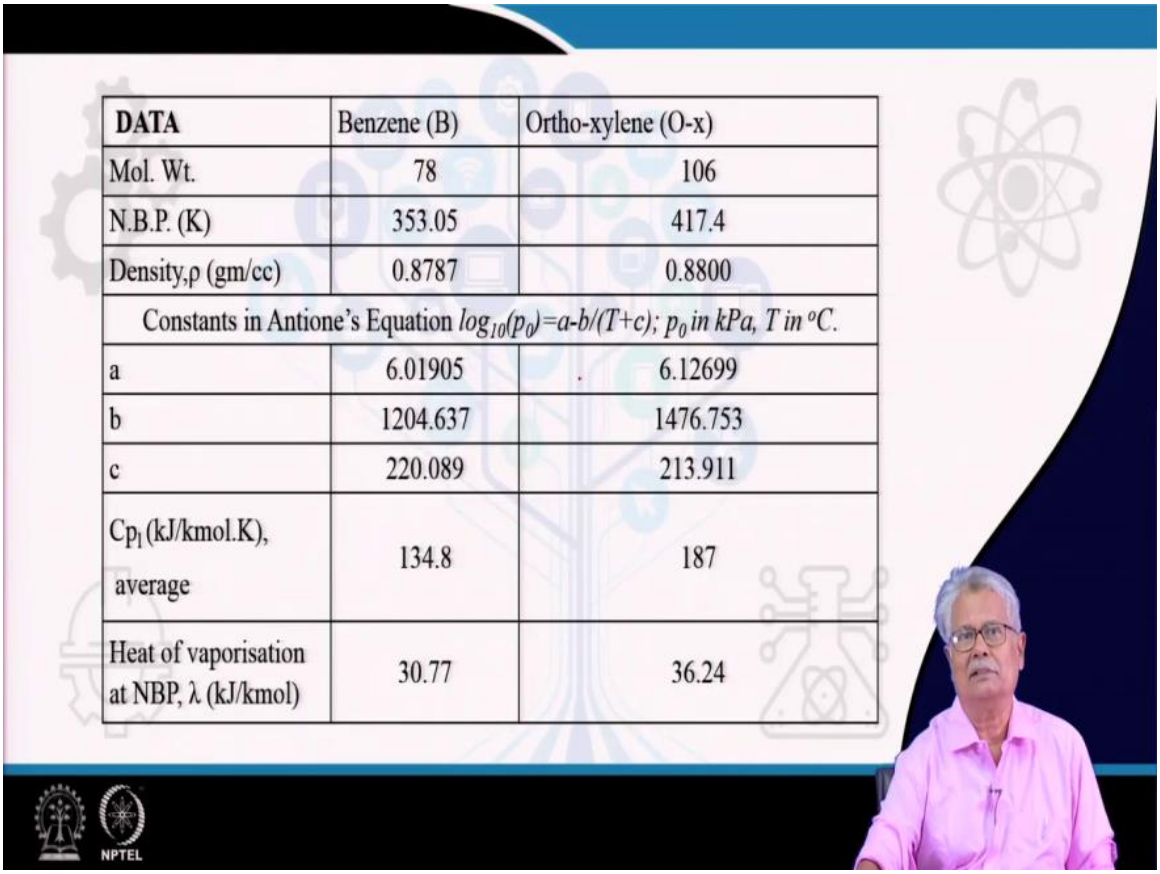

So, once we have decided this. Then, we go for data collection. The system contains benzene and ortho-xylene. The molecular weights are given here, and the normal boiling point in Kelvin is given here as well. The density approximately of the liquid density we do not consider that these are varying too much with temperature and pressure right now and we put these as the expected density of 0.8787 and 0.8800 grams per cc which amounts to 878.7 and 880 kg per meter cube.

To calculate the vapour pressure, we are going to use the Antoine equation. The Antoine equation is applicable, when as long as your prediction remains below two atmospheres and here it is a low-pressure system it is pretty. I will say a volatile system and in this specific system, the Antoine equation is applicable. That we know from the thermodynamic fundamentals we are not going to go into the details of that.

The specific heat of the liquid phase has an average value in kJ/kmolK are 134.8 and 187 and the heat of vaporization at the normal boiling point is also noted as 30.77 and 36.24 kilo Joule per kilo mole. We are going to use all of this data as we proceed.

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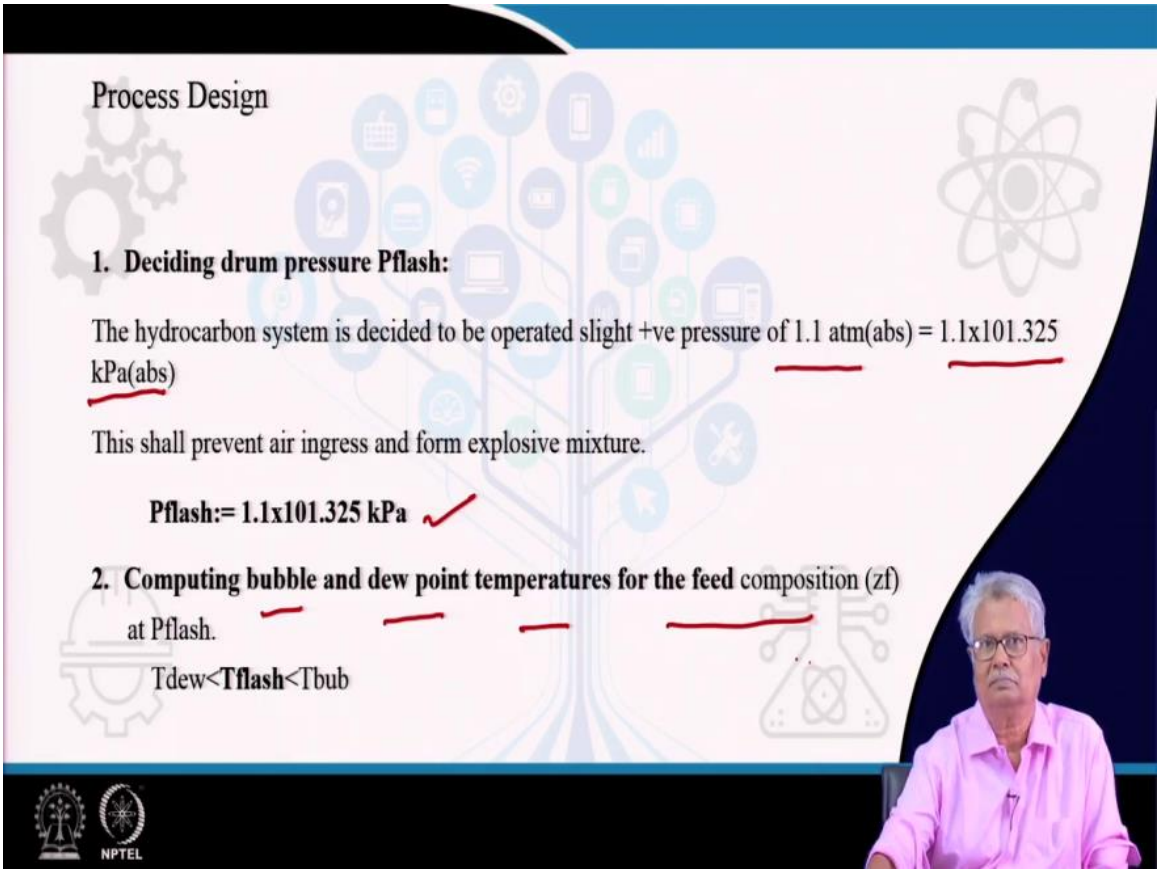

Now, we go for the process design procedure. The first thing that we need to decide is on the drum pressure. This is a hydrocarbon system that is inflammable in a mix with air. So, we will prefer that the drum operates at a pressure above the ambient pressure; that means, it operates at a slightly above atmospheric pressure of around 1.1 atmosphere absolute, which is “1.1 X 101.325” kPa (absolute).

This would prevent the ingress of air in the form and forming an explosive mixture. So, according to this, we decide the P_{flash} is going to be this much value; that means, 1.1 X 101.325 kPa. The next step is to estimate the bubble point and the dew point temperatures for the feed. Why do we do it?

Because we know that the feed will vapourize fully at dew point and it will be 100 % liquid at its bubble point. So, obviously, my flash temperature T_{flash} is bound to be something between these two temperature values. So, we move forward to the estimation of dew point and the bubble point.

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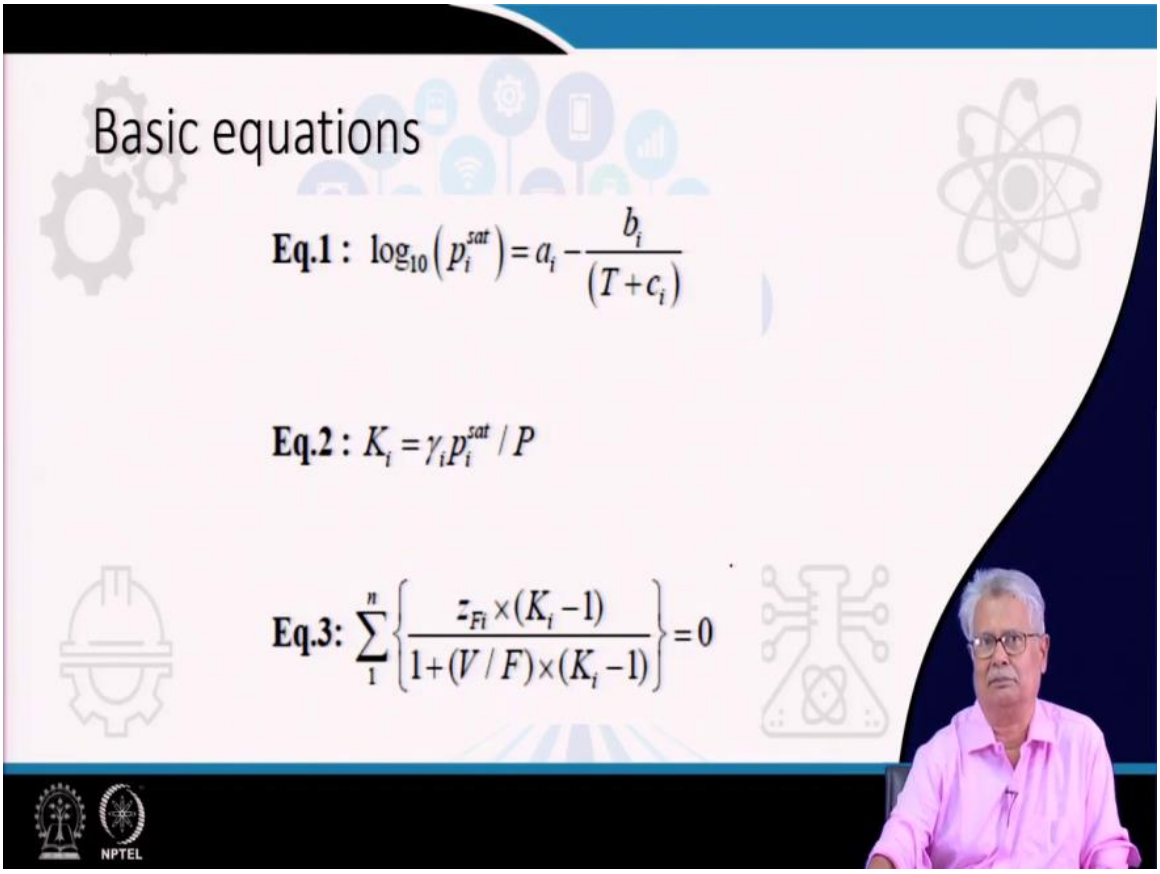

The basic equation the first is the equation number 1, which is nothing, but the Antoine equation which is written here for the i^{th} component. In general, the constants are given there. The same equation is also there in that particular table of data. We have already understood and we know that K_i, the distribution coefficient is given by $\gamma_i p_i^{sat}/P$. P is the total pressure of flash. This being a simple system γ_i is going to be nearly 1.

So, henceforth we are not going to use γ_i because we are going to consider it to be 1. The third equation which is equation 3 is a summation equal to 0. It is a simplified form of "$\sum x_i - \sum y_i$" equals 0. So, what we have here right now is a set of 3 equations that will have to be satisfied for the case of equilibrium let us move forward beyond this.

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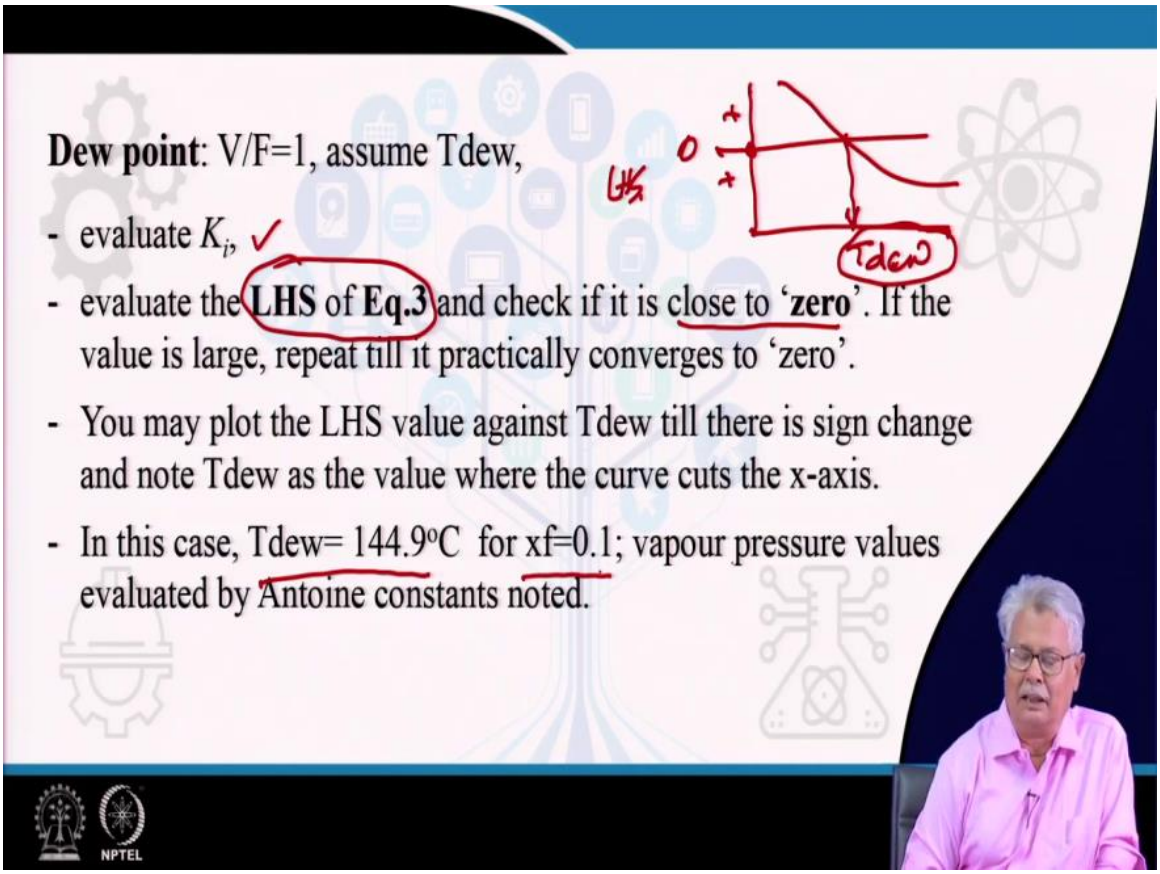

The first thing that we calculate is the dew point for which my V/F equals 1. So, we assume a dew temperature. Correspondingly we know the vapour pressures so we can very easily evaluate the Ki values. As we already know the Ki values and V/F is equal to 1, we evaluate the left-hand side of equation 3; that means, the summation expression and check if it is close to 'zero'.

If it is not, we have to reassume T_{dew} till we come to a convergence. At the point of convergence, of course, within a tolerance, you will possibly while working will never be able to get it 0, but it is also possible for you to find the value of T_{dew} in a way.

If you plot the left-hand side of the equation value against T_{dew} till there is a sign change from positive to a negative value and note Tdew as the value where the curve cuts the x-axis.

In this specific case what we did is the same and we note that my dew point is 145°C which is 144.9 as per calculations and this is for the feed which has got z_f is equal to 0.1 and this dew point is corresponding to a P_{flash} of 1.1 atm.

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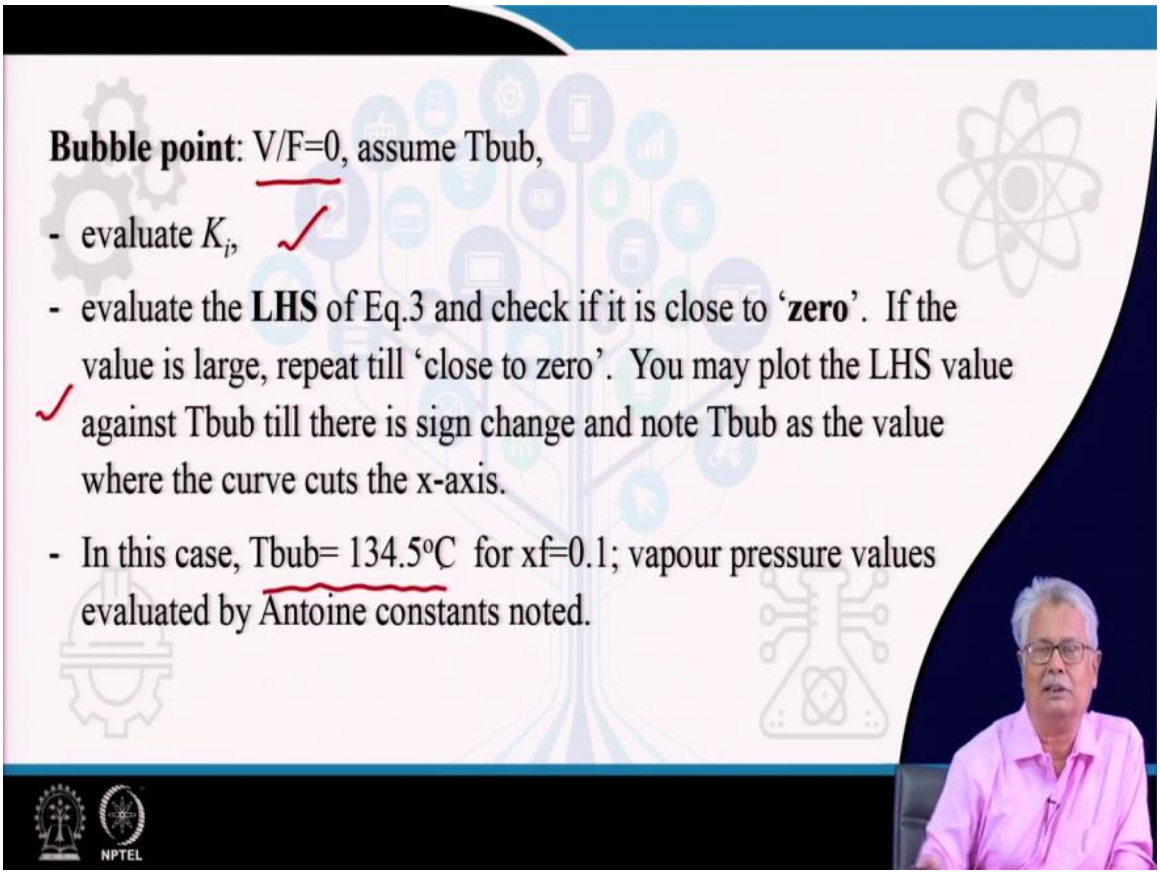

Exactly, in the same way, we solve for the bubble point for which we know that my V/F is going to be 0. we evaluate K_i. We evaluate the left-hand side and we find that the bubble point is 134.5 °C.

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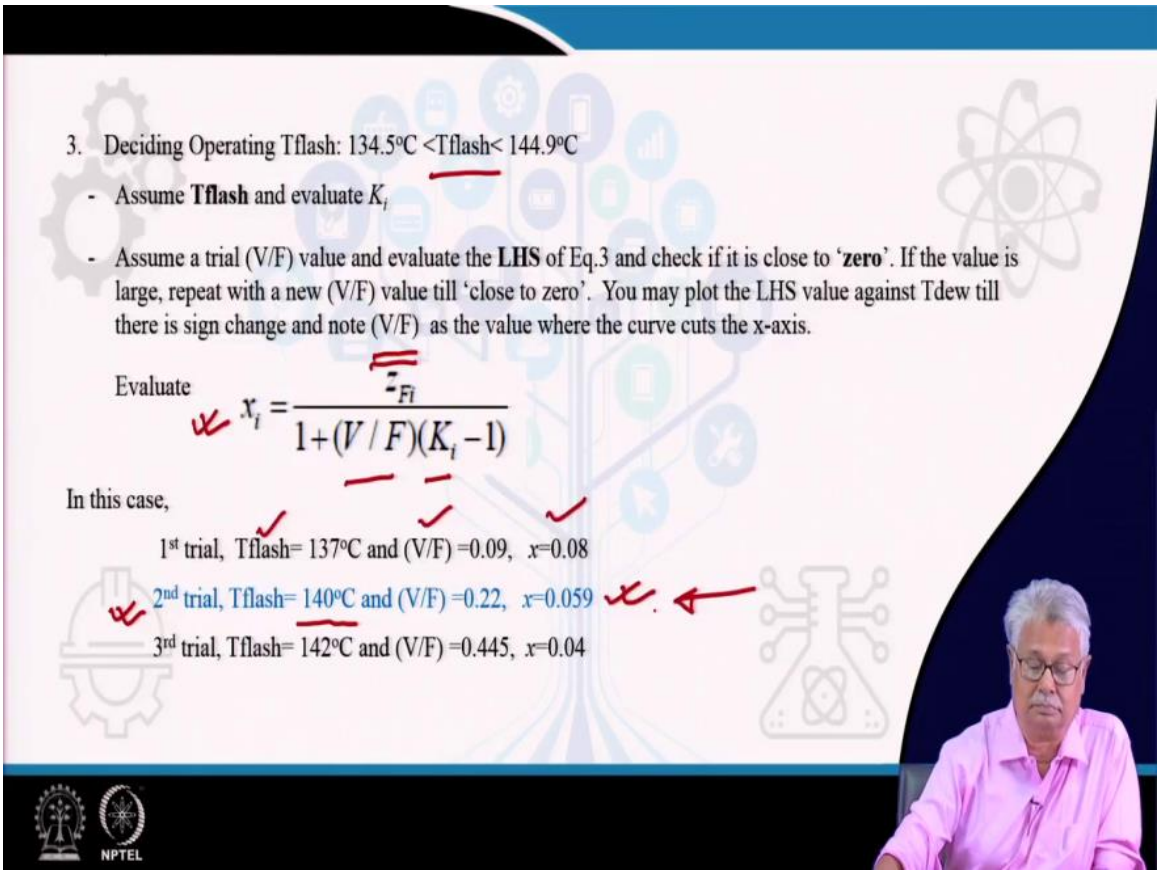

The next is deciding the flash temperature which has to lie between 134.5 and 144.9°C. We assume a T_{flash} value which is lying between these two. Evaluate p_i values, evaluate the K_i values and we also assume a trial value V/F and evaluate the left-hand side. We check if the summation is 0 again.

If it is not we need to try another value of V/F till we get the convergence of that summation value or the left-hand side value coming close to 0. At this particular point what we do not know is that we have arrived at the V/F value for a corresponding T_{flash}.

After this, we are going to calculate the value of the liquid phase composition for each component which is x_i which is given by this expression.

We know the K_i value, and the V/F values. The K_i values are corresponding to a temperature of T_{flash}. For every T_{flash}, there will be a particular V/F for which the convergence happens and there is a corresponding x_i.

We find here in my first trial the values of T_{flash}, V/F and x_i are 137.5 0.09 and 0.08 respectively. Beyond that, we got some other trial values which we find is quite satisfactory.

We have a temperature flash drum temperature of 140 °C and my bottom liquid has got 5.9% of benzene which is 0.059 is the value of x. So, this is an acceptable solution with a very small margin in my composition.

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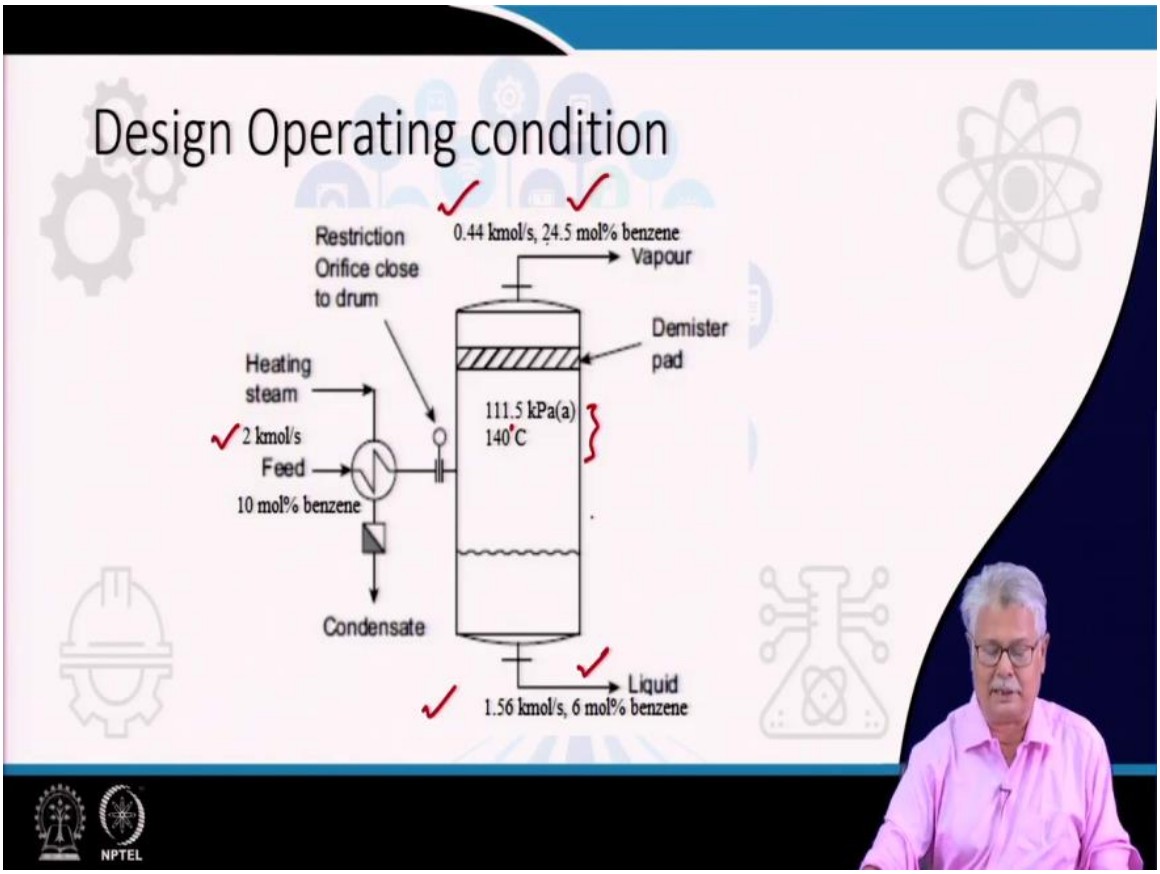

Now, we put down all the values here. We know the feed, we naturally know the compositions as well. So, we note down and we note that the flow rate of the vapour and the liquid values are here. The composition of the vapour and the composition of the liquid are also known here. The operating conditions are 140 °C and 111.5 kPa (absolute).

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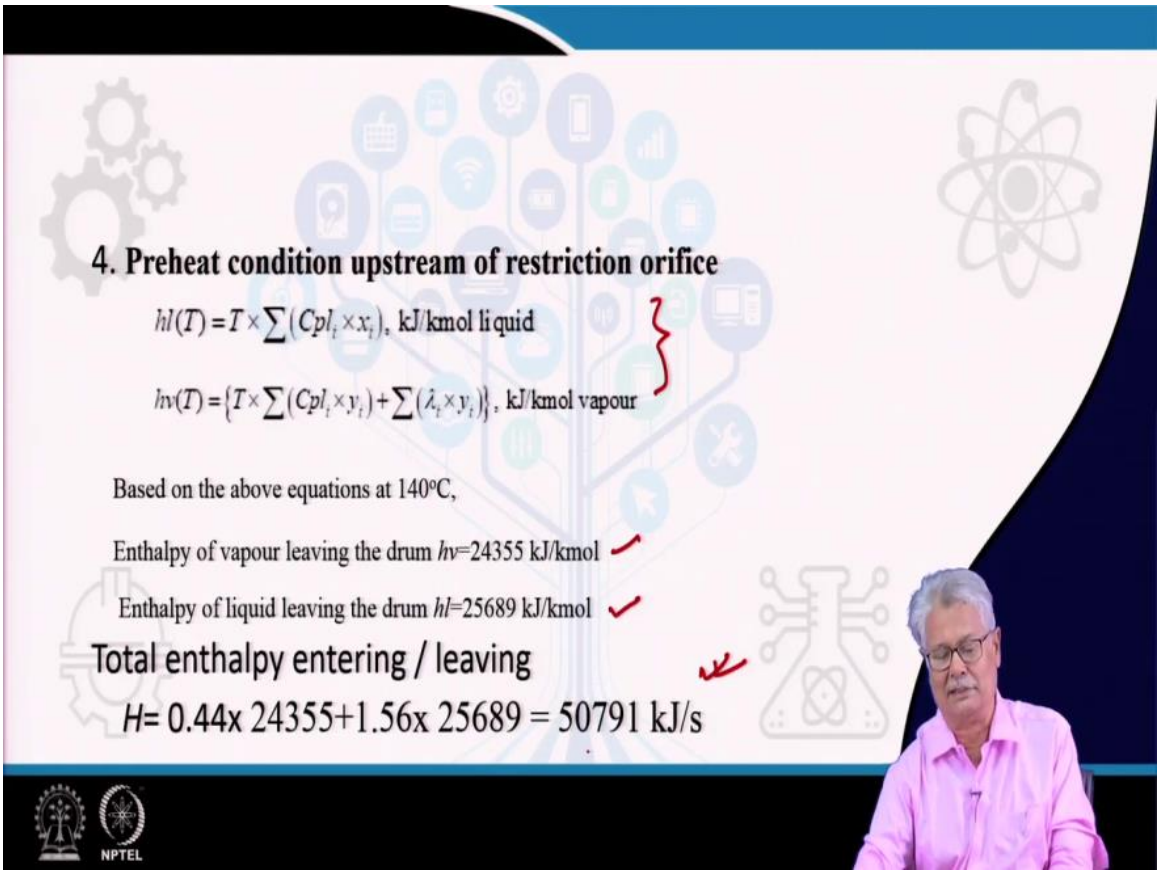

The next question comes to achieve these parametric conditions what will be the upstream condition that approaches the orifice. That means downstream of the preheater. The preheated stream should have a particulate amount of enthalpy and this enthalpy will be the sum of the enthalpy of the vapour and the liquid stream which are leaving.

So, we find out the temperature and pressure of the vapour and the liquid streams. We use these two equations to evaluate the liquid and the vapour enthalpy at 140 °C and we find these values to be 24355 kJ/mol for h_v and h_l is 25689 kJ/mol.

The total enthalpy is a sum multiplied by the individual mass flow rates. So, this gives us the rate at which the enthalpy leaves this particular system. In other words, we also know this amount of energy has to enter the system, as well as the enthalpy, has to enter the system by preheating.

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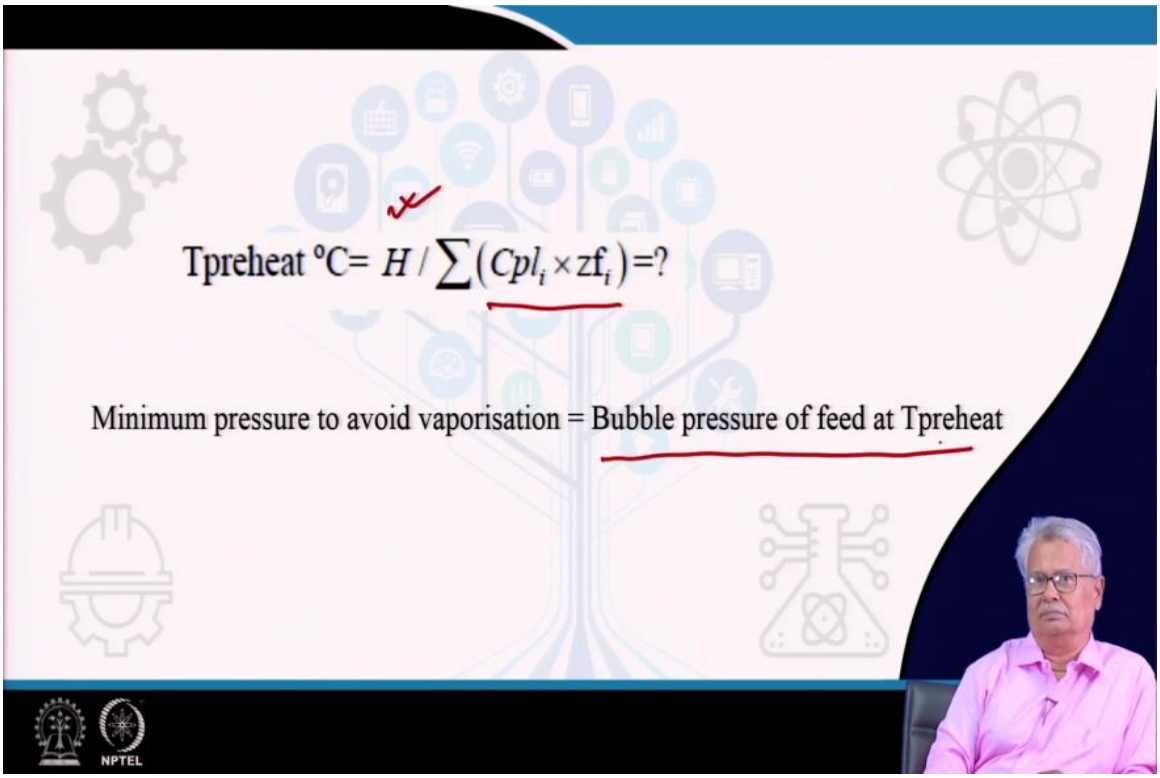

So, we need to find the preheat. We know the value of enthalpy. We know the C_{pl} values. We know the feed composition. So, the $T_{preheat}$ can be found out by evaluating this expression $H/\sum(C_{pli} \times z_{fi})$.

Now it is also essential that it should not vaporize at this particular location. So, the pressure here has to be above the bubble pressure of the feed at this preheat temperature. So, the next thing is the minimum pressure to avoid vaporization is estimated as the bubble pressure of the feed at $T_{preheat}$.

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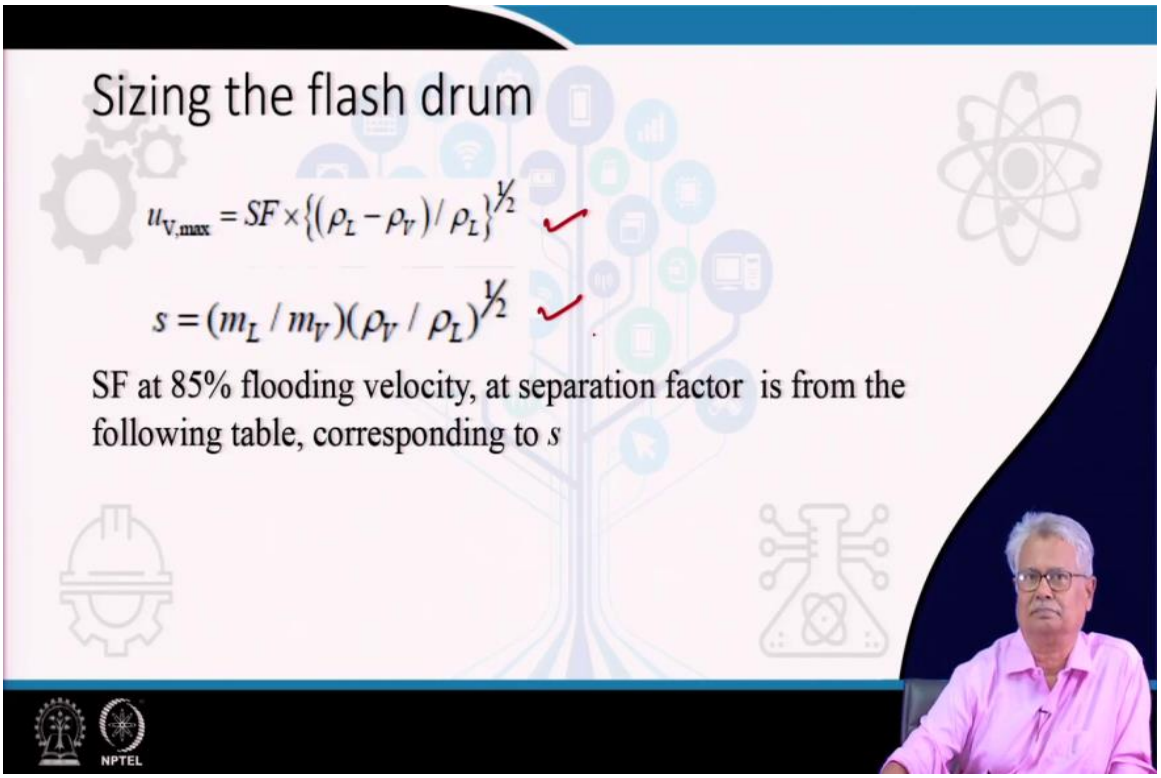

The next part is finding the size of the flash drum. The size or diameter is found out or the cross-section of the drum is found out by finding out the maximum allowable vapour velocity at the vapour-liquid interface. The velocity is given by the first expression which involves ρ_L, ρ_V and a system factor, SF.

To find out SF, we require one more parameter which is the small "s". The value of SF is at 85% flooding velocity. The separation factor SF is found in the table which I am going to show you next, this corresponds to a value a particular value of s.

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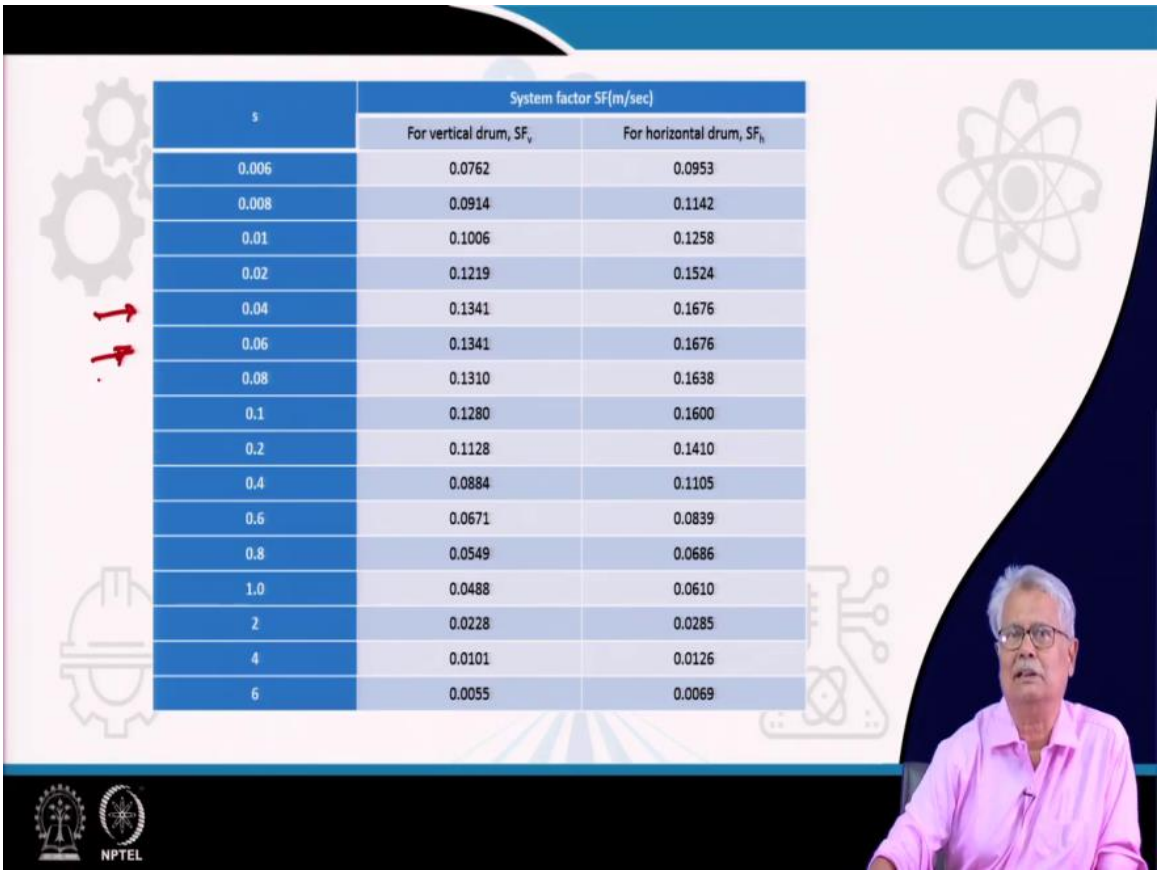

So, this is the table. In fact, what we do is we look at this value (s=0.4), we look at this value (s=0.6) and we will find that our value of s lies in between these two and we will be making a linear interpolation in this.

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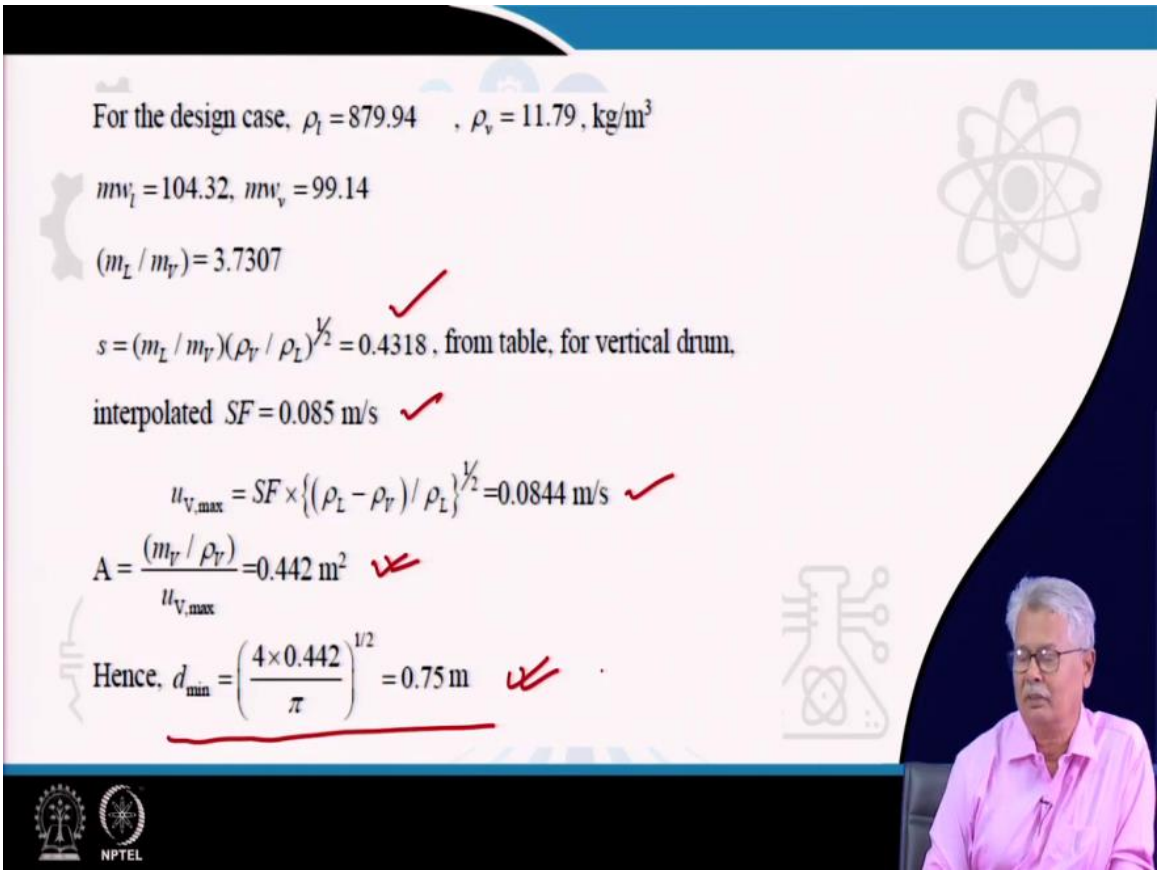

So, what we do here is we simply evaluate and we find s value is 0.4318. The interpolated SF naturally from that table is 0.085. There is a correction to $u_{v,max}$ based on this which slightly reduces it to 0.0844. We know a mass flow rate m_v for the vapour, ρ_V is my vapour density and $u_{v,max}$ which we have just found out to be 0.0844.

So, by putting these values, we find that we require an area cross-section of the vapour-liquid interface to be 0.442 m^2. If you have a circular vertical drum of diameter d quite naturally the minimum diameter turns out to be 0.75 m.

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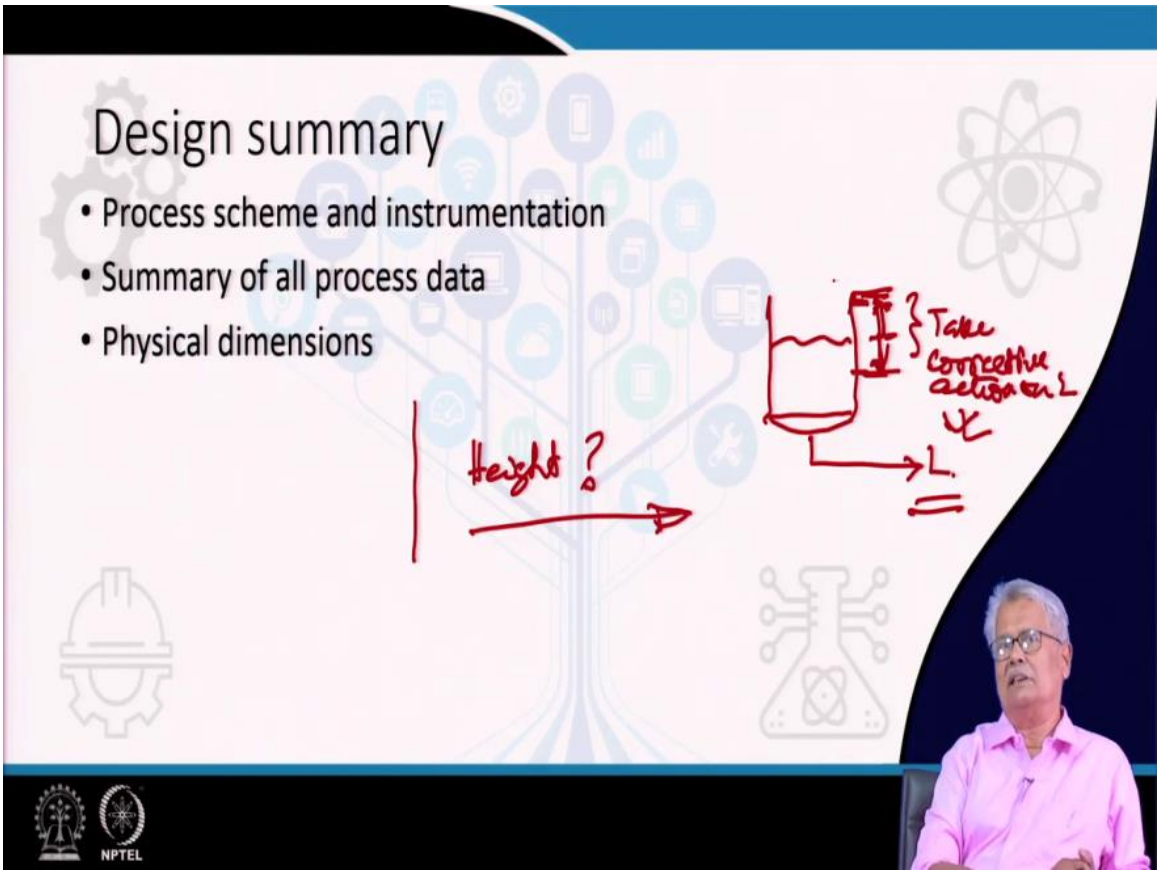

So, we have found out the dimensions. We make a design summary. There is something that is still left out, we have not found out the height. I am just telling you here, but it will be dealt with in more detail when we discuss the design of such drums which are vapour liquid separators. This is shown in the above schematic diagram.

This height consideration is basically if you have a liquid level here in this particular drum from which liquid is going out and here basically the level should be such that in case you have any interruption in L the level rise should be such within that time you can correct the interruption.

So, that between this level and this level it if it rises within this or it falls within this, in that case, we should be in a position to take the corrective action on the L; that means, this is decided on the rate of flow of L and you require a sufficient time to ensure that corrective action on L can be taken in case of emergency and that would allow a variation of L, but within a limited range.

You already have decided the diameter of the vessel which is a minimum of 0.75 m. Possibly, you will be going for 800 mm diameter and you know the value of L in meter cube per hour. So, you decide the residence time accordingly. Finally, you will decide that this is going to be your basic design which consists of a design summary of the process scheme and instrumentation summary of all process data and physical dimensions.

Thank you.