Fluid Mechanics
Prof. Madivala G. Basavaraj
Department of Chemical Engineering
Indian Institute of Technology, Madras

Lecture - 41
Flow through packed bed

So, actually today I would like to start with a new topic which is on Flow through packed bed; is it clear, as to in the case of multi particle systems ok.

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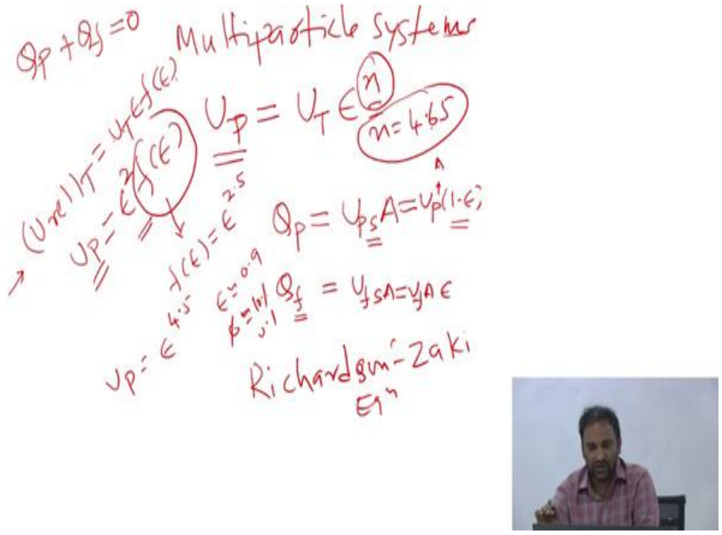

So, we kind of derived this in U T is, sorry U P that is the particle settling velocity under you know hindered settling condition goes as U T power epsilon power n right. Is that clear, is that clear how we got this right? We basically said that U relative terminal goes as U T times epsilon times f of epsilon right, we derived that. Then we said that you know U T, U particle under hinder settling, it goes as epsilon square into f of epsilon we derive that.

This was basically derived by bringing in the concept of you know the volumetric flow rate of the particles plus volumetric flow rate of the fluid should be equal to 0, because there is no net flow in the system right. And, then we define couple of terms called as actual velocities and the superficial velocities ok. You can actually think about writing a very simple continuity equation.

So, your Q P which is the volumetric flow rate of the solids goes as U P superficial; S for superficial times A which is the area of cross section there is available for the entire fluid particle system to flow or that is equal to U P times 1 minus epsilon, because you know times A of course, right there is A as well. Only thing I have done is I have only taken the area that is available for the particles to flow right.

Similarly, I can write U Q f which is the volumetric flow rate of the liquid as U fluid superficial times A that is equal to U fluid times A into epsilon right. This basically comes from the couple of definitions of you know the superficial velocities and the actual velocities right. Then we went on to say that you know this f of epsilon is a function which is typically less than 1 and there are different models that people have proposed, and according to one of the you know models you have your f of epsilon was you know epsilon to the power 2.5 right we derived that.

Therefore, your U P comes out to be epsilon to the power of 4.5 and we said you know this is typically applicable for you know your epsilon which is of the order of 0.9 or you know your phi of the order of about 10 percentage you know order of 0.1 percentage right. And, there are people have a lot of experiments to kind of verify some of these things and I said that this value of n depends on the kind of condition that you are working with right, Newton's regime you know Stokes regime and things like that.

There is a very famous equation which is what is called as a Richardson Zaki, I think equation in which what people they did, they did a lot of experiments on you know hindered settling conditions and they did they worked with lot of particles of different types. And, then they kind of showed that this experiment n is 4.65 ok, though according to theory it should be about 4.5 and experimentally people have shown that you know this value is typically slightly higher and which is about 4.65 ok.

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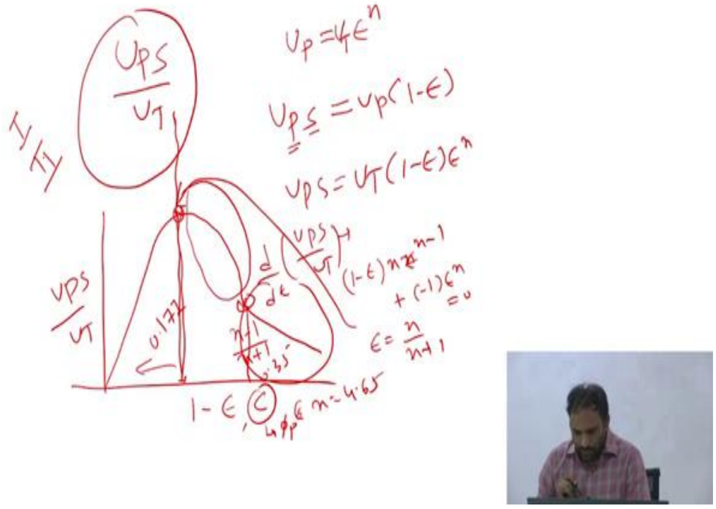

And, other thing that we did was we started talking about U P S by U T that is a settling flux non dimensional settling flux and the way we did that was your U P is you know epsilon to the power of n times right U T right ok. And therefore, your U P S which is the, the particle settling velocity, but the superficial velocity right goes as U P times 1 minus I am just quickly do that ok, it goes as U P times 1 minus epsilon right therefore, your U P S is going to be U T into 1 minus epsilon into epsilon power n right.

And, we said if you want to plot this ok. So, it would the function would go something like that is what I had mentioned ok. This is actually plot of U P S by U T versus 1 minus epsilon I did a mistake in the last class. It is not epsilon is 1 minus epsilon, it turns out I can get this point and this point just by differentiating this 1 you know a couple of times right. So, if I do that, so, if I take this U P S by U T and if I differentiate it once d by d epsilon if you do it ok.

What I will do is I will get this as 1 minus epsilon into n into n minus you know epsilon power n minus 1 plus of minus 1 into epsilon power n is equal to 0 if I equate that to 0. Therefore, if I work this out I would basically get an expression for epsilon as n divided by n plus 1 that is your this point and if I do the double derivative and if I do it you basically come you know this particular point comes across to be n minus 1 divided by n plus 1. And, this is this particular plot is you know what I have drawn is for epsilon sorry n is equal to 4.65 that is the Richardson Zaki equation ok.

And it turns out you know this particular point corresponds to 0.177 and this 0.35; that means, if I have you know this is 1 minus epsilon or its in its a concentration right or you can think about this is a particle fraction. And, if your particle concentration is less than 0.177 you know you will see some kind of settling behavior in your system and then you know of course, there is some region where you see some other settling region and you know.

So, basically depending upon the initial concentration that you work with ok; so, the settling if you were to do this batch settling experiments you will see different behavior that I discussed in the last class right there is a type 1 settling or type 2 settling or something very different from the these two, everything depends on the initial concentration of the you know particle that you work with.

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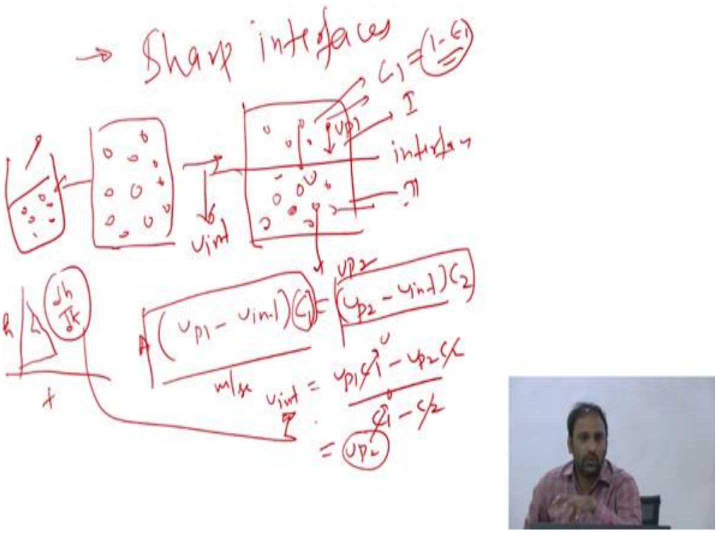

And in the case of so the other point that I wanted to mention is what is called as you know there are when you do the settling experiments you will always have sharp interfaces that is what I kind of showed in those batch settling you know experiments right. So; that means, I could have a case where you know I have a uniform dispersion to begin with. Everywhere the particle concentration is the same, but then you know at some point in time you would have a case where I have an interface and I could have a case where I have a clear fluid at the top and you know all the particles are bottom or in general I could have a case where the particle concentration is less here. Concentration could be C 1 here and the particle concentration could be bit more here right.

So, in such a case I can have a settling velocity associated with each of these phases ok. This could be U P 1 you can take this regime 1 or 2 and in this case you know the settling velocity is going to be U P 2 and if your interface is moving down with a velocity U int that is the interface velocity. And, I said you can think about writing a simple mass balance which basically is U P 1 minus U interface multiplied by your concentration, concentration C 1 in this case is 1 minus epsilon 1 you are basically expressing this in terms of the you know void fractions right should be equal to U P 2 minus U int into C 2 right. If you work it out it turns out you know this basically will have units of mass per second ok.

Because this is you know meter per second right and this is your concentration volume fraction of course, I can have the area multiplied on both sides right. So, basically this is a mass balance which basically is telling you that if you want to have a clear interface whatever the number of particles or the concentrations of particle that that will reach the interface the same number of particles have to go ok. So, if you work it out your U int becomes U P 1 C 1 minus U P 2 C 2 divided by C 1 minus C 2. If I have a case where I have a clear fluid here and then all the particles are in the you know in the bottom region regime. So, one of the concentration is going to be 0 right. If you say the C 1 is 0 that is a in the top regime. So, basically this gets canceled you basically get U P 2 itself right.

So, therefore, when you do this settling experiment; so, when you are following the interface velocity right which is basically you know I said that right. If you have different interfaces there could be a case where some interfaces are basically you know following as a function of time, there could be cases where the interface is you know rising as a function of time all I need to do is get this slope that as you are plotting you know height versus time I get this dh by dt that is basically my interface velocity and from that I have a way of calculating the settling velocity ok.

So, we will stop here at this point. So, we have talked about you know different things in the previous lectures right. We talked about settling of single particles then we talked about how do we extend that to an aggregate of particles and then again extension of the similar concept to cases where we have multiple particle systems right.

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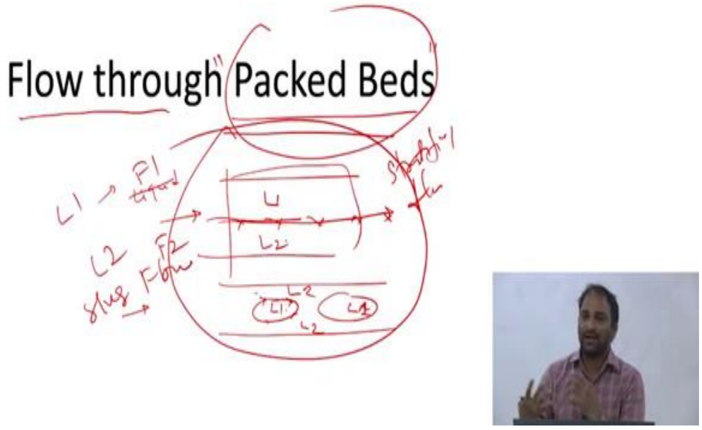

Flow through Packed Beds

So, now we will talk about a concept called flow through packed beds ok.

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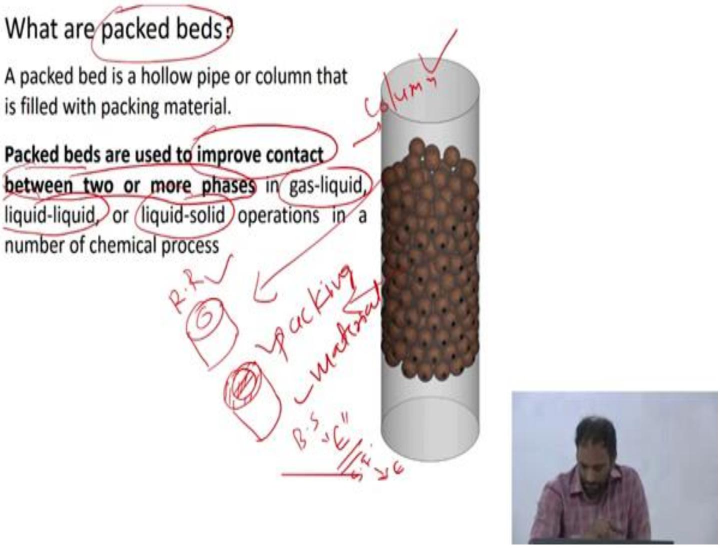

What are packed beds?

A packed bed is a hollow pipe or column that is filled with packing material.

Packed beds are used to improve contact between two or more phases in gas-liquid, liquid-liquid, or liquid-solid operations in a number of chemical process

And, in a sense packed are packed beds are kind of it is a simple concept you know what do you basically mean by packed bed is you basically have a column ok. It could be a pipe, it could be you know a container right and this column is basically filled with this is your column ok. This is your packing material ok.

Now, I had mentioned in you know few lectures ago that the reason why the packed beds are used are because they want you know they provide as a way of improving the contact between two or more phases ok. I could have a case you know for example, say that you know have a say a simple pipe hollow pipe and in which you know I am want to send 2 liquids like say you know maybe some methane or you know some liquid on a gas for example, if I am going to ensure a proper contact between the two if I were to have a simple pipe without any of these abstraction you know you know obstruction. So, there is no proper contact between the two phases right two fluid phases ok.

So, therefore, the one of the main advantages of using this packed beds is you know they essentially ensure that if you have a two phase or three phase you know systems they give you a way of improving the contact between different phases. And, people typically use this for cases where there is a gas liquid operation or a liquid liquid or a liquid solid, depending upon you know there are a lot of cases in chemical industries where you come across you know different you know fluids that are going to be you know you want them to be in contact either liquid liquid, liquid solid or gas solid. So, in such cases people make use of these devices to ensure that you know there is a proper contact between the different between different phases.

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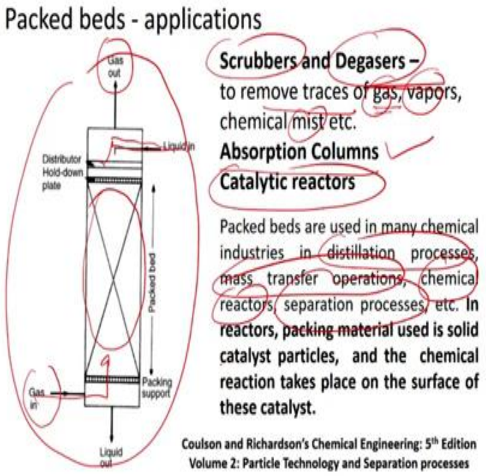

Packed beds - applications

Scrubbers and Degasers –
to remove traces of gas, vapors, chemical mist etc.

Absorption Columns

Catalytic reactors

Packed beds are used in many chemical industries in distillation processes, mass transfer operations, chemical reactors, separation processes, etc. **In reactors, packing material used is solid catalyst particles, and the chemical reaction takes place on the surface of these catalyst.**

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Now so, this is again a schematic that I picked up this is an example of a case where people have this is an absorption column. Again typically what you will have is you know some packing material in the pipe, there is some liquid is coming in there could be some gas that is coming out you know if your objective is to either you know take out if you have a if there is a gas for example, if the gas has some trace amount of chemical for example, mist you know.

Or if there is some for example, if I want to have a clean gather that I want to come out if there is some unwanted gas that you want to separate out one of the best weight of doing this would be use of this packed bed ok. Let it pass through the pass up through the column and then you know use an appropriate liquid which basically takes out this unwanted you know material and it comes out of the bottom and again you can you know subject to whatever purification that you want to do ok.

And people use them for the scrubbing or degassing operations which is to remove traces of gas, vapors or chemical mist. Absorption column people use it for you know catalytic reactors ok. If you really want to if you want to have a particular reaction that I want to occur over a solid surface the best way of doing this would be again you pack them into these columns and as you let either a liquid or a gas through this column on the surface of this catalyst you know some reaction may occur right.

So, yeah as I said right they are used for distillation operations a lot of mass transfer operation in absorption is one example I talked about chemical reactors separators ok. So, these have very wide applications and you will have couple of experiments in the in the next semester to look at you know different aspects of flow through packed beds ok.

So, now before we go to so the reason why we are interested in the packed column is because like we talked about pressure drop in a pipe right. Now that now if you have a pipe that is filled with you know particles right. Again now the fact that you know there is much more obstruction for the liquid to flow through your delta P is going to be much much larger compared to the you know case of flow through pipe right.

So, the ultimate aim of some other thing that we are going to discuss is to look at how do we think about pressure drop through this such systems and we are going to think about some ways of analyzing you know flow through the packed bed. And, you know how do we kind of correlate the pressure drop to different parameters like you know the structure of the packing in a flow of the flow rate of the liquid and you know a few things like that is what we are going to do ok.

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Filtration-special case of flow through packed beds

One of the important example where flow through a bed of solids is encountered is in filtration processes. In filtration, the bed of solids consists of small particles that are removed from the liquid by a filter cloth or fine screen.

http://en.wikipedia.org/wiki/File:Kalolis.jpg

So, it turns out that you know. So, you know of a particular operation called filtration which is some kind of a its a special case of flow through packed bed right. Again filtration one of the simplest thing that you can think about it you know when people do this coffee or tea at home right when you when you strain now the coffee or the tea on the you know strainer right you have some solid bed that is initially its a its a clean you know cloth or something like that at some point in time you know as you saw start straining it you have a bed of solid that form right.

So, ultimately you know the liquid starts flowing through the bed of solid that is formed on the surface right. So, therefore, we are going to talk about filtration at some point ok. We are going to say that you know whatever you know working equation that we developed for packed beds we can actually modify it to you know suit the need of filtration processes we will talk a little bit about that.

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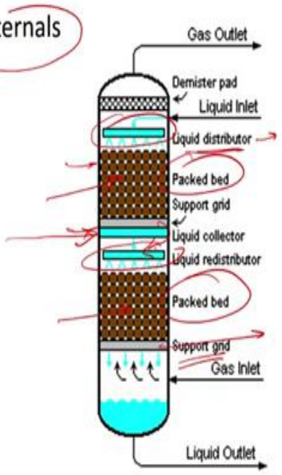
Packed beds – internals



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Before we do that I am going to talk a little bit about what are called as packed bed internals. So, let us look at the construction ok. So, what you are seeing is a as a picture where there is a packed column. So, this is two regions where there is particles are kind of packed right. Right this is solid particle which are put in the column and the bottom you have a support grid because I mean this grid is basically required because I want to hold the packing right. If I do not have this grid all this particles would fall off right.

So, they typically there is a support grid is typically a porous plate and again people use different kinds of design to ensure that you know there is a proper flow of fluid through these you know fluid through these columns. At the top somewhere here and somewhere here you have what is called as a liquid distributor or liquid the redistributor. And, the job of this liquid distributor is to ensure that there is a proper distribution of liquid across the entire packed bed that is the job of these liquid distributors.

And, if you look at somewhere here they have what is called as a liquid collector and these the job of this liquid collector is you know if you have a really long column what may happen is there you know as it flows through what typically fluid does is, it wants to go through the least resistance path right. It will find out you know some least resistance path you know after sometime of course, if you look at the top of the bed there could be a proper distribution of the fluid because of this liquid distributors ok.

However, if you go down the column if the column is really really high you know you know this liquid take some preferential paths and these are the least resistance path ok. One of the way to avoid that would be you put in this liquid collector ok. The job of this liquid collector is we basically collect the liquid as coming out down the packed column and then you know it kind of feeds it to a liquid redistributor ok. So, these operations you know these kind of internals are really required to ensure that the flow rate across the different cross sections of the bed is kind of uniform. So, there you know there is a proper contact between the fluids that you are trying to work with ok.

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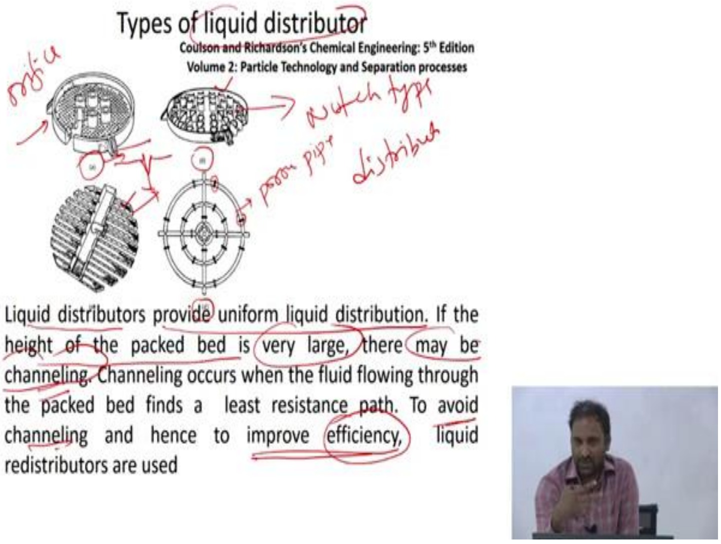

Types of liquid distributor

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Liquid distributors provide uniform liquid distribution. If the height of the packed bed is very large, there may be channeling. Channeling occurs when the fluid flowing through the packed bed finds a least resistance path. To avoid channeling and hence to improve efficiency, liquid redistributors are used

So, this is a different kind of liquid distributor as I was mentioning. Liquid distributor basically provide uniform distribution of liquid and as I said if the height of the packed bed is very very large ok, there may be something called as a channeling ok. The channeling is what I said you know when the liquid starts taking some preferential paths; that means, there is a larger flow in one region of the packed bed versus the other region that is when you have what is called as a channeling and channeling can be avoided if you use these redistributors somethings like that ok.

So, these are four different types of distributor people use. These are some kind of a porous pipes ok. This is a pipe through which the liquid is flowing, but you know there are regions where you know I let the liquid into the column. These two this and this, these what is called as a notch type distributor if you see this right. There is a wedged kind of thing right if you look at these things. So, there is the construction is something like that its a parallel channel like that channel like that and then there is a notch and basically you fill the liquid in this you know this you know channels and then through the notch liquid basically comes down that is the case here and here ok.

This is an example of what is called as a orifice you know type of liquid distributor which basically has porous you know porous openings right and then through that the liquid basically flows ok. So, these are what people typically you know use and as I said right the objective of this liquid distributor is to ensure that to avoid channeling and to ensure that there is a improved efficiency right that is the whole point.

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Some important definitions

Superficial velocity
Sphericity
Porosity

Now, I just want to define a few terms, first term that we are going to do is something called as a porosity or if you already know this concept, but I still want to do it quickly ok.

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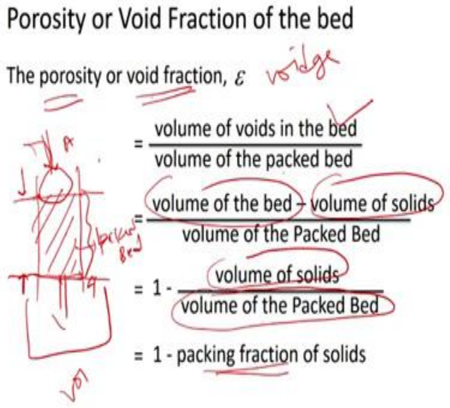


Porosity or Void Fraction of the bed

The porosity or void fraction, ε

$$= \frac{\text{volume of voids in the bed}}{\text{volume of the packed bed}}$$

$$= \frac{\text{volume of the bed} - \text{volume of solids}}{\text{volume of the Packed Bed}}$$

$$= 1 - \frac{\text{volume of solids}}{\text{volume of the Packed Bed}}$$

$$= 1 - \text{packing fraction of solids}$$

So, porosity it is also called as a void fraction void fraction or porosity or people also called as voidage as defined as volume of the voids in the bed divided by the volume of the packed bed and volume of the voids in the bed I can basically write it as volume of the bed minus volume of the solids right. And therefore, I can write this as 1 minus volume of the solids divided by volume of the a packed bed and volume of the solids divided by volume of the packed bed we know that you know its the packing fraction of the solid right. So, that is a typical definition of you know the voidage

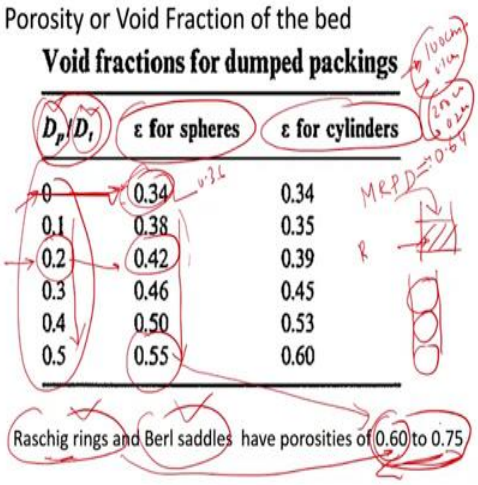
Now, so, how do we find voidage in the packed bed ok? So, I say that you know I have a column ok. I am going to say that hey look you know I have a column that is filled with this my packed bed and I want to find out what is the voidage ok. What do you think is a you know, can you think of some ways of by which I can measure the void fraction ok?

Experimentally you can think of a couple of different simple ways of doing it ok. What you do is so you take a empty column and with a packed bed what you do is you start going on filling the fluid ok. You start going on filling the fluid. So, what fluid is going to do is if I have a support plate and it will start occupying all the pores in the bed right. The liquid that I am is going to add is going to basically occupy all the pores in the fluid.

Now, what you do is if you have a some way of collecting that fluid and then measure its volume ok. If I know if the is a cylindrical column if I know the length and the cross sectional area right. I can get the volume of the bed and if I measure what is the volume that I have collected right that is one way of doing it. Other ways of doing this would be you finish up your packed bed experiment and ensure that you know your liquid is basically kind of filled up to the height of the packed bed and will basically drain the fluid right. So, you can different ways of doing that.

Now, it turns out the porosity is one of the really important parameters that is you know kind of helping the you know kind of achieving. So, when I talked about this efficiency right, efficiency when I mean by what I mean by efficiency is that you know, if you are able to ensure a better contact between the different phases that is when you know I can say, you know the efficiency of the operation that I am looking at that its you know reactions or whether it is in a mass transfer operation that is when that is what I am looking for right.

To ensure you know improved efficiency one of the parameter that you can play with this is porosity ok. Can you think of ways by which I can play with the porosity of the bed? So, I have a packed column is filled with solids ok. Now what are the different ways by which I can manipulate the porosity in the bed? You can change the. You can change the dimensions of the particle ok. That is one way of doing it.



Porosity or Void Fraction of the bed

Void fractions for dumped packings

D_p/D_t	ε for spheres	ε for cylinders
0	0.34	0.34
0.1	0.38	0.35
0.2	0.42	0.39
0.3	0.46	0.45
0.4	0.50	0.53
0.5	0.55	0.60

Raschig rings and Berl saddles have porosities of 0.60 to 0.75

So, he is saying what he is trying to say let me just go back ok. So, this is a so, what you seeing here is D p by D t where D p is the a particle diameter and D t is the you are you know if you have a packed bed you can think about it as a diameter of the you know column in which the particles are put right. Now so, what you are looking at is two columns epsilon for spheres ok. I am already giving the second end this is epsilon for cylinders ok. Now, when you say D p by D t is 0 what does it mean?

That, basically means you know I have a really large column ok, whose diameter is much much larger than the diameter of the particle that are basically being used for making the packed bed right ok. In such a case your epsilon is 0.0 you know is point 0.34 right. Now this value is very close to, very close to if you have a spherical particle yeah. So, there was a maximum random packing density right; that means, if I have a column I pour the particles into the column. If all the particles in the bed right, if they are arranged in a random you know configuration right ok.

So, it turns out that you know that maximum random packing density roughly of the order of 0.64 right. Therefore, you know the closest that you can get if you really work with ideally this should be 0.36 ok, but the closest that you get if you really take a very large diameter column. And, if you put in the particle such that you know the particle diameter is much much smaller compared to the diameter of the column right.

So, you can achieve 0.34, but you can clearly see, but if I go on you know if this if I go on increasing the diameter of the particle it turns out you know this porosity basically increases right. Does it make sense? Because you know let us think about a simple case right. If I have a column I am going to fill in the column with exactly the same you know diameter particles right. I am sure another in this case you know whatever volume there is available for the liquid is very very little right ok. So, one of the way of doing this would be basically I can play with the diameter of you know particle to the diameter of the column.

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(a) Ceramic Raschig rings; (b) Ceramic Lessing ring; (c) Ceramic Berl saddle; (d) Pall ring (plastic); (e) Pall ring (metal); (f) Metal Nutter rings;

But the other ways of doing this would be by using packing material different you know types either. So, either you can work with regular particles, you can work with like say spherical particles or cylindrical particles for example, or ellipsoids ok. You can work with particles of you know different shapes or people have kind of designed different types of packing material itself ok. What you are looking at is this a, a is the case of what is called as the Raschig rings. These are basically you know yeah go ahead.

Now, when you say volume of the packed bed that is the volume of the so, if I have a like say that I have a container a cylindrical pipe say that you know my the packing that I have filled it is up to say length l for example. And, if the diameter is d right that you know pi D square by 4 times L is your volume right that is the volume of the packed bed for me ok. It is not just the volume of the just the packing itself when I say volume of the packed bed.

So, therefore so in the example that we saw so, what I can do is I can take a column of some dimension and I can fill it up with part of the different sizes that is one way of doing it ok. So, other way I mean the same you know one of the ways of expressing exactly the same experiment that I said right. I fix the column I take particles of different sizes right. One of the way of expressing that would be a I basically express it as you know a ratio of D P by D L right that is what was basically done yes yeah it will.

I think so, basically no what this basically tells you know as long as if you were to do you work with any combination of you know your particle and the you know the column. So, as long as you know this is actually I have taken from one of the books ok. So, the idea is as long as you maintain this ratio you are the value would be typically close to 0.64. I mean you know or the other way of doing this would be say you know I have like say a column which is like say 100 centimeter diameter see that I have basically taking 0.1 centimeter packing for example, ok.

Now, if I do an experiment where I you know kind of increase the size of this by twice. So, I say I take 200 centimeter and if I also take you know so in both the cases you would get a similar packing density ok. So, yeah so this something was a Raschig ring. So, you can think about them as you know hollow cylinders right this is something called as a Lessing rings ok

So, now, if you look at so, for example, if I look at this and this right in terms of the shape they are very similar what do you think is in between I basically have another you know basically kind of a rectangular this thing right. So, now if I look at compared these two, this would definitely offer me a you know much more solid surface there is available for any contact right. If I look at this and this case the fact that you know I have an additional you know a region there. So, I basically have more solid surface available for any operation that I want to do.

So, people have using Raschig rings, Lessing ring this something was a Berl saddle something was a Berl saddles and this is what is called as a Pall ring, this is Pall ring these two are Pall, Pall rings right and this is one something called as a Nutter ring and Nutter ok. These are different names that people have you know these are used. These are all industrially used packings of different shapes and as you can clearly see that you know it is becoming more complex shape like if you go from a to f for example, the shape becomes much more complicated right. And, the reason you know is that you know that will again help you in you know playing with your you know solid you know fluid surface you know areas right.

So, another way of so like we talked about you know this D p by D t as a parameter for playing with your porosity ok. The other way of playing with the porosity is basically use packing material of different you know types the Raschig rings, Lessing rings ok. So, if you play with some of these things right. So, I have a table which is not the porosity I just wanted I do not seem to have it ok. So, maybe I had something here I thought no I have it here right.

So, if you look at Raschig rings right, it turns out the porosity that I can reach is larger ok. So, if you take Berl saddles the typical porosity that you get is about 0.60 and again if you use Berl saddles the typical porosity that you will be getting it will be in this range you know compare it with you know spheres for example, you see for the case of spheres if I really take a very small diameter particles ok.

The porosity that I can have is about 0.34, even if I increase the, if I play with the this dimension ok. I can maximum I can go is up to 0.55, but; however, if you use different shaped in a packing material I can see there you know basically there is a more porosity right. A more porosity would be good for you know a better efficiency of the operation or a better fluid you know particle contact yeah. So, these are the Raschig rings and the Berl saddles are the shapes. So, basically if you go back here right this is your Raschig ring this is your Berl saddles. Correct yeah.

Correct yeah. So, what you do is when you when you make a packed bed right as I said packed bed is basically a column filled with a particles right. Now, the particles I have a freedom of choosing whatever particles I am working with of course, if somebody is working with like say a catalytic reactor, I would have to use a packing material there is a a catalyst that you want to use for a particular reaction right. Or, if I want to basically use an inert packing; that means, you know these are not participating in any reaction, if the objective is only to improve the liquid fluid you know liquid gas contact for example, I would like to have a much more surface area that is available right or more porosity for example

So, in such cases what you do is you use one of these packing material. So, you know I can basically play with the a porosity that will also help you in playing regulating the pressure drop through the packed bed plus it will also ensure a efficiency increase in the efficiency of the operation. So, any other ways of doing this so, I said you can play with the particle in that and the column diameters and I can play with the porosity. I can play with different objects of different shapes or you know different you know complex geometries and I can play with epsilon that way any other yeah you have a question

So, these are basically let me go back here I showed that you know in this image it looks like a sphere right. I have put in a spherical particle in the column instead of that I can use a Raschig ring right. I can use a Lessing ring right. So, that was actually your column like that, but with the right I can use that I can use Berl saddles ok. Any of the packing you know shape that you saw I can actually replace that the spherical particle that you are seeing here I can replace with any of these things. And, that will help me in regulating your epsilon that will help me in regulating the solid fluid you know contact and it will also help me in regulating the efficiency of the operation yeah. So, any other methods of regulating epsilon? Yeah. No. Yeah.

No, when you say more porosity what does it mean to you? So, essentially the volume that is available for the fluid is more right. Now, when the volume that is available for the liquid is more ok, if I say then you know I am using a liquid gas operation you know of course, the part of this you know the fractional voidage that is available there will be liquid and the gas right. The more the voidage there is available there is more contact between the gas in the liquid right. In that sense you know regulating porosity is a way of I mean people go for more porosity because you know if you want to really improve the efficiency of the operation I would definitely like to have more porous. Correct.

No, like I give an example where if I have a pipe right ok. I let the liquid and the gas flow through the column. When people talk about this 2 phase flow in the columns people talk about let me just go back when you talk about 2 phase flow let me just go back here ok. So, when you talk about 2 phase flow to for example, say then I have a pipe. I want to have liquid one or I say let us say fluid 1 and fluid 2 that is flowing through the column through the pipe for example, ok.

What do you think would be the how the flow look like? Or, let us say two immiscible liquids; liquid 1, liquid 2 there 2 immiscible say, but I would like to have a proper contact would contact between the two. But, people talk about something was a stratified flow in which I have liquid 1 flowing above maybe and liquid 2 flowing below depends on the density of fluid. So, there is it two right that is one way of doing think about it. The other way of doing this would be people talk about slug flow ok, in which you have you know your liquid 1 could be here and you know liquid 2 will be outside right, this is liquid 1 ok. So, it basically goes as right.

Now, if you look at these two cases the liquid liquid contact actually is happens here right. You are only at the interfaces when there is liquid contact. If I look at this slug flow there is a little bit better contact because you know I am able to break the stream into you know maybe you know these slugs ok. But however, you know your liquid liquid contact is still limited.

Now, if I you know what is the best way to ensure that you know there is a larger you know kind of a interaction between the two fluids ok. When I say interaction not the you know the interaction in terms of the molecular interactions, but I would like to have a proper contact between the two ok. The best way of doing this would be you know using these devices where you know you can ensure that you know there is a better interactions.

Why do you say the less porosity more than break? So, I mean say you cannot think of the; so, in this case are you talking about porosity in this case. Why would you talk about porosity in this case? Because if I look at this you know your entire column is filled with a liquid, so, in that sense you know there is no pores as such right.

I would not say what do you really call it as break the fluids no I mean you know you see you have just like you know just like a liquid flowing through a column you should imagine that you know there is also a liquid flowing through a bed of solids ok. There are channels available for the liquid to flow through ok. Now, as it flows through if I have 1 or 2 different fluids and you know it will have a you know it will basically give more chance for the liquids to interact let it put the for in that that way yeah ok.

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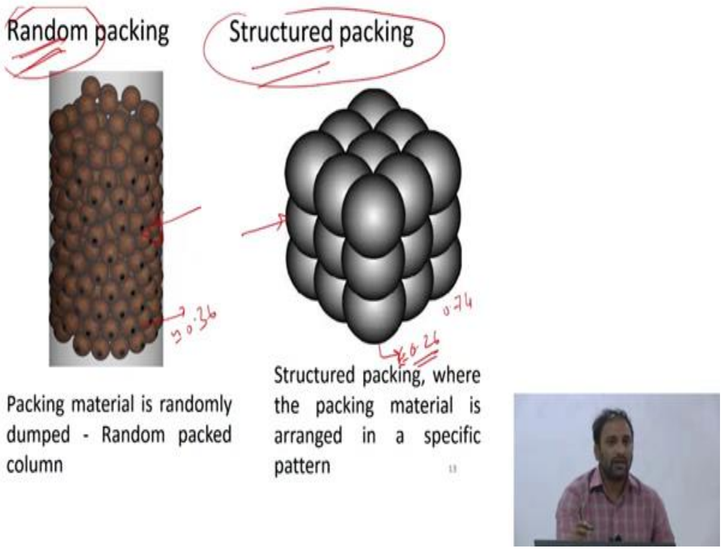

Random packing

Structured packing

Packing material is randomly dumped - Random packed column

Structured packing, where the packing material is arranged in a specific pattern

So, the other way of doing this would be looking at something called as a random packing versus structured packing ok. So, if you take a column you just pour your you know particles into the column ok. They pack in a particular way and typically if you again there are ways there are actually kind of prescription as to how you should fill the packing into your you know column. And, if you follow some procedures you will basically end up with a truly random packing and other way of doing this would be what is called as a structured packing in which I have a some predefined way in which you know the solid material is basically arranged ok.

So, I am basically you know showing you the random packing of spherical particles here and a structured packing of spherical particles here. And, as you can clearly see there you know in this case the typically the porosities that you can achieve would be of the order of 0.36. Now, if you do a you know a random packing here, but however, if you look at this case you know packing fraction is more if I assume a particular kind of packing you know right your porosity is going to be right. So, basically the other way of you know playing with your you know a porosity is go for random versus structured packing. People typically do not use particles and then do a structure packing.

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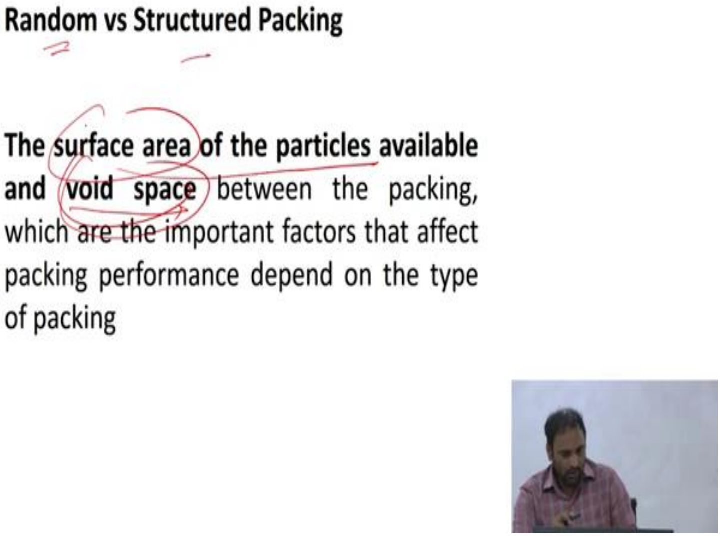

Random vs Structured Packing

The surface area of the particles available and void space between the packing, which are the important factors that affect packing performance depend on the type of packing

So, what is done in the ok so, I will come back to this point.

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Structures packing commonly used in industry:

Figure 4.15. Structured packings (a) metal gauze (b) carbon (c) corrosion-resistant plastic

15

So, these are some kind of structured packing the people use. So, these are what you have is you basically have structure which are either made of some polymer or it could be made of some metal in which you basically you are if you look at these pictures right the solid part right, the solid material that make the packed bed. There is a you know particular way in which it is constructed right ok.

And, that forms the solid in the packed bed and whatever pores that you see here right that there is a pore spaces through which the liquid basically flows through ok. So, and the idea of use it going for random versus the structured packing is that you know the surface area available for the liquid and the void space I can basically manipulate right like just the point that I made earlier. So, I can basically play with the voidage plus also I can play with the surface area that are available for the fluid contact by using these devices.

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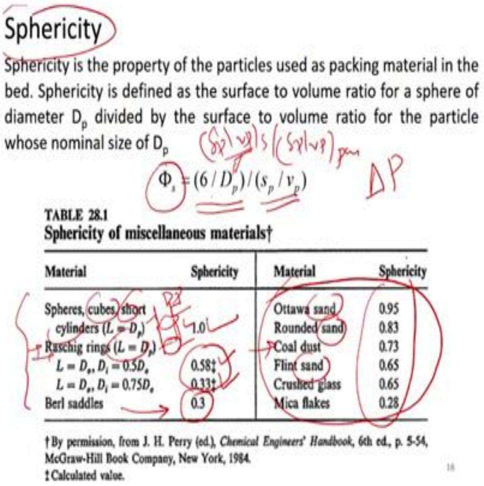

Sphericity

Sphericity is the property of the particles used as packing material in the bed. Sphericity is defined as the surface to volume ratio for a sphere of diameter D_p divided by the surface to volume ratio for the particle whose nominal size of D_p

$(S_p/v_p)_s / (S_p/v_p)_{par}$

$$\Phi_s = (6/D_p)/(s_p/v_p)$$

ΔP

TABLE 28.1
Sphericity of miscellaneous materials†

Material	Sphericity	Material	Sphericity
Spheres, cubes, short cylinders ($L = D_p$)	1.0	Ottawa sand	0.95
Raschig rings ($L = D_p$)		Rounded sand	0.83
$L = D_o, D_i = 0.5D_o$	0.58‡	Coal dust	0.73
$L = D_o, D_i = 0.75D_o$	0.33‡	Flint sand	0.65
Berl saddles	0.3	Crushed glass	0.65
		Mica flakes	0.28

† By permission, from J. H. Perry (ed.), *Chemical Engineers' Handbook*, 6th ed., p. 5-54, McGraw-Hill Book Company, New York, 1984.
‡ Calculated value.

So, we have defined this parameter for sphericity and it turns out you know if you look at when you are going to talk about this delta P is a pressure drop through the packed bed the sphericity also becomes important parameter ok. We define more it is already it is defined as s p by v p of a s p by v p of a sphere divided by s p by v p of the particle right. And, s p by v p for the sphere is 6 by D p and s p by v p that is for the particle that is your sphericity. And, if you see here if you look at spherical particles or you know or cubes or short cylinders your sphericity is 1.

And, if you go for Raschig rings this is L is equal to D p that is your you know your if you have this Raschig rings right that is your cylinder kind of thing that is your length and that is your D p right. So, if L is equal to D p if it is a short cylinder sorry Raschig ring. So, if you I can play with these dimensions are actually play with the porosity right 0.53 in 1.8 in one case you know 0.33 in the other case. Berl saddles typically have a sphericity of 0.3 and these are the kind of industrial packing the people use. And, people also work with for example, you could you can have a column in which you know you may be working with some kind of sand particles or you could be working with coal dust for example, in such case again you know your sphericity would varying. And, there are ways by which as we will discuss in the class there are ways by which I can basically calculate sphericity right.

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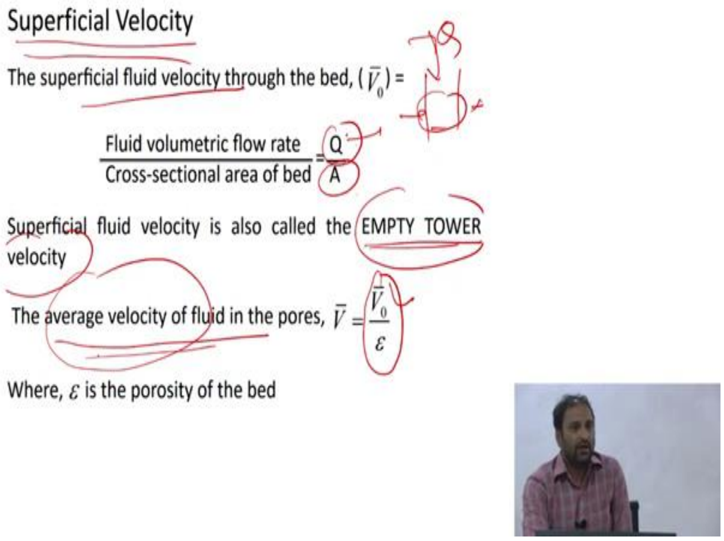

Superficial Velocity

The superficial fluid velocity through the bed, ($\bar{V}_0$) =

$$\frac{\text{Fluid volumetric flow rate}}{\text{Cross-sectional area of bed}} = \frac{Q}{A}$$

Superficial fluid velocity is also called the EMPTY TOWER velocity

The average velocity of fluid in the pores, $\bar{V} = \frac{\bar{V}_0}{\varepsilon}$

Where, ε is the porosity of the bed

Other term similar to the multi particle system there is a concept called superficial velocity which is basically defined as the volumetric flow rate of the fluid through the column divided by the cross sectional area that is your Q by A. It is also called as a EMPTY TOWER velocity ok. Superficial velocity is also called as a EMPTY TOWER velocity. This is the velocity of the fluid through the column when there is no packing that is your Qth I know if have a column if have a way of measuring what is the fluid through the column.

And, if I know what is the cross sectional area that Q by A is what gives you the superficial velocity right also called as a EMPTY TOWER velocity. But, the average velocity of the fluid through the pores is basically your superficial velocity divided by epsilon right, because epsilon will tell you what is the cross sectional area that is available for the liquid to flow through right that is the actual velocity or the average velocity of the fluid through the pores yeah.

So, that is about it ok. I just wanted to briefly introduce you to the concept of packed beds today. We are talked about what a packed beds where are they used. We talked a little bit about packed bed internals that there is a liquid distributors, liquid collectors you know and you know some concepts like that we defined a few parameters voidage the sphericity. We talked a little bit about superficial velocity and we also talked about different types of packing and different types of packing material. And, what are the different methods by which people manipulate your porosities and you know the fluid solid contact area that is available for them ok.

We will stop here. On Monday we will have we talk start a talk, we will start talking a little bit about pressure drop through the bed ok. We will what we do is we are going to take the knowledge of flow through pipes and you know we kind of apply that to the flow through pack that is what we will do on Monday yeah.

Thanks.