Process Equipment Design
Prof. Shabina Khanam
Department of Chemical Engineering
Indian Institute of Technology – Roorkee

Lecture –53
Distillation Column – 6

Hello everyone. I welcome you all in the 3rd lecture of 11th week of the course Process Equipment Design and here we are going to discuss design of distillation column. And as far as this design is concerned we first focus on the process design.

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And different milestones we have already covered as you can see here like distillation and continuous process, binary system design, multi component system design, how to find out the plate efficiency using different methods and now we will focus on plate hydraulic design. So, let us start with the plate hydraulic design.

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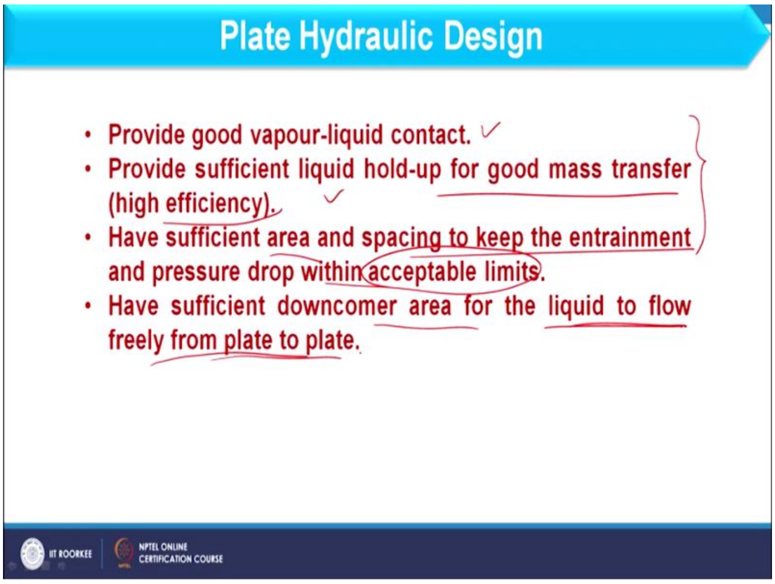

So, when we consider the plate hydraulic design what it means basically? This provides good vapour liquid contact it means whatever plate we will design it must have vapour liquid contact properly. It should provide sufficient liquid hold up for good mass transfer and that we consider as high efficiency. It has sufficient area and spacing to keep the entrainment and pressure drop within the acceptable limit.

So, all these points we should consider in design of plate. And finally it should have sufficient downcomer area for liquid to flow freely from plate-to-plate. So, all these points we need to consider when I consider design of a particular plate and different criteria are there to check all these points and those criteria will be discussed in due time. So, as far as plate hydraulic design is concerned first of all we will discuss the operating range as far as flow rates are concerned.

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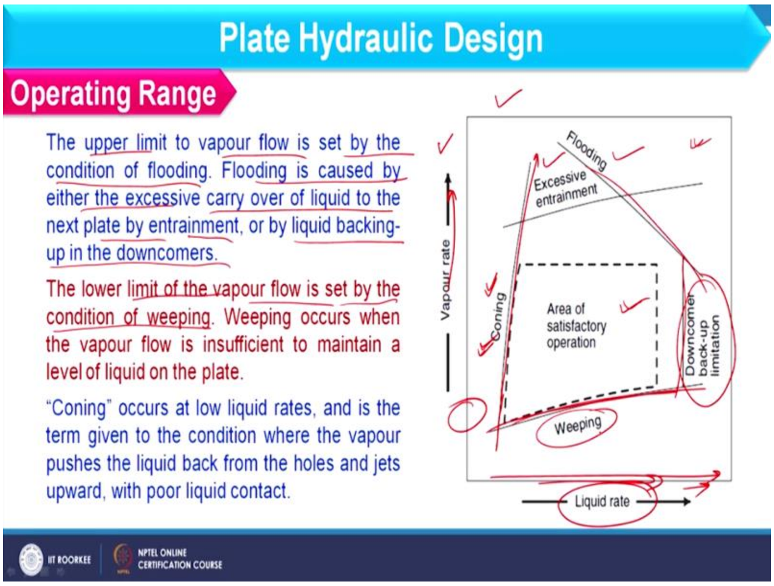

So, if you see here I am having this graph where vapour flow rate is available on y direction and liquid flow rate is available in x axis or x direction. So, if you focus on this we basically consider the proper area of operation over the plate. So, we have different points let us discuss these points. First of all, the upper limit to vapour flow is set by the condition of flooding.

And flooding is caused by either the excessive carryover of the liquid to the next plate by entrainment or by liquid backing up in the downcomer. So, basically what this flooding is? Flooding is basically when I am having the liquid which is instead of moving downward it will stay over the plate and because liquid is already available over the plate it cannot take extra liquid and then whatever liquid is coming from the top it starts flowing it upward only.

So, that happens with two conditions only when I am having the entrainment. So, what is entrainment? When vapour carries the liquid droplet with it and so it throws the liquid to upward direction and secondly when the liquid is coming from downcomer because liquid is already available in the bottom tray it will not allow liquid to further come to the bottom tray. So, liquid is basically backing up from the downcomer section.

So, that we can consider in this image also that excessive entrainment is there and then we have the flooding and then downcomer backup condition. So, that happens when the liquid flow rate is continuously increasing along with this vapour. However, when we consider that what is the controlling flow rate for that. Controlling flow rate is of vapour because vapour is basically causing liquid to hold over the plate.

And therefore liquid is not able to move downward. So, when we check the condition of entrainment as well as flooding over the plate we should check vapour flow rate and we should set the vapour flow rate accordingly so that these condition should not occur. Next is the lower limit of the vapour flow rate is set by the condition of weeping. As we have already discuss that weeping occur when vapour is not able to hold the liquid over the plate.

So, in both way this is the vapour flow rate which decides the upper limit as well as lower limit. Upper limit to stop flooding, lower limit to stop weeping because when vapour will not able to hold the liquid over the plate liquid will start moving downward through the holes and that also occurs when the liquid flow rate is low, but because of flow rate of vapour it is occurring.

So, if you see when I am considering the weeping condition it is basically occurring at lower vapour flow rates. However, liquid flow rate will vary from less to higher value. So, both condition that is flooding as well as weeping are addressed by vapour flow rate only. Next, I am having another condition which we call as coning and that happens when liquid flow rate is low and vapour flow rate is very high.

So, what will happen when the liquid flow rate is less and vapour moves upward through the hole with very high value so what will happen vapour simply pass through the liquid without any further interaction with the liquid over the plate so that we consider as if vapour is passing like jet through the hole. So, that condition basically we call as the coning because it does not interact, it simply make the cone and move upward.

So, that condition is also undesirable as far as design of plate is concerned and considering all these limitations we can finally consider the area where plate can be operated satisfactorily. So, we have to decide the operating range accordingly.

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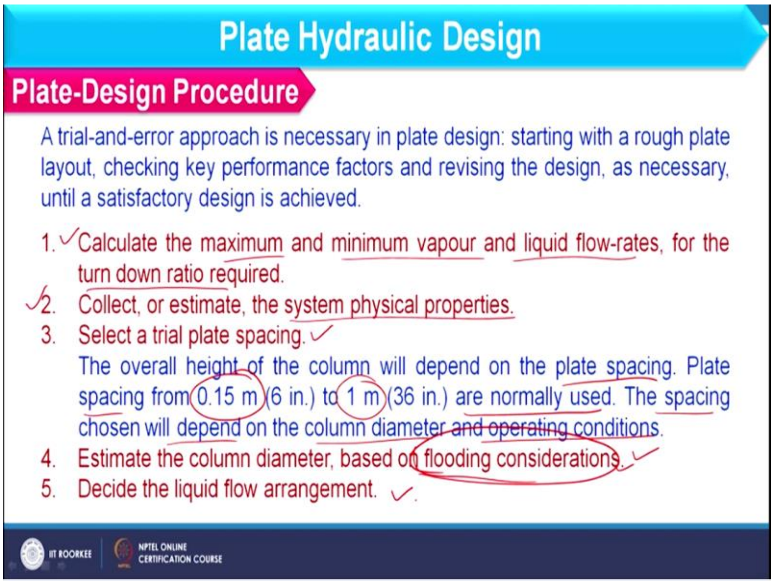

Now, let us focus on plate design procedure. Here we have different steps and these steps are required trial and error approach. So, the first is we have to calculate maximum and minimum vapour and liquid flow rates for a given turndown ratio and that turndown ratio is the ratio of maximum to minimum vapour as well as liquid flow rates and usually it has the value around 0.7, so 70% is the turndown ratio.

So, usually its value is around 0.7 then we need to collect or estimate the system physical properties and then we have to decide the plate spacing. Spacing means the distance between two consecutive plate and here we will consider one trial value and then in subsequent calculation we will fix that value and if trial will be required we can change this spacing. So, how we can change this spacing what are the values let us discuss that.

So, as far as plate spacing is concerned it varies from 0.15 meter to 1 meter for normal use and spacing chosen will depend on the column diameter and operating conditions. So, between this range you can choose the value of spacing and we can have different spacing that we will discuss in due time. And you can further understand that as far as this plate spacing is concerned it basically decides the column height.

When we consider the upper section of the distillation column or the absorption column or the bottom section in between section are basically because of the spacing of the plates and number of plates. Now, once I have decided the plate spacing I should calculate the column diameter and that will be depend on flooding conditions. And then we can choose right liquid flow arrangement over the plate.

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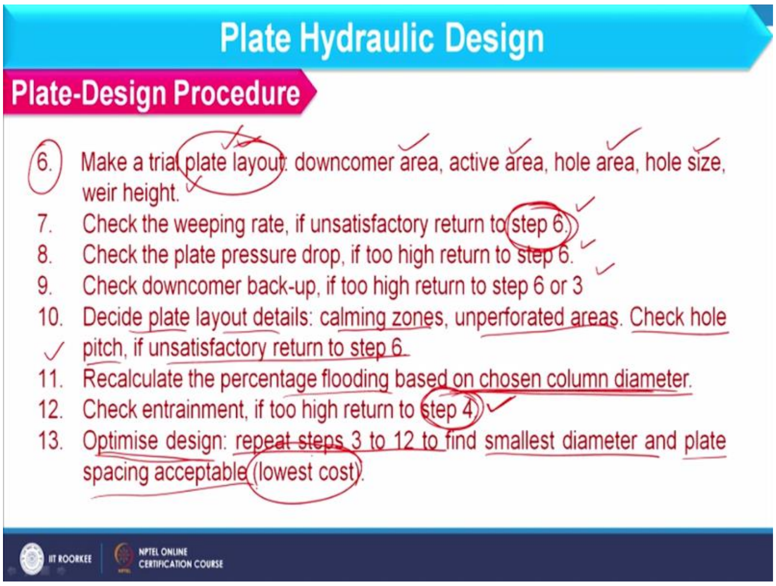

So, along with this we have other steps also as we need to consider plate layout such as downcomer area, active area, whole area, whole size and weir height and further we need to check the weeping condition if it is unsatisfactory we should again choose the plate layout properly and after that we have to check plate pressure drop if too high we should choose the plate layout properly.

Further, we need to check the downcomer backup if too high return to step 6 or 3 what we have to do that we will discuss further. Next, we have to decide the plate layout details like calming zone, unperforated area, check hole pitch if unsatisfactory we should again consider step 6. What is this calming zone, unperforated area all these we will discuss when detail design of plate will be considered.

In fact you know already what is the calming zone. So, here we should also check the tube check that is the distance between center point of two consecutive holes. So, we have to select all these parameters and then we will recalculate the percentage flooding based on the column diameter which we will choose and further we will check the entrainment if too high we should again consider step 4 where we have design the column diameter.

And then we have to optimize the design by repeating steps 3 to 12 to find out smallest diameter and plate spacing acceptable that should be with the lowest cost. So, based on all these steps we will consider design of plate and from now onward we will consider different points in detail. So, first of all we will focus on calculation of diameter.

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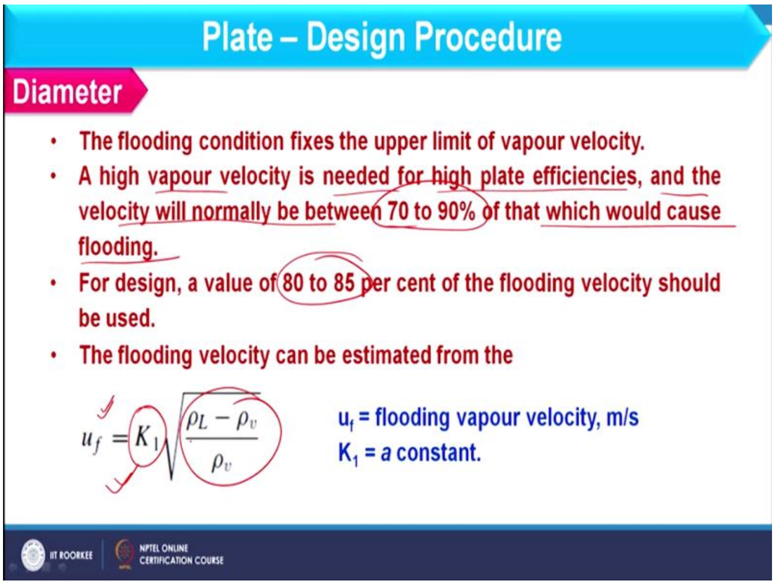

Now as far as column diameter is concerned this is basically depending upon the flooding condition. And as far as flooding condition is concerned that you can understand it can be fixed by the vapour flow rate. So, we should put the limit of upper flow rate of the vapour. So, in other word what we can say that we should choose the vapour velocity in such a way so that flooding should not occur.

So, depending upon this vapour velocity flooding condition will be fixed and then we will fix the column diameter. So, let us see the step. A high vapour velocity is needed for high plate efficiency and velocity will normally be between 70% to 90% of that which will cause flooding. As far as proper operation of the plate is concerned we should avoid flooding and so we should choose the vapour velocity accordingly which should be 70% to 90% of the velocity at which flooding will occur.

And if we consider the recommended value in this range so that is basically 80% to 85%. So, what we have to do over here? We should first calculate the velocity at which flooding will occur and we consider that as a flooding velocity then we will choose the vapour velocity like 80% or 85% of the flooding velocity which we will calculate and based on that vapour velocity whatever mass flow rate of vapour is there because whatever mass flow rate of vapour is occurring in the distillation column its value we cannot change because that is the process condition.

However, we can design the plate to accommodate the flow rate which will be required from vapour side and liquid side in the distillation column. So, we will proceed to calculate diameter accordingly. So, first of all let us see how to calculate flooding velocity. So, here I am having this empirical correlation for flooding velocity where u f is the flooding vapour velocity and K 1 is constant.

How to find this K 1 value that we will see and here you can observe the physical property that is the density of vapour as well as liquid.

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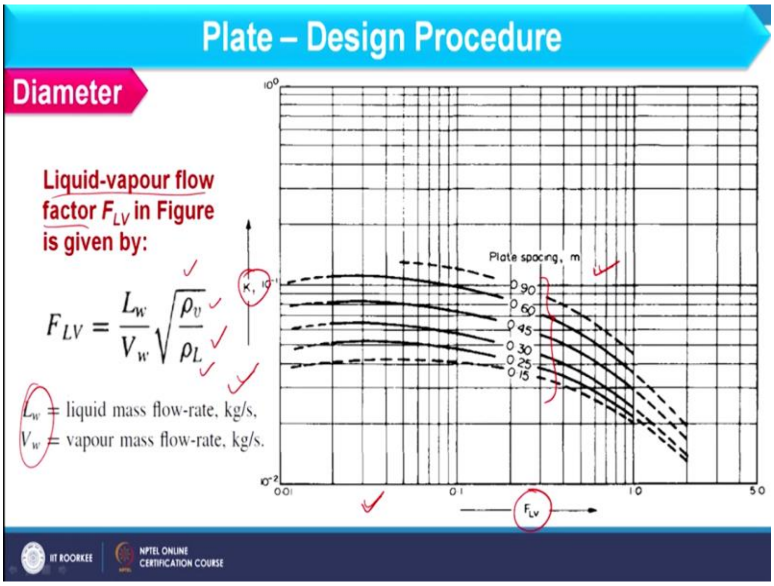

So, let us see how to find out this K 1 factor. It will depend on this FLV value and that FLV value we can consider as liquid vapour flow factor and we can calculate its value by this expression that is L w / V w root over rho v / rho L and U w and L w are basically liquid and mass flow rates and as per the process condition these value will be given. So, when we use this graph if I am having the value of FLV I will fix plate spacing.

So, depending upon all these value you can choose a plate spacing and accordingly you can find out value of K 1. Now, when I am using this graph there are some limitations.

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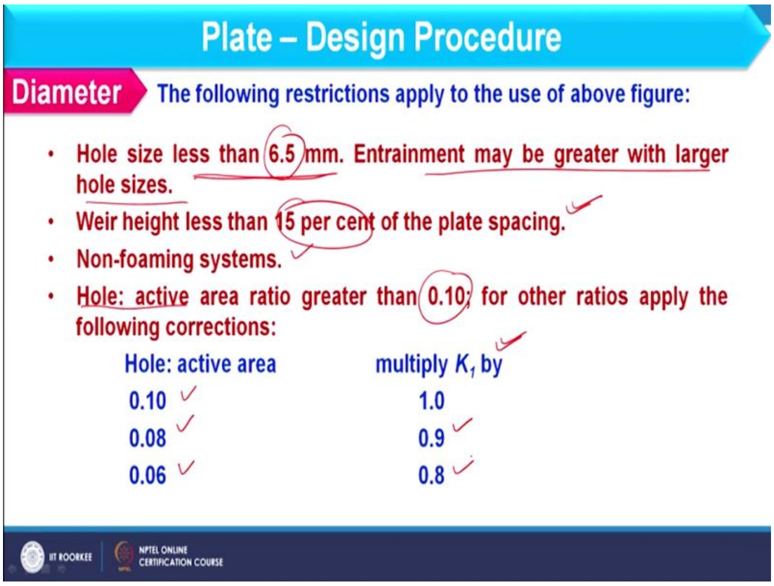

And these limitations are in this case hole size should be less than 6.55 mm, entrainment maybe greater with large hole size and therefore the size should be lesser than 6.5 mm, weir height should be less than 15% of plate spacing. No foaming should occur in the system and hole to active area ratio should not be more than 10%. However, as far as this figure is concerned we have consider 10% hole to active area.

So, we have consider 10% hole area in comparison to active area. So, if I am having different values of these hole to active area ratio how we should make correction in K 1 value let us see that. So, let us say if I am having hole to active area ratio is 0.1 K 1 will remain whatever we will read from the graph and if this ratio is 0.08 we have to correct the K 1 value by 0.9 and if it is 0.6 the correction should be with 0.8. So, we need to multiply K 1 value with all these correction factor.

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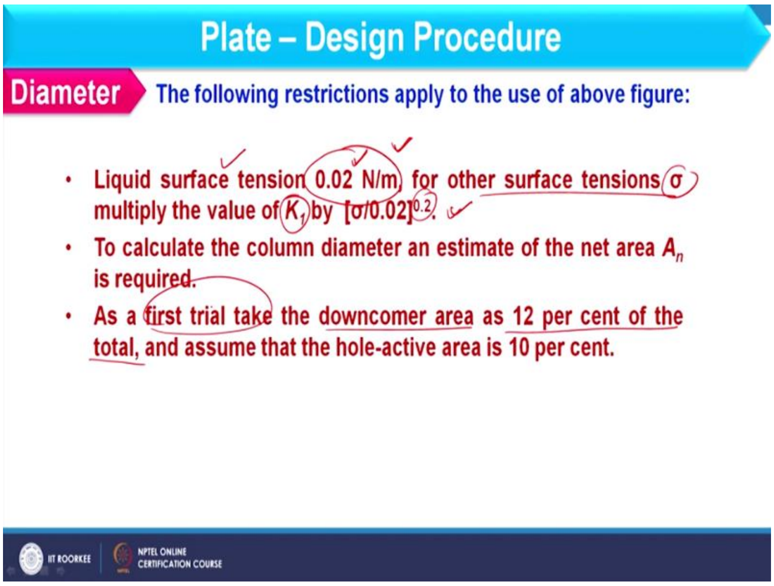

And let us see further we also consider liquid surface tension because for this graph surface tension of the liquid was consider as 0.02 newton per meter. For other surface tension that is sigma value K 1 should be multiplied by this factor that is sigma whatever is given other than this divided by 0.02 power 0.2 and further we need to calculate column diameter considering net area of the column.

And how that net area can be obtained that we will discuss in detail or you can understand that when I am having the mass flow rate of the vapour I can convert that into the volumetric flow rate of the vapour. And that will be divided by the velocity of vapour which would be like 80% to 85% of the flooding velocity. So, division of these two will give the net area and then we will find out the column diameter.

However, this calculation also requires the downcomer area and that should be 12% of the total area and that we consider as the initial trial. So, in this way we can calculate the diameter of the column.

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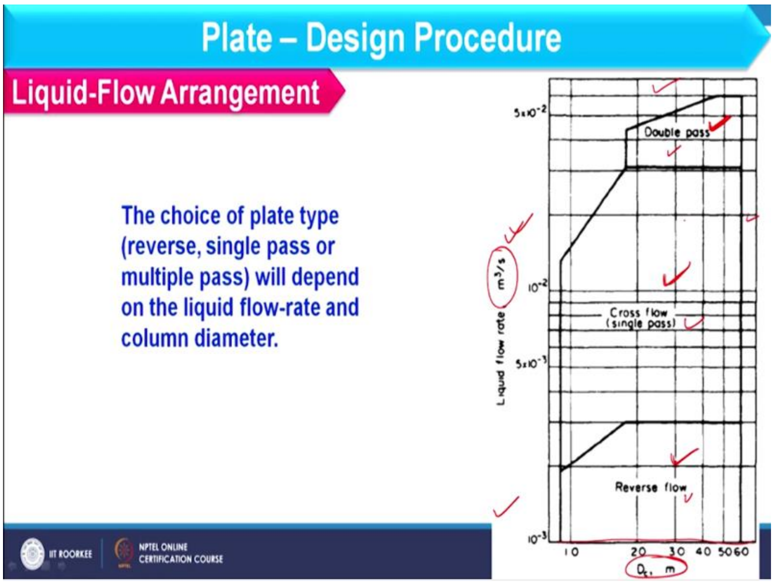

And next we have the flow liquid arrangement. If you see here I am having this graph where liquid flow rate is there and on x axis we have column diameter. So, according to this that is column diameter value and liquid flow rate we can choose that which type of passage or the flow pattern we have to consider over the plate. So, this graph will help you to choose that. So, here if you focus on this graph here we have different type of arrangement like single pass, reverse flow as well as double pass. And all these we have already discussed in the last lecture so you can refer that.

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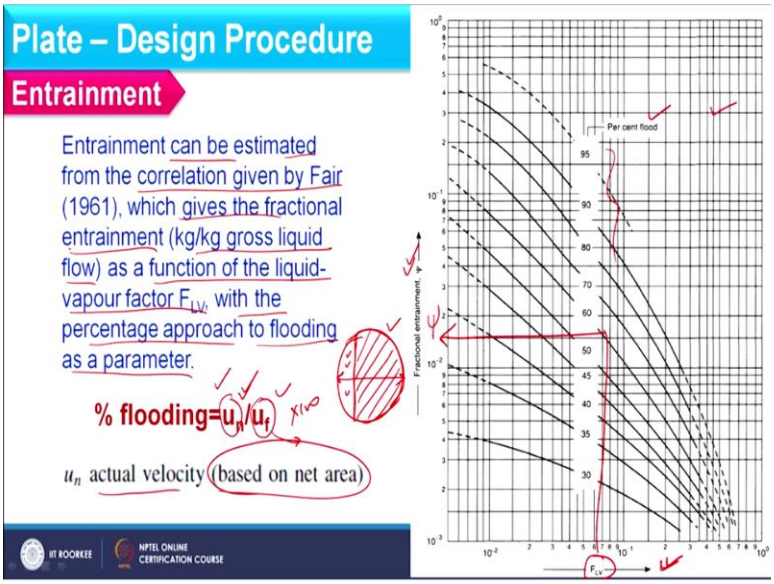

So, once I have chosen the correct diameter as well as liquid flow pattern I will focus on entrainment whether the entrainment should not be more than the permissiblse limit. So, let us see that how to calculate the entrainment. So, entrainment can be estimated by the correlation given by Fair which gives the fractional entrainment that is kg per kg gross liquid flow rate as a function of liquid vapour factor that is FLV with percentage approach to flooding as per the parameter.

So, as far as this entrainment is concerned you need to refer this graph where on x axis I am having FLV value which we have already calculated in diameter calculation and here I am having fractional entrainment and it will depend on the percentage flooding because once I am having the excessive entrainment then the flooding will occur. So, flooding should be the criteria to decide the entrainment in the plate.

So, first of all we have to find out the percentage flooding and that can be calculated by u n / u f into 100. So, u f is the flooding velocity which we have already calculated in diameter calculation and u n is basically the actual velocity based on net area. So, when you have the mass flow rate of the vapour and that you have already calculated while calculating the diameter it means you already have the mass flow rate of vapour along with the net area.

What is net area that we will further discuss in detail, but let me explain that quickly like if I am having the plate like this and this is basically the downcomer, this is the complete plate and as far as diameter of column is concerned this is basically this diameter. So, if I am considering the plate and removing the area which is covered by downcomer from the total cross sectional area of the column the remaining section available to us it will be nothing, but the net area as we can see here.

So, we can calculate the vapour velocity considering volumetric flow and the net area we can find out value of u n and once I am having this percentage flooding and FLV value we have already calculated in diameter calculation. So, accordingly you can choose the percentage flooding and this wherever it will lie you can find out the value of fractional entrainment and that is basically psi value.

And what is the limit? This psi value should be less than 0.1 if entrainment should be more than 0.1 we should choose the diameter of the column accordingly. So, in this way you can consider the entrainment and you can maintain the entrainment condition while designing the plate. And I am stopping this lecture right here we will continue design of the plate in next lecture also. So, that is all for now. Thank you.