Fluidization Engineering

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Lecture – 01
Introduction

Welcome to massive online course on Fluidization Engineering sponsored by Ministry of Human Resource Development, Government of India. Today this course will be discussed on fluidization engineering.

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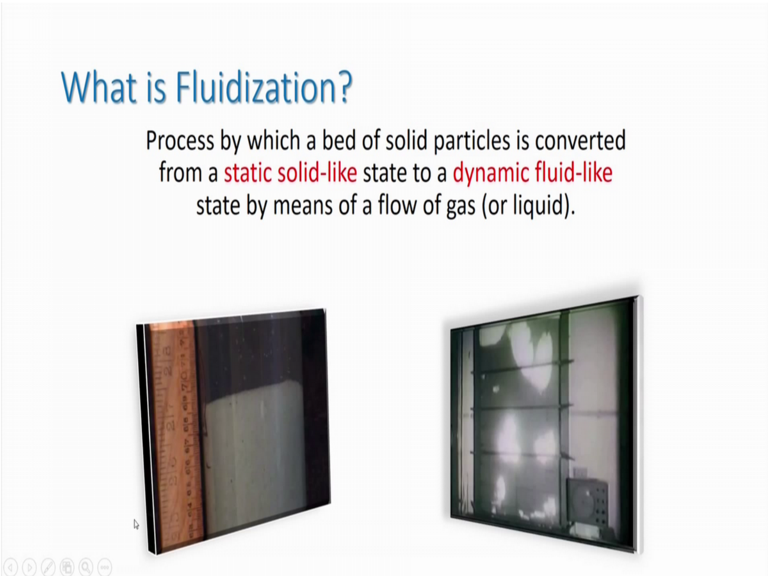

Now, what is a fluidization? The fluidization is a process by which a bed of solid particle is converted from a static solid like state to dynamic fluid like state, by means of flow of gas or liquid.

Here see one or two video regarding this fluidization then, you will understand what is this fluidization? Here see initially, the bed is of full of solid particles which is rest without moving any bar any gas or liquid is supplied from the bottom of this column of the solid bed you will see the solid particles will try to lose from its rest position due to this flow of gas or liquid. And it will get fluidized state; that means, called dynamic fluid like state.

Now, in this case another example if we increase the gas or liquid velocity from the bed we will see another different type of fluidization phenomena occurs. In this case gas is coming from the bottom as a dispersed phase of bubbles; that means, here this white space here we are seeing in the video that this space of white space these are nothing but the empty space without solid particle. And here the solid particles are entering by this gas bubbles from the bottom to the top and this gas is dispersed at a dispersed phase of bubbles from the bottom of the bed.

Whereas in this case the left video you will see there is no formation of bubble. Why? Because the gas velocity or liquid velocity it is supplied from the bottom of this column in such way that and here a minimum gas velocity or liquid velocity is maintained. So, that the solid particle just to become fluidized. So, this minimum fluidization state is called minimum fluidization and the velocity at which this minimum fluidization condition is maintained is called incipient velocity or incipient fluidization velocity or minimum fluidization velocity. Beyond this minimum fluidization velocity you will see there are several other different types of pattern of this fluidization will occur.

The question is that then you are getting this type of fluidization we will discuss later and also what is the different application of the fluidization system based on this dynamic fluid like state. Now, before coming to that point we will discuss that this fluidization is nothing, but multiphase system phenomena multiphase phenomena. What is that multiphase system? Multiphase system means more than one phases will be coming in contact to each other and governs to some processes in chemical and biochemical industries and what is that then multiphase system. You know that phases different phases like gas liquid and solids, now combination of these phases forms multiphase system.

Now, this suppose gas and liquid the two phases, these two phases this two phases. Again this gas and solid, again this liquid and solid liquid liquid and gas liquid solid there are different combination of these systems and this different combinations are called the multiphase combination system.

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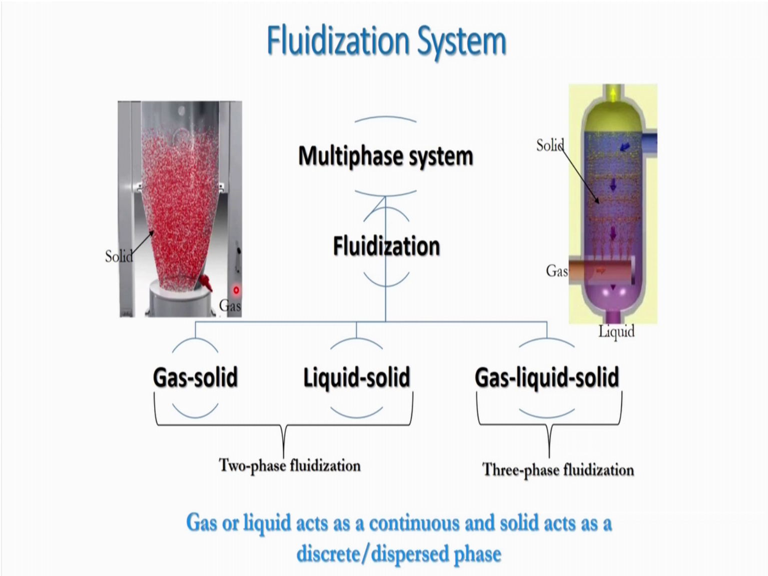

Now, this fluidization is one of the multiphase systems. Now fluidization basically occurs in two phase system and three phase systems in two phase fluidization you will see here the two phase fluidization means here see two phase fluidization is gas solid combination and liquid solid content combination. Here gas is coming contact with solids and there is an application of gas solid reactions or any other application like adsorption, absorption etcetera. Similarly liquid and solid liquid is coming with solid in contact and in three phase fluidization gas liquid and solids three phases are coming in contact.

Now, in case of gas and solids you will see or gas liquid solid, the gas or liquid acts as a continuous and solid act as a discrete medium or you can say the dispersed phase medium. Now in two phases this gas is a continuous phase and solid has a discrete phase whereas, in the three phase systems the gas and solid both maybe as a dispersed phase and liquid as a continuous phase. Even gas will be continuous phase, but liquid and solid will be discrete phases. Now, depending on the application of the process it will be applied in a three phase fluidization system.

Now, if suppose gas is supplied in the liquid medium and now this gas will be dispersed as a dispersed phase of bubbles now bubbles will be forming through a distributor, now the distributor will hold some holes with different sizes. Based on that size the different sizes of the bubbles will form. We will discuss later on the distribution process of the gas and the fluidized bed.

Now, see this gas will be dispersed this dispersed phase of bubbles in that case liquid phase would continuous where in the liquid solid also would be discretized and this solid and liquid will be forming as a slurry. Now, this solid and liquid medium will be acting as a slurry medium and gas will be disperse medium.

Now, there are different aspects of this application of this gas liquid solid injection sometimes gas shaded a slurry reactor, maybe you will see that Fischer Tropsch synthesis they are in presence of catalyst particles the formation of the carbon monoxide and hydrogen mixture this is gas production that is applied in slurry bubble column reactor. So, that is one application of three phase fluidization system.

Whereas two phase fluidization like gas and solid they are suppose adsorption of some gas in a solid medium. Even adsorption of organic gas into the solid even adsorption of liquid into the solid also there, even gas is adsorbed on the liquid on liquid and solid operation there liquid is absorbed in the solid. And also there are some other applications like granulation coating in that case gas solid operations with important liquid solid fluidization is very important. In the gas solid operations we will see there is a solid will be dispersing in the gas medium in such way that there will be some uniform mixing of the bed so that the fluid like behavior of this solid bed will be applied for the different processes.

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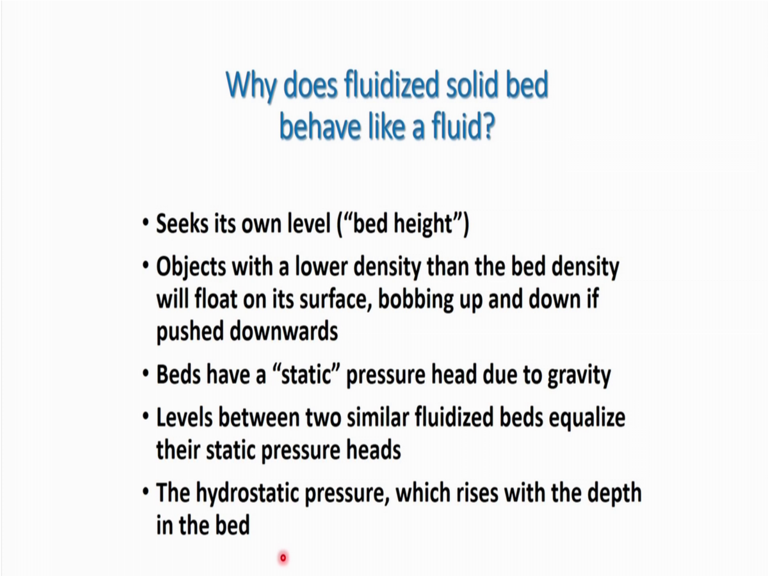

Now, this why does this fluidized solid bed behave like a fluid. Now, you will see any fluid whenever it will behave it will have some properties like it will seek some level. Of course, whenever this fluidized bed will behave like a fluid it will seek its own level like bed height.

Even when in this case you will see in the fluidized bed compared to this fluid like behavior if you insert some object with a lower density then a bed density you will see there will be floating of that object or bobbing up and down if pushed downwards in the bed. So, this is one property by which you can say that this fluidization bed solid or solid bed behave like a fluid.

Another example of course, this fluidized beds have a static pressure head due to the gravity and levels between two similar fluidized bed equalized their static pressure heads. The hydrostatic pressure which rises with the depth in the bed also, as like that suppose in a liquid of course, the fluidized hydrostatic pressure will be depending on the depth of the bed.

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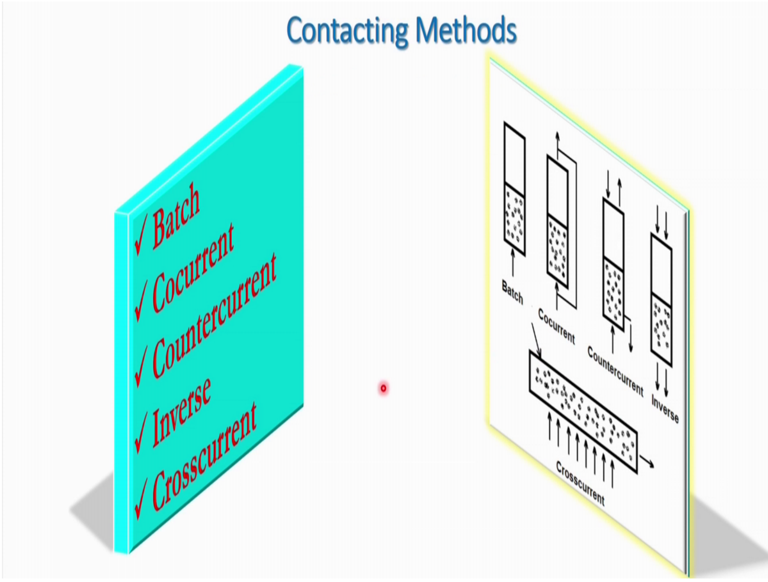

Now, contacting method, you will see there are several ways or modes of contacting of the solid liquid or solid liquid gas in the fluidized fluidization bed or fluidization operation. Here batch processes there in that case will you see in this gas, in this case the solid is moving due to the supply of gas the solid will be supplied as a batch wise whereas, in the cocurrent process or concurrent modes in that case gas and solid input will be supplied in a continuous mode, continuous mode and it will be moving in the same direction of the bed. And then cocurrent means here both gas and solids will be moving in the same direction.

And countercurrent in this case if gas and solids are there the solids will be flowing opposite to that gas flow and if it is liquid solid then solid will be flowing opposite to the liquid and also in the case of counter current operation will see for gas liquid solid operation the gas and liquid will be flowing opposite to each other in a base of solid. Where the solid particles if any catalyst particle or solid particles is lighter than the liquid then we will see due to their buoyancy of the solid particles will try to move up whereas, liquid will be moving downwards. So, in that case the due to the downward movement of the liquid solid particles will try to move downward against its buoyancy. So, this type of fluidization process is called inverse fluidization.

Cross current another one type of operations, like here the in this case the gas or liquid will be flowing in the direction perpendicular to the movement of the solids or solid is moving cross currently to the direction of the fluid or gases.

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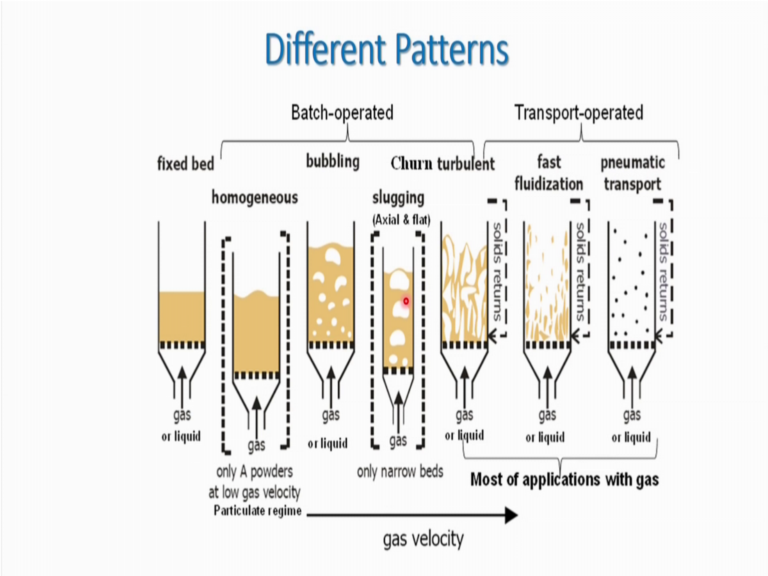

Now, you see there are different patterns based on the gas velocity or liquid velocity that is applied to the fluidized bed. You will see some are batch operated some are transport operated. Now, batch operated systems are like fixed bed bubbling bed churn turbulent bed fixed bed means here it is not as that that fluidizing condition, but you will see if just simply this fluidization operation is maintained at a minimum gas velocity the solid will be fluidizing from its rest just from its rest at a minimum fluidization condition. So, that minimum fluidization condition whenever fluidized bed is operated it is called particulate fluidized bed or it is called homogenous fluidization condition.

And you will see if you gradually increase the gas velocity or liquid velocity. Here see if you increase this gas or liquid velocity the fluidized bed is operated under bubbling condition. From at that condition the gas will be flowing from the bottom of the column to the distributed as the dispersed phase of bubbles. So, this type of phenomena is called bubbling fluidization.

And another is called if you increase again the gas velocity and if it is the narrow fluidized bed then what will happen the gas will be dispositive dispersed bubbles, but size of the gas will be something different than previous one. If the size of the bubbles is almost near about the diameter of the column of this fluidized bed then you will see that type of condition is called slugging fluidization. This slugging may be axial and flat you will see sometimes the bubble which is bigger in size and almost equal to size of its diameter then it will go vertically in a chain wise. So, this type of it is called axial fluidization. And if the size of these bubbles, the size of this bubble is flatter, like if the gas bubble size occupy or gas bubble is occupied whole cross sectional area of the bed then it will move up just occupying the whole cross sectional area and this type of slugging is called flat slugging.

Even if you increase more gas velocity there in the bed then you will see there will be a intermixing of the gas and solid in such way that there will be formation of churn inside the bed. So, this type of bed operation or pattern of this fluidization is called churn turbulent pattern of the fluidization. And here this is the churn turbulent fluidization. Even if you increase the size of the increase the velocity you will see there will be fast fluidization in this case the settling velocity of the solids, if they are suppose any settling velocities there vt then 20 times higher than if it is there this gas velocity then we will see fast fluidization occurs, even if you increase more than 20 times of the settling velocity of the solid particles you will get pneumatic transport type of fluidization operation.

This fast fluidization and pneumatic transport fluidization you will see there will be no formation of individual shape or bubbles, but there will be a discontinuous shape of bubbles and there will be sometimes will see the continuous gas phase will be occurring inside the bed. And also the porosity of the solid particles inside the bed will be higher in case of pneumatic transport, but here this dilute medium of the bed of pneumatic transport will be having in the process.

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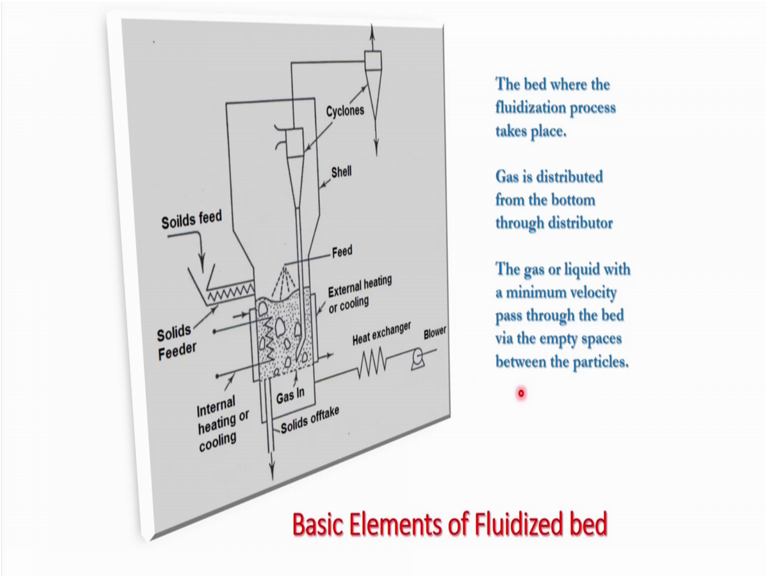

Now, see what are the basic elements of fluidization bed? Of course, you should know that if suppose any fluidization operation occurs in the bed this is called fluidized bed; that means, the bed where the fluidization process takes place. Now in that fluidization fluidized bed you will see some components of this fluidized bed will be having basic components you can say there will be having someone distributor through which gas will be distributed and what is that internal heating or cooling system will be there because for some operations you will see the medium to be of course, controlled at a certain temperature and pressure. So, that a certain temperature to be maintained and that temperature to control of course, it will be heating at a certain temperature. And also this heating of this medium to be controlled by externally heating so there are two provisions that heating conditions that internal and external provision of the heating.

And also the solids whenever it will be loaded in into the solid bed you will see there will be a provision to supply this solids into the bed. So, this is your solid feeds provision and there will be a feeder of the solids. And another if you want to supply the feed at liquid feed inside the bed there will be some distributor of liquid inside the bed by which you can supply the liquid into the bed. And there are some other this is called this part is called shell this shell part and inside this shell this of fluidization occurs this called totally fluidized bed.

And another one important component is called cyclones these cyclones are being used because if solid particles is coming up through the gas there is generally fine particles whose size is very fine then small, then it will be coming out by this gas and of course, these fine particles to be separated now. This cyclone separator is being used to separate the solid particles. And these cyclone separators are used internally sometimes or maybe externally, but some sometimes this both externally and internally cyclone separators are being installed because of more separation of the finer particles they are. And then after separation these solid particles again will be reused or in the bed.

And then what is that another component is blower of course, by which gas will be supplied and before going to that fluidized bed this gas will be maintained certain temperature and that maintaining temperature of course, on heat exchanger to be used for heating this gas medium. And extra that is solid optics of course, there will be some prohibitions by who is the solid particles to be given up taken off from this bed for reuse or maybe refreshment or maybe which are not being used for that after use, maybe if it is combustion then solid particles which are not being again used it would be taken off from the bed. So, that is why solids optic option of course, will be there.

Now, gas is distributed from the bottom through distribute, there are several different kinds of distributor of course, you will have we will be discussing later on the distributor part. The gas or liquid with a minimum velocity which passed through the bed via the empty space between the particles will cause the minimum fluidization. So, these are the basic elements of fluidization bed. So, there are operation, they of course, there are some other accessories of course, that depending on the operation and that is installation and also design of the fluidized bed that depends on.

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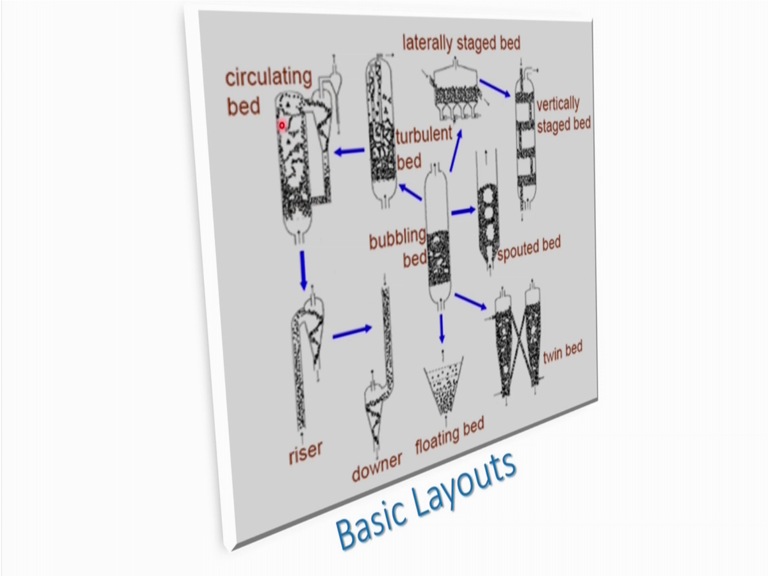

Now, what are the different layouts of the fluidized bed? Basically outs you will see sometimes some fluidized bed will be circulating fluidized bed, the circulating fluidization bed sometimes it is being you after fluidization if the solid particles will be reused or recycled. So, that is what this called circulating fluidization bed. Some fluidized bed will be internally recycling after separation of the solid particles by cyclone separators and it will be used as a turbulent fluidization bed where high rigorous fluidization due to the high velocity of the solid or liquid inside the bed to be maintained. So, that turbulence will occur there. In intense mixing of the solid and gas will be there inside the bed that of course, will be used for specific application.

Now, laterally staged bed also it is a one that is pattern or layouts you can say in this case here in this direction solids are being supplied and loaded and after drying it would be coming out. So, laterally it is actually supplied the solid particles are literally moving compared to that what is that gas and liquid. And also particle staged bed also it is one important layout in this case solid particles would be loading from the top of the bed and gas will be supplied from the bottom of the bed, and it will be stage wise it will be supplied. Also there other provisions like twin type bed and also protein fluidized bed even in the fluidized bed you will see whenever solid particles will be recycling that will down comer will be used and also when it will be fluidized to be called a riser, in the riser of course, the solid particles will be fluidizing.

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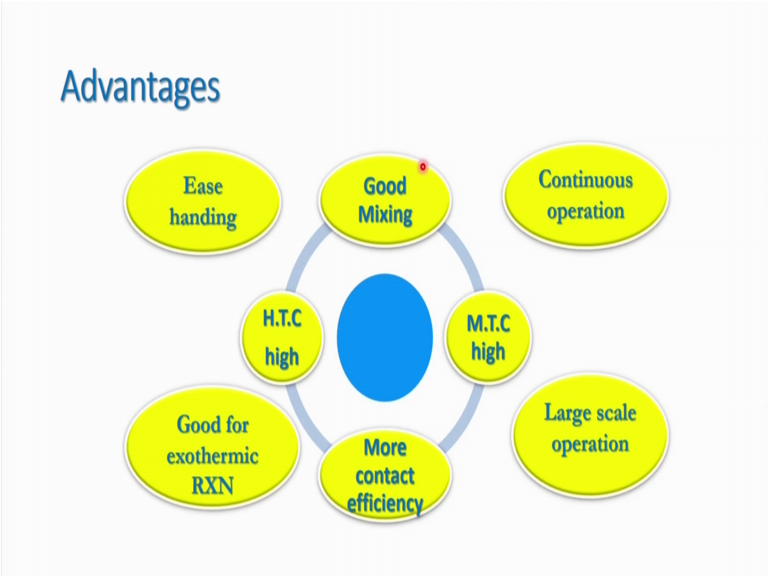

Now, question is that what the advantage of this fluidization there are so many things regarding that there are some applications of course, will be there, but what are the advantages. You will see this if you apply the solid liquid operation or solid gas operations or gas liquid solid operations for specific chemical processes and like drying process drying processes, now solid will be drying in the fluidized bed. So, in that case ease handling of the solid particles and also there will be good mixing of the solid particles during this operation, and also continuous operation you can do in a fluidized bed otherwise in the conventional way like in the atmosphere open sources open just field. If suppose PDs kept for drying then it will be best wise that you cannot continuously doing this operation, but in a fluidized bed they due to the mixing of the solid particles you will see for a certain temperature if you dry it immediately you can get the dried solid particles there.

So, there it is possible for continuous operation. Even for some other chemical operations it is seen that there will be higher mass transfer coefficient and also there will be a distribution of heat for that because of inter mixing of the solid particles with the fluid then it will give the higher heat transfer coefficient. It is also good for exothermic reactions and also we will see there are more contact efficiency more contact residence time also inside the bed. So, these are the advantages even for large scale operation you can do of any chemical or biochemical industry or any physical operations, in large scale operation pilot plant scale operations you can do by this fluidized bed.

But of course, every system though it has some advantages there will be some disadvantage also.

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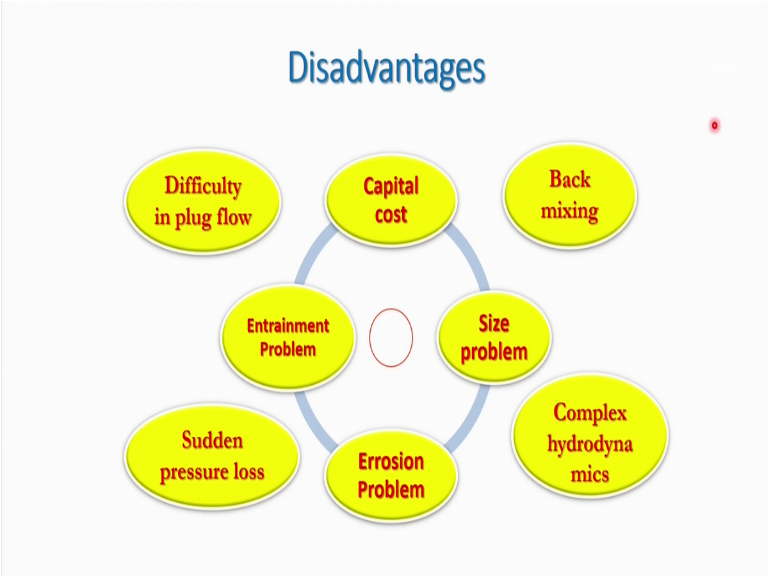

What are those disadvantages? Disadvantages like sometimes it is difficult to get the plug flow operations this plug flow, plug flow operations is actually suitable for higher yield for chemical processes. So, in that case the fluidized bed sometimes there will be back mixing, so non ideal flow even plug flow phenomenal not be actually feasible in this fluid bed operations. Of course, there are several provisions are made to get it plug flow because some baffle or some other provisions are made so that the plug flow operations can be possible in the fluidized bed.

Some other disadvantage like of course, initial capital cost is so high to design this fluidized bed, and sometimes back mixing also is a very crucial factor whenever it is fluidized some solid particles whenever it will be going up and it will of course go down due to its weight. And some of course, segregation of this higher solid particles coarser solid particles it will be moving down even not only that any size of these particles it will be moving inside the bed in a circular motion. So, there will be some back mixing when you will not get the plug mixing there, so back mixing is sometimes is not actually suggested for getting the intensified yield of the processes. So, back mixing sometimes hinder the yield of the process.

Entering problem also entrainment sometimes some spine particles will clog this some, what is that devices like cyclone separators, even the distributor of the gas in the fluidized bed. So, this type of problem may be problematic in the fluidized bed operation. Of course, the fine particles is coming out because of its low buoyancy and low size and this entrainment of the solid particles of course, a hinder the process efficiency.

Size problem of course, there will be you have to make the you have to design this fluidized bed in a bigger size sometimes for of course, the it is not suitable for some specific applications if you are making it large way, there will be some you know static zone, there will be some dynamic zone, there will be mixing not mixing properly there are huge cost. So, there will be some problem in that case.

Complex hydrodynamics of course, you will see you cannot predict that hydrodynamics precisely they are inside the bed what is happening there. You will see there will be sometimes solid liquid interactions, liquid liquid interactions, if there is any bubble is forming inside the bed bubbling fluidized bed then bubble bubble interactions some you cannot predict that bubble size accurately what is going on. Even in dynamic way it is very difficult to predict, but still we are scientist or economic persons they are developing different models for that.

Even some other what is the intermixing criteria or attrition how it will be happening, how it will be minimized and what are the other heat transfer mass transfer coefficient that will be related to this hydrodynamic aspect, what is the different flow regimes, how we can regulate this flow regime like particular to bubble, bubbling fluidized bed it is very difficult to get that uniform flow pattern inside the bed. And also errosion of course, the important the high velocity or fast fluidization of the coarser particles is trying to break into smaller particles and again it will be entrained and it will be coming out from the top of the bed. So, there will be a loss of fine particles. Of course, there is a high costly catalyst particle it is broken down then it will be very problematic in place.

So, these are the disadvantage we can say we can summarize here some difficulty in plug flow capital cost back mixing entrainment problem, size problem, complex of hydrodynamics inside the bed errosion problem is there, sudden pressure loss of course, they are during the operation because of sudden; that means, interaction of the bubble or any other fluid bed particles inside the bed there will sudden fluctuation sudden pressure loss inside the bed which will may the creative problem inside the bed for its operation.

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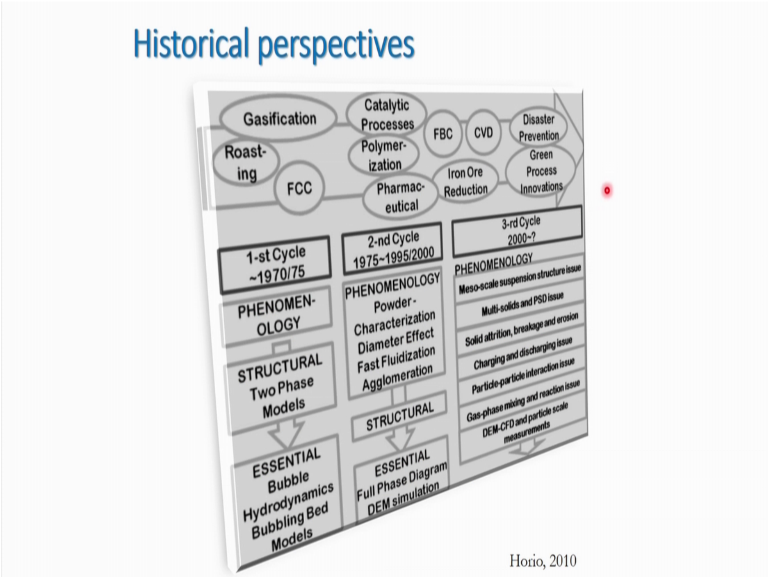

Now, of course, it is advisable to tell of historical perspectives. Now, all the operations in fluidized bed has categorized into three cycles like first cycle, second cycle and this is third cycle. In first cycle actually generally around 1970 to 75 what happens regarding this fluidization phenomena. So, there are different investigators they have reported, different investigations based on their experimental work and different of course, information that you can get here.

Now, first cycle like 1970 to 75 informs the phenomenology of the fluidization, even for 1975 to 1995, 2000 you can say some other phenomenology of the fluidization even after that 2000s the phenomenology in different way in the fluidization operation are reported by various investigators.

Now, in this case 1970 around 1970 to 75 will see first development is the structural two phase models of this fluidization operation. And then going on and then there are other several important investigations, like what would be the hydrodynamics of the bubbling fluidized bed, what are the models, how it can be modeled and what are the size of the bubbles and based on the size distribution, how these bubble bubble interactions inside the bed, how these bubble bubble interactions actually will affect the process of the process in fluidization.

And also in 1975 onward to 1995 and 2000, you will see there are several things actually which are very important like what are solids actually that are been used whether the size will be what will be the size of that particles, so what should be the classification of the size whether it is coarser whether should be very fine particles to be used. So, Gelder actually he actually classified the solid particles different way like abcd different types of classifications of the solid particles. So, classification even then what would be the diameter effect of the solid particles, even fast fluidization whether this coarser particles to be used or not even if we use the finer particles whether this agglomeration will happen or not that also has been in a reported in different investigator as in different way.

Now, it will be discussed above one by one later on also. This classification of the powder how this powder classification will effect this different flow pattern of the fluidization to be discussed later on. And then structural of course, there are different type of you know that fluidized bed and also the different shape of the particles how to be effect on that process in of course, it is important even if there any hydrodynamics like is there any fluctuation of the pressure heat transfer operation mass transfer operations what will be the effect of fluctuation of the pressure and how this fluctuation of the pressure will enhance this or if it is decreased or in the fast fluidization, how it will affect the process yield that is our efficiency of the fluidized bed will be discussed later on and also it is reported in the literature.

Now, essential of full phase diagram of the, of course, this simulation of the fluidized bed. So, full phase diagram even what are the full pattern that has been discussed in 1975 2000s. And 2000 onward there are several other different phenomena other fluidization has been reported now this meso scale suspension structure issue also it has been reported in the fluidization operation. Multi solids and particle size distribution what will be the effect on the particle size distribution for the modeling of the fluidized bed. Even charging and discharging issue is there any effect of charging and discharging issue whenever applied in for a particular process whether it will effect on the performance of the reactor or not.

Even particle particle interaction issues very important if one particle is interacting to another particle whether this adsorption or any other mass transfer operation will effect or not that also been reported. Even gas phase mixing and reduction retention time is very important of course, any process yield depends on the mixing of the phases more mixing or back mixing sometimes retard this process and also back mixing also not suitable some operations. But sometimes mixing is very important back mixing also very important suppose for uniform distribution of the heat inside the bed in a back mixing is very important. And also retention time of course, this adsorption suppose this adsorption retention time is very important how long these solid particles will be inside the bed that will effect the performance of the reactor.

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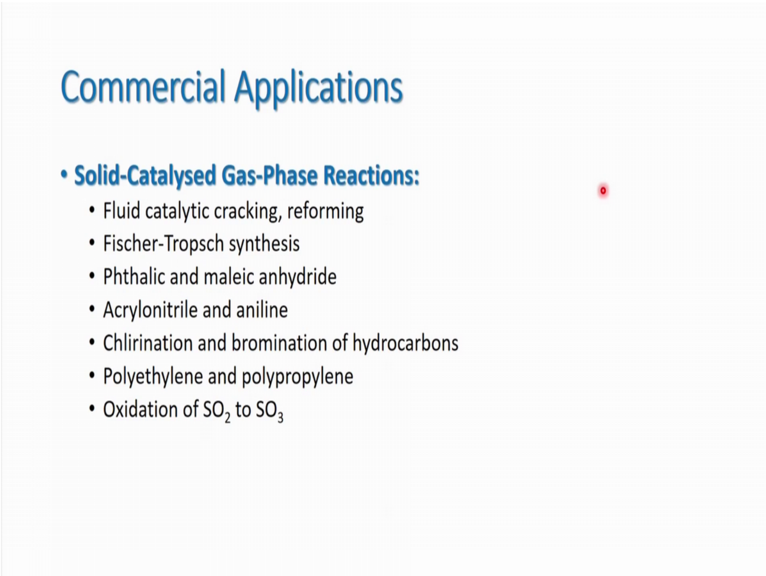

Let us come to that what are the different application of the fluidized bed. Different applications of the fluidized bed if you see that we are getting the different like solid liquid, liquid solid, gas liquid solid there are several applications. If we categorize to these things as solid catalyzed gas phase reactions you can see is done in fluidized bed like fluid catalytic cracking, reforming operation Fischer-Tropsch synthesis like this, and what is the phthalic and maleic anhydride formation or production in the fluidized bed, acrylonitrile and aniline production in the fluidized bed, chlorination and bromination of the hydrocarbons in the fluidized bed, polyethylene and polypropylene production in the fluidized bed, even oxidation of sulfur dioxide and sulfur trioxide inside the bed it is being done in the fluidized bed.

Some other operations some other applications you can say gas solid reactions, like roasting of ores like zinc sulphide, copper sulphide, nickel sulphides all are roasting from the ores and different products of that ores are coming after fluidization. Combustion and incineration coal combustion it will give the different gaseous products from the coal incineration of the solid waste it will give you the different of products by fluidization gasification, coking, pyrolysis, carbonization, calcinations, limestone phosphates, aluminum hydroxide all are being calcined in a fluidized bed.

Fluorination of uranium oxide is very important in atomic energy section that is done in fluidized bed. Fluid coking is very important which is being done in fluidized bed reduction of iron oxide is being done in fluidization bed, even catalyze catalyst regeneration is very important which are also being by which is being done by fluidization operation.

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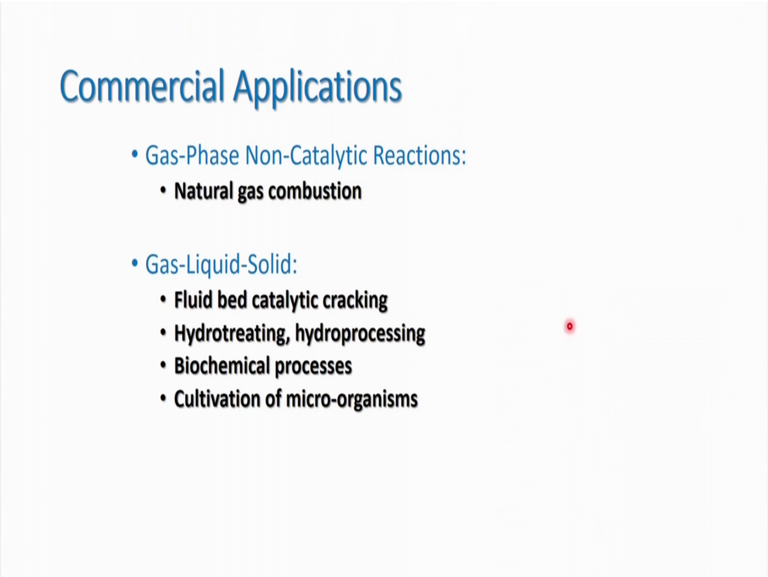

Commercial applications you will see other commercial applications like gas phase non catalytic reactions like natural gas combustion is very important which is being done in fluidization phenomena. Gas liquid solid now fluid bed catalytic cracking, hydro treating, hydro processing, biochemical processes, cultivation of microorganism, all are these biochemical applications are being done in fluidization fluidized bed. Even hydrotreating, hydro processing are being feasible to do in fluidization, in fluidized bed.

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Other operation like physical processes drying of particles, coating of surfaces, granulation, heat treatment, medical beds, filtration, blending, classification, particle classification that is being done in a fluidized bed. These are all physical operations like dying of particles in a fluidized bed coating of the surface like coating of the tablet us in pharmaceutical industries even you know that heat treatment by fluidization operation blending these are the some applications physical applications which have been done in fluidized bed.

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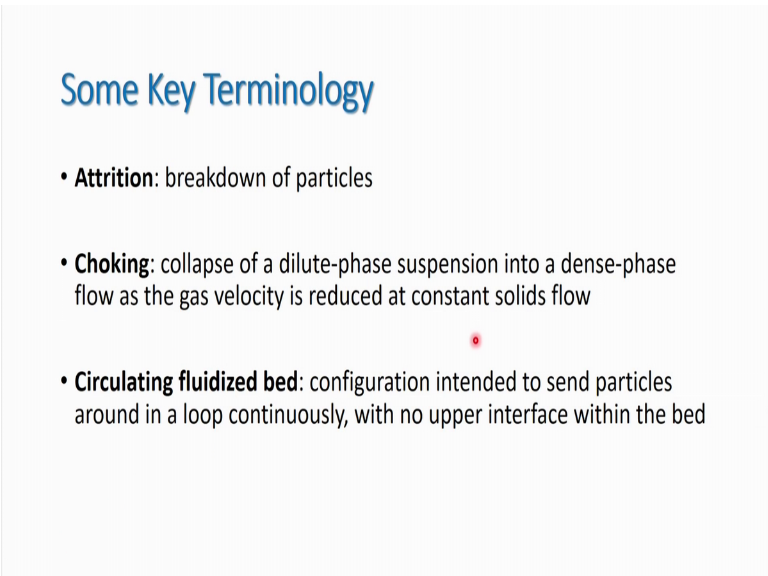

Now, some key terminology of course, you have to know some key terminology like attrition. What is that attrition? Attrition is nothing but the breakdown of particles. Actually whenever at high velocity solids being fluidized in the bed you will see there will be a breaking of solid particles this breakdown of the solid particles are called attritions. Then choking, what is the choking? Choking means now collapse of dilute phase suspension in fluidized bed into dense space flow as the gas velocity is reduced at constant solids flow. So, if the gas velocity is reduced at constant solid flow you will see sometimes this dilute phase will be collapsing in dense space. So, this type of phenomena is called choking.

Circulating fluidized bed what is that circulating fluidized bed? The circulating fluidized bed is nothing, but is the when the solid particles have been send around in loop continuously with no offer interface within the bed; that means, a solid particles are recycled to the bed. So, the configuration will be done in such a way that configuration intended to same particles around in loop continuously with no upper interface within the bed. So, this type of is called circulating fluidized bed.

And then what is downer? Down is one important terms that this is one type of column where the particles are made to fall to under gravity usually with cocurrent gas flow. Distributor or grid this is very important crucial one design aspect that the gas or liquid which are being supplied from the bottom of the bed of course, it will be a distributor. Now this distributor of course, it will be a some support plate at bottom which introduces the gas to the bottom of the bed and supports the weight of the bed when it is shut down. Now this distributor of course, consist consist of holes now this holes will decide what will be the size of the bubbles will be formed inside the fluidizedbed. So, it depending on the size of the bubbles and it will be designed in such way different type of distributor are being used in the bed.

What is that elutriation? This elutriation is nothing, but a tendency for the fine particles to be preferentially entrained from the reactor entering from the reactors.

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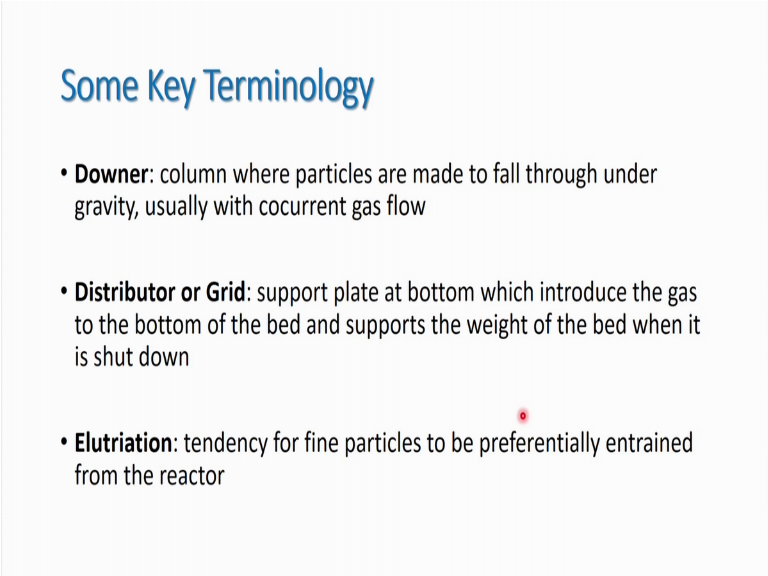

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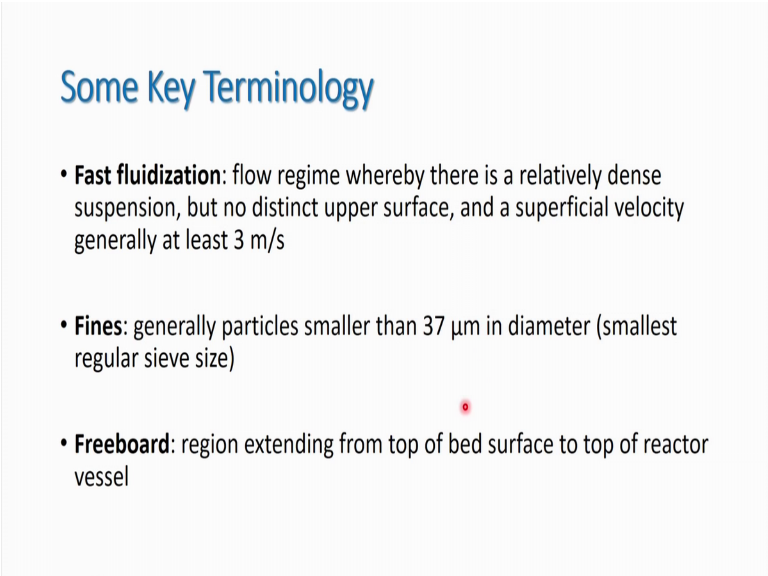

What is fast fluidization? This is one terms fast fluidization, this is one type of flow regime of the fluidization bed; however, there is a relatively dense suspension, but no distinct upper surface and a superficial velocity generally at least 3 meter per second are being actually maintained so that you can get the fast fluidization. Of course, we will learn that different onset of the pattern of the fluidization later on.

What is fines? Fines on sub fines a generally particles smaller than 37 micrometer in diameter it is smallest regulars ship size. What is free mode? You will see in the fluidized bed one region to the extending from top of beds are placed at the top of reactor vessel. So, this is the region extended bed that is from some location of the bed to the top, this is a free board where the very dilution of the solid particles or bed will be there.

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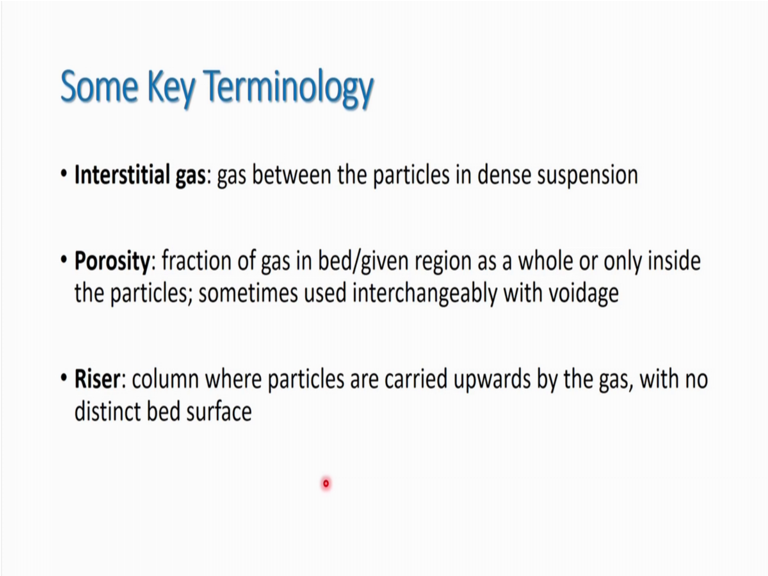

Interstitial gas, what is that interstitial gas? Gas between the particles gas between the particles in the dense suspension it is called interstitial gas that is how much volume of gas is occupying between those particles in whenever bed is in operation, so interstitial gas.

And what is porosity? Porosity is nothing but whatever the volume fraction of the gas in the bed in a given region as a whole or only inside the particles sometimes used interchangeably with the voidages. So, this is porosity what are the fraction of gas in the bed or given region as a whole or only inside the particles.

What is riser? Riser that is also one type column this is a fluidized column where the particles are carried upwards by the gas with no making any distinction bed surface.

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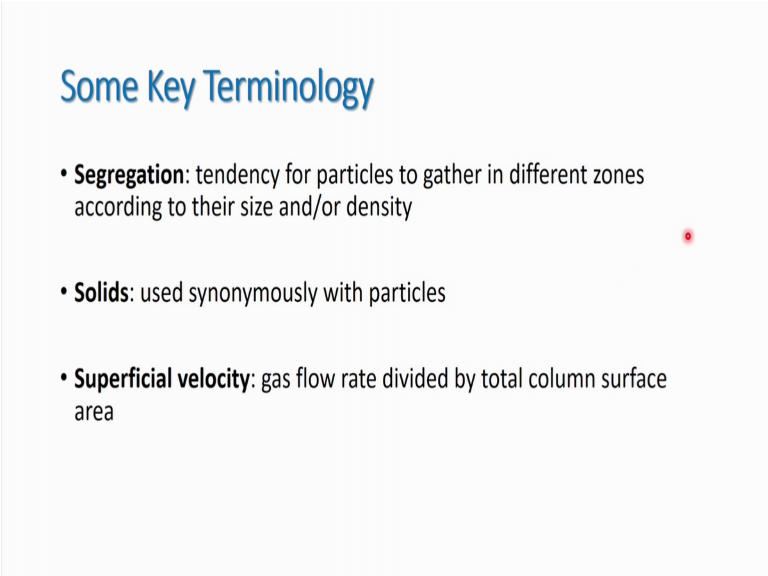

Segregation, what is that segregation? Segregation is nothing but the separation of the solid particles from its size like tendency for particles to gather in different zones according to their size or you can say density. Solids what is they used for actually synonymously you can say with particles, this is this terms is being used in fluidized bed. And superficial velocity of course, this is very important whenever you are going to correlate with various variables of course, you have to consider the superficial velocity. What is that superficial velocity? This is the gas flow rate divided by the column cross sectional area of course, this is empty cross sectional area there is nothing inside the column that you have to consider. So, this is the superficial velocity.

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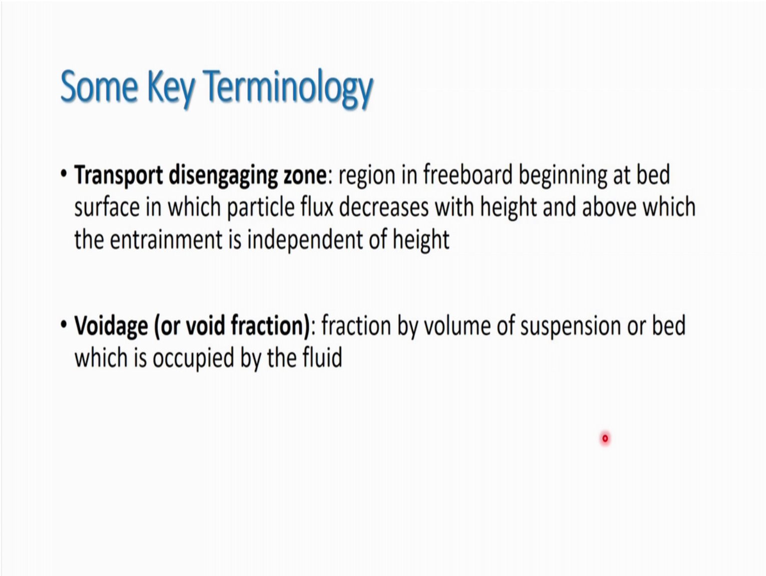

And then what is this transport disengaging zone? Transport disengagement zone is the region in the freeboard beginning at bed surface in which particle flux decreases with height and above which the entrainment is independent of height. So, this is one important that is depending or that is being used this term is being used for entrainment purpose. And voidage or void fraction what is that fraction by volume of suspension or made which is occupied by the fluid.

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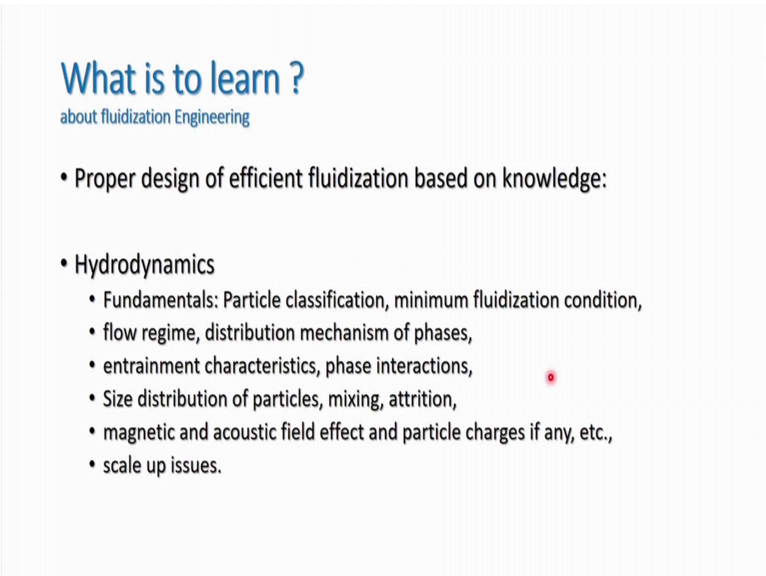

Now, we have learnt lot of things about that what is this fluidization, what is the fluidized bed, what are the different pattern of the fluidization, and what are the advantages, what are the disadvantages of the fluidized bed and what are the different terminologies, what are the different layouts, all these things we have studied. Now what is actually to learn in this fluidization engineering course? Of course, you have to know something more about this fluidization what is that you have to know the design proper design of efficient fluidization system.

So, of course, for designing of efficient fluidization bed you have to know some hydrodynamics. What is that hydrodynamics? Hydrodynamics means fundamentally you can say that what is that particle classification which is being actually taking part in a role for enhancing or just changing the design parameters. Minimum fluidization condition what is that and how does it depends on different operating variables now what would be the flow regime. So, that this flow regimes depending on that your other different factors or not, what is the distribution mechanism of phases, what is the entrainment characteristics, what is the phase interactions, what is the size distribution of the particles, what is the mixing of the phases inside the bed, what is the attrition that you have to know.

What is magnetic and what is these there any acoustic field effect on the particle size in the bed of course, you have to know and also what is the scale of issues all these things you have to know.

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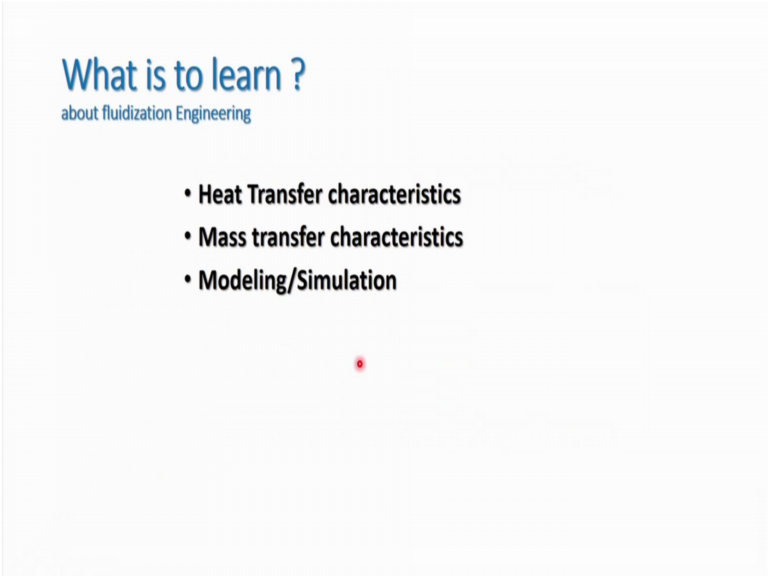

And other thing is that except this hydrodynamic some other transport processes of course, you have to know like what is the heat transfer characteristics inside the bed, what is the mass transfer characteristics inside the bed, and what is that how this fluidized bed can be modeled or simulated based on this hydrodynamic and transport phenomena of this fluidized bed.

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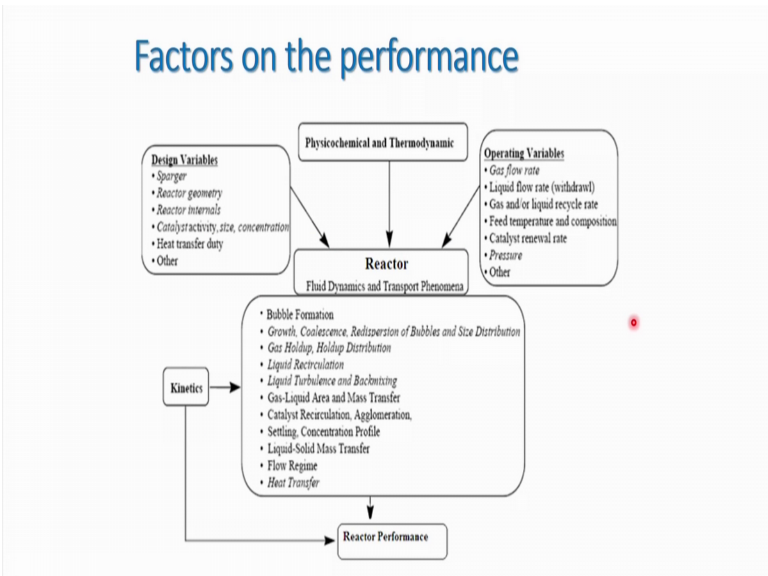

Now, see this is one performance sheet you can say the performance of the reactor what are the different factors that effect the performance of the fluidized bed. Now, we will see like some variables, like design variables, like operating variables, like physico chemical and thermodynamic properties that will effect on the performance of the fluidized bed.

Now, of course, along with these variables of course, this fluidized bed the dynamics of the fluidized bed and the transport phenomena of course it is very important to study and know and then there is design variables like a spudger design, reactor geometry, what should be the reactor geometry reactor internals catalyst, activity size and concentration heat transfer duty and others. What are the other operating variables like gas flow rate, liquid flow rate, gas and liquid recycle rate, what are the free temperature and composition, what is the catalyst renewal rate, what is the pressure and other several variables that will be included. And different variables of course, effect on different fluid dynamics and transport characteristics inside the bed.

Like see here bubble formation growth, coalescence, removal of bubble size destruction, even gas hold up distribution liquid recirculation phenomena even liquid turbulence and back mixing is there or not, even you will see catalyst recirculation agglomeration all these phenomena, even liquid solid mass transfer flow regime. All this phenomena depends on the factors like design variables and operating variables. Of course, detail depends on the spudger design, reactant geometry, even gas flow rate, liquid flow rate, size of the particles type of the particles, even pressure frictional pressure what is the frictional, frictional pressure all these important variables that effect on these characteristics.

Now, if you consider the reactor performance you have to of course, consider these fluid dynamics and transport phenomena and also kinetics of this fluidized bed. So, all the kinetics transport phenomena, fluid dynamics, depending on basically variables like geometric variables what is the size of the bed, what the size of the particles, what is the size of the column, and what is the length, what is the breadth, if it is two dimensional, if it is cylindrical, what is the diameter and also you can say the is there any internals are being used like any bubbles for internals to reduce the mixing, is there any provisions are being used or not and what is the size of that provisions that size also will effect on the hydrodynamics and transport characteristics of the fluidized bed.

Even what is that operating variables like or dynamic variables you can say gas flow rate, liquid flow rates, even gas and liquid recirculation rate, this will effect on the hydrodynamics and transport characteristics. Even other thermodynamic variables like what is that pressure temperature that will also change the hydrodynamic characteristics of the fluidized bed.

So, thank you for this class. Next class we will be discus with some other topics.