Principles and Practices of Process Equipment and Plant Design
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Module - 02
Lecture - 30
Tower and Tower internals (Packed Tower Design - Contd.)

Welcome to the continuation on the topic on Tower and Tower internal design particularly the design of Pack Towers.

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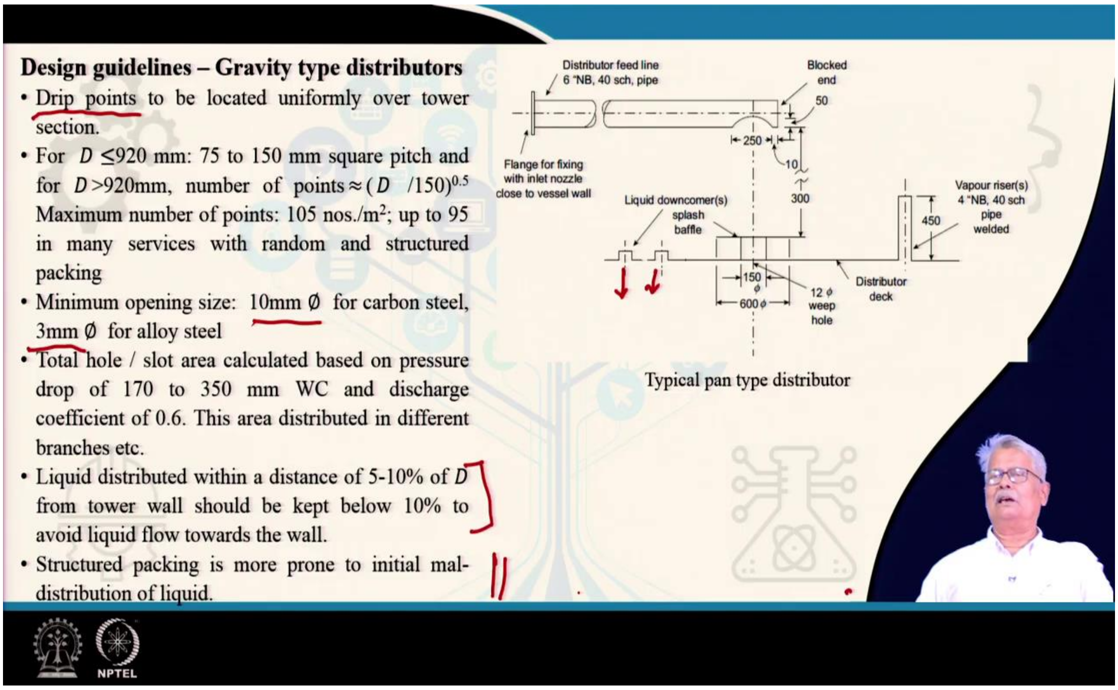

What we have been discussing in the last class is regarding the gravity type of distributor, where we have seen what are the different components and what these details are. The first thing here is the drip points. That means, we have to have the weeping arrangement and also the drip points means these are the drip points and they are to be located as uniform as possible.

At the same time, we must have seen that we do not have much liquid discharge close to the tower edge. That means, the end 5 to 10 % of the D should not get more than 10 % of the liquid. We also have seen that since we are going to provide these drip points whether should they these should be in square pitch or it should be in triangular pitch and what it should be basically?

The industry practice is typical if your diameter is below 920 mm. See this is not a very sacrosanct figure whenever I say 920 that does not mean 920.0. It could be 900 or it could be 950 also it depends on the convenience and experience of the designer. But these are the general guidelines and many of these have been arrived at by converting from the standard fps practices.

So, basically what you have is you can have 75 to 100 mm^2 pitch with the dimensions of these holes as shown here. A number of points on how to find out it are also told here. Typically, say up to a maximum of 105 numbers holes per m^2 of the tower area. Most of the applications use up to 1995 number of holes per m^2. It's true in the case of random as well as structure packing.

In fact, it's very important to have a good distributor in case of structured packing. The minimum opening size for a carbon steel deck is about 10 mm and it's 3 mm for alloy steel. In fact, this is something which I thought that I must explain or rather tell here carbon steel whatever may be the service will rust.

So, if you have a very narrow hole, there will definitely be some reduction in that particular hole divided because either debris collection or due to rusting and that is why you will find that carbon steel whenever you are required to provide this type of opening, they are normally not below 5 mm.

Here the typical opening size is about 10 mm and in the case of alloy steel which does not rust and if you are sure that your liquid is not going to contain something which is going to be deposited you can go for 3 mm diameter holes otherwise you could go for 5 mm also.

The total hole or slot area is calculated based on the pressure drop of 170 to 350 mm water column and the discharge coefficient typically is 0.6 which is the same as a standard orifice.

The liquid is distributed within a distance of 5 to 10 % that I already have mentioned and we warn you once more that your structured packing requires special attention in the design of the distributors particularly this type of distributor. You already are aware of the other different types of distributors whose design we have illustrated. But we have not gone into the detailed dimensioning of these. This is a very common type of distributor that you use.

In the case of small towers, this type of gravity distributor are usually more popular. A spray distributor is normally used when you have your liquid supplied at a reasonably high pressure typically around one say about 1 kg/cm^2 gauge. At least that or it could be even more.

A vendor of that particular spray decides what is the minimum required pressure for that particular nozzle spray nozzle and what is its capacity and based on that you have to design the network of the header which will be fitted with those nozzles. There is one thing that is quite important in the case of spray nozzles naturally the height at which it is to be positioned above the bed. Quite naturally, this is important because it's an angle of spray which has to be considered for that.

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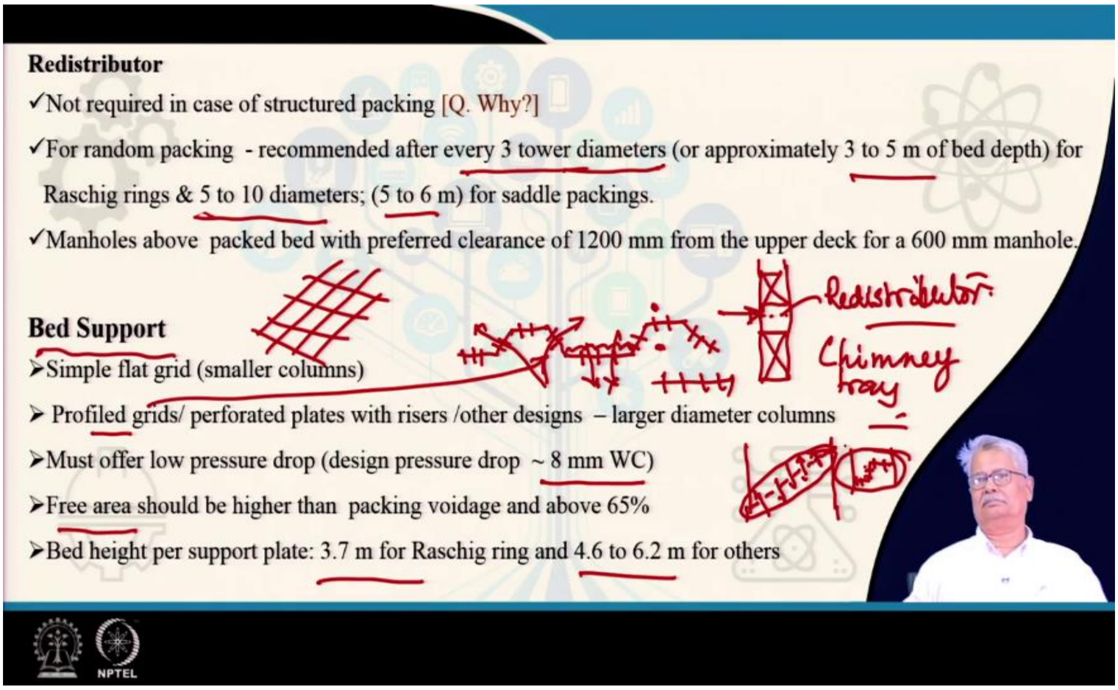

We have talked about the distribution. In some cases, you require a redistributor. Suppose I am talking about a column in which I have two sections and I have feed entry in between or even if I do not have I require a very large amount of packing height. I require the packed height to be substantially large in that case what I do is, I may have to split it into two different back sections and in doing that I will be having the requirement of fitting in a redistributor.

I will require a redistributor what will I use as a redistributor? The simplest thing to use as a redistributor is the chimney tray. The chimney tray details we already have been given an input on that when we are talking about the other components of your tray internals. How these dimensions are? What is the construct? What exactly are the construction and things like that. Now the question is when do we need a redistributor?

One thing is if I have a feed entry I will need it. But there are other cases like when my packing height is large. A conservative estimation is after every 3 diameters the channelling tendency increases. That means, if I could have a redistribution every 3 times the tower diameter. I will be very happy, but it becomes uneconomic in most cases typically for random packings the depth is anything between 3 to 5 m.

That means, you will find that most of these pack towers have a diameter of around 1, 1.3, 1.5 m or even of course, there are larger diameter packed beds also. In the case of rasching rings typically the range is about 5 to 10 diameters. it's 5 to 6 meters for saddle packings. it's slightly higher.

Now, above the packed bed you must have a manhole because in most cases you have to load your packing through that particular manhole only. So, for that what you require some clearance from the upper deck for about a 600 mm manhole diameter.

Now, we have talked about the top distributor, liquid distributor. We had talked about the redistributor in between the packings also below the first top bed. Now, every bed must have bed support the simplest thing is to provide a flat grid. That means, what you could have is narrow bars are there to form a grid, the opening has to be smaller than the minimum size of your nominal size packing. So that they do not fall through and a flat grid is normally enough.

Remember the free area of a grid should be at least the epsilon or the void fraction of the packing. In fact, even if we use a packing which has got a white fraction below 65%, the minimum open area of this particular grid should be around 65%. Now, in the case of larger diameter columns, what is done is you require a good amount of strength of these.

For example, if you are having perforated plates which support I will put it like this. If you have perforated plate support which is acting as a grid you will have holes here, holes here, holes here, holes here, holes here, holes here. This has got a particular profile this is a profile grid of perforated plates.

The main advantage of this is first you are providing more number of perforations or you are having more number of the area. So that you can have a flow like this. The liquid if it segregates it can fall through. This is the second advantage. The third advantage is this will have more strain compared to a flat grid.

So, this is why the large diameter columns will normally have profile grids. Now if you can provide more amount of open areas in your grid your pressure drop would be low. Typically the grid offers or grids are designed to offer below 8 mm water column pressure drop what does it mean?

That means if the pressure here is more than the pressure here by about 8 mm of water column and if you are having an aqueous liquid falling, the maximum level of liquid will be 8 mm. This is ok because you have a large number of openings and it does not stand the 8 mm depth, but definitely, you have this low-pressure drop.

So, that you do not incur any additional extra power for your pumping through the grid itself. We talked about the free area of the grid. It should be a minimum 65 % and at least higher than the packing voidage. Sometimes you do not bother you just provide if it is packing voidage is 95 you provide 95 %, but providing that 95 % is also not that easy.

Now, the question comes that the bed height per support plate. It basically will be dependent on the strength of your support plate. For raschig rings, it is 3.7 meters and for others, it can vary between 4.6 to 6.2. It also depends on the packing certainly that we have already mentioned. Now there could be a construction I mean if you find that your pressure drop is large, you don't have to have a horizontal grid.

You could also in some very special cases particularly when you are doing retrofit work. You can have a transverse grid also. This would provide here a larger area for the vapour and the liquid to pass through and it will have one advantage that is your pressure drop across the grid will be less.

It is not common, but you may be required to do this. In some cases, you can find this type of step construction also. But that is also not very common you have holes here, holes here, holes here, holes here. Quite naturally this portion of the packing is in that case not much of use for vapour-liquid contacting.

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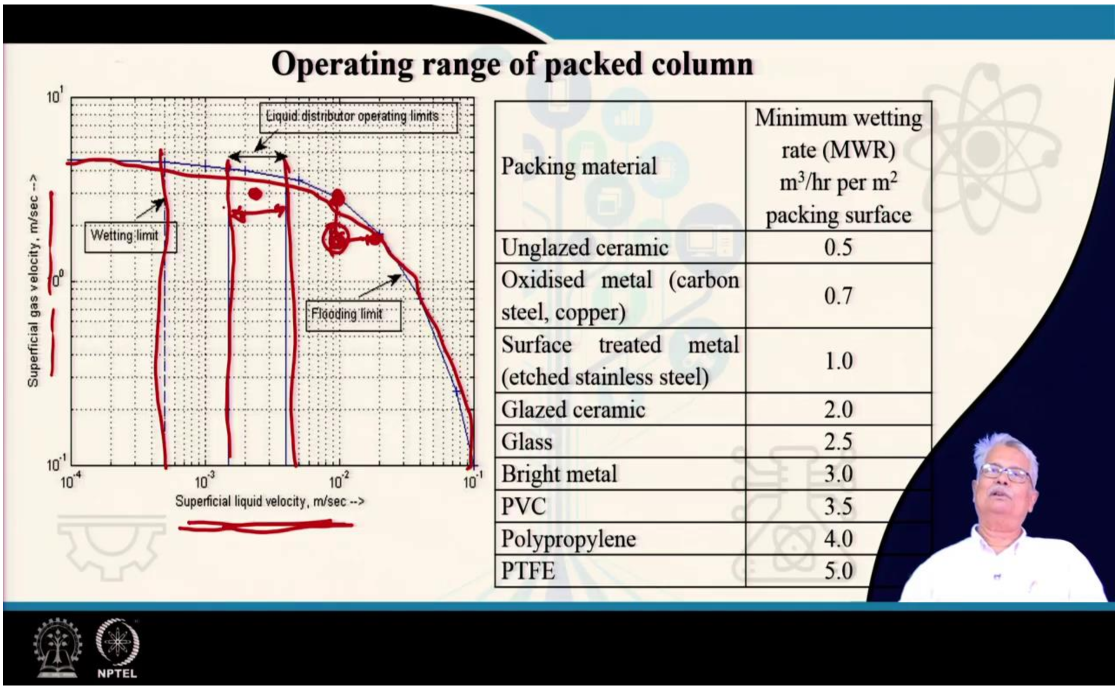

Now, we talk about the operating range of the packed column. This is a flooding correlation. This is a generalized relationship between the superficial liquid velocity in m/S and the superficial gas velocity in m/S. They are plotted in log-log scale and what you have here is obviously, a curve that represents the flooding limit. That means if I have my operating point here and if I increase my vapour flow rate, my superficial velocity will go up and it will start flooding at this particular point. If I keep my liquid rate the same and if I increase my superficial gas velocity more, it will reach here and beyond this, it will flood. So, obviously, we have already seen that we would like to have both a highly liquid and a vapour velocity.

So, possibly, this is some reasonable operating zone which we are thinking. But in the case of a packed bed this is not enough, in the case of a packed bed, usually you have a wetting limit. That means, we talked about the minimum wetting rate. So, you definitely will be having a minimum liquid velocity as well.

So, that is shown here. You also have a liquid distributor which distributes the liquid as uniformly as possible over the entire tower packed cross-section and that liquid distributor normally will be having a much lower operating range. So, that liquid distributor if it is having a zone of this, your operating zone of this is only from here to here your liquid rate can be here to here. I will prefer that you have to have your design here.

So, you will see here that the operating range of a packed column is greatly affected by that limited by the liquid distributor operating limits and why the limits are there? That we have talked about in the last class. So, any type of distributor that you use whether it's a gravity type of distributor or a pressurized distributor, will have its operating range of superficial liquid velocity and that limits the operating range of your packed column.

Here for different packing materials, the minimum wetting rates are given. It is given here as we have mentioned earlier as m^3/h of the liquid flow per m^2 of the packing surface mind it, it is a packing surface. Why packing surface? The packing surface is basically what is to be irrigated and an ideal condition of irrigation is a thin layer over the packing surface of the liquid.

I mean the liquid forming over the packing surface. You will notice here that unglazed ceramic requires a smaller amount of minimum wetting liquid flow as compared to polypropylene. All depends on the wetting characteristics of the surface. So, these provide you, the guidelines that if you are going to use what type of packing you have to check for this as well. The next thing that we are left out is finding out the pressure drop in the column itself.

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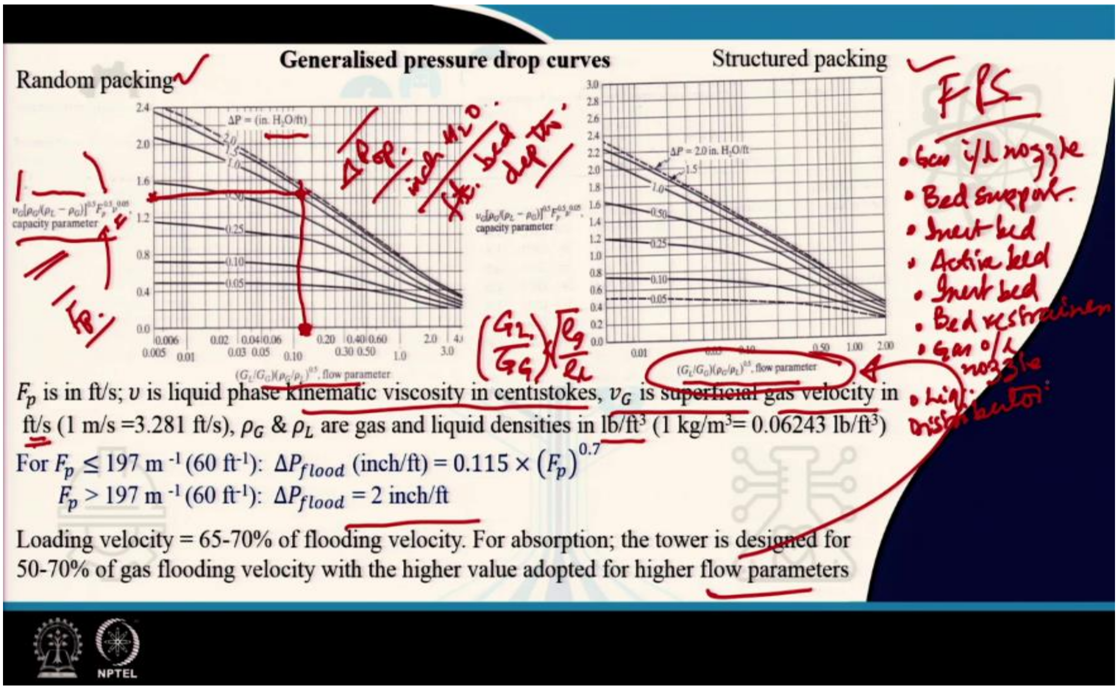

There are generalized pressure drop cards that are used in the industry. These are available in standard textbooks including your (Refer Time: 17:46) and book. We talked about the packing characteristics. If you look at these curves very carefully what you will find that here there is a parameter which is G_L/G_G that is the liquid to the gas flow rate and this is multiplied with $\sqrt{(\rho_G/\rho_L)}$.

What you will find here is the flow parameter which is there in the x-axis and there are two similar curves similar, but not the same, one for the random packing and the another is for the structured packing. So, you have your flow parameter with the x-axis and against that what is plotted is another parameter which is v_G.

v_G is what? v_G is the superficial gas velocity in foot per second. Mind it. This is in fps and is not in SI units. So, we need to use this here to use these specific units which pertain to this particular graph. Rho G and rho L are basically liquid densities in pound per feet cube. In this case, the unit will cancel off and its a non-dimensional unit, but in your y-axis remember that this is a dimensional quantity.

Now, the liquid kind of liquid phase kinematic viscosity is important. The liquid phase kinematic viscosity is important because it is related to the pressure drop because if you have a higher viscosity there will be a thicker liquid sticking to the surface of your packing.

If you have a thicker liquid film on the surface of your packing, the space through which the gas can move is less. So, quite naturally when you are talking of this ΔP. This ΔP is for the gas phase and here not once more it is in inches of water per feet of bed depth. In most cases, the maximum limit here for operation is about 2 inches of water column per foot of bed depth.

So, what you can find here is, it also involves the term F_p. I am sure that when we talked here in the last class about the packing parameter F_p and its needs to be used later on I had meant about this specific random packing and structured packing pressure drop calculations.

When my F_p is below 197 m^{-1}, my pressure drop specific pressure drop in inch per inch of water column per foot is given by $0.115 \times F_p^{0.7}$ and if $F_p > 197$, the ΔP flood is fixed more or less 2 inches of water column per foot.

Your loading velocity or operating velocity is typically kept as 65 to 70 % of the flooding velocity. For absorption, the tower is designed for 50 to 70 % of the gas flooding velocity with the higher value adopted for high flow parameters. Now, what is the flow parameter? The flow parameter is this expression. I believe (Refer Time: 21:44) with this you have an idea that how we can calculate the pressure drop.

In your design problem whatever you are working with definitely know the liquid and the gas rates and the density properties. So, possibly by this time, you must have found out the x-axis location. Now in your case you know the superficial velocity v of gas you know the density.

So, naturally, whatever is within the bracket you know, you have you know the liquid. So, you have you are also knowing the kinematic viscosity of the liquid on the packed bed the average one and you have chosen your packing and from the packing characteristic table, you know your F P.

So, it is obvious that you have found out your y-axis value also and what you have to do now is simply go up, find out the intersection, find out the line that passes through this particular intersection which gives the ΔP operating under these conditions and in which unit it is an inch of water per feet bed depth.

You will notice one thing the parameters in the case of the random packing and the structured packing are the same, the only thing different that differentiate these two are the actual curves that are presented here. Once you have found it out; that means, you can use this to estimate the delta P across your bed also because you already have found decided the HETP of the bed.

But remember by using this what you have found out the pressure drop across the active bed only. For the total pressure drop across the tower, you have to include the pressure drop in the nozzles in the bottom tray support. If you have any other inert packing just above that, the active bed if you have any bed and a bed you see re-strainer at the top that also has to be given taken care of and finally, they exit nozzle.

So, I will just write one by one what these items are. Gas inlet, nozzle, then you have the pressure drop across the bed support it is small, we usually design it for about 8 millimetres. So, then you have an inert bed this you may have you may not have. Then you have active bed, you may have another inert bed at the top, the inert bed could be for preventing the smaller size packing material to fall through. The top inert bed usually is to ensure that your bed does not get disturbed.

If anything gets disturbed it's an inert bed which is of no functional work gets disturbed to some extent in case of pressure surges. Then you have the bed re-strainer and definitely, you have the gas outlet nozzle and I had missed out on one very thing very important thing that is the liquid distributor.

So, you definitely have to add all these components of pressure drop to have an estimate of the total gas-phase pressure drop across your packed tower.

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Type	Material	Nominal Size, mm (in)	ε	a_p m^2/m^3 (ft^2/ft^3)	F_p m^{-1} (ft^{-1})	Relative mass transfer coefficien
		Random packing				
Raschig rings	Ceramic	13 (0.5)	0.64	364 (111)	1900 (580)	1.52
		25 (1)	0.74	190 (58)	587 (179)	1.2
		38 (1.5)	073	121 (37)	312 (95)	1.0
		50 (2)	0.74	92 (28)	213 (65)	0.85
Berl Saddles	Ceramic	13 (0.5)	0.62	466 (142)	787 (240)	1.58
		25 (1)	0.68	249 (76)	361 (110)	1.36
		50 (2)		105 (32)	148 (45)	
Pall Rings	Metal	25 (1)	0.94	207 (63)	184 (56)	1.61
		38 (1.5)	0.95	128 (39)	131 (40)	1.34
		50 (2)	0.96	102 (31)	89 (27)	1.14
Metal Intalox IMTP	Metal	25 (1)	0.97	230 (70)	134 (41)	1.78
		50(2)	0.98	98 (30)	59 (18)	1.27
Nor-Pac	Plastic	25 (1)	0.92	180 (55)	82 (25)	
		50 (2)	0.94	102 (31)	39 (12)	
Hy-Pak	Metal	25 (1)	0.96	177 (54)	148 (45)	1.51
		50 (2)	0.97	95 (29)	85 (26)	1.07
	Plastic	25 (1)	0.92	180 (55)	82 (25)	
		50 (2)	0.94	102 (31)	39 (12)	
		Structured Packing				
Mellapak 250Y	Metal		0.95	249 (76)	66 (20)	
500Y				499 (152)	112 (34)	
Flexipac 2			0.93	223 (68)	72 (22)	
4			0.98		20 (6)	
Gempak 2A			0.93	220 (67)	52 (16)	
4A			0.91	452 (138)	105 (32)	
Norton Intalox 2T			0.97	213 (65)	56 (17)	1.98
3T			0.97	177 (54)	43 (13)	1.94
Montz B300				299 (91)	108 (33)	
Sulzer CY	Wire mesh		0.85	700 (213)	230 (70)	
BX			0.90	492 (150)	69 (21)	

I had brought the same old slide which we have used in the last class so that you can have a ready reference and you can find out F_p from here you know the a_p and the epsilon values for the structured and random packings which are tabulated here.

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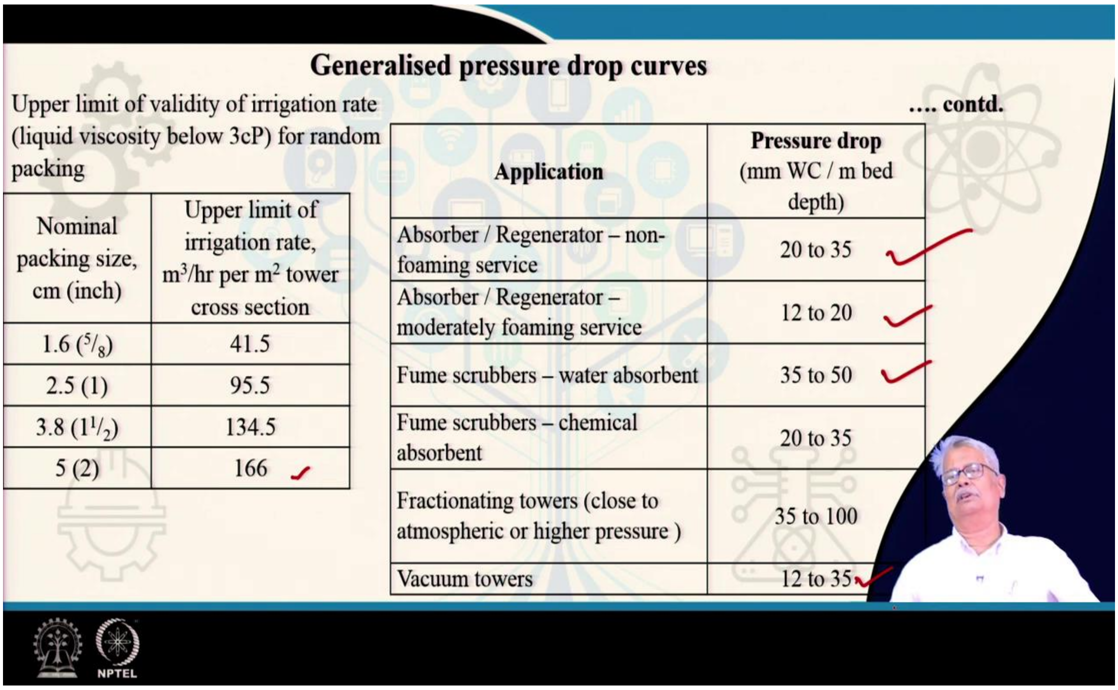

Nominal packing size, cm (inch)	Upper limit of irrigation rate, m^3/hr per m^2 tower cross section
1.6 ($^5/_8$)	41.5
2.5 (1)	95.5
3.8 ($1^1/_2$)	134.5
5 (2)	166

Application	Pressure drop (mm WC / m bed depth)
Absorber / Regenerator – non-foaming service	20 to 35
Absorber / Regenerator – moderately foaming service	12 to 20
Fume scrubbers – water absorbent	35 to 50
Fume scrubbers – chemical absorbent	20 to 35
Fractionating towers (close to atmospheric or higher pressure)	35 to 100
Vacuum towers	12 to 35

To generalize pressure drop curves which we have presented in the two slides before this, we also have something. We have an upper limit of irrigation rate was shown to you earlier is dependent on the packing size and why it is so, that is explained earlier as well.

Now, there is something. Typically for absorber and regenerators non-foaming services the pressure drop which is considered in millimetre water column per meter of bed depth is in the range of 20 to 35. This is in case of this is for packed beds. In the case of absorbers and regenerators. Typically you could say that in the case of amine wash absorber for H_2S or carbon dioxide and amine regenerators.

If its also in a packed bed the pressure drop is considered to be anything between 12 to 20 for fume scrubbers, water-absorbent it will be 35 to 50. These are all basically the suggested ranges for design and in the case of vacuum towers it's 12 to 35 mm per m of bed depth.

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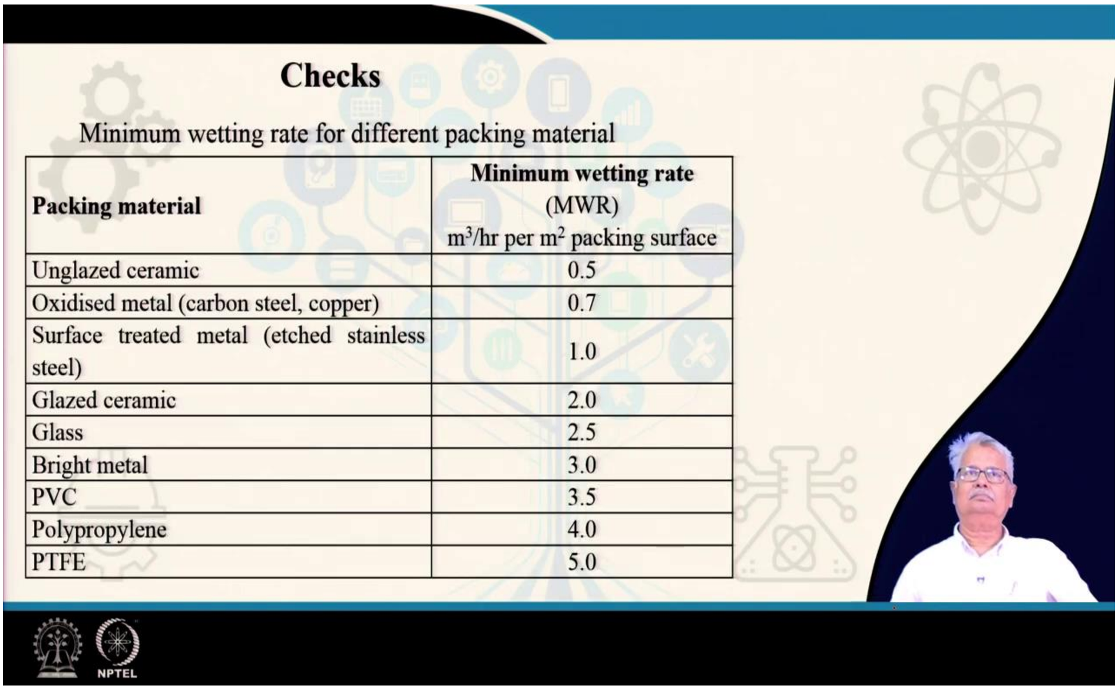

Checks

Minimum wetting rate for different packing material

Packing material	Minimum wetting rate (MWR) m^3/hr per m^2 packing surface
Unglazed ceramic	0.5
Oxidised metal (carbon steel, copper)	0.7
Surface treated metal (etched stainless steel)	1.0
Glazed ceramic	2.0
Glass	2.5
Bright metal	3.0
PVC	3.5
Polypropylene	4.0
PTFE	5.0

There are a few checks that you got to make. The minimum wetting rate for different packing materials needs to be checked that you remain within. I mean you remain above the minimum wetting rate and you are utilizing the entire surface of the bed which is available for your mass transfer.

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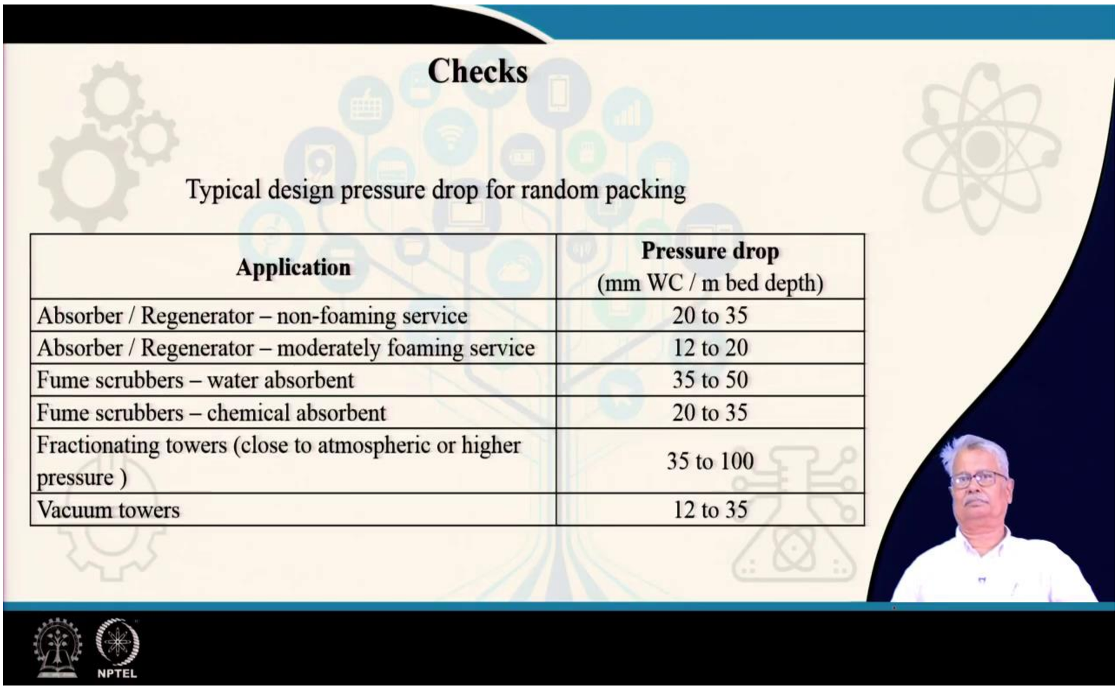

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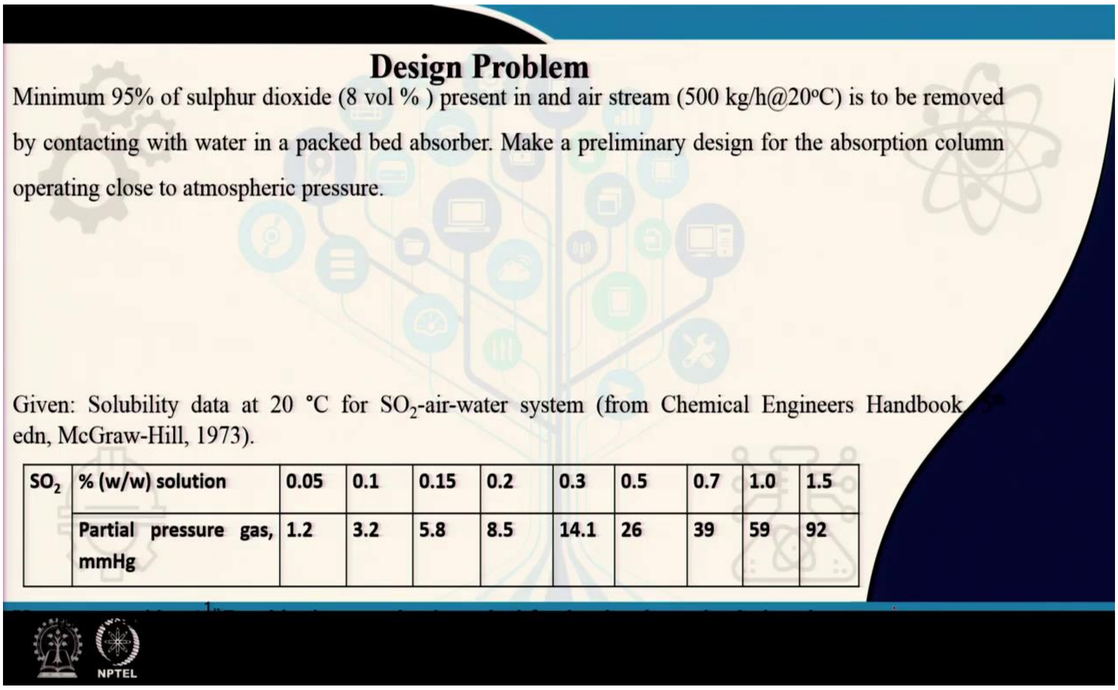

This again is the same thing and before we end here today, I just would like to add here that I repeat the same design problem and maybe you will be trying it out sometime and find what are the dimensions of the bed and you can start finding out the dimensions of the bed details including the design of your distributor.

It's the same design problem that was there in the case that I had presented to you and perhaps this should be a good exercise for you to try it out yourself and we will do it when we detail when we have more detailed exercises. Now, before I close this topic of tower internals, I think I must mention once more that a very important part. I would like to tell you again that is which we did not cover very well that is we have talked about choosing between the tray towers and the packed towers, but there are different options of tray tower and how to choose between them. I think this is what we will talk about and the end of the mass transfer will be with this.

Thank you.