Chemical Reaction Engineering II
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Lecture - 18
Fluidized bed reactor design – I

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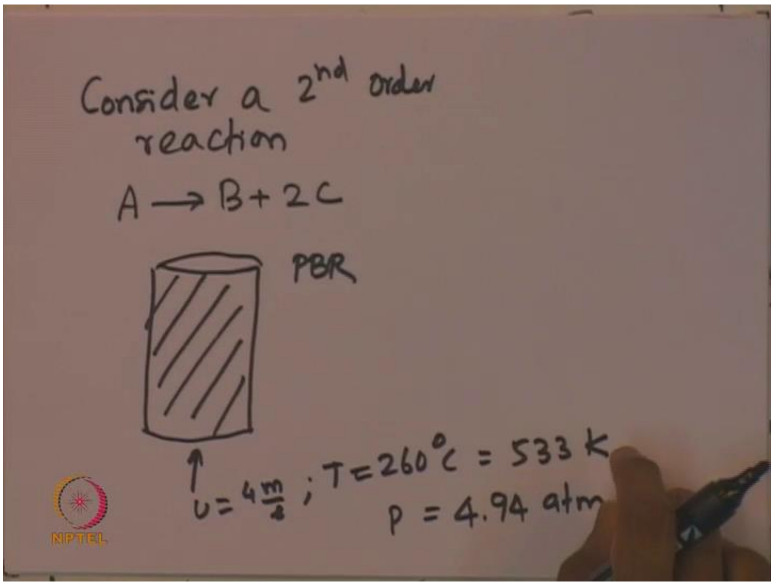

Friends, let us look at an example problem for packed bed reactor design. So, consider a second order reaction consider A going to b plus 2c. So, now, suppose if this is the tubular reactor. Suppose, if this is a tubular packed bed reactor filled with catalyst filled with catalyst. And if the gas fluid feed stream is actually flowing at a superficial velocity of 4 meters per seconds. So, that is the superficial velocity with is the feed stream is flowing.

If the, feed temperature is 200 and 60 degree c which is equal to 500 and 33 kelvin. and if the pressure at which the fluid is flowing into the stream is 4.9 atmospheres and it is undergoing reaction a giving a giving b plus 2c. And suppose if the diffusivity of the species diffusivity of the species d e a effective diffusivity is given by 2.68 into 10 to the power minus 8 meters square per second.

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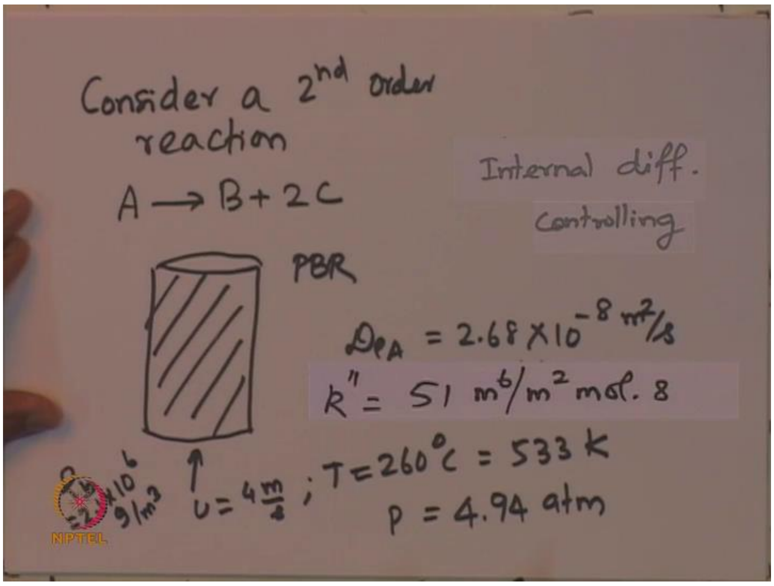

So that is the diffusivity of the species and if the corresponding intrinsic reaction rate specific reaction rate is 51 meter power 6 divided by meter square mole seconds. So, that is the specific reaction rate and the other properties that are given. So, density of the catalyst particle is about 2.1 into 10 power 6 gram per meter cube that is the density of the catalyst. And then the a surface area which is available for the catalytic reaction is the is 410 meter square dips per gram of the catalyst.

Now so, we need to find out what is the pore diffusion in this is supposed to be a strongly internal diffusion controlled diffusion limited reaction. So, it then we need to design the reactor find out what is the size of the reactor etcetera. So, now the first step towards doing this is to find out what is the concentration with, which the fluid is actually flowing into reactor.

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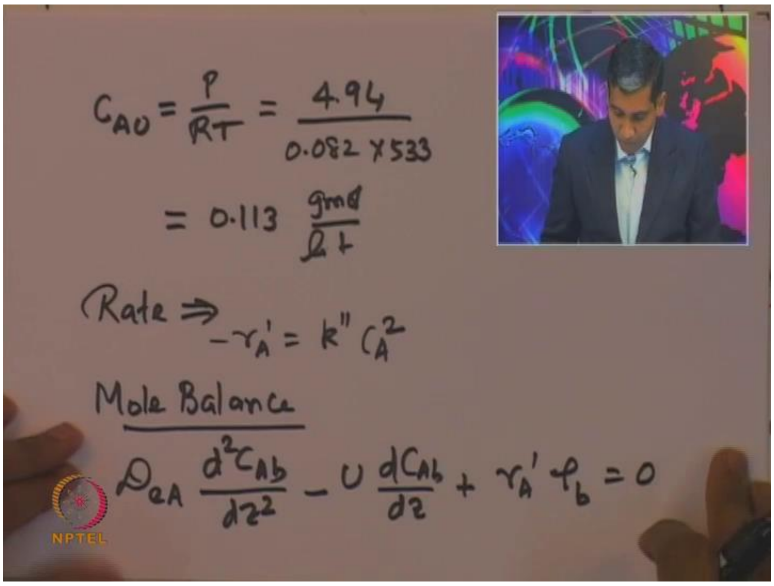

So, CA naught is the inlet concentration that is equal to p by RT that is the pressure at which the fluid is these species is flowing into the reactor divided by the gas constant r multiply by divided by the temperature of the fluid extreme at the inlet. So, that is given by 4.94 divided by 0.82 into 533. So, that comes out to be about 0.113 gram moles per liter. So, that is the concentration with which a feed actually enters the reactor. So, now if a look at what is the rate law the next step is look at the rate law. So, we said it is second order reaction.

So, therefore, the rate law rate law minus r a prime that is equal to the specific reaction constant multiplied by the c a square, which is the second order reaction. And now we can write a mole balance with the mole balance, which we have already looked at in the in the previous lecture. So, mole balance for a such packed bed reactor will be the axial dispersion coefficient of the reactant species DEA into t square CAb which is the bulk concentration of the species at any location in the reacted divided by d z square minus u which is the superficial velocity.

Let us assume that the superficial velocity; velocity is remains constant and also that the volume expansion is negligible. So, into d CAb bulk divided by d z plus r a prime density of the catalyst. So, now plugging in the rate law which is basically given by the plugging in the rate law we find that d.

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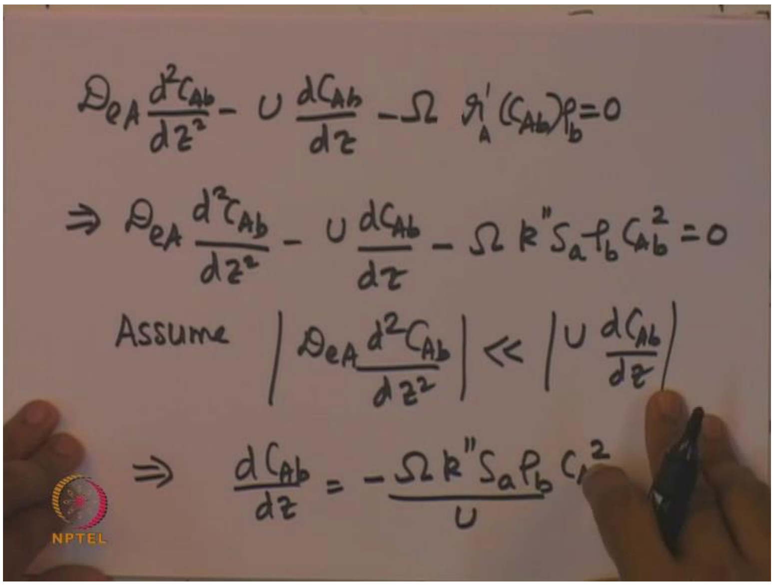

We can write the mole balance as the axial dispersion coefficient DEA multiplied by d square CA by d z square minus u d c a bulk by d z minus. If capital omega is the overall effectiveness factor then the overall the rate is given by the overall effectiveness factor multiplied by d corresponding rate evaluate at the surface concentration. So, if the mass transport limitations are negligible, because the reaction is now, happening at a strongly internal diffusion controlled the reaction rate now, has to be estimated at the bulk concentration itself.

So, therefore, we can we can write the it expression as the effectiveness factor omega multiplied by the reaction rate evaluated at the bulk concentrations CAb. So, that is equal to that is equal to 0. So, that is the mole balance. Now, we can rewrite this as into bed density of the catalyst. So, this can plugging in the rate law, we can write this as axial dispersion coefficient into d square CAb by d z square minus into d CAb by d z minus omega into k double prime.

That is the specific reaction constant multiplied by the area of the catalyst, which is available for the reaction per unit gram of catalyst multiply by the density of the bulk density of the catalyst into CAb square, that is equal to 0 that is the mole balance which captures the heterogeneous catalytic reaction, which is happening inside the packed bed reactor. Note that the explicit expression for effectiveness factor may not be available and it will be a function of bulk concentration CAb.

Now, suppose as before if we assume that the rate of diffusion of the species d square CAb by d z square that if that is significantly smaller compared to the rate of the bulk flow of the species and their corresponding. Let us assume, that the corresponding condition is satisfied then 1 can we can rewrite this mole balance as d c a b by d z that is equal to minus omega k double prime, which is the specific reaction constant into s a into rho b into c a b square divided by u.

So, that is mole balance for a second order reaction the overall effectiveness factor is general a function of the conversion. However, as a reaction is internal diffusion controlled we assume, overall effectiveness factor to be approximately equal to the internal effectiveness factor. In fact, it turns out that this is the case for this problem as will be shown shortly. Now, we can integrate this expression and we need some initial boundary conditions to integrate this expression. So, suppose the initial suppose the concentration of the species that is actually fed into the reactor at z equal to 0. So, z is equal to 0 is the inlet to the reactor at that location the concentration of the species is CAb naught.

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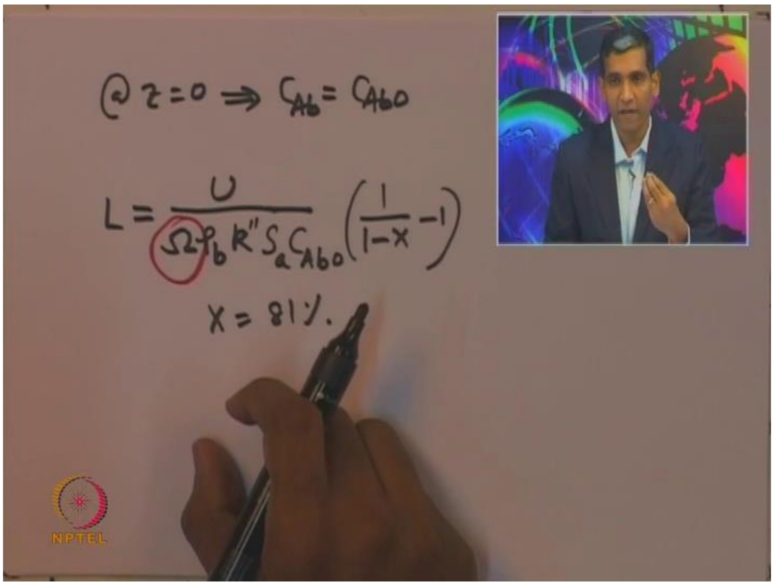

So, suppose at z equal to 0 the concentration of the species is equal to CAb naught. So, that is the boundary condition with this we can integrate the mole balance and on integration, we can find out what is the length of the reactor as a function of conversion. So, length of the reactor is u divided by the overall effectiveness factor rho b is the bulk density of the catalyst k is the corresponding specific reaction constant into a CAb naught into 1 by 1 minus x minus 1. So, that is the relationship between length and the corresponding other parameters of the reactor and the conversion.

So, now, suppose if I specify that the conversion has to be 0.81. Suppose, if the conversion has to be 81 percent then, what is the length of the reactor that is required to achieve such a conversion. So, now, what is the first step here, we need to find out what is the overall effectiveness factor we need to find what is the overall effectiveness factor and if we know, all the other parameters then we should be able to calculate, what is the length of the reactor which is required for that particular to achieve particular conversion.

So, therefore, now in order to find out the overall effectiveness factor see overall effectiveness factor is basically a combination of the resistance, that is offered by the internal by the at the internal effectiveness factor and the resistance t is offered because of the external mass transport.

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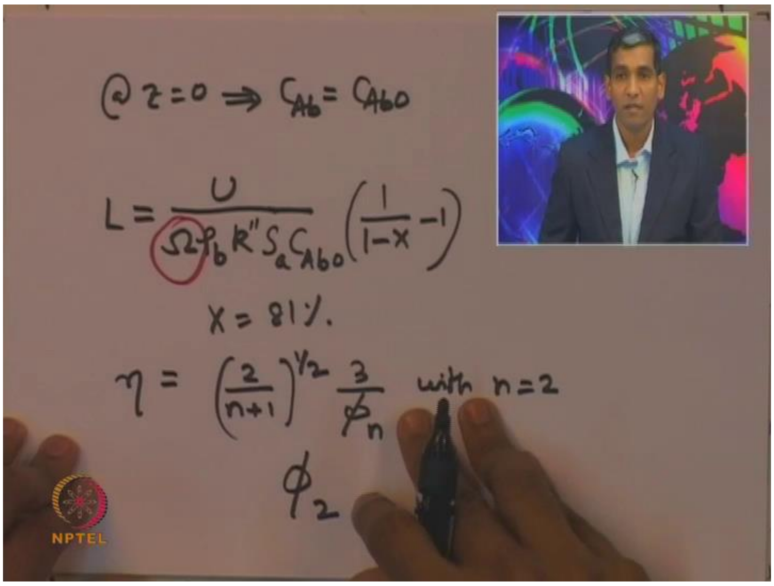

So, therefore, the first step is to calculate the effectiveness factor eta and that will be for a for a general n-th order reaction the effectiveness factor is given by 2 by n plus 1 to the power of 1 by 2 multiplied by 3 divided by the corresponding Thiele modulus with n equal to 2, n is the it is basically the second order reaction. So, we have to find out the Thiele modulus corresponding to the second order reaction and by plugging in the Thiele modulus, we will be able to find out what is the effectiveness factor for this particular system. So, we need to find out what is the Thiele modulus for the for this reaction system.

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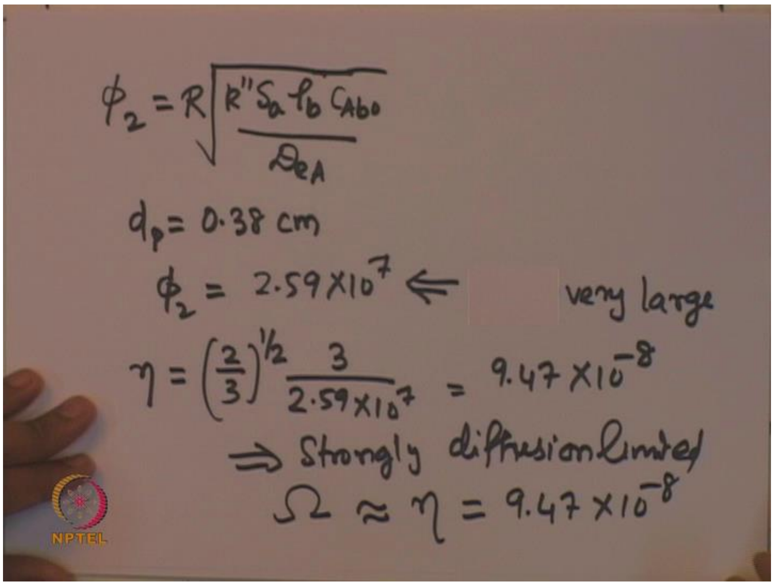

So, now the Thiele modulus for a second order reaction is given by r, which is the length scale or the radius of the spherical catalyst pellet into k double prime into s a which is the area of the catalyst per gram or area of surface area of the catalyst available for reaction per gram of catalyst. And that is the that is the value of s a and suppose if the a multiplied by the density bulk density of the catalyst into CAb naught, which is the concentration of the species at the inlet divided by the corresponding diffusivity DEa.

Note that Thiele modulus now, will be a function of local concentration and therefore, a function of position; however, for the parameter values chosen the Thiele modulus is not very different with respect to position. And hence it is evaluated at the inlet concentration. Now, if the diameter of the particle that is being used for this particular reaction if that is equal to 0.38 centimeters of the particle that is filled inside the reactor is 0.38 centimeters then we can calculate the Thiele modulus phi 2 and that is equal to 2 0.59 into 10 to the power 7.

So, that is a significantly large quantity. So, it is very large with suggest that that clearly it is an internal diffusion limited system. And now, we can calculate what the effectiveness factor eta is. So, that is equal to 2 by 3 to the power of half into 3 divided by 2.59 into 10 to the power 7. And that is equal to 9.47 into 10 to the power minus 8. So, the effectiveness factor is extremely small which suggests that, it is strongly diffusion limited.

So, it is strongly diffusion limited then, the overall effectiveness factor omega will be approximately equal to the internal effectiveness factor itself and. So, that should be equal to 9 point 4 7 into 10 power minus 8. So, now, plugging in this expression the all the details of overall effectiveness factor etcetera into the into the model equation to find out into the expression to that relates the length verses all the other parameters in the conversion.

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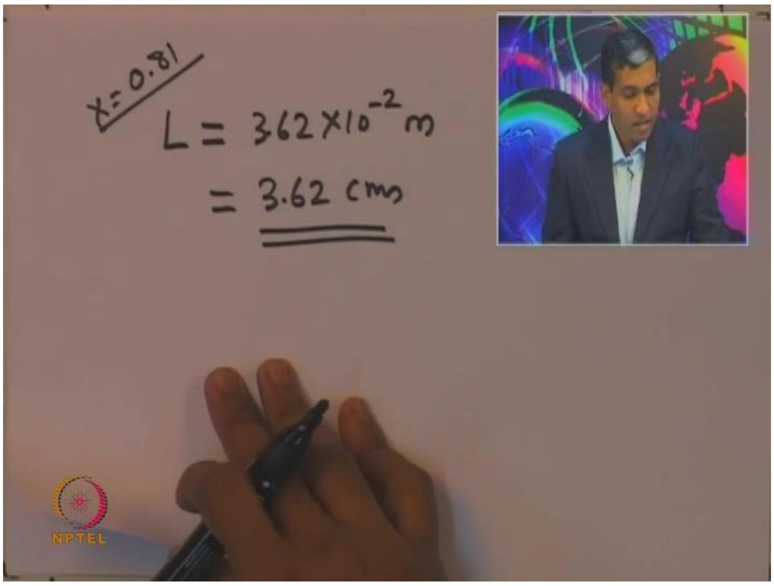

So, we can find out that the length of the reactor in, which the reaction has to be conducted in order to achieve a conversion of a 0.81 is basically given by 3.62 into 10 to the power of minus 2 meters. So, that is basically 3.62 centimeter. So, in order to achieve this conversion for the given set of conditions the reactor that needs to be used is extremely small. So, it is important to perform such kind of design to get a feed of what should be the dimensions of the reactor in which the corresponding reaction has to be conducted in order to achieve a second conversion.

So now, with this we move 1 to the next aspect where we want to now look at fluidized bed reactor. So, this is another type of reactor which is commonly used industries for many different purposes.

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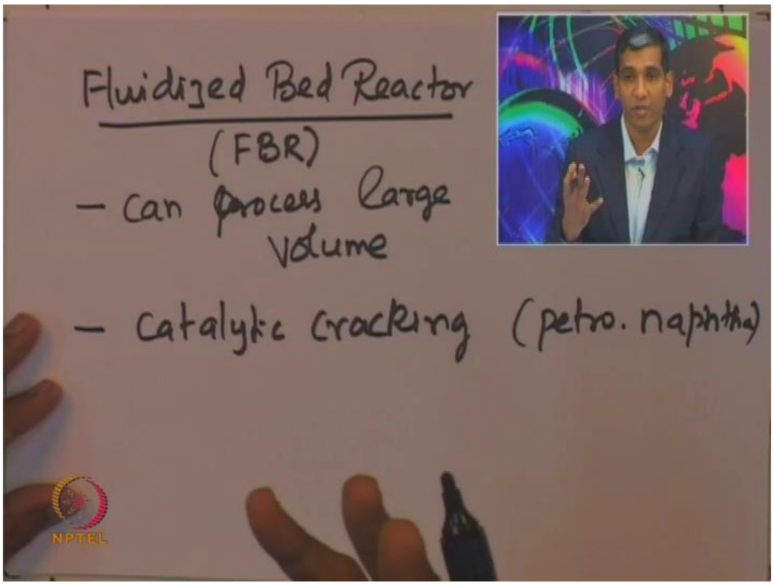

So, let us look at the fluidized look at fluidized as bed reactor. So, here after it will be refer to as FBR which is the fluidized bed reactor remember PBR is the packed bed reactor f b r will be the fluidized bed reactor. Now, the major advantage of a fluidized bed reactor that it can process large volume of reactants. So, it is can actually process can process large volume. So, that is an important advantage of using a fluidized bed reactor and it is very commonly used in catalytic cracking catalytic cracking a particularly of petroleum naphtha, which is again an important process in a in petroleum industry.

So, catalytic cracking is 1 very common example where fluidized bed reactor is actually being used in the industry settings. So, what is fluidization? So, fluidization is essentially where a small solid particles are actually suspended in a upward moving flow. So, suppose, if there is a tube which and there is a fluid, which is flowing through the tube then the velocity of the fluid is such that these particles, which are percent inside the reactor, which is catalyst particles which are present inside the reactor are actually gets they get suspended in the fluid acid moves. So, this process of getting suspended in the upward moving fluid is what is called as a fluidization process.

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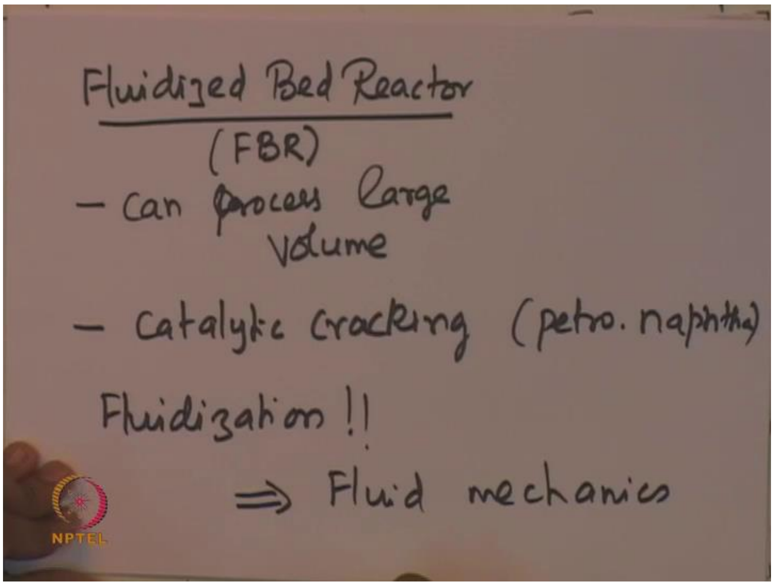

So, it is the fluidization, which is actually a key plays a key role in this kind of reactors a clear is the, because fluidization is involved clearly there is lot of fluid mechanics which is required in order to model or design such kind of a reactor some aspects of which is what we are going to see in this lecture.

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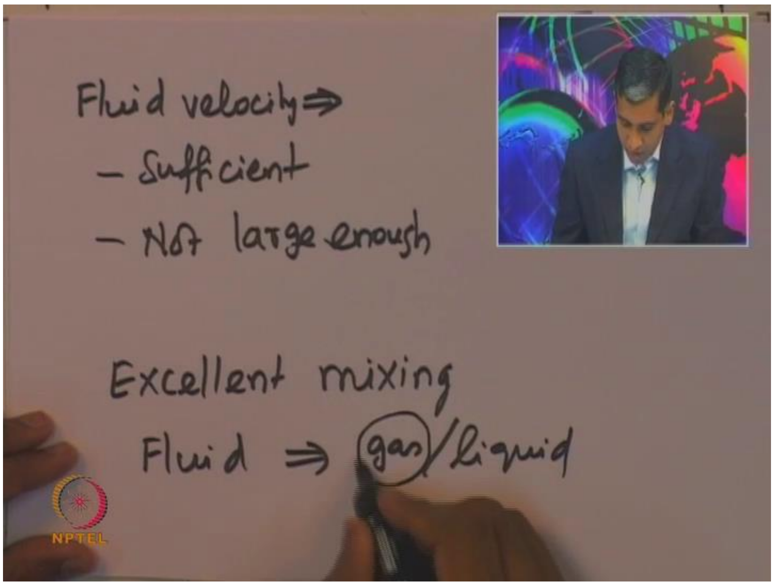

So now, the fluid velocity in order for fluidization to occur the fluid velocity should be such that, if fluid velocity should be such that, it is just sufficient to suspended particles in the fluid stream, but, not large enough it should not be large enough to actually take the particles outside the reactor. So, remember that these are particles, which are present inside the reactor which may a tube and then there is fluid which is flowing from the bottom of this tube and the fluid velocity should be just sufficient in order for these catalyst particles to raise along with the along with the fluid; however, it should not be significantly large enough in order for these particles to be washed away from the tube.

So, therefore, the controlling the fluid velocity has actually an important step in the fluidization process. So, that another important aspect of the fluidized bed reactor is that it provides excellent mixing. Because while the fluidization process occurs these particles are carried by the fluid and it is not fluid velocity is not large enough. So, that the particles leave, but, there is recirculation of the catalyst particles and that causes a bigger as an excellent mixing, which is required a main different kinds of reactions.

So, the fluid that is typically used for fluidization process could actually be a gas or a liquid stream it could be either of these 2 which is commonly used in this particular discussion. We are going to concentrate main assume that it is a gas which is actually fluidizing the catalyst particles. So, let us look a little bit more deeply into what is this fluidization process. So, there are different kinds of flow regimes which may which may be obtained while the fluidization occurs.

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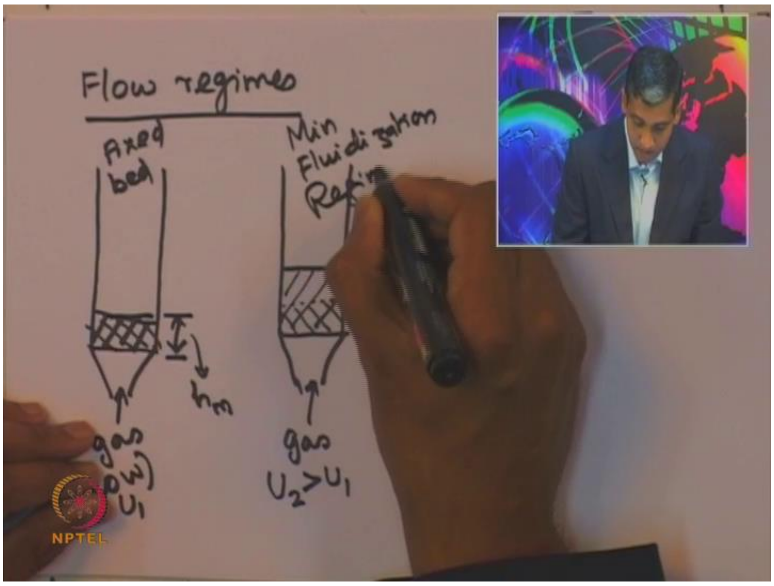

So, let us look at what these flow regimes are. So, now, suppose if there is a tube here and this is filled with, to say catalyst particles filled with catalyst particles. Now, there is a gas there is a fluid which is actually flowing through this tube. So, let us say it is a gas if the velocity is very low if the flow velocity is very small then what happens is that the velocity of the fluid is not sufficient dole to lift the particles; that means, that these particles they exert gravity force due to its naturally weight, while these gas when they actually moved through these particles they exert a drag force on the particles.

Now, if the gravitational force that, the solid particles are exerting is significantly larger than the a drag force that is that good experiences from the gas which is moving fasten then these particles will not be displaced. And they will tend to stay as it is and the gas will simply escape from the pores and then leave the reactor. So, this kind of an operation where, the gas flow rate is extremely small is called the fixed bed operation. And the height of the catalyst bed which is present inside the reactor in this fixed bed operation is called the is called h m.

We referred that as h m which is the height up to which the fluid catalyst particles are actually packed in its settled condition. Now, as a next step suppose, if we gradually increase the velocity of the gas suppose if we gradually increase the superficial velocity. So, if the superficial velocity of the gas in the fixed bed condition, if this is u 1 and suppose if the superficial velocity here is u 2 which is slightly greater than u 1 then what happens is that the fluid particles the drag force that is exerted by the gas stream, which is moving fast these particles is now, going to be just equal to the gravitational force which is exerted by the particles due to its natural weight.

Therefore, the particles will be fluidized. And so, the particles will start rising. So, here 1 could see that there will be 2 phases, where that will be some section which is raised and some section which actually stays as packed as it was before. So, this kind of regime is what is called as the minimum fluidization regime is called as the minimum fluidization regime. So, now if I look at the third case where, there will be a aggressive bubbling suppose, if I further increased the flow rate superficial velocity of the fluid which is act flowing into the tube. So, suppose if I increase the superficial velocity if its u 3 which is greater than u 2.

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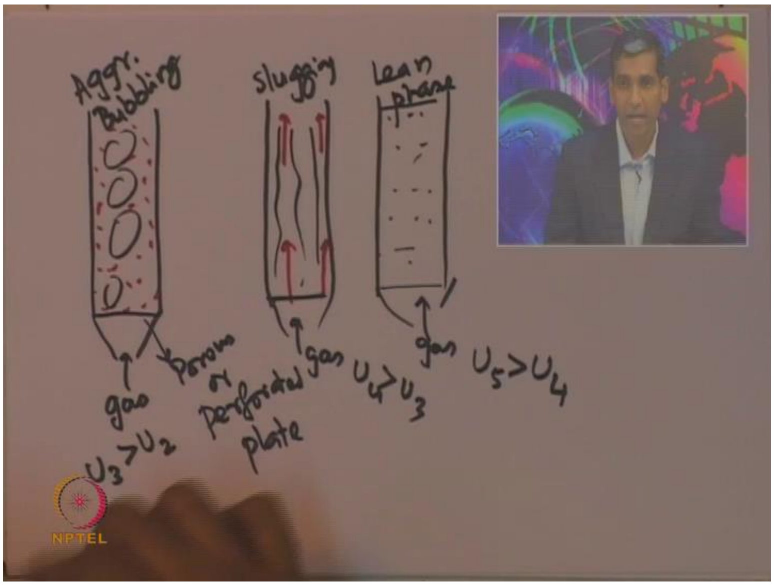

If its further increase the superficial velocity then there is the there is going to be aggressive bubbling of the gas. So, the gas bubbling starts inside. So, there will be aggressive bubbling of the gas and along with these fluid particles are now, going to be suspended around these bubbles. So, these bubbles now, carry the fluid particles along with it and therefore, there will be aggressive bubbling and it is also going to have aggressive amount of mixing of these particles and therefore, there will be aggressive mixing of the of the reactance species in the gas stream.

So, typically there will be a porous or a perforated plate typically, there will be a porous or a perforated plate, which prevents these particles from going back into the gas stream. So, this is regime is called the aggressive bubbling regime then the next regime is suppose, if we have a tube with gas flowing inside and if the superficial velocity is u4 which is lets greater than u3. So, the velocity is now, slightly greater than what it was in the aggressive bubbling case then what happens is call the slugging process where the gas is now the gas velocity is significantly higher.

The drag force is now, going to be significantly higher than the gravitational force which is exerted by the by the solid particles, because of its natural rate and that is going to be that inequality is going to be a significantly predominate which is going to be predominant then the aggressive bubbling case and. So, there will be a slug which will be formed, where the gas stream is now going to escape through these channels, which is presents. So, the gas stream is simply going to escape through these channels and the and. So, you can see that there will be channels of particles and the gas stream is created inside the tube.

So, this process of fluidization is called the slugging process, where it happens at a significantly higher velocity and the last regime is call the lean regime. So, if this is the gas which is flowing here and the velocity superficial velocity is u5, which is greater than the superficial velocity in the case of slugging then, there is going to be a lean phase where the particles are suspended with very low density all through the reactors. So, that is call the lean phase. So, in this discussion today, we are primarily going to look at the fluidization regime.

We will not look into the slugging and the aggressive bubbling regimes even in the fluidization regime there will always be some minimum bubbling which will be present. And the particles will be carried by these bubbles and. So, we going to look at how these bubbles how these particles are carried by bubbles and what fluid mechanics is involved and how it, can be used in terms of designing the fluidized bed reactor which is objective.

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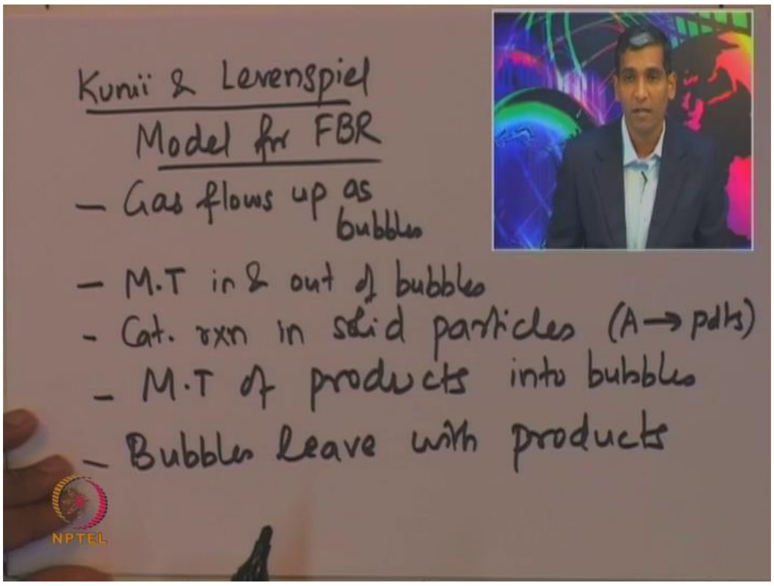

So, Kunii and Levenspiel, came up with a modeled Kunii and Levenspiel they came up with a modeled for the fluidized bed reactor. So, the modeled that we will describe here, is basically that of Kunii and Levenspiel and there are certain assumptions important assumptions that were made while formulating the modeled the assumptions are that the gas flows up as bubbles.

So, as long the velocity with which the gas is flowing in above the minimal fluidization velocity that is the velocity at which, the drag force exerted by the solid by the gas on the solid particle is equal to the gravitational force that is actually exerted, because of the weight of the catalyst. So, if that equals then the fluidization is going occur. So, as long as the velocity of the fluid is slightly higher than the fluidization velocity then, we will see that this is bubble gases will start bubbling at the plate which is presented at the bottom of the reactor.

So, the molded assumes that the gas flow actually it flows up as bubbles. In fact, the velocity at which the bubbling will start and the velocity at which the just fluidization will start will be insignificantly different their expected to be very close to each other. In fact, it has been observed that the 2 velocities are these 2 superficial velocities are very close to each other therefore, the assumption that the gas flows up as the bubbles is not very poor assumption and then the other process is that there will be mass transport in and out of bubbles.

So, remember that the reaction is occurring at the surface of these catalytic particles reaction is occurring in the active sites of these catalytic particles. So, therefore, the recants stream which is actually being carried in the gas phase has to get transported from the bubbles. So, the recant is now, present in the bubbles and this species has to be transported from the bubble into the catalytic. So, therefore, there has to be mass transport in and out of the bubbles and after the reaction is completed the product which is formed in the catalyst is now, going to get transported to the gas stream. And the gas stream takes the product out of the fluidized bed reactor.

So, therefore, the next will be there is a catalytic reaction in the solid particles in the solid particles and then there will be mass transport of products mass transport of products the reaction would some a species a giving some corresponding products and. So, mass transport of products into bubbles and the bubbles leave the reactor. So, bubbles essentially leave the reactor with products. So, it carries the products and it leaves the reactor. So, now, let us look at what are the factors that actually affects the performance of fluidized bed reactor.

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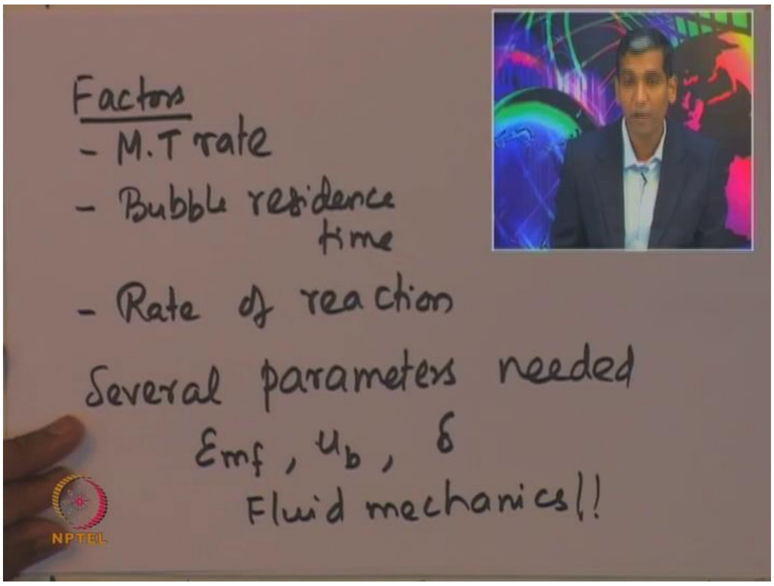

So, the key factor which affect are the mass transport rate, because there is transport of species from the gas phase into the solids and also transport of the products, which is formed because, of the catalytic reaction in this solid phase that is transported back into the bubbles into the as phase. So, the mass transport rate is actually a key factor determining the performance of the fluidized bed reactor. And then another key factor which dictates the performance of the reactor is the bubble residence time. So, this characterizes the time for which the bubble actually stays inside the fluidize bed reactor.

In fact, it is related to the superficial velocity. And the velocity with which the bubble raised superficial velocity is the velocity with which gas phase gas is actually fed into the reactor and then the bubble is now, going to raise with the different velocity and. So, the residence time is now, going to be a function of the superficial velocity and also the velocity with which the bubble is actually raising inside the fluidize bed reactor and the third factor which is obvious is the rate of reaction. So, these 3 factors are very important.

In fact, there are several fixed fluidize bed reactor properties need to be known in order to get these 3 important term in order to estimate these 3 factors and also account them in the mole balance, which would be writing in a short. So, several parameters needs to be define: several parameters are needed in order to perform a design of such a fluidize bed reactor for example, what is the porosity of the bed under the minimum fluidization conditions, what is the velocity with, which the bubbles are actually raising insides the fluidized bed reactor. And then what is the fraction of the reactor which is actually consisting of bubbles with which is characterize by this value delta and.

So, all kinds of parameters, which are required to estimates. So, if we do not estimate if we do not estimate. If we do not know what this parameters are then design of a fluidize bed reactor cannot be conducted and these parameters as can be the depend they depend up on the fluid mechanics of this particular problem they, strongly depend up on the fluid mechanics. So, let us look at some of these fluid mechanics aspects and then try to estimate some of these parameters, which is going to help in the design of the fluidized bed reactor. So, now, the first step is we have to look at what is the mass of the solid which is present inside the bed.

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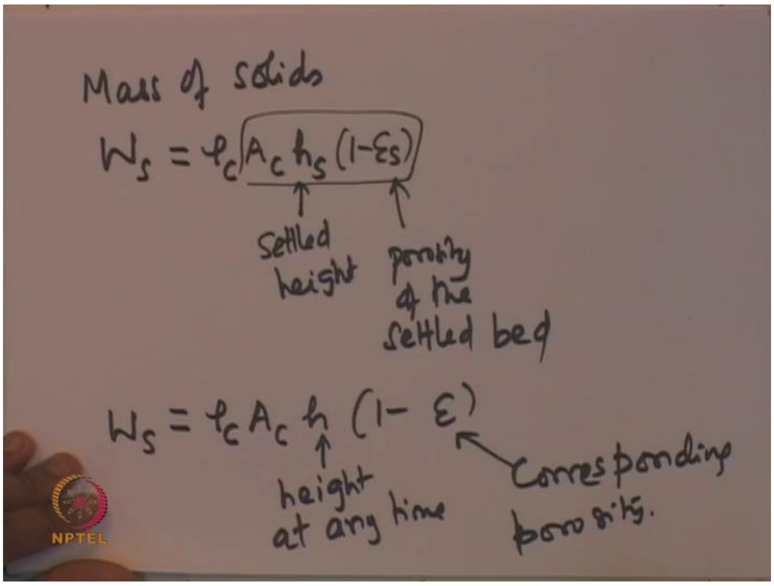

So, the mass of the solid which is present. So, if w s is the total mass of the solid catalyst particles, which is present inside. So, that is given by the density of the catalyst rho v multiplied by the cross sectional area a c into the height of the catalyst suppose, if the catalyst particles are completely settled then h s refers to the settled height. The height inside the bed up to which the catalyst particles are settled into 1 minus epsilon s; epsilon s is the porosity, it is the porosity of the bed of the settled of the settled bed what is the porosity and.

So, density of the catalyst multiplied by the area a c h s which is the settled height into 1 minus epsilon. So, this gives the volume and multiplied by the corresponding density will tell you what is the weight of the catalyst. Similarly, the same expression w s suppose if the bed is fluidized then, what is the weight of the catalyst the weight remains because, we are not adding new catalyst particles, but, the height of the bed is now, change because some of the particles are now, fluidized and they started they have started raising.

So, therefore, the weight of the catalyst bed at any time during the fluidization process is given by rho c, which is the density of the catalyst multiplied by a c which is cross sectional of the fluidized bed multiplied by height which is the by h which is the height at any time height at any time multiplied by 1 minus epsilon this is the corresponding porosity at the corresponding porosity. So, that provides an estimate of what is the mass of the solid. So, if we know the height at any time then we should be able to estimate the value of the porosity by simply equating these 2 expressions here, because this is the settled height and this is the porosity of the settled bed.

So, we should be able to estimate what is the porosity of the bed at any time simply by using this expression and also that is because the height of the bed at any time is something that can be measured it is a measurable quantity. So, now, the next process next parameter that, we need to estimate is what is the minimum fluidization velocity.

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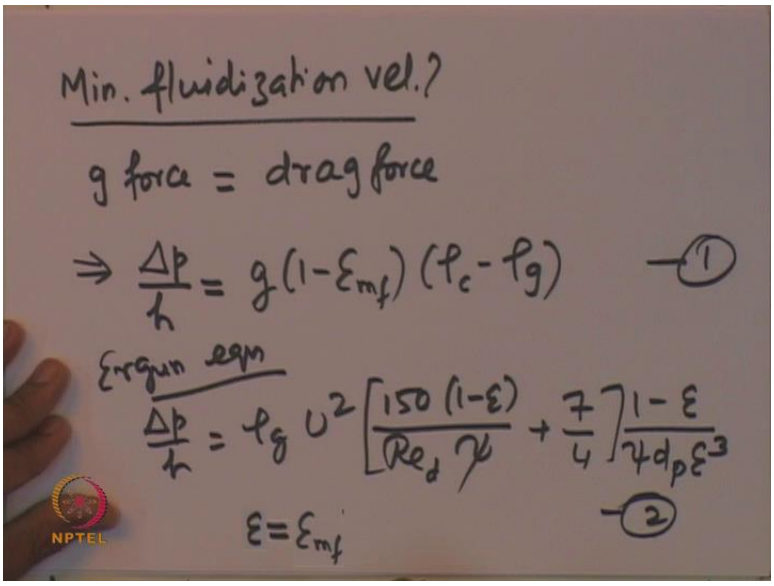

What is the minimum fluidization velocity. So, the fluidization occurs when the drag force that is exerted by the gas stream, which is moving which is raising up if that balances the gravitational force that is exerted by the catalyst particle, because of its natural weight. So, clearly you can estimate the minimum fluidization velocity by simple balancing the drag force that is exerted by the gas phase and the gravitational force that is exerted by the solids because of its weight.

So, therefore, the gravitational force that should be equal to the drag force that is which is exerted by the gas stream on the fluid on the catalyst particles. So, that is so that balance will give us pressure relationships. So, that will be delta p by h that should be equal to gravity g into 1 minus epsilon m f which is the porosity at the minimum fluidization velocity into difference in the densities. So, rho c and rho gas are the densities of the catalyst particles and density of the gas stream.

So, if I call this equation 1 and we also know that there is an we also know from the fluid mechanics that the ergun equation provides a relationship between the pressure drop and other parameters of the system that is superficial velocity etcetera. So, therefore, delta p by h is equal to rho g into u square. So, that this is the pressure relationship because of the gravity force and then we can find out what is the drag force because of the gas stream.

So, that is given by the ergun equation into 150 into 1 minus epsilon divided by the Reynolds number into psi is the sphericity of the particle plus 7 by 4 into 1 minus epsilon divided by psi into diameter of the particle into epsilon cube. So, that is the drag force. Now, by equating the these 2 expressions 1 and 2 we can find out what is the minimum fluidization velocity.

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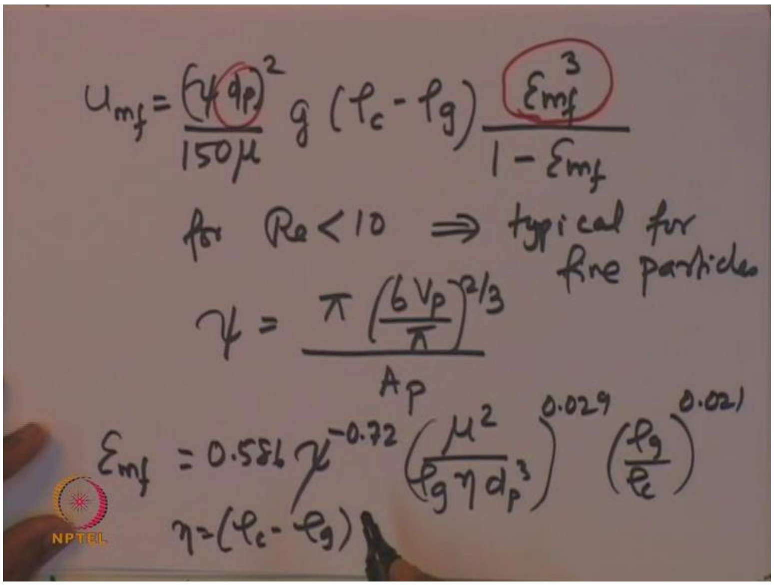

So, the minimum fluidization velocity is given by psi d p square divided by 150 mu into gravity into the difference in the density of the catalyst and the density of the gas stream into the porosity at the minimum fluidization velocity divided by 1 minus epsilon m f ok. So, now this is valid only for Reynolds number which is less than 10 and this is typically the case for fine particles. It is a typical Reynolds number for fine particles, it is a typical Reynolds number for fine particles and the sphericity is given by pi into 6 times volume of the particle divided by pi to the power of 2 by 3 whole divided by the area of the particle.

So, now, if we know what is the porosity at the minimum fluidization velocity then we will be and the diameter of the particle then, we should be able to estimate the minimum fluidization velocity. So, we need to know what is the porosity at the minimum fluidization velocity and there are correlation, which are available to relate the porosity at minimum fluidization velocity with the other system parameters. So, epsilon m f which is the minimum fluidization velocity is given by 0.586 into the sphericity to the power minus 0.72 into mu square divided by rho g into eta; eta is essentially the difference in the density.

So, eta is essentially the difference in the density of the catalyst particle and the gas mu square divided by rho g into eta into d p cube to the power of 0.029 into rho g by rho c to the power of 0.021. So, this is basically the relationship which gives what is the porosity at the minimum fluidization velocity and plugging in this value here 1 can find out what is the minimum fluidization velocity. So, remember that this is correlation and there will be obtained it is been found to be correct for different systems and particularly, if the if we assume that the catalyst particles appropriately all of them have same size then this gives a very good estimate.

Now, if the if there is a distribution of the catalyst particles then 1 needs use a certain weight average in order to find out what is the diameter of this particle. So, the diameter of the particle if the if all the particles are of same size then, we have to use a constant value for the diameter if this is a distribution then the we need to use a some weighted average a diameter which is a represented diameter for the whole distribution.

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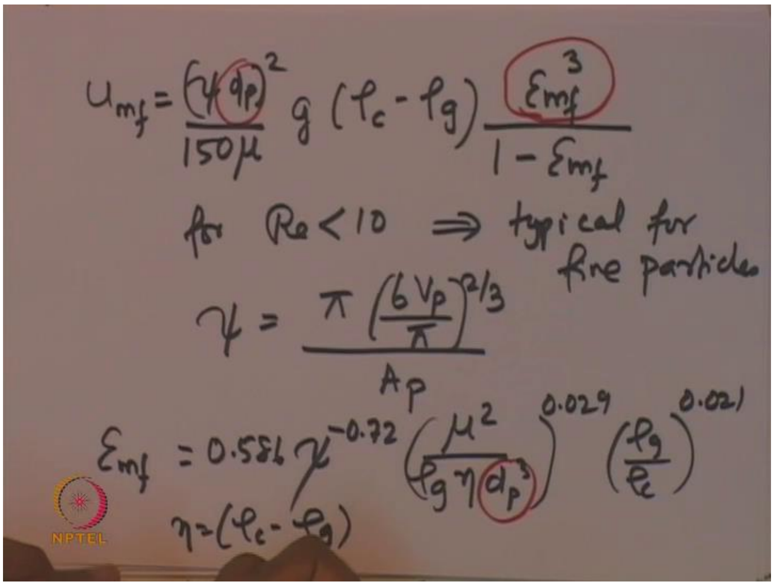

So, next let us look at what is the maximum fluidization velocity. So, the maximum fluidization velocity occurs, when the drag force is significantly higher than the gravity force.

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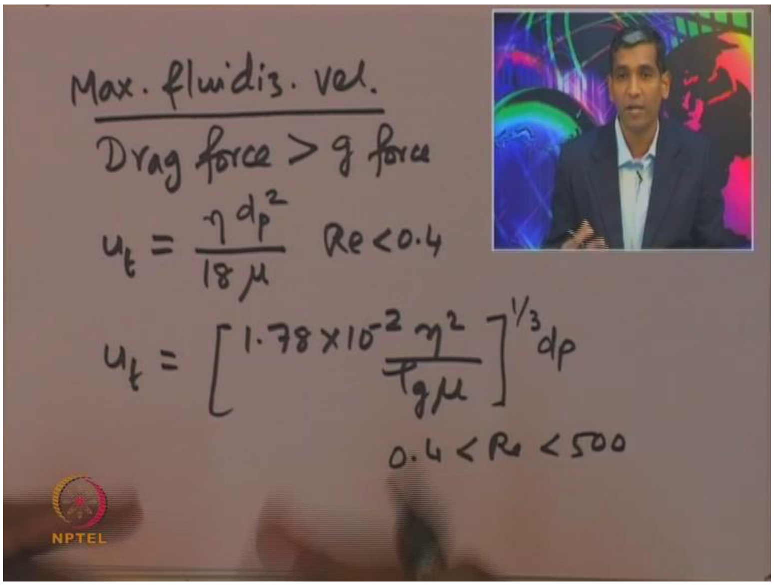

So, the maximum fluidization velocity this is when, the drag force is greater than the gravity force and remember that this velocity should not be greater than a certain values such that the particles would actually leave the reactor. So, if the maximum fluidization velocity we will less than the velocity at which the particles would leave. So, which is typically given by certain correlation which is u t its call the eta into d p square divided by 18 into mu for Reynolds number of less than 0.4 eta once again is the difference between the density of the catalyst and the density of the gas stream.

For other ranges of Reynolds number the correlation is 1.78 into 10 power minus 2 into eta square divided by the density of the gas stream into corresponding the mu to the power of 1 by 3 into d p. This is for Reynolds number between 0.4 and 500. So, this range of Reynolds number pretty much covers most of the fluidization; fluidization operations that has been observed. So, far that is been used so, far in real systems. So, next what happens when the bubble rises. So, what is it is actually happening inside the reactor.

So, suppose if we look into the details of what happens inside the fluidized bed reactor. So, when the gas stream flows into the reactor through the perforated or the porous plate then the bubbles are initiated bubbles are generated at the at the plate and while the bubbles move they also carry these particles along with them how do they do that.

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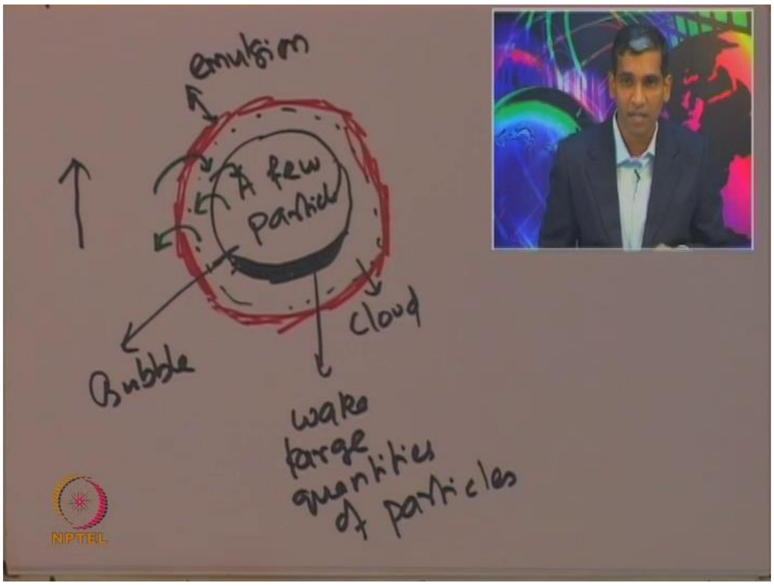

So, suppose if you have a bubble, which is typically not very spherical then these bubbles will carry a few particles. So, this is the bubble now, when the bubble raises they carry a few particles along with it and more importantly there is a region which is just below the bubble when, it is raising suppose if I assume that the bubble is raising in the direction pointed by the arrow then this region called wake which actually contains large quantity of. So, this wake essentially which is the trailing part of the bubble it carries large quantities of particles it carries large quantities of particles. And then there is a small cloud region.

So, this is call the cloud region where, the density of the particle is not significantly higher and then there is this emulsion region, which is because the where this emulsion region around the could. So, this is call the emulsion region and. In fact, this emulsion region actually has the particles, which is as then densely packed as the resting particles. So, this is basically the emulsion region. So, now, the transport of the species occurs from the bubbles. So, the transport of the species occurs from the bubble to the could phase and from could phase to the emulsion phase remember that the catalyst particles are predominately present in the emulsion phase.

So, therefore, the reaction is actually occurring in the emulsion phase. So, the recant species they have to they have to get transported from the bubble into the could and from the cloud into the emulsion phase and the product has to be transported back into the could into the bubble phase. So, that is that is basically the how the transport occurs in the bubble and which actually facilities the catalytic reaction and that dictates. So, this process actually dictates the performance of the fluidized bed reactor. So, let us look at the little more detail of the modeled of the Kunii Levenspiel model.

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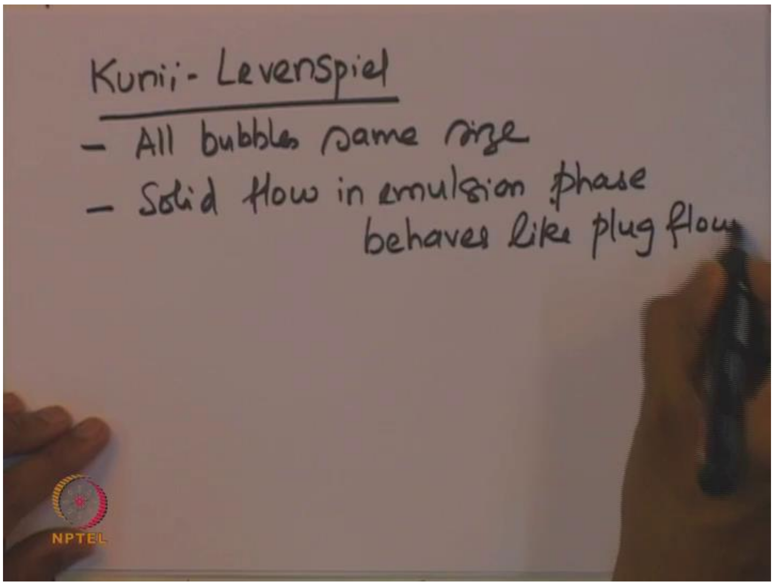

So, the Kunii Levenspiel model, it makes certain important assumptions and 1 important assumption besides all those that, we have that has been illustrated so, far will be that all bubbles are of same size. Now, bubbles that is generated inside the fluidized bed reactor or definitely not of same size; however, because the very the distribution of the size is not going to is not excepted to be significantly larger. So, it is a its region able to assume to start with that all bubbles are of same size then the next important assumption is that the solid which solid flow in emulsion phase emulsion phase behaves like a plug flow.

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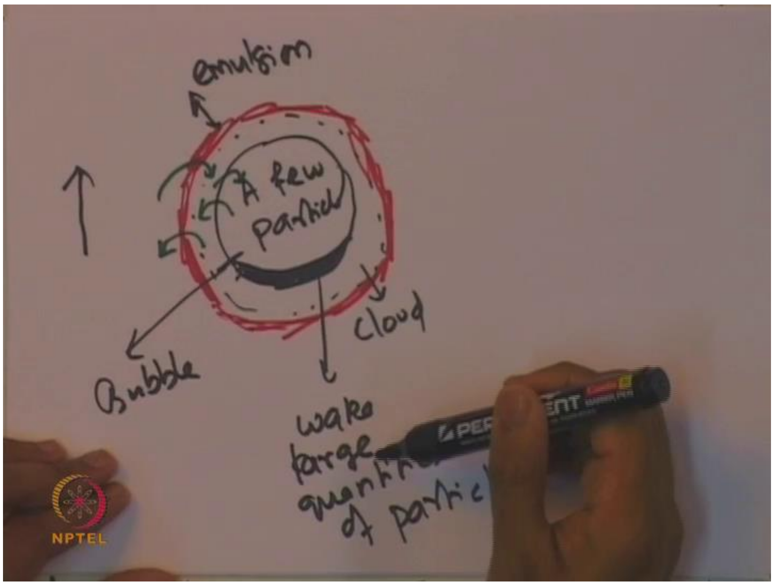

If we look at the different phases that we just illustrated, we will find that the this particles which are actually carried by the bubble phase this particles, which are carried in the bubble phase and the wake phase they actually move into the emulsion phase and they start moving downwards because of its natural weight. And therefore, the moment of these particles in the emulsion phase a velocity with which it moves strongly dependents up on the velocity of the bubbles which carries these particles and. So, it is assumed here that the solid flow in the emulsion phase actually behaves like a plus flow, where it moves like a plus stream.

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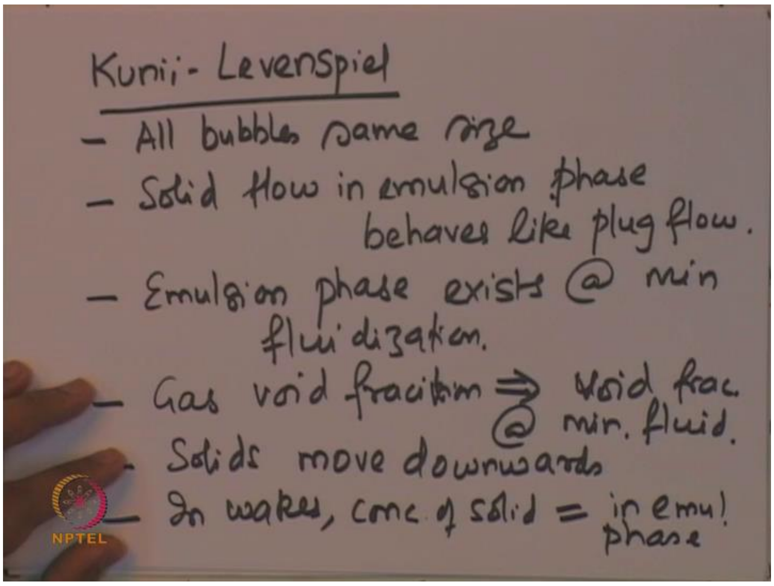

Then it also assumes that the emulsion phase exists, at minimum fluidization conditions. So, remember that minimum fluidization is essentially a situation where, the drag force that is actually experienced by the solid particles, because of the flow of the gas stream is actually balanced exactly with the balances the gravitational force exerted by the catalyst particle because of its natural weight. So, the as we observed before the bubbling process the velocity at which the bubbling process is superficial velocity, with which the bubbling process is going to occur is very close to that of the superficial velocity which is required for minimum fluidization.

So, therefore, virtually not possible to in distinguish practice, whether the emulsion phase whether the bubbling phase is actually present during the minimum fluidization state stage or not. So, therefore, it is a safe to assume that the bubbling phase exist at the minimum fluidization. And therefore, the emulsion phase also coexist along with it and then next important assumptions is that the gas void fraction the gas void fraction that actually is experienced in the emulsion phase that is considered, to be approximately equal to the void fraction at the minimum fluidization conditions at minimum fluidization conditions.

Then the ,it is also assume that, the solid which actually move out of the bubble phase into the emulsion phase they, actually move downwards solid move downwards because of the gravity. And then it is assume that in the wakes which are present, in wakes which are present note that the wakes are essentially these particles, which are actually carried along with the bubbles and its is now, present at the receiving end of the bubble. So, in wakes the concentration of solid is assumed to be equal to that of the concentration in the emulsion phase. So, with these assumptions let us look, at how estimate different parameters and different quantity and also find out on to how to design these fluidized bed reactor.

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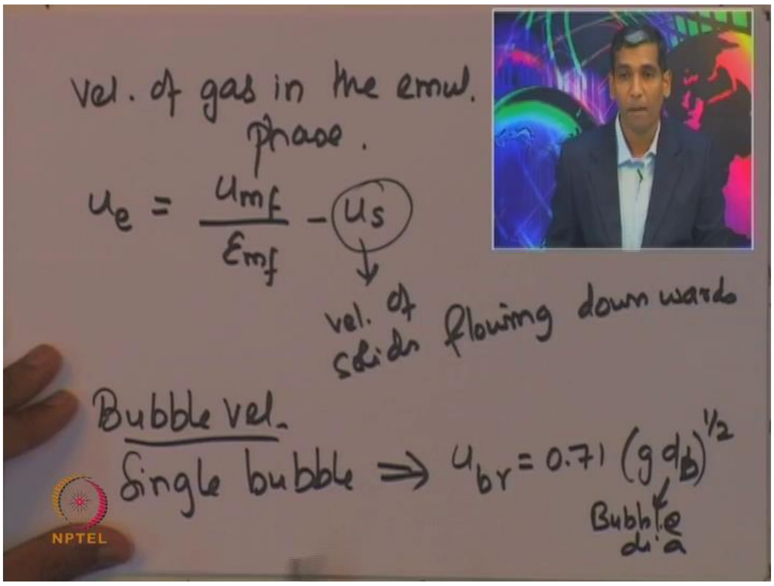

So, the first step is to estimate the velocity of the gas in the emulsion phase, if u is the velocity of the gas in the emulsion phase and that is typically, given by the minimum fluidization velocity u m f divided by the porosity of the bed under minimum fluidization conditions minus us what is us; us is then velocity of solids flowing downwards velocity solid which is actually flowing downwards in the emulsion phase, its flowing downwards in the emulsion phase.

So, therefore, in order to estimate this 1, we can we can write a certain material balance in order to find out the velocity of the solid with, which it is velocity of the solids which is actually flowing downwards. So, we in the lecture we will actually write material balance in order to estimate the velocity of the solids and the next step is to estimate what is the bubble velocity suppose, if it is a single bubble then, there is a correlation which actually relates the diameter of the particle to the velocity of the single bubble.

So, that is given by u b r which is equal to 0.71 into gravity into diameter of the particle to the power of 1 by 2 and this is the diameter of the bubble, this is the bubble diameter. So, now, there is a in the fluidized when many bubbles are present together then the velocity of the bubble is excepted to get affected, because of the a interaction between different bubbles.

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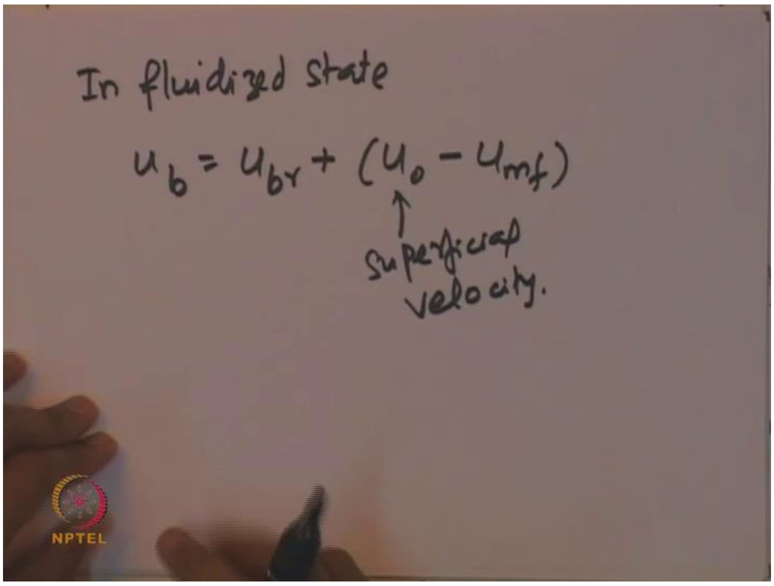

So, in fluidized state, the bubble velocity is excepted to be ub which is equal to ubr plus u naught minus umf where, u naught is the superficial velocity. So, once we know these parameters and there are several other parameters that need to be estimated particularly, we need to know the what is the diameter of the bubble and there are different correlations which are available. So, what which is what we will see, in the next lecture.

So, we have seen in today's lecture, is essentially the an example problem for how to use the packed bed reactor to find out what is the length of the reactor. And also we initiated discussion to on the fluidized bed reactor and look at what are the different flow regimes, which are actually which actually exist in the fluidized bed reactor. And what are the different parameters and properties that need to estimated in order to design the reactor.

Thank you.