Process Equipment Design

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

Lecture –47
Design of Packed Column-5

Hello everyone. This is 47th lecture of the course Process Equipment Design and I welcome you all in this lecture. And here we are going to discuss design of packed column with the help of some examples. So, if you remember the last week where we have discuss design of packed column and in that we have computed height of the packed bed as well as diameter of the packed column.

And here we are illustrating the design of packed column through some example. So, let us start with the example one.

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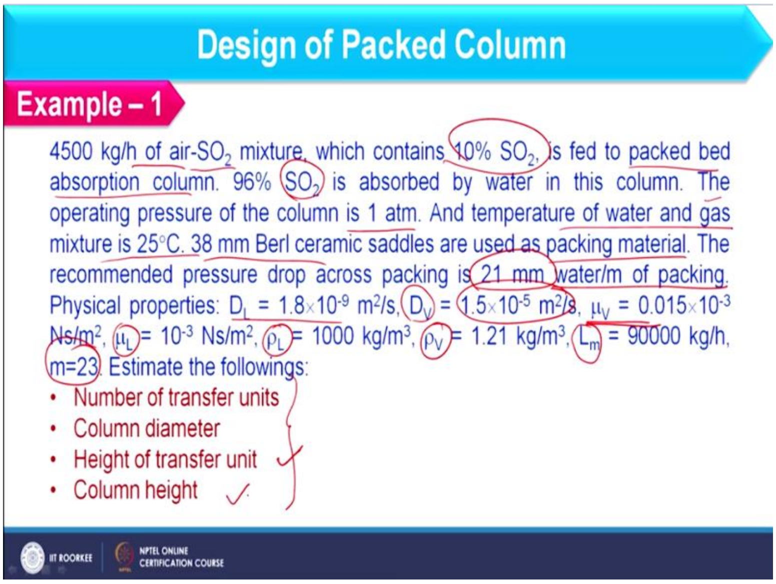

So, in this example 45 kg per hour of air and sulfur dioxide mixture which contains 10% S0 2 is fed to the packed column and that is specifically as absorption column. 96% of SO 2 is absorbed by the water in this column. So, what is the remaining percentage of SO 2 in the air and S02 mixture that should be 4%. So, the operating pressure of the column is one atmosphere and temperature of water and gas mixture is 25% degree Celsius.

38% mm Berl ceramic saddles are used as a packing material. The recommended pressure drop across the packing is 21 mm of water per mm of packing. And along with these some physical properties are also given such as DL that is diffusivity in liquid phase and DV is the diffusivity in gas phase. So, because gas is easily diffusive so its value is lesser than the diffusivity of liquid.

Further, we have physical properties like mu v that is the viscosity of the liquid, density of the liquid, density of the vapour and here we are given Lm and that is liquid mass flow rate and that value is around 90,000 kg per hour and m value is given as 23 which is the slope of the equilibrium line. And what we have to estimate are number of transfer units, column diameter, height of transfer unit and column height.

So, this is the example which we have to solve where design of packed column is considered where height as well as diameter of the packed column are to be computed and in this example we will consider Cornell's method for design of packed column.

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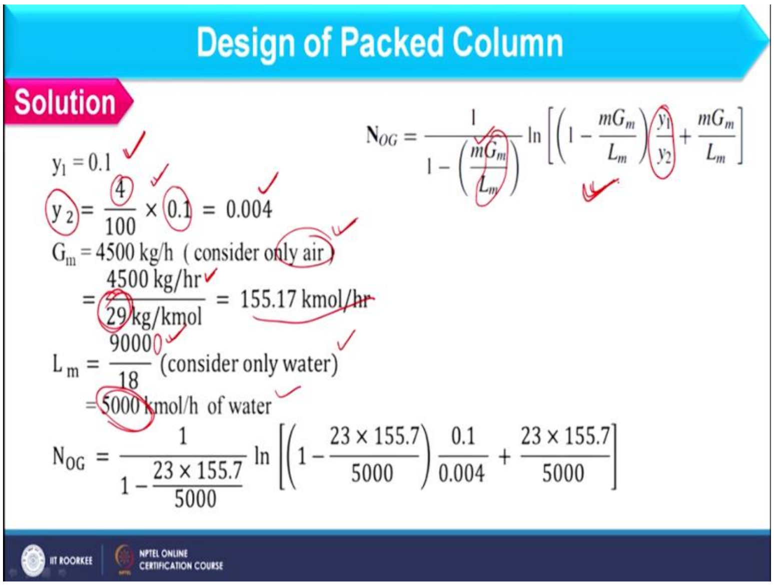

So, let us start the calculation of this. So, as far as height of the packed column is concerned that is basically H O G as well as N O G. So, first of all we will find out N O G and then we will proceed for H O G calculation. So, N O G if you consider that depends on initial and final concentration of the solute in gas phase. So, if we consider the initial concentration of sulfur dioxide in gas phase so that is given as 10%.

So that value I am considering as 0.1 and y 2 is the concentration of the solute at exit condition and here because 96% is dissolved in the water so 4% is available so 4% of 0.1 so that should be 0.004. So, in this way you can find y 1 as well as y 2 and next we have to find out G m and L m value. And these G m and L m are basically molar flow rate not mass flow rate.

And if you consider in this example we are given the mass flow rate of the gas mixture as well as liquid stream and that is water. So, mass flow rate is given as 4,500 kg per hour and to convert that into molar flow rate we will consider the molecular weight of the air because it has 10% of SO 2. So, molecular weight of air will dominate. So, I am considering 4,500 kg per hour as the mass flow rate of the gas stream divided by 29 that is the molecular weight of the air.

So, molar flow rate of gas you can find as 155.17 kilomole per hour. In the similar line, I can find the molar flow rate of liquid stream and that is water. So, here you consider 90,000 it is not 9,000 90,000 is given to us and that should be divided by 18 so 5,000 kilomole per hour of water is available. So, now we have all values to find out N O G. So, if you focus on the expression of the N O G it is like this where m is given as 23.

Gm and Lm values I have already calculated y 1 and y 2 you know already. So, considering this expression I can put the values of all parameters into this and it is shown over here.

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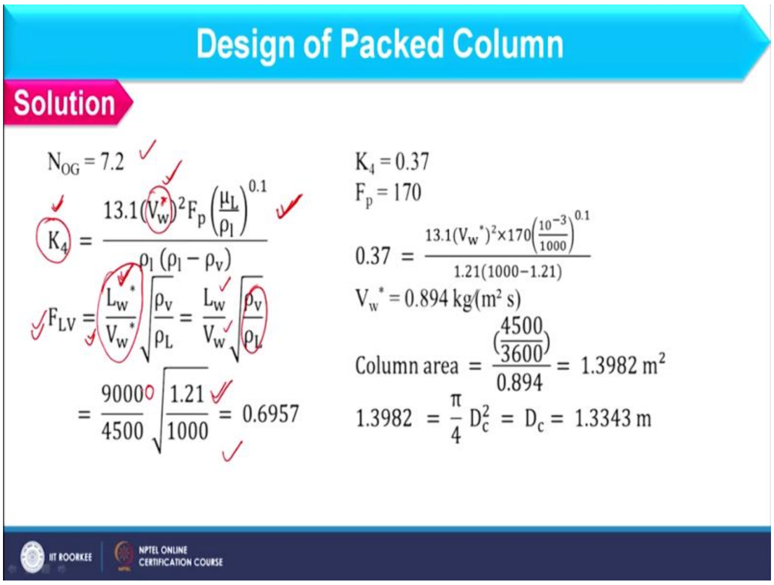

And when I solve this equation we can find N O G value as 7.2. So, this is basically number of transfer unit. Next, we have to find out H O G value that is height of the transfer unit and if you recall the Cornell’s correlations in that case we have N O G which is dependent on the diameter of the column as well as height of the column. So, first of all we will compute diameter of the column and then we will proceed for H O G calculation.

So, as far as diameter of the column is concerned that is the expression and based on that we can calculate V w and here it should be star because it is per unit area value. So, we have to find out K 4 value first and then we can find out V w star and K 4 value is basically dependent on the FLV value and this is the expression of FLV. Here, you consider L w star as well as V w star and these both are based on per unit area value.

So, area will be cancelled out from 2 and then we can simply represent this as L w / V w that is the mass flow rate. So, considering these value we can find out FLV value which is coming out as 0.6957. Rho v, rho L all these values are given to us and please consider here 90.000 not 9,000. So, once I am having the FLV value I need to find out K 4 value through the graph.

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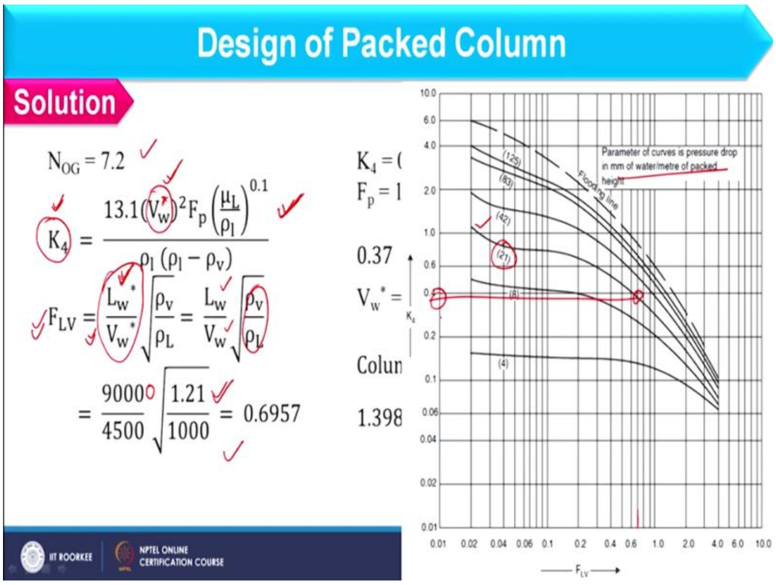

And you see this is the graph and in this example you see the pressure drop is given as 21 mm of water per meter of packed height. So, we have to use this curve and as far as FLV value is concerned it is coming around 0.7. So, that will be somewhere here. So, when we consider this point we can find out value of K 4 and that should be like this. When you draw the straight line you can find the exact value and the value comes as 0.37 if you read the graph properly.

And if I focus on this equation further I have found out K 4 value and next we have to find out F p that is the packing factor.

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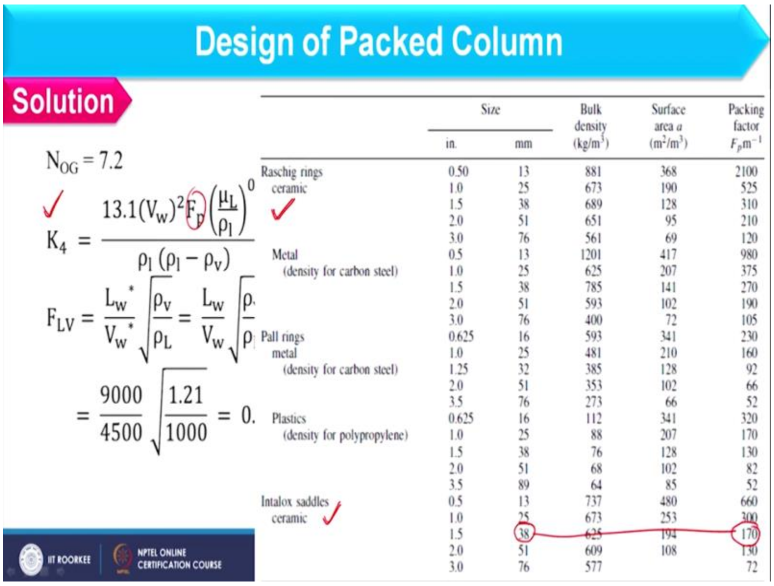

And here we have the table of the packings and if you see we are given 38 mm Berl saddle because Berl saddle is not available in this table that will be close to the intalox saddle and we can use this packing instead of Berl saddle. However, some difference is there, but more or less it is falling in the same category. So, here I am having 38 mm size and corresponding to this F p value you can find out as 170.

So, here you can see F p value we are taken as 170. So, considering K 4, F p and all other properties we can find out V w star value which is coming out as 0.894 kg per meter square second. And further you are given with the mass flow rate of the gas and that is 4,500 kg per hour. So, that we can consider so this we can divide by this V w star and this is basically 4,500 / 3,600 as it is considered in per second and we are given V w star value as this.

So 1.3982 meter square is the column cross section area and considering that you can find out column diameter as 1.334. So, in this way we can find out the column diameter.

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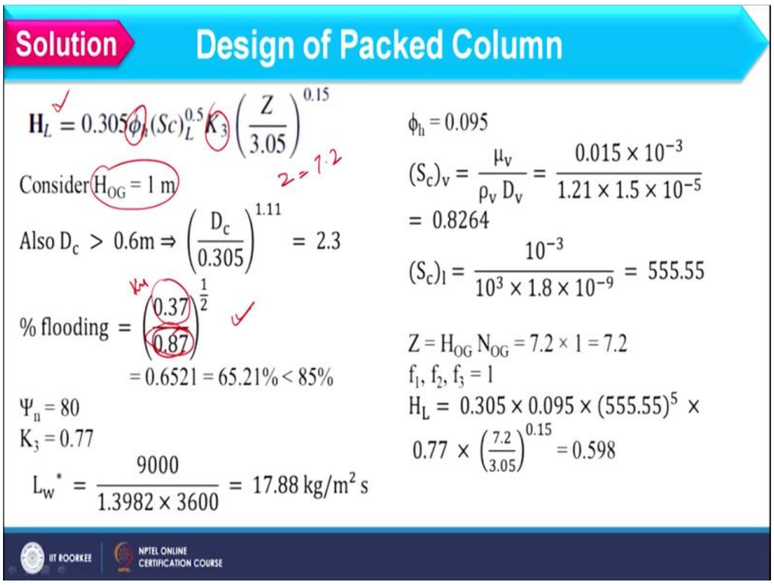

Now, next we have to find out the value of H O G and H O G will depend on the diameter as well as Z value and Z value will depend on H O G into N O G. Till now only N O G you have obtained, but H O G you need to obtain and for that you have to consider Z value so that will be an iterative method. So, first of all we will assume the value of Z. And then we will proceed to find out the value of H G as well as H L.

So, how we should consider the value of Z? Initially, Z value we will consider based on assumption of H O G because N O G value I have already calculated. So, H O G value initially I am considering as 1 meter. So, initial assumption is H O G = 1. So, once I am having this we can find out Z value as 7.2 because 7.2 is the N O G and one H O G value I have considered. And so if you consider HL correlation here I need K 3 and phi h.

Along with this psi h is also required which is for the calculation of H G over here that we will see in the next slide, but find out the values of K 3, phi h and psi h and for that I need percent flooding. So, how I can find out the percent flooding 0.37 is the K 4 value which we have seen in the last slide and how this value 0.87 comes? So, to find out K 4 we have to see this figure and if you see here I am having FLV value which is equal to 0.7.

And when we have drawn the line upward we can find the value of K 4 at operating condition here and if I extend this line up to flooding condition I can find K 4 value at flooding condition like this. So, in this way you can find out the K 4 value at flooding condition and it will come out as 0.87. So, considering this we can find out flooding as 65% which should be less than 85%. Now at this 65% we have to find out value of psi h K 3 and phi h.

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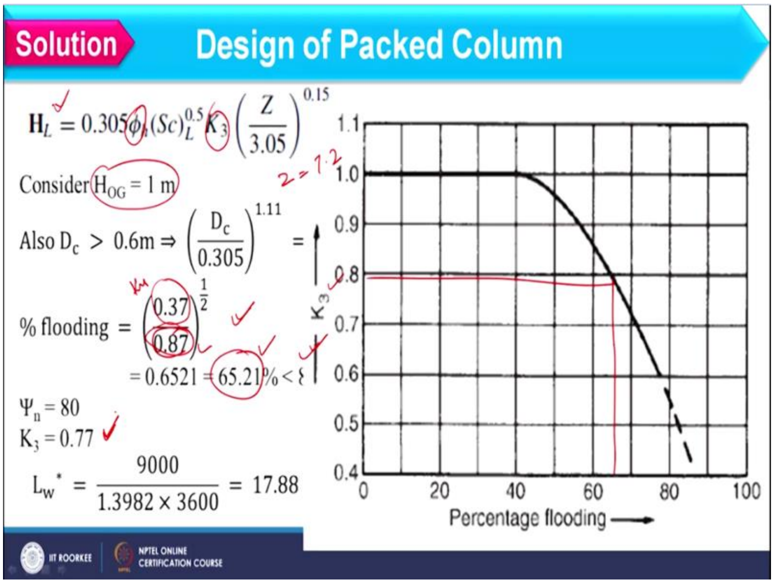

And for that we can consider the graphs like this. Here we can read the value of K 3 corresponding to 65% flooding condition. So that should be somewhere here and you can read the value. So, if you read the value properly it is coming out as 0.77.

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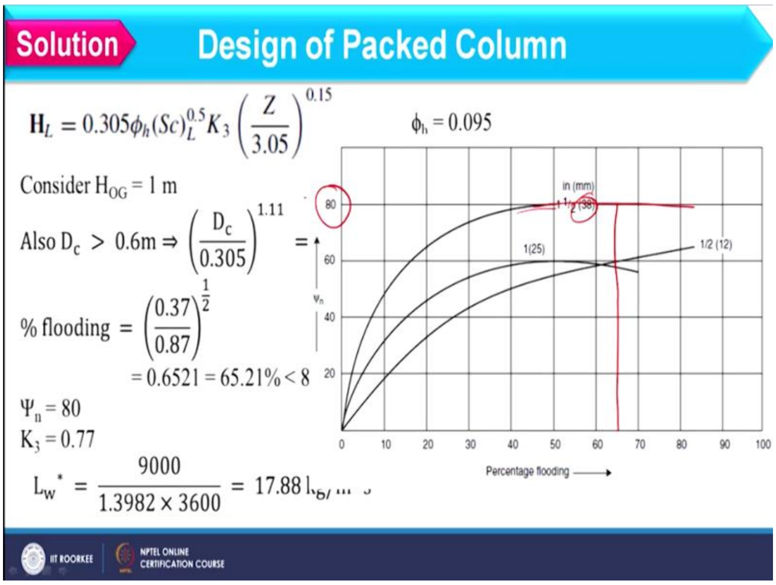

And further we can find out value of phi h so here you see we have flooding condition around 65% and when we draw the line upward you can see we can have the packing as 38 mm Berl saddle and here if you see asymptotic line is falling and it will be extended further. So, we can consider the value as 80.

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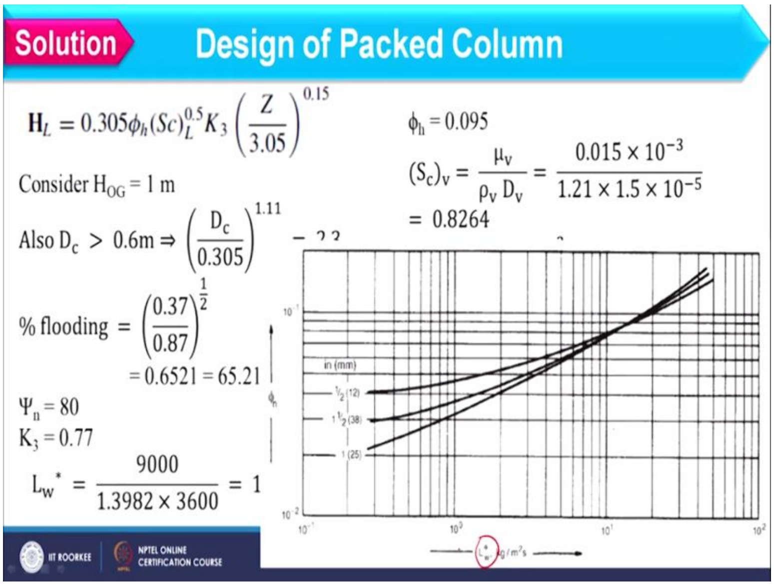

And for phi h value we have to find out L w star and that L w star you can calculate considering liquid flow rate and that should be 90,000 divided by 3,600 and divided by the cross sectional area. So, its value comes as 17.88 so when we consider this graph 17.88 will lie somewhere here and we can consider value of phi h at this point and its value should come as 0.095 when you read the value from here.

So, in this way we can find out the value of different factors and once you have these factors we can find out the Schmidt number for liquid condition as well as vapour condition because vapour condition will be used to find out value of H G. So, we will do the calculation together. So, here we have the Schmidt number for vapour and this is the expression all properties are given. So, we can find the value of Schmidt number at vapour as 0.8264.

Schmidt number for liquid condition we can find value of 555.55 and Z value we have already seen it is 7.2. So, considering all these value we can find H L value from this expression and its value should come as 0.598. All values you can put in the given expression.

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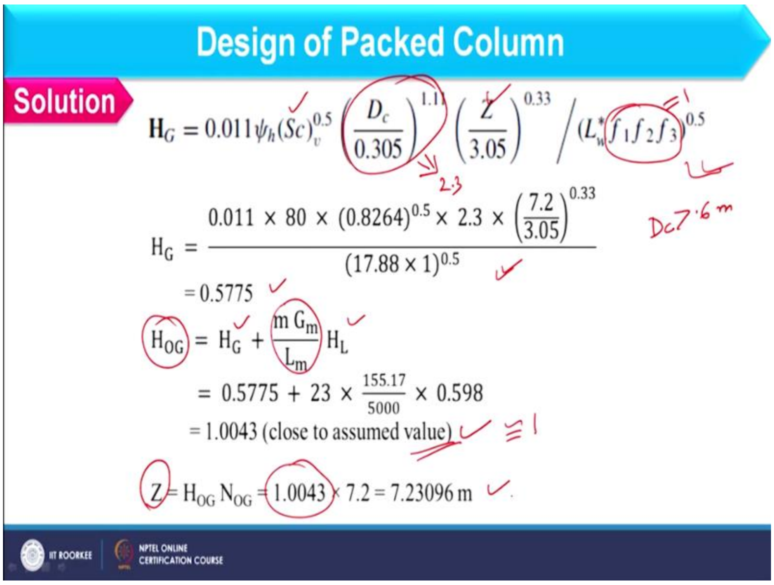

And next we have to find out H G value and this is the expression of H G where this D c expression I have to see first because in this example diameter is more than 0.6 meter. So, we will replace this whole expression with 2.3 and because solvent is water only so we will consider f 1, f 2, f 3 value should be equal to 1. So, other parameters you have already calculated, Z you know.

And when you put the values in H G expression in this way we can find the H G value as 0.5775. So, we can find out H O G based on H G as well as H L value. And considering m G m / L m so considering all these value we can find out H O G value as 1.0043 so that will be close to the assumption which is 1. So, I consider that assumption is correct and so I can find out the Z value as H O G into N O G.

Now, I will put correct value of H O G and the height we can obtain as 7.23096. So, in this way we can find out the height as well as diameter of the packed column. Now, if in this case H O G is not close to the assumed value. So, what we have to do? We have to do like whatever calculated H O G we have obtained based on that we will further calculate Z value because N O G has the fixed value.

So, in this way considering revised value of H O G we will calculate Z then H G and H L and then H O G and then Z value. So, this we keep on doing till two consecutive iterations have zero value difference. So, that should be almost zero as here we can see that we have consider 1 meter and we have obtained 1.0043 value. So, in this way we consider the design of packed column and further we will see few more examples to illustrate the design of this column.

So, let us focus on example 2 and this example I will cover quickly because details I have already explained in previous example.

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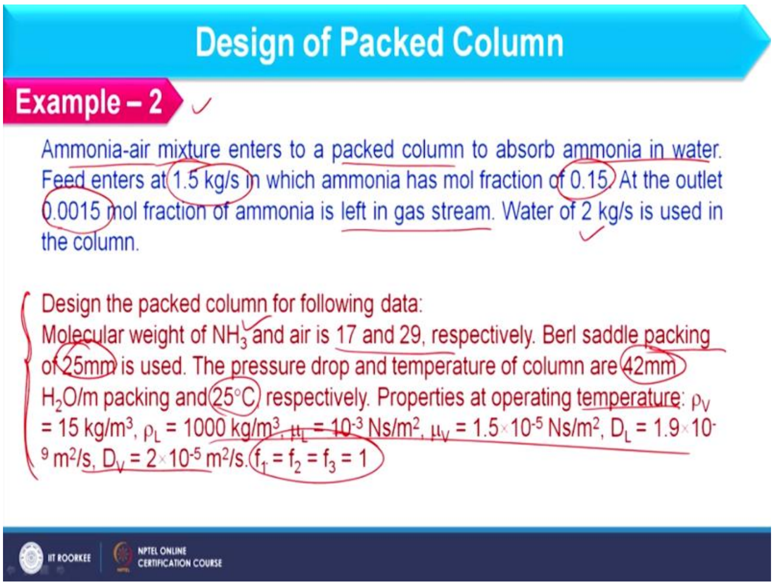

So, here I am having second example. In this ammonia and air mixture is entering to the packed column to absorb ammonia in the water. Feed enters at 1.5 kg per second where ammonia has mol fraction of 0.15. At the outlet 0.0015 mol fraction of ammonia is left in the gas stream. Water which is available as 2 kg per second and that will be used as a solvent in the column.

I need some data which are given here as molecular weight of ammonia and air are given. Berl saddle packing is used with 25 mm size, pressure drop in the column is 42 mm water per meter of packing and that is available at 25 degree Celsius. Property at the operating temperatures are given like this because water is there. So, f 1, f 2 and f 3 should be consider (()) (20:50) and this should be used in H G calculation. So, here again I am considering Cornell’s expression to find out H G as well as H L.

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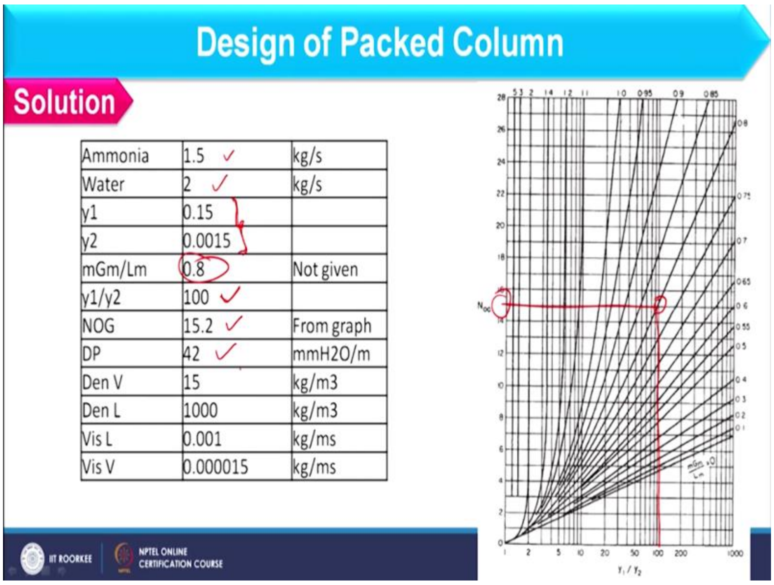

So, you see the flow rate of gas stream that is ammonia and air is given as 1.5, water flow rate 2 and here I am having y 1 and y 2 values and I can simply find out y 1 divided by y 2. So, first of all I have to find out N O G value and for that we should consider m G m / L m. So, in this case you see we are given G m as well as L m actually mass flow rate is given, but that we can consider in molar flow rate that is not the problem, but I am not given m value.

So, I cannot calculate m G m / L m. So, if you remember the design of packed column there if m G m / L m value is not given we consider the optimum value. And that optimum value is 0.8 so that we can consider over here y 1 / y 2 we can obtain as 100 and so we can see the value of N O G from the graph so that would be y 1 / y 2 and that is 100 and here I am having the value as m G m / L m 0.8.

So, this value we can consider as N O G value if we consider 100 y 1 / y 2. So, value will come as 15.2 from the graph if you see it carefully. So, pressure drop is given as 42 all parameters are given like this.

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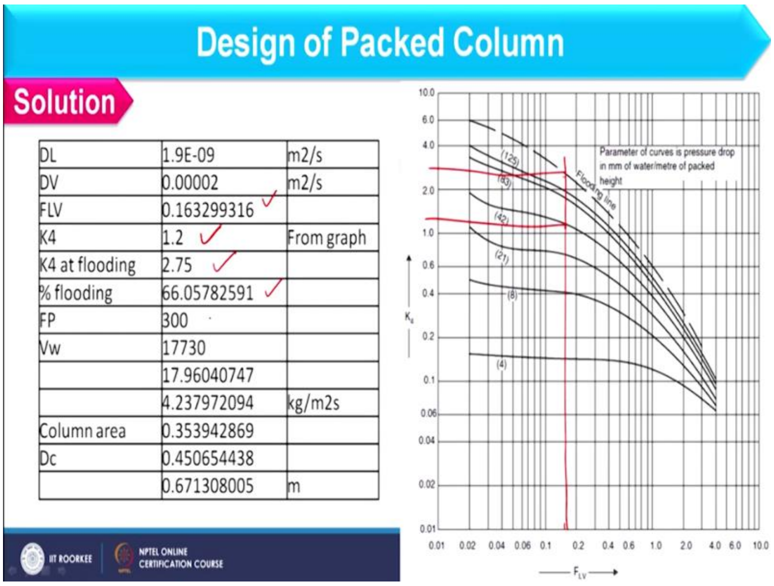

So, next we have to find the column diameter and for that we should see the value of K 4 from the graph and for that I should know FLV value which we can calculate from this. So, once I am having the FLV value which is equal to 0.16 somewhere here it will lie and 42 is the value. So, we can consider this plot and we can draw the line like this. So, K 4 value we can obtain as 1.2 when we extrapolate this to flooding line this should be K 4 at the flooding condition and that should be 2.75 if you see it carefully. So, around 66% flooding is there.

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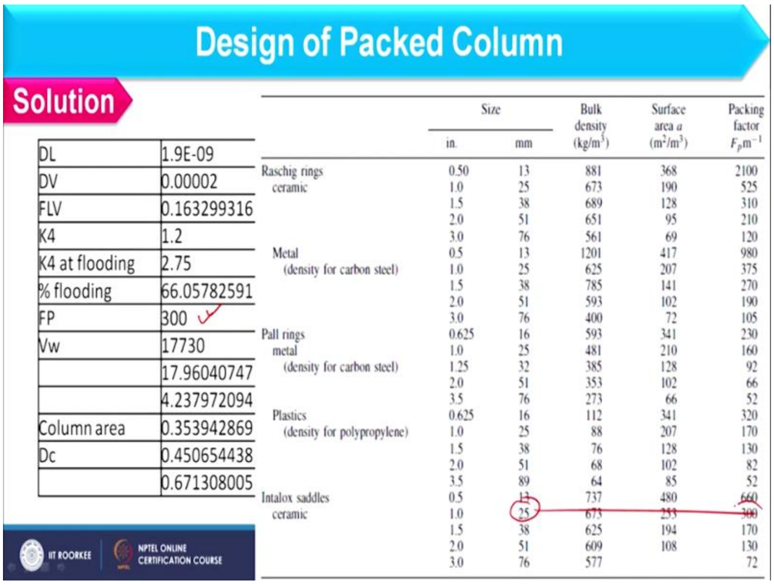

F p value we can consider as 300 from this table corresponding to 25 size in this way we can obtain the value and we can further calculate V w star. And that value we can obtain as 4.238 kg per meter square second and so we can calculate the column diameter which is again coming more than 0.6 m. So, this we have to consider in H G calculation using Cornell’s method.

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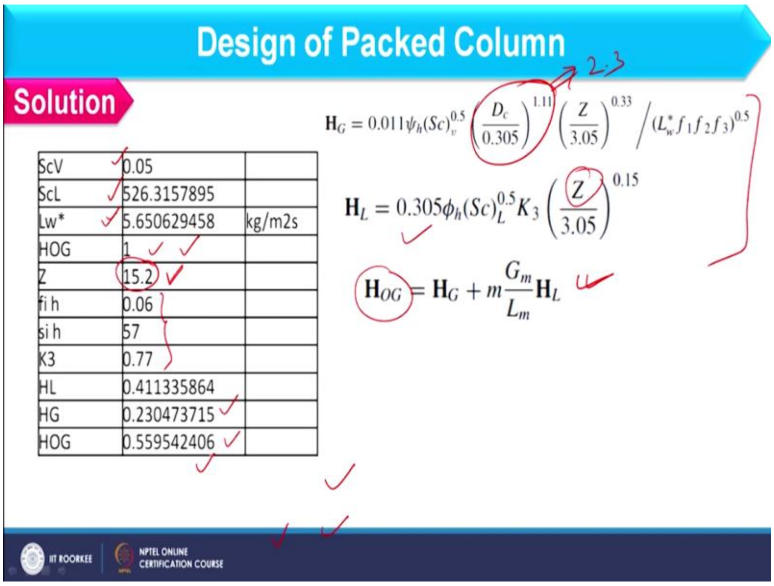

So, here I am having the equations for the Cornell's method. So, Schmidt number for vapour and liquid condition we can calculate as we have discussed in the previous example L w star we can find because mass flow rate of liquid is given to us. Initially, I am assuming H O G value as 1. N O G we can obtain as 15.2 so Z value should be 15.2 only. This is phi psi and K 3 values from these graphs.

These graphs I have already explained in the last example so I am not going into detail of that. So, considering this we can find out H L value as well as H G value. So, here again this you should replace by 2.3 and Z is 15.2. So, considering all these value we can find HL and HG and through this H O G calculation can be considered and the value of H O G should come as 0.5595.

So, you see initially I have assumed H O G as 1 and now I have obtained just half value of that so that will not be acceptable.

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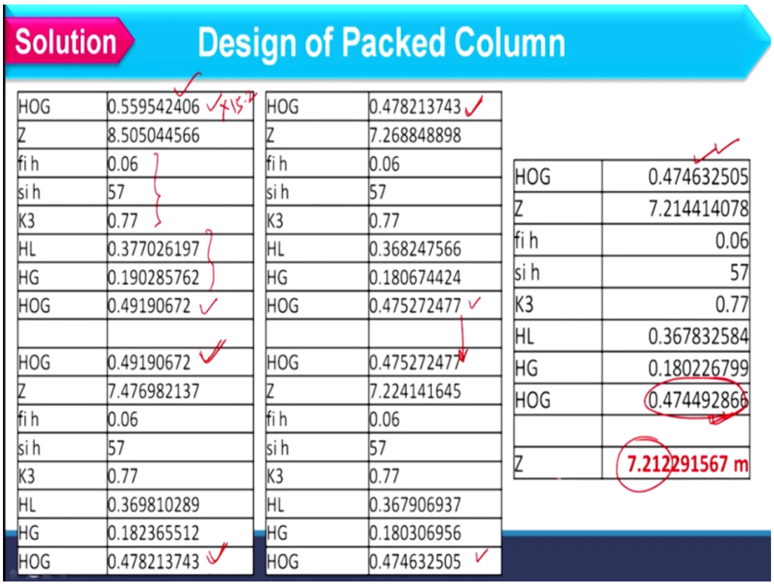

HOG	0.559542406 ×15.2
Z	8.505044566
fi h	0.06
si h	57
K3	0.77
HL	0.377026197
HG	0.190285762
HOG	0.49190672
HOG	0.49190672
Z	7.476982137
fi h	0.06
si h	57
K3	0.77
HL	0.369810289
HG	0.182365512
HOG	0.478213743

HOG	0.478213743
Z	7.268848898
fi h	0.06
si h	57
K3	0.77
HL	0.368247566
HG	0.180674424
HOG	0.475272477
HOG	0.475272477
Z	7.224141645
fi h	0.06
si h	57
K3	0.77
HL	0.367906937
HG	0.180306956
HOG	0.474632505

HOG	0.474632505
Z	7.214414078
fi h	0.06
si h	57
K3	0.77
HL	0.367832584
HG	0.180226799
HOG	0.474492866
Z	7.212291567 m

So, considering this H O G we can find out Z by multiplying this with 15.2 N O G and phi psi and K 3 values will be same and further I can find out revised value of H O G as 0.49 still it is differ than the previous value. So, I keep on doing the iterations like this you see 0.49 we have assumed. We have obtained 0.478. Further, this value we have assumed and find out 0.475.

And further considering this value we can find out H O G value as 4745. So, we can consider that it is pretty close to the assumed value and so 7.2 meter will be the total height of the packed column. So, in this way we can consider the solution of this example. Now here I am having third example and I will cover that quickly because I have to tell a different point over here.

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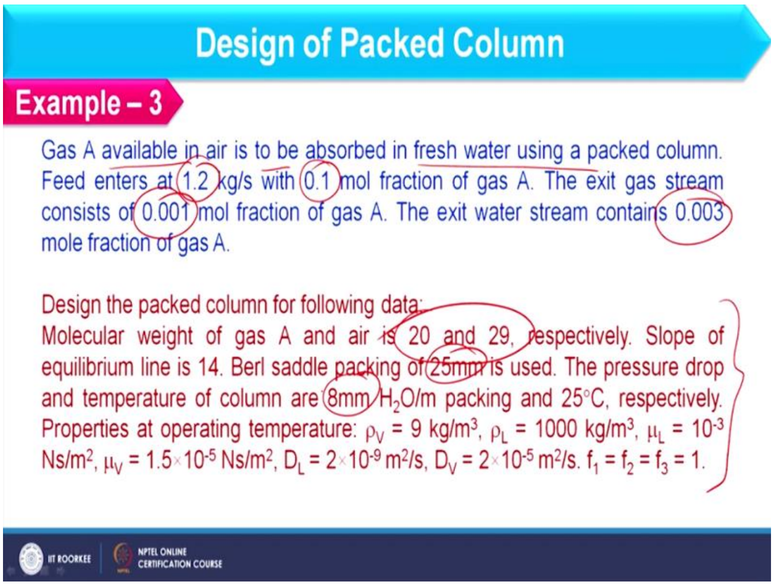

So, in this example gas A is available in air and that should be absorbed in the water, feed is 1.2 kg per second 0.1 is the mol fraction of gas A at exit this much mol fraction is there and exit water stream contains this much mol fraction of gas A. And here we are having the properties where gas A and air molecular weight are given packing 25 mm. So, you can consider pressure drop as 8 mm water per meter of packing.

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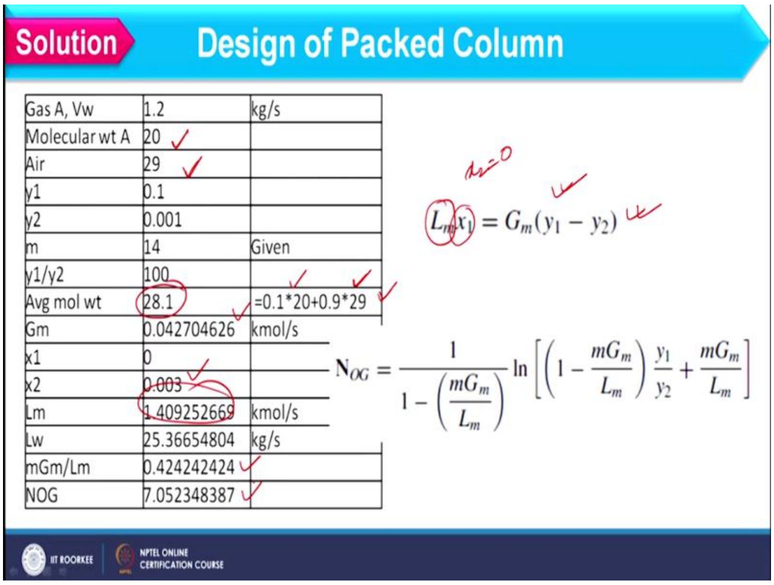

So, here you see we have different parameters and in this example m value is given to us that is 14. So, you see here we are given molecular weight of A and air. So, average molecular weight I can find out that is 0.1 into 20 plus 90% air so that should be multiplied by 29. This I have not considered in example 1 so that you can see. And here I am having the gas molar flow rate as this and I do not know the liquid molar flow rate.

So, I can obtain that by making the balancing I am considering that initially water has zero gas A. So, by making the balance over here we can find out Lm value and that should be 1.40325 because x 2 or we can say the final concentration of gas A in liquid is given as 0.003. So m G m / L m we can find out and then we can find out N O G value considering this expression.

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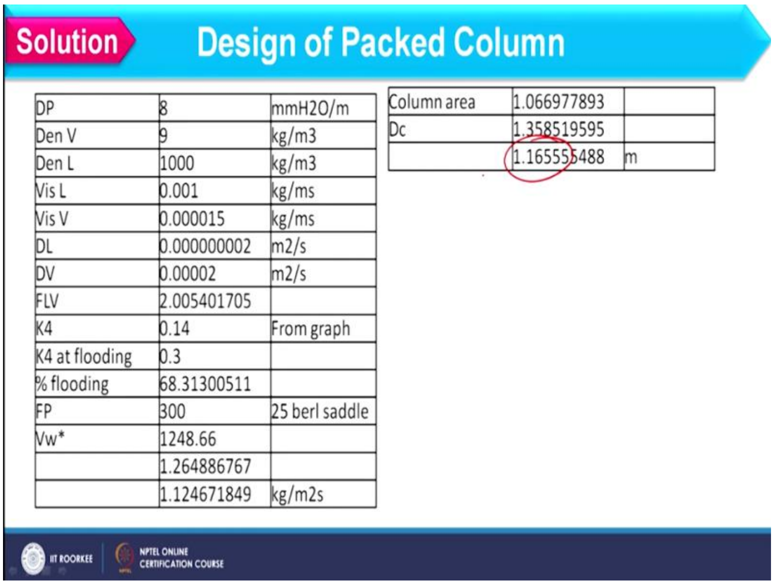

And here all calculations are repeated and we can find out diameter of the column as 1.1655.

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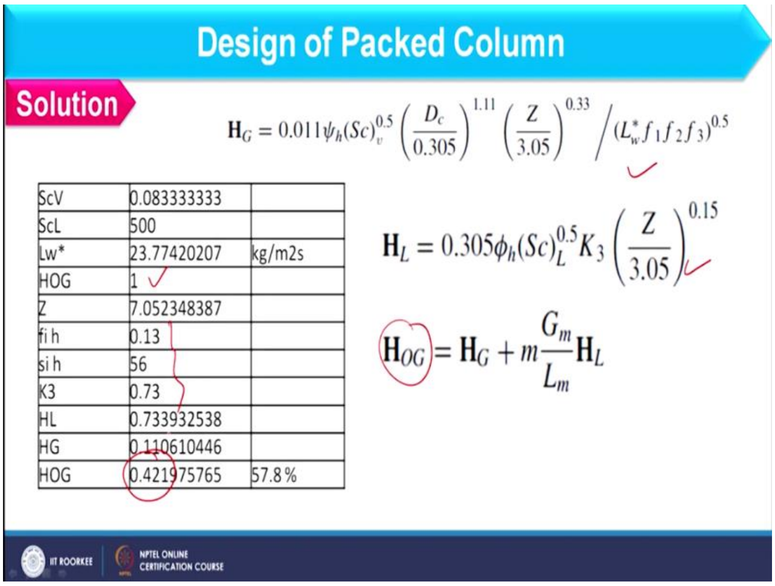

And considering H G H L value and H O G value we can find out H O G value as 0.422 and one value we have assumed all these value you can see on your own and we can see that sufficient error is there.

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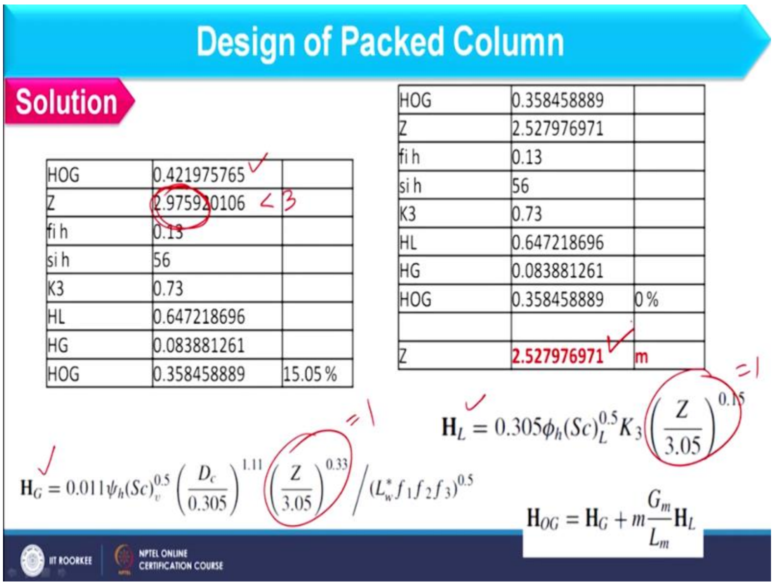

And further we can consider this H O G and now the Z value you can obtain as 2.97 multiplying H O G with N O G. So, here you see Z value is coming less than 3 meter and if this is the condition we consider H G value as well as H L value considering this factor as 1. So, this change you have to do rest calculations are same. So, you can find out final height of the column as 2.53 meter. So, in this way we have considered different examples.

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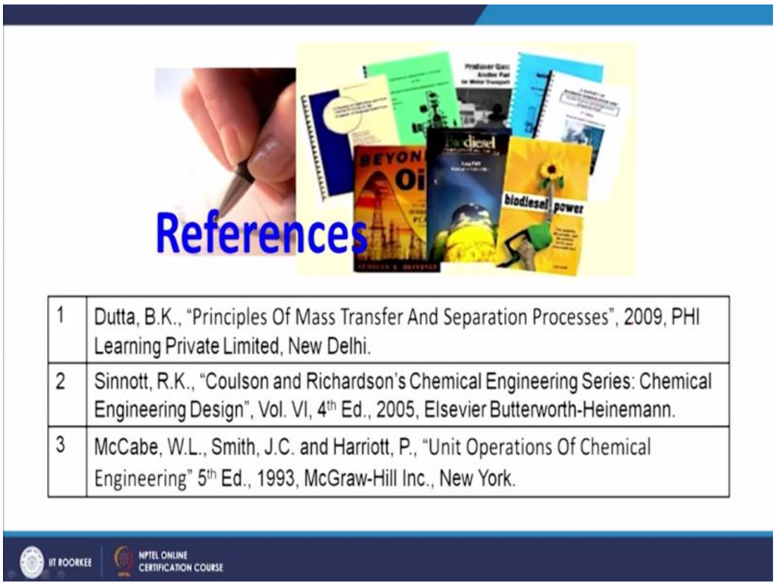

These are the references.

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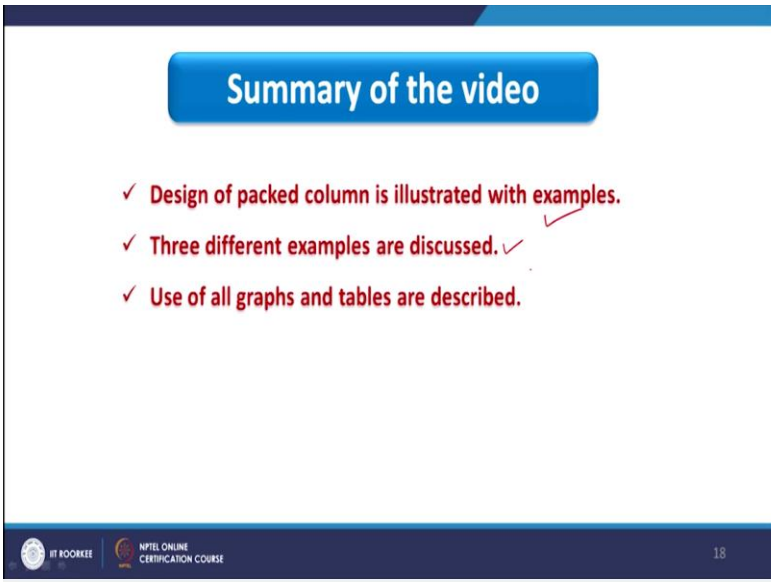

And here I have the summary of this video that design of packed column is illustrated with examples. Three different examples are discussed, use of all graphs and tables are described in detail and that is all for now. Thank you.