INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
NPTEL
NPTEL ONLINE CERTIFICATION COURSE

Mechanical Operations
Lecture-19
Classification and Jigging-1

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Welcome to the fourth lecture of week 4 of mechanical operations course and in this lecture I will cover classification as well as jigging. So lecture 4 has two part, in part 1 I will discuss classification and industrial equipment related to classification, in second part of this lecture I will discuss worked example on classification and concept of jigging. So let us start the part 1 of lecture 4 which is on classification.

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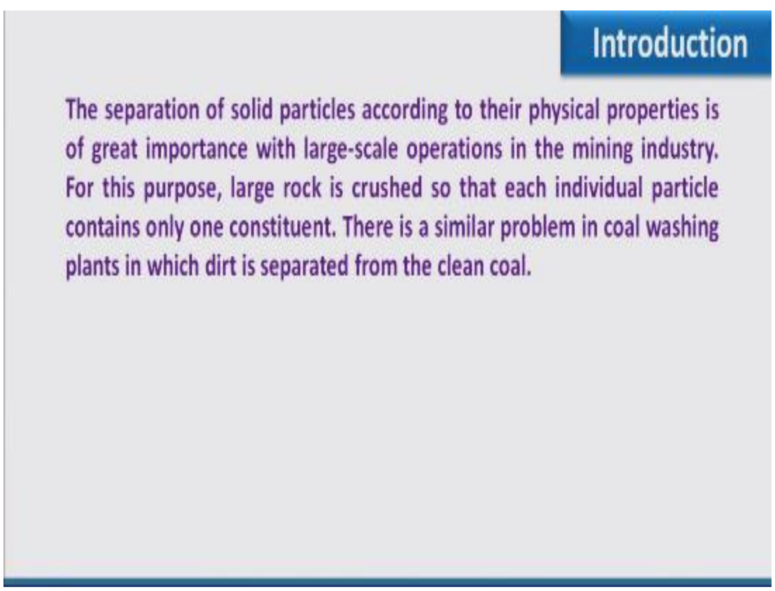

The separation of solid particles according to their physical properties is of great importance with large-scale operations in mining industry. For this purpose large rock is crushed so that each individual particle contains only one constituent. There is a similar problem in coal washing plants in which dirt is separated from the clean coal. So here you see we have to discuss again the separation.

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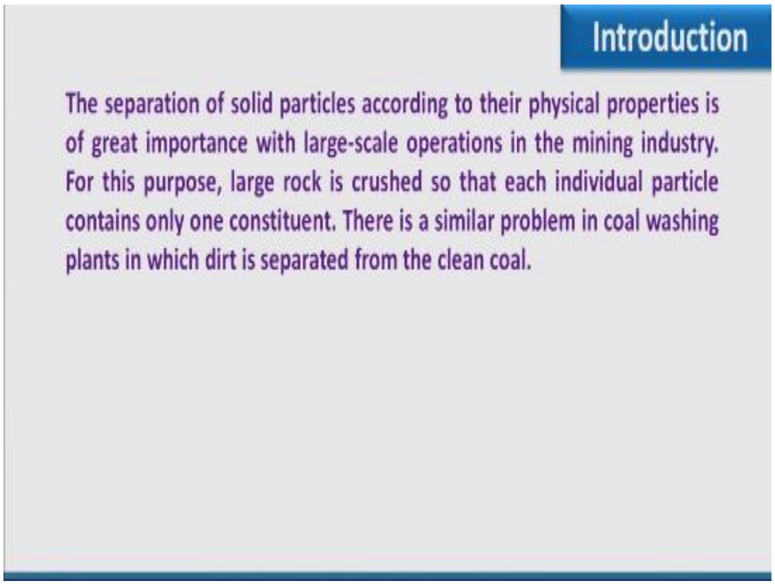

We have already discussed this when we were discussing the screen analysis.

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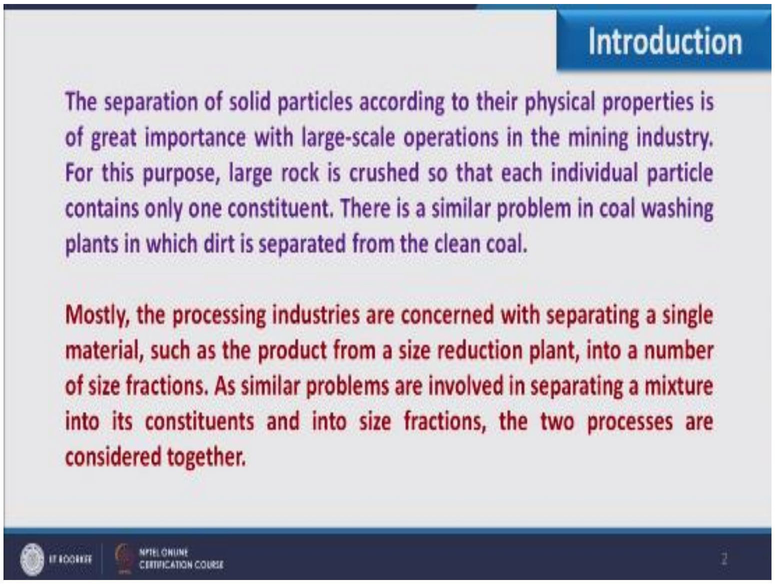

Mostly the processing industries are concerned with separating a single material, such as the product from the size reduction plant into a number of size fractions. As similar problem are involved in separating a mixture into its constituents and into size fraction the two processes are considered together.

Two processes are, first is to convert the mixture into its constituent and to convert the mixture into different size fractions. Where constituents may mix but according to size we will separate.

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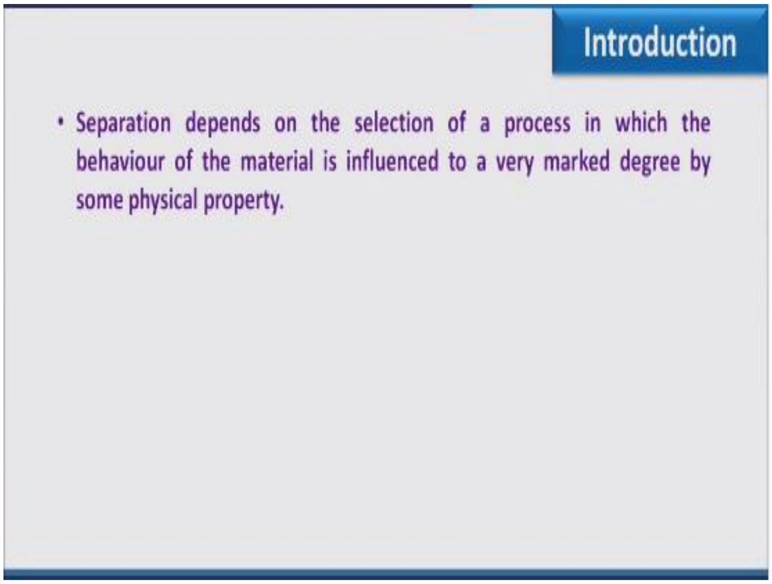

So the separation depends on the selection of process in which the behavior of material is influenced to a very marked degree by some physical property. So based on some physical property we consider the, we carry out the separation of material. For example, if material is to be separated into various size fractions a sieve method may be used, because this process depends primarily on size of the particles.

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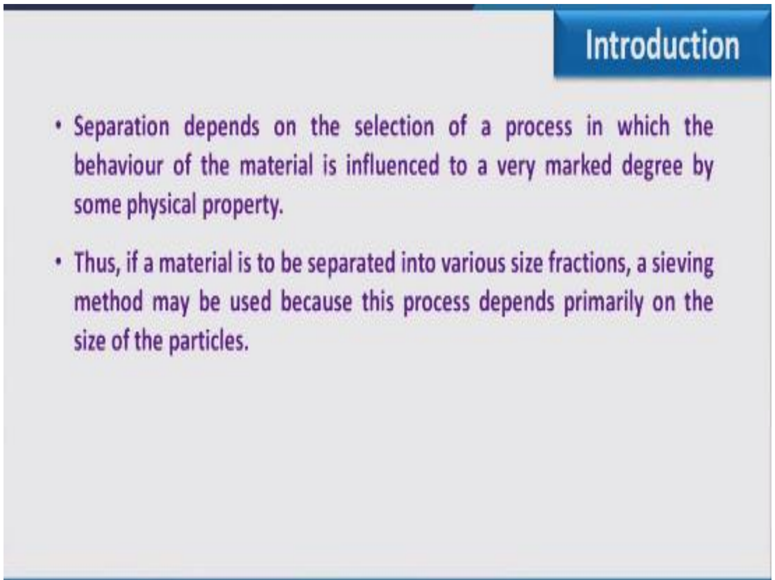

Therefore, when we have the mixture of particles and when we have to separate them by their size it means it is not important that they are separated by constituent we, our only focus is to separate the mixture by the size of the particle, then sieve analysis is the method for that.

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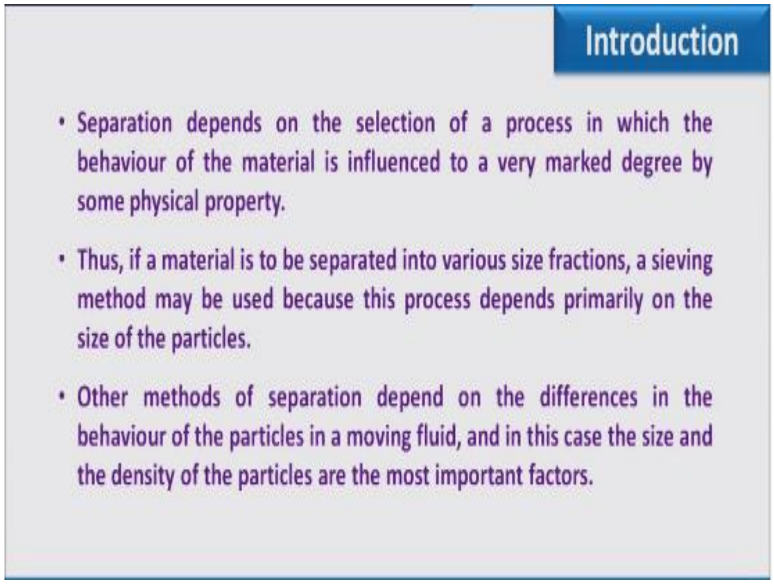

In the similar line other methods of separation depend on differences in the behavior of particles in a moving fluid, and in this case the size and density of the particles are most important factors. Because when we consider size as well as density, when we consider size it means we can separate the mixture in a different size fraction and when we consider density it means we can separate the constituents which are present in the mixture.

And the basic point is that in the, the separation based on size as well as density is done when the mixture is moving in a fluid.

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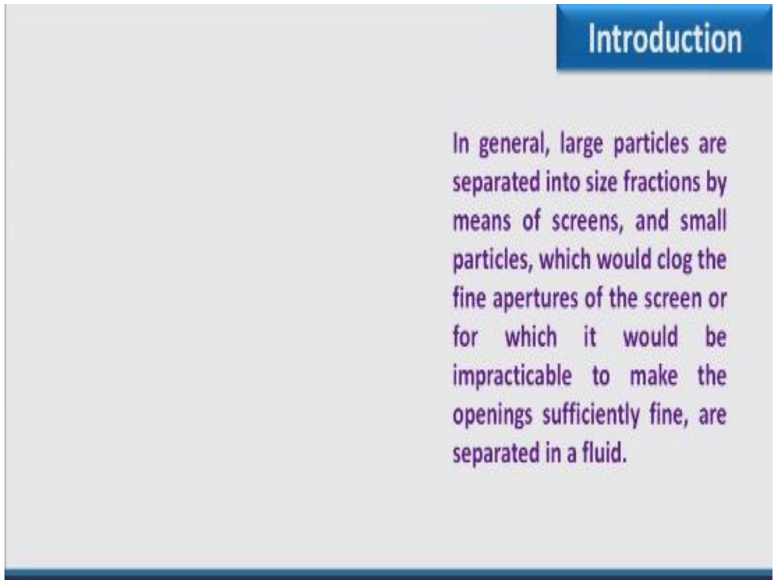

So in general large particles are separated into size fractions by means of screens, and small particles which would clog the fine apertures of the screen or for which it would be impracticable to make the opening sufficiently fine are separated in a fluid. So what is the main point over here is, when we have to separate the particles through the fluid we can separate, we can handle fine particles in this method.

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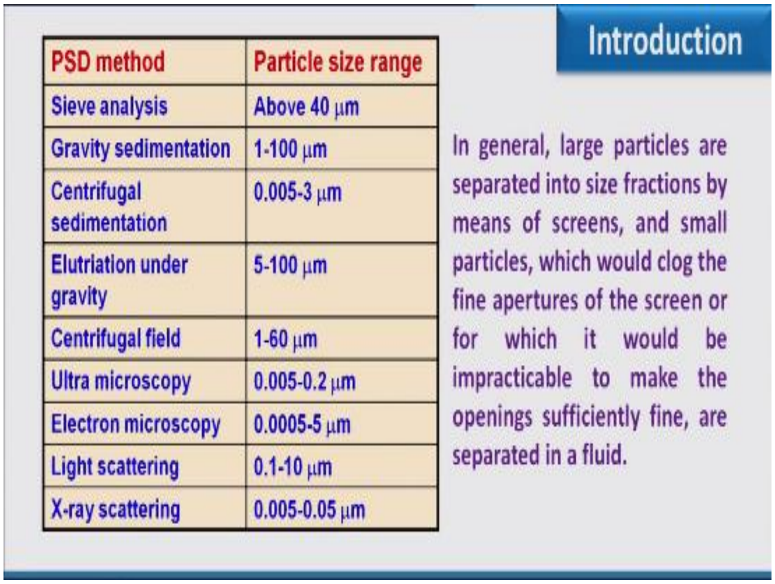

PSD method	Particle size range
Sieve analysis	Above 40 μm
Gravity sedimentation	1-100 μm
Centrifugal sedimentation	0.005-3 μm
Elutriation under gravity	5-100 μm
Centrifugal field	1-60 μm
Ultra microscopy	0.005-0.2 μm
Electron microscopy	0.0005-5 μm
Light scattering	0.1-10 μm
X-ray scattering	0.005-0.05 μm

And if you refer this table it is particle size distribution method. The particle size distribution methods are shown in this table and the corresponding particle size range for example, sieve analysis if we consider it measure size above 40 micrometer, and when we go for the gravity sedimentation, centrifugal sedimentation, elutriation under gravity it means all these three process will use fluid for, all these process will use fluid as a media.

So when we consider gravity sedimentation the size vary from 1-100 micrometer and elutriation you can see it, the size vary in this from 5-100 micrometer. So you can see the size range available when we go for the separation through fluid, it means it handles quite smaller size in comparison to sieve analysis. So when we see sedimentation, centrifugal sedimentation and elutriation it covers a small size particle in comparison to sieve analysis.

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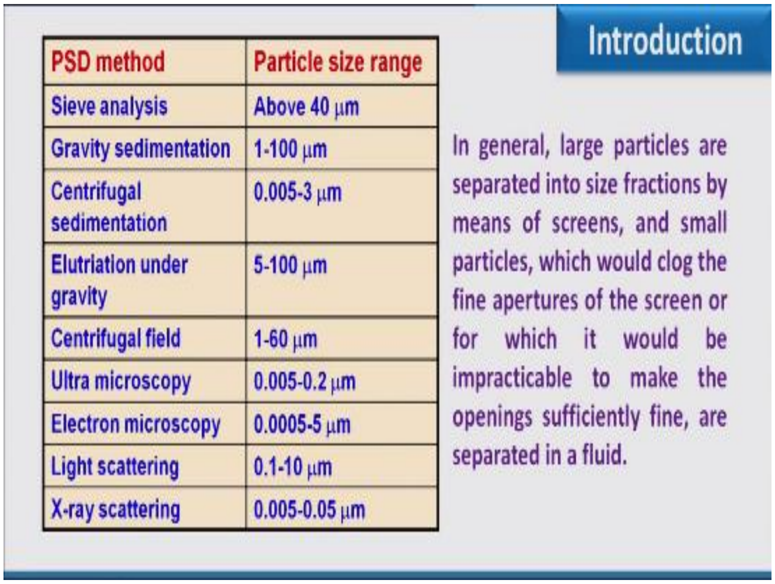

And basically in these processes fluid is the media. So the basic point is when we consider, when we have to separate fine particles in different sizes according to their size as well as density then fluid should be incorporated in all these.

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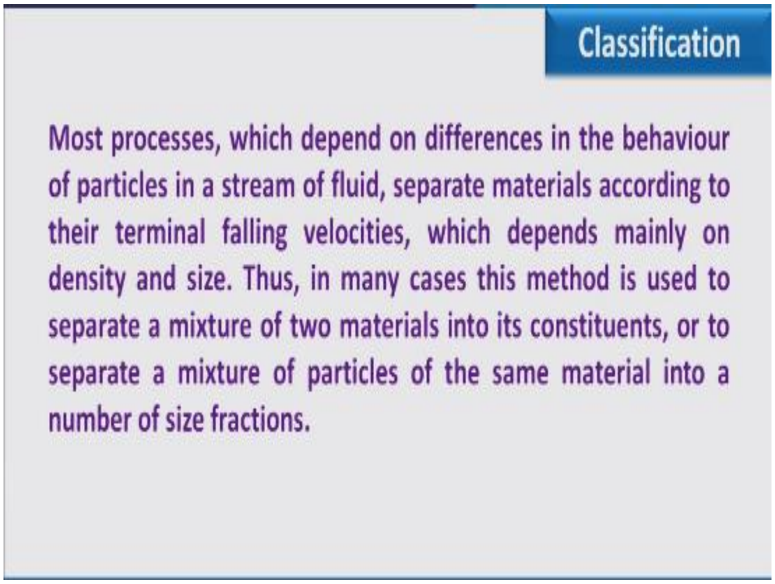

So most processes which depend on differences in the behavior of particles in a stream of fluid, separate materials according to their terminal falling velocities, or terminal settling velocities, which depends mainly on density as well as size. Thus, in many cases this method is used to separate a mixture of two materials into its constituents, or to separate a mixture of particles of same material into number of size fractions.

So here you can say that according to size as well as density both we will use to separate the particles from mixture.

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For example, if I am having two material that is material A of density ρ_A and material B of density ρ_B then what will happen, if ρ_A is greater than ρ_B, if A is having more density in comparison to B so obviously when we separate based on the density material A will settle first before B, therefore we can have material A as underflow and material B as overflow but there will be some mixture also of A and B.

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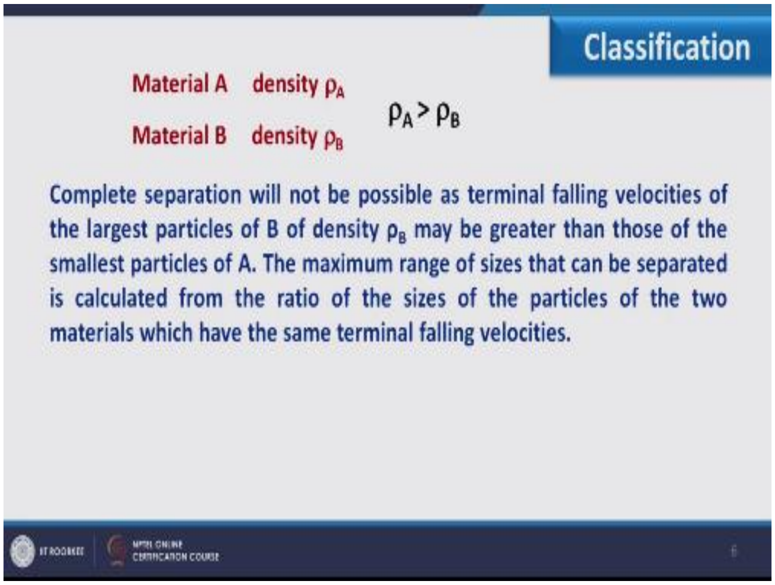

So sometimes we can say that complete separation will not be possible as terminal falling velocities of largest particle of B of density row B may be greater than those of the smallest particle of A, though material A is heavier it will settle before B but it will also depend on the size of the material, so largest particle of B can be settle faster than the smallest particle of A.

So complete separation if we consider it is not possible so the maximum range of sizes that can be separated is calculated from the ratio of sizes of the particle of two materials which have same terminal falling velocity, and this concept we will also discuss in worked example and then it will be clear more easily.

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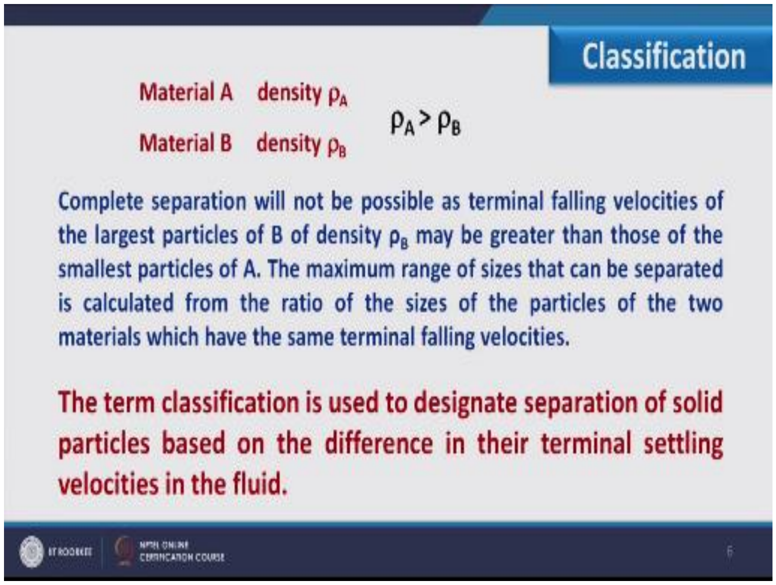

So the term classification is used to designate separation of solid particles based on difference in their terminal settling velocity in the fluid. So here you see the main point is when we have to separate the particle according to the settling velocity then we go for the method which we call classification, and you understand that when we speak about terminal settling velocity size as well as density material will come into the picture, so based on these two property we will separate and then we call that we are separating based on terminal settling velocity.

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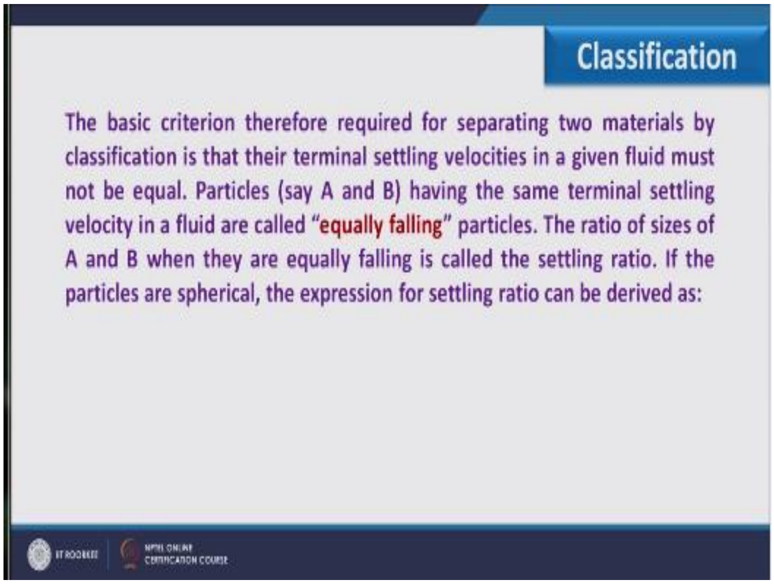

So the basic criteria therefore required for separating two materials by classification is that they are terminal settling velocity in a given fluid must not be equal. So you can understand when two particle I am considering and both are having same terminal velocity so both will settle at the same time so it will not be separated, so the basic point is the terminal settling velocity of the material should be different when we have to classify, when we have to separate them from the mixture.

So here I have selected two particles, particle A and particle B having same terminal velocity and therefore we call these particle as equally falling particle because both will fall simultaneously and the same time they will settle, so the ratio of sizes of A and B when they are equally falling is called the settling ratio, if the particle are spherical the expression of settling ratio can be derived.

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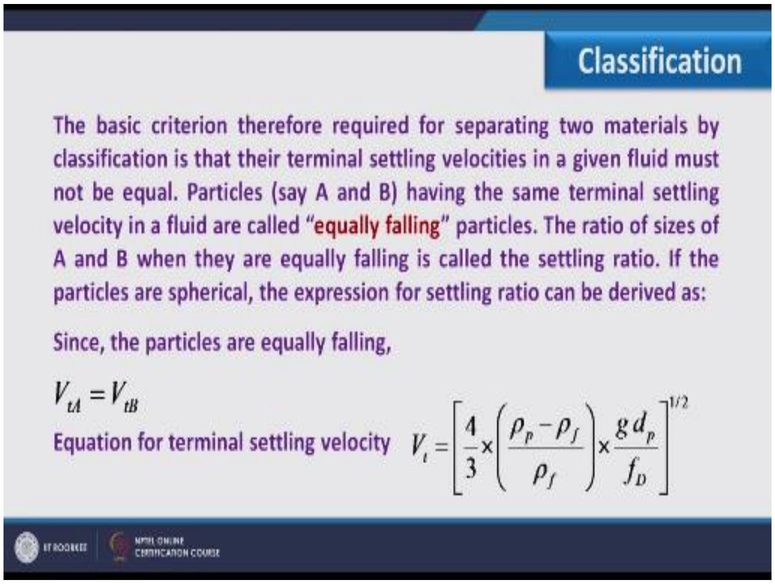

As since particles are equally falling then we can say that both are having same terminal settling velocity so Vt_A would be equal to $V_{tB.}$ Equation of terminal settling velocity this is the generalized equation and this equation we will use here also.

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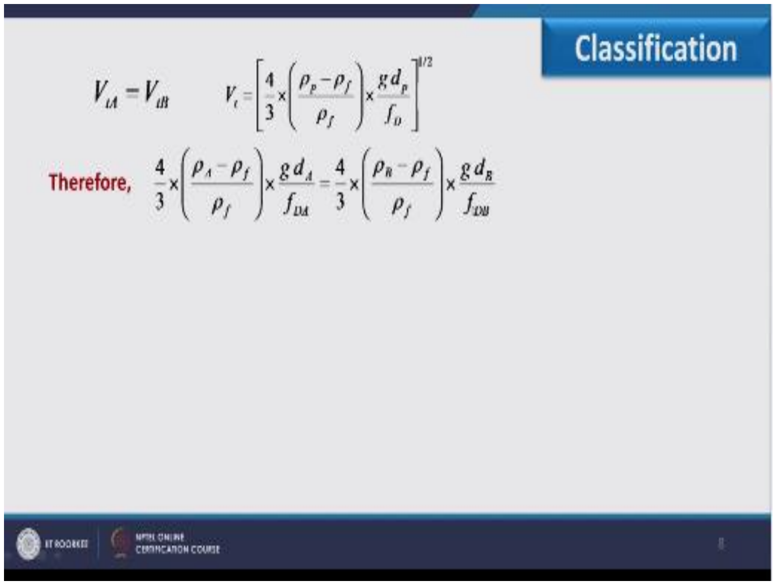

Therefore Vt_A and Vt_E we can elaborate using this generalized equation, you can see here particle density we have taken here row A and diameter d_A / $f_{DA} = \rho_B$ - ρ_f so here in this part we have taken density of solid as ρ_B and diameter d_B / f_{DB}. By equating these two and resolving it we can have d_A / d_B as.

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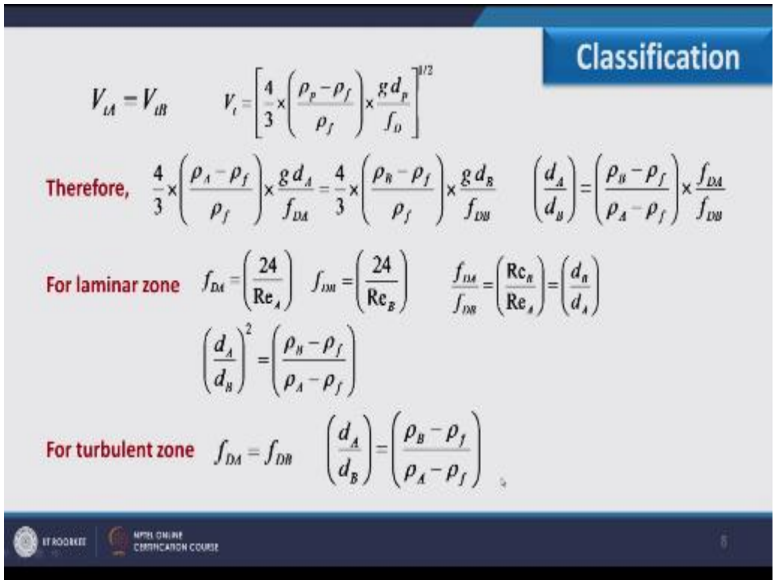

ρ_B - ρ_f / ρ_A - ρ_f x f_{dA}/ f_{dB} so here we have a drag coefficient ratio also which further we can resolve by considering different zones. For example if I am having laminar zone then you can understand f_d we can consider as 24/ Re_A that is a Reynolds number of particle A and similarly f_{dB} is equal to 24 / Re_B so from these expressions of fd_A as well as f_{dB} we can calculate the ratio of fd_A and fd_B which is coming as a Reynolds number of particle B / Reynolds number of particle A. When we resolve this, when we consider in terms of diameter because both are having same velocity so, and fluid is same and viscosity is same so we have the relationship in terms of ratio of diameters only.

So finally f_{dA}/ f_{dB} we can write as d_B/ d_A therefore when we put the f_{dA}/ f_{dB} from this equation to here then we can write final equation as d_A/d_B square which is equal to ρ_B - ρ_f / ρ_A - $\rho_{f.}$ Further when we consider the turbulent zone then what will happen in turbulent zone f_{dA} is equal to f_{dB} because in that reason drag coefficient is a constant so when we consider this thenfinal expression of d_A/ d_B is equal to ρ_B - ρ_f / ρ_A - $\rho_{f,}$ so you see while considering terminal settling velocity expression and equating this we can calculate the settling ratio in laminar zone as well as in turbulent zone. It means when we consider d_A/ d_B in this ratio the particle will fall equally.

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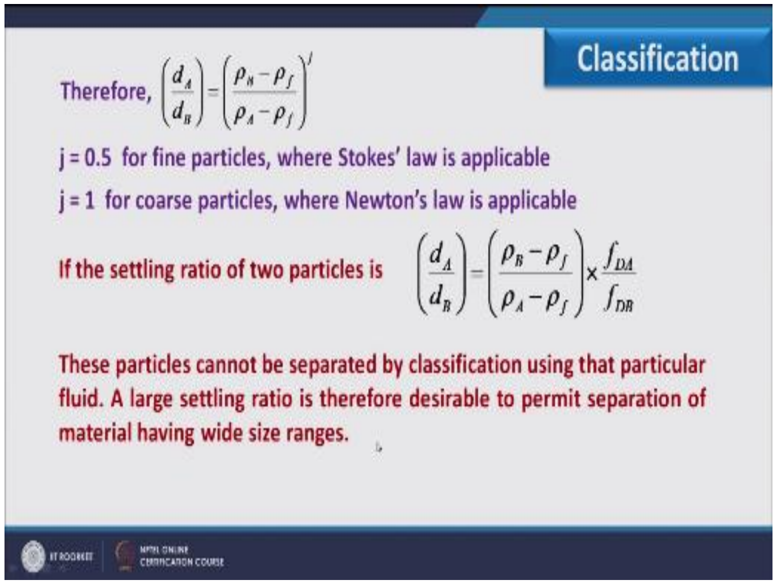

So therefore d_A/d_B we can show in generalized form $(\rho_B - \rho_f / \rho_A - \rho_f)^j$ where j is equal to 0.5 for fine particle where Stokes' law is applicable and j= 1 for coarse particle where Newton's law is applicable, so if the settling ratio of two particles is $d_A/d_B = \rho_B - \rho_f / \rho_A - \rho_f \text{ x } F_{dA}/f_{DB}$ this the generalized relation of settling ratio of two particles so you can understand that this is the settling ratio of equally falling particle.

So these particles cannot be separated by classification because they are equally falling using a particular fluid, a large settling ratio is therefore desirable to permit separation of the material having wide size ranges, so if we have to change the settling ratio what we have to do because we do not have to maintain this settling ratio otherwise separation will not be possible.

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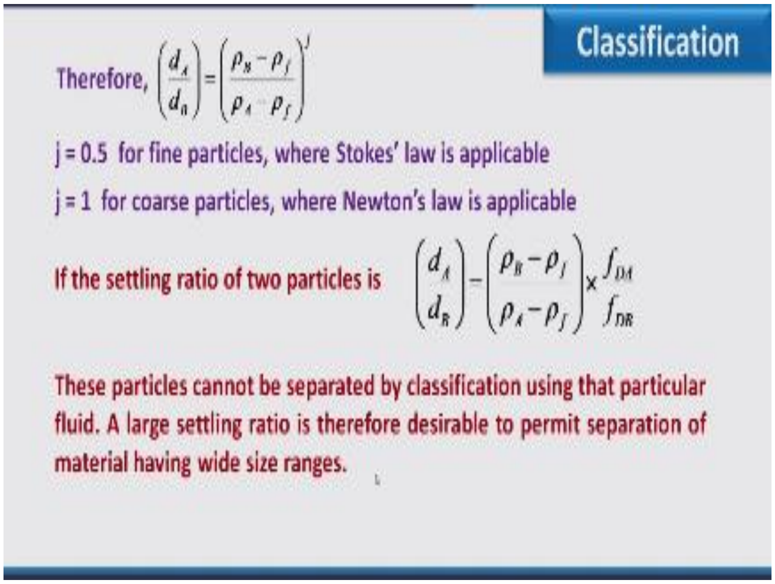

So if you consider this ratio and here we have $p_B – p_F/ p_A – p_F$ and this F_{DA} and F_{DB} we can also write in terms of diameter so how the separation will be possible? I cannot change the diameters of particle, I cannot change the densities of material, I can only change the density of the fluid so while changing the density of the fluid we can make the separation possible, so one way to achieve.

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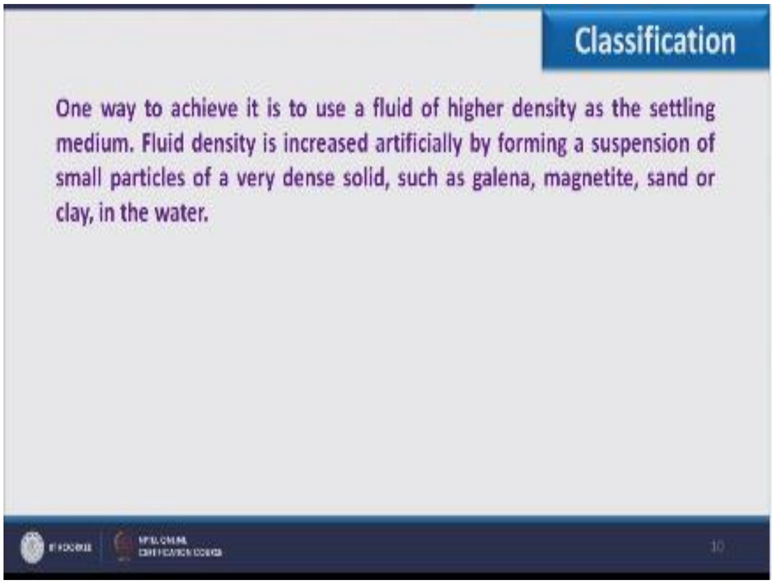

It that is to change the density or to carry out separation is to use a fluid of higher density as the settling media. Fluid density is increased artificially by forming as a suspension of a small particles of very dense solid such as galena, magnetite, sand or clay in the water so we can change the density of the fluid of the media and so that the settling ratio can be changed.

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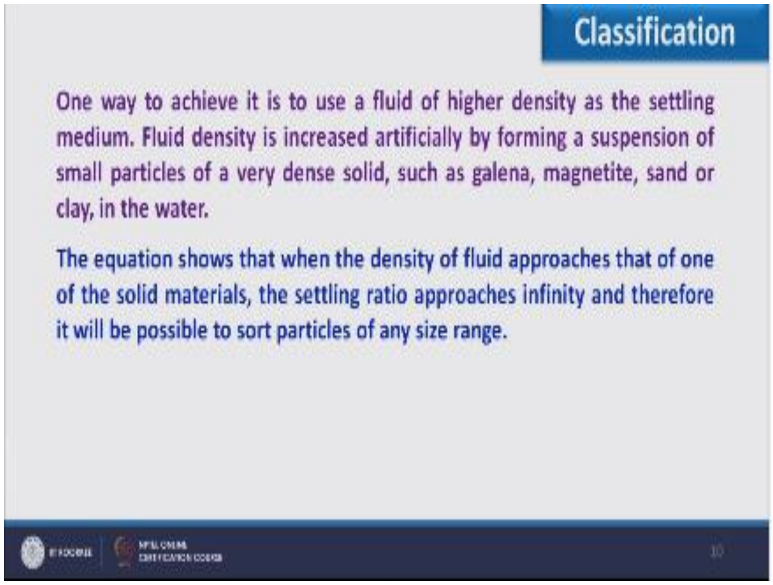

So the equation shows that when the density of fluid approaches that one of the solid particles solid material the settling ratio approaches infinite and therefore it is possible to sort the particle of any size range. If you remember the equation there we have the $\rho_A - \rho_F$ and ρ_b - ρ_F so if we can increase the density of fluid up to some extent so that it will be close to the solid density then the DA/ DE ratio becomes infinite and then the sorting is possible completely.

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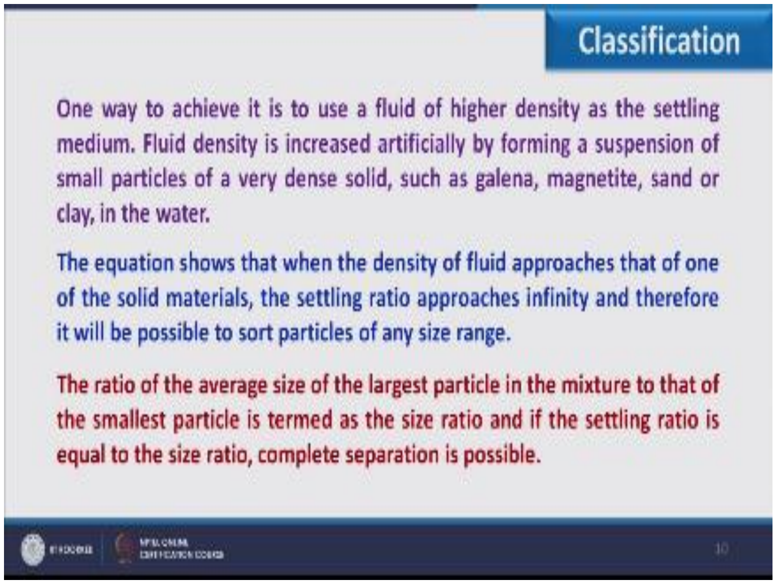

So the ratio of the average size of the largest particle in a mixture to that of the smallest particle is termed as the size ratio and if the settling ratio is equal to the size ratio then obviously complete separation is possible so that is the concept of classification, now from here onward we will discuss some of the major equipment used in the industry for classification.

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And these are first one is the settling tank, second elutriator, then we have double come classifier, then spiral classifier and finally we have the bowl classifier, so in subsequent slide we will discuss working of these equipment one by one, let us start with the settling tank.

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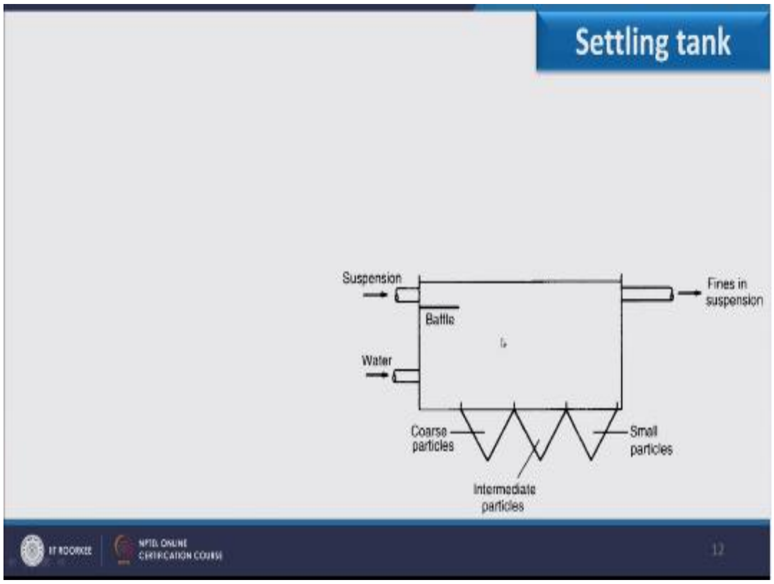

This is the schematic of settling tank, what will happen over here if you see this tank from here we have the suspension in which mixture of particle is available and here if you see a bottom of this here we have different compartments, so what happen fluid from here, suspension from here from this nozzle enters into this and this suspension enters with high velocity and if you consider the settling tank it is very wide as far as diameter is concerned so when the.

Suspension enters into this it come across with larger cross sectional area then what happen the velocity from which suspension is entering into the tank it retarded very fast because now it comes or it come across with large cross sectional area so when velocity deceases the particles available in this that.

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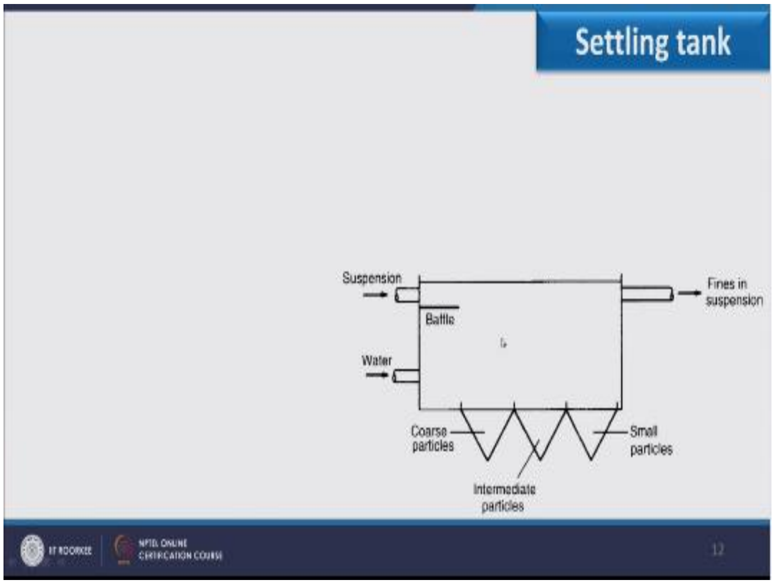

Those particle will start settling into the tank so that is the basic concept.

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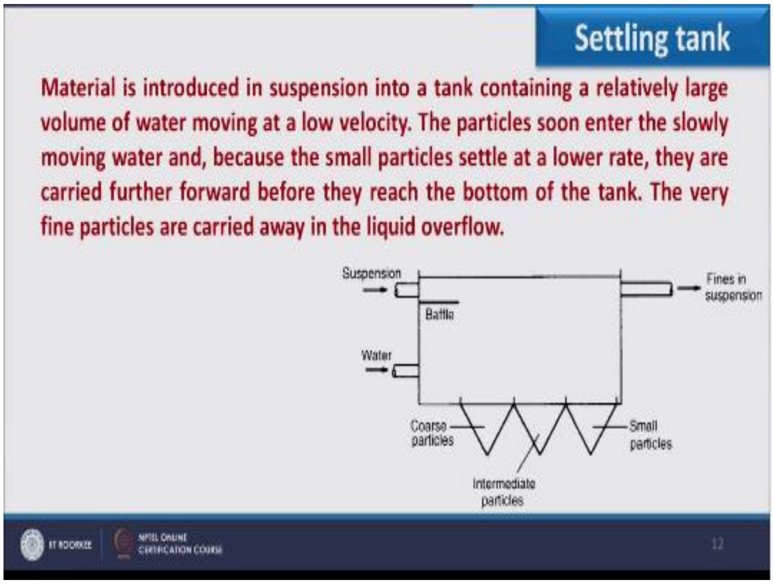

Material is introduced in the suspension into a tank containing relatively large volume of water moving at slow velocity or low velocity, so what happens when the velocity become decreases.

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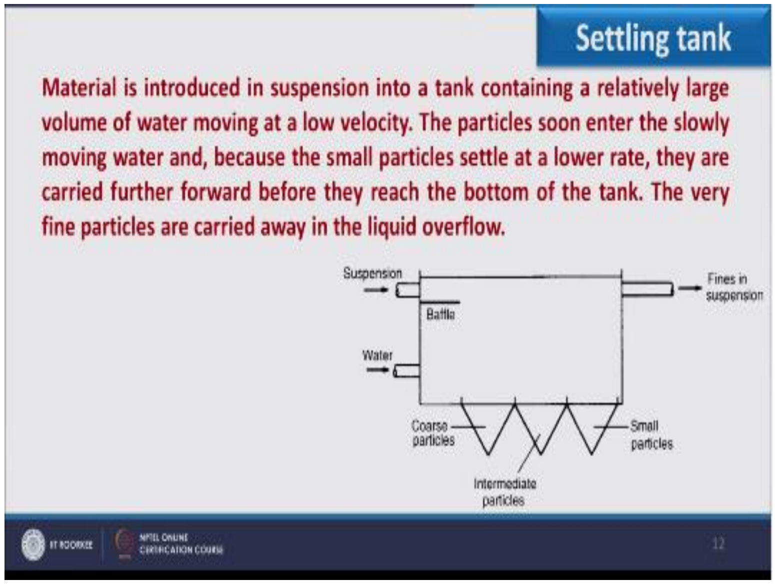

The particle which are available in this they start settling, now how the settling of particle will occur that purely depend on the size as well as density of the particle. For example if we consider heaviest particle as well as largest particle or we call it coarse particle it will settle first and when it is lighter as well as smaller in size.

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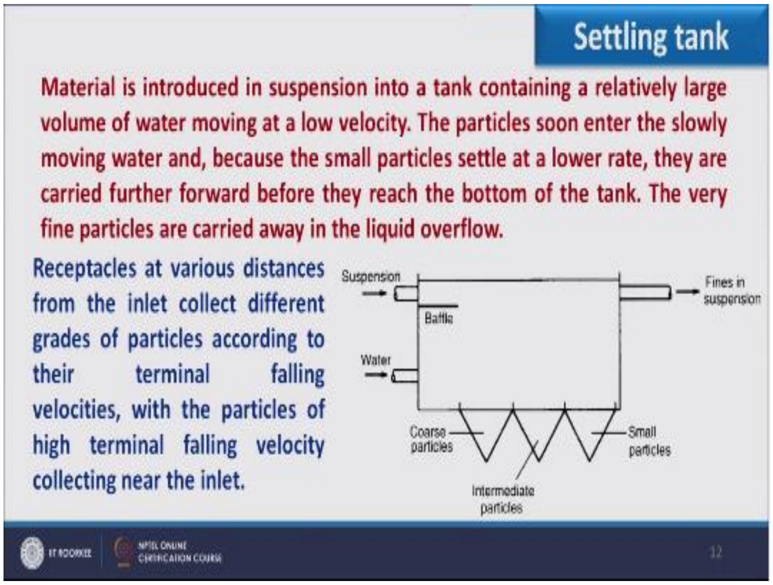

It will move for longer time in the suspension in the tank and then it will start settling so you see the, as far as collection is concerned different receptacles at various distances from the inlet collect different grades of particle according to their terminal settling velocity. So when we consider the chamber or the receptacle which is closest to the inlet of the suspension there we have coarse collection of particle where heaviest as well as largest particle will be collected, intermediate particle will be collected.

The chamber which is available at the center and finally we have the small particle collection chamber. Further when we have the finest particle as well as lightest particle they keep on moving with the liquid in the suspension itself and then we can take them out as a overflow. So you can see that based on difference of their terminal settling velocity particle will keep on settling in different zones or different chambers.

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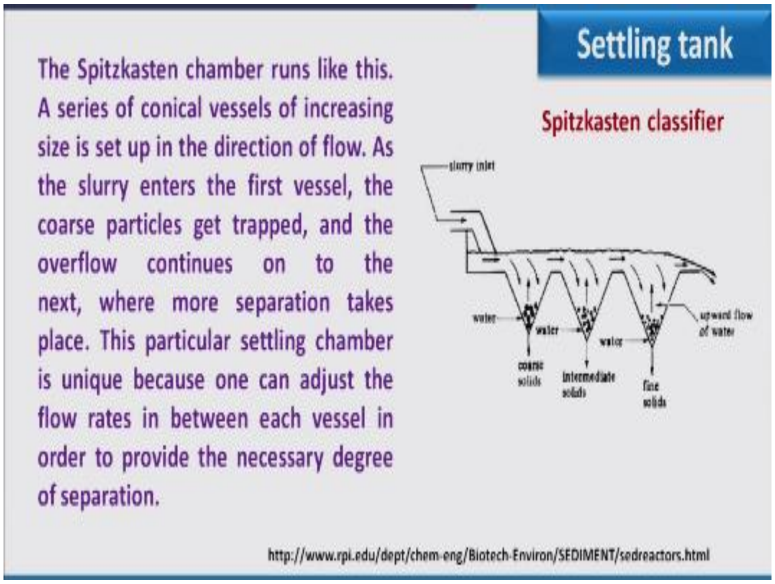

In this slide we have another settling tank which we call Spitzkasten classifier. Now what is this Spitzkasten classifier, if you see here in this schematic we have different chambers as we have in the previous slide also, but what is the difference, these chamber will keep on increasing in area, so when the fluid or when slurry comes over here then it will come across with this first one so velocity will decrease the largest as well as heaviest particle will settle, settle in the first chamber and after that the finer particle which are present they will move with the fluid, because they cannot be settled in the first chamber.

So it will move with the fluid. Now when they enter into the second chamber which is more in the area in comparison to first so obviously here velocity of the feed decreases further and particle will have chance to settle. And similar concept will be applicable when we have the, when we, when the fluid enters into the third chamber which is again in larger size in comparison to second.

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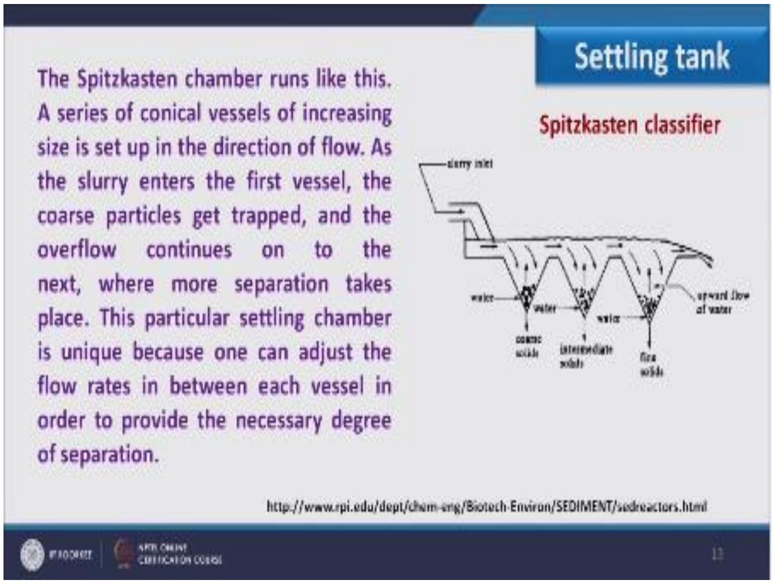

So the Spitzkasten chamber run in a series where different chambers are or conical sections are arranged in a series in a direction of flow. As the slurry enters into the first vessel the coarse particle get trapped and overflow continues to the next one. So in this way the separation in different chambers is possible, so but what is the specialty of this kind of classified that from one to second chamber when the fluid moves then we have the control walls to control the velocity. So here we have the possibility for clear separation in comparison to the previous one.

If you want to study about this more you can visit this link.

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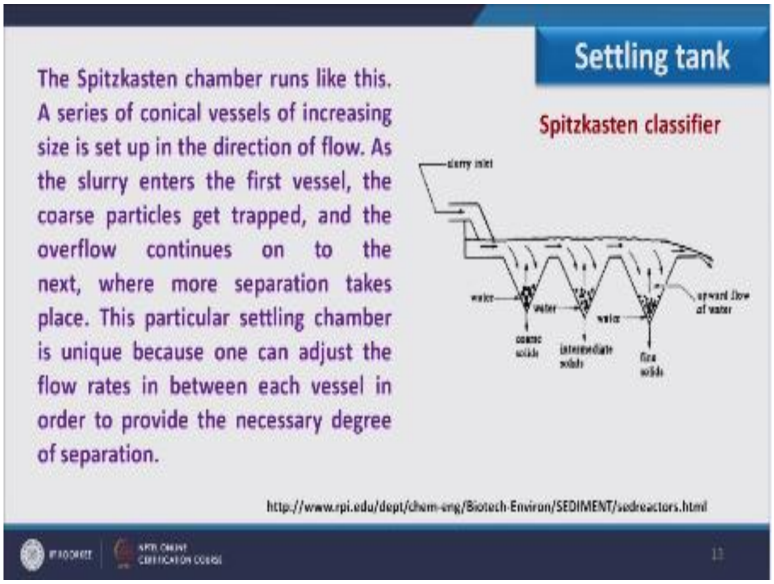

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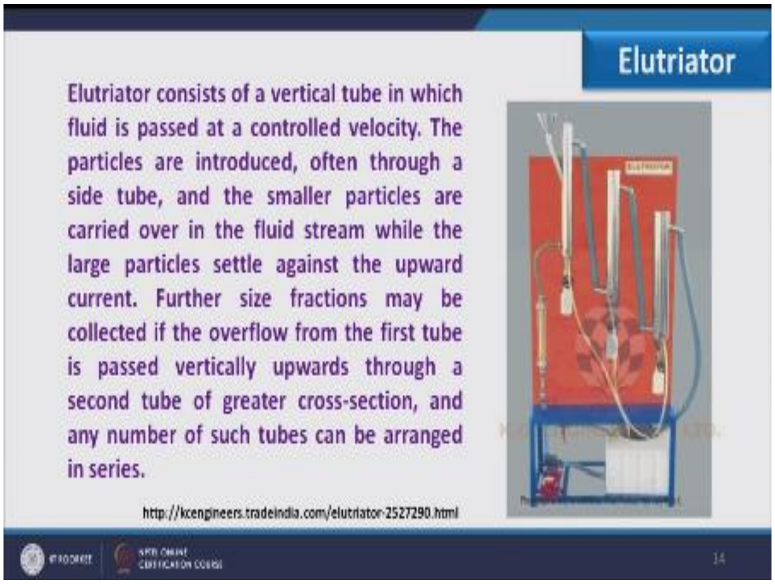

Now we have the elutriator, what is elutriator? If you see this view of this photographic view of elutriator here we have the entering of the water or the fluid, so what happens in elutriator feed enters from this, these are basically huge cylinder kind of equipment, feed enters from this and water usually enters from bottom. So what happens when the, we have to make the separation of the mixture so we have to adjust the velocity of water which is moving upward in such a way so that some particle will be settle. So what happens when the feed enters from here the particle which are having larger settling velocity.

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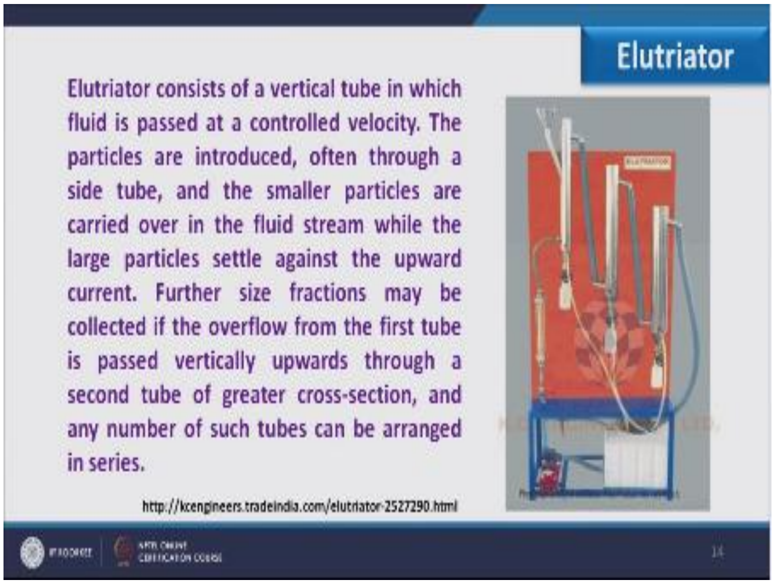

Then the upward water velocity so those particle will be settled and rest of the particle will move with the liquid. So elutriator consist of vertical tube and here fluid passes with the control velocity. Now what happens into this the material which are present in the fluid when it is suspended in the liquid where the settling velocity of particle is lesser than that of the water, so they are taken away with the water. Now where they are taken away, they are taken away to the next chamber where we have larger cross sectional area cylinder and further we have the separations or heavier particle will settle over here, and lighter particle can move with the fluid to the next available chamber.

So for that size reduction maybe collected if overflow from tube is.

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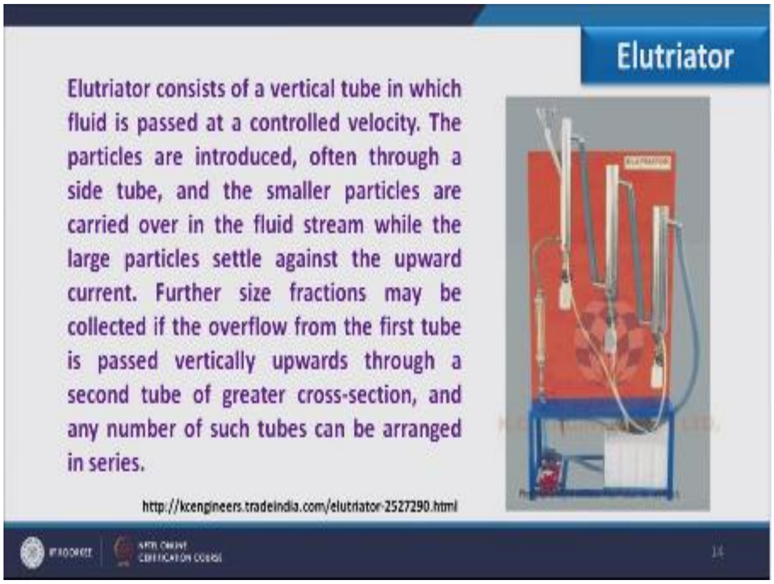

Passed vertically upward through the, another or subsequent tube of greater cross sectional area, so in this way we have different cylinder in the series and separation is possible purely based on their size and density, because.

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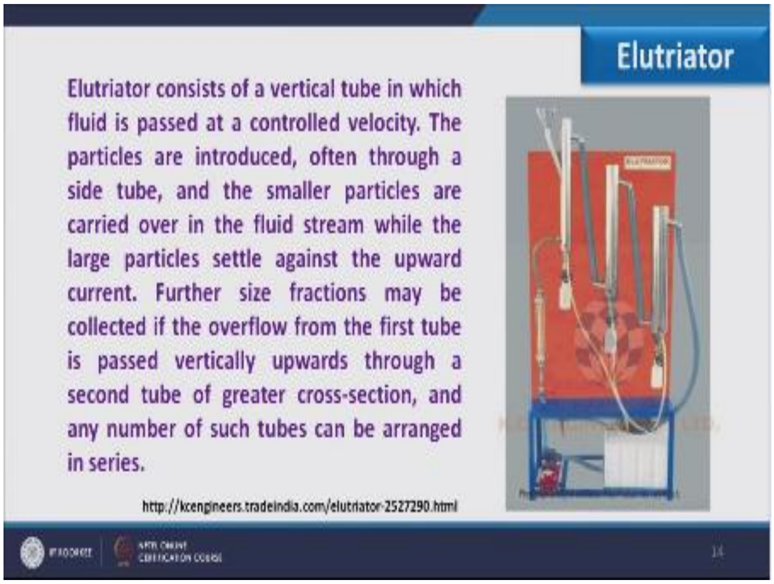

Then only the terminal settling velocity of the mixture is affected. More on this you can study in this link.

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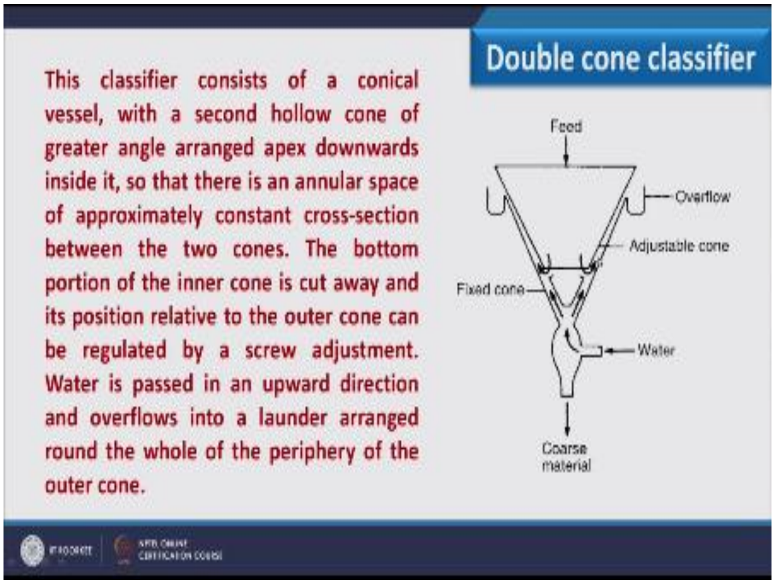

So that is the elutriator, now we have double cone classifier. Now what is the double cone classifier, if you see here we have two cone, one cone is we call outer cone and second is basically the adjustable cone which is placed inside this the first cone. Now here the outer cone is basically fixed cone and inner cone is adjustable, so how we adjust this, it is adjusted in such a way so that the between two cones there must be some space.

So this classifier consist of a conical vessel with the second hollow cone of greater angle are inch apex downward, you see it has the apex downward inside it so that there is a angular space of approximately constant cross section between the two cones. And the bottom position of the inner cone is cut away you see here, here the bottom section of the cone is having a cut so what happens when feed enters from this side and water flows from this side the particle which are having larger terminal settling velocity they will settle, they will pass through the water stream and then they can settle at the bottom or we call it undersize.

Now the lighter particle or which has lesser terminal velocity they will pass through this angular space, now if you see this angular space it has very less cross sectional area. So when particle come over it will have increment in its velocity and due to this it is collected in this overflow chambers. So in that way the separation is possible as coarser particle are collected as underflow and lighter particle is collected as overflow, so due to the double cone available in this it is called double cone classifier. Now here we have the

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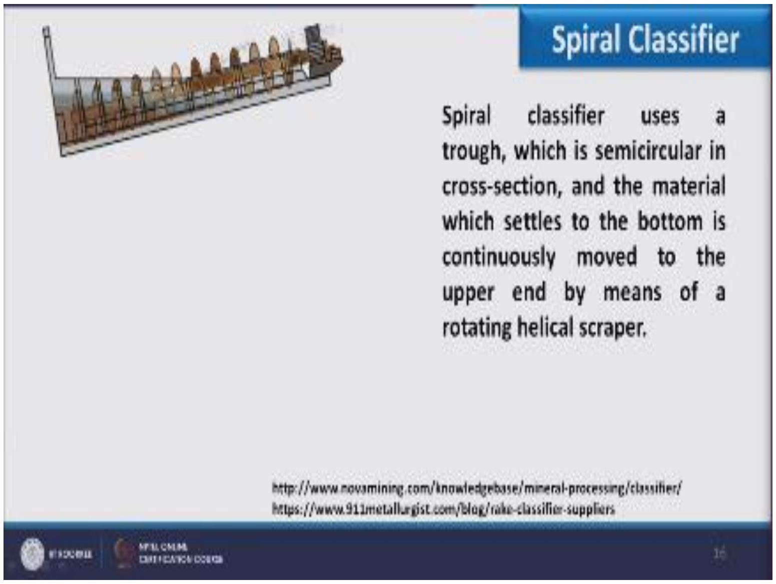

Spiral classifier, now what happens, here we screw type of structure is there and slurry is available in this so slurry is basically have suspension and the coarser particle will settle near to this and final particle will settle over here, so as its movement is like a screw so whatever material accumulated at the bottom they keep on moving towards upward and then we can collect this, so this kind of classifier is called as spiral classifier which is a semi circular in cross section and material which settles to the bottom is continuously moved to the upper end by means of the rotating helical scraper.

So this screw kind of structure we call helical scarper, and

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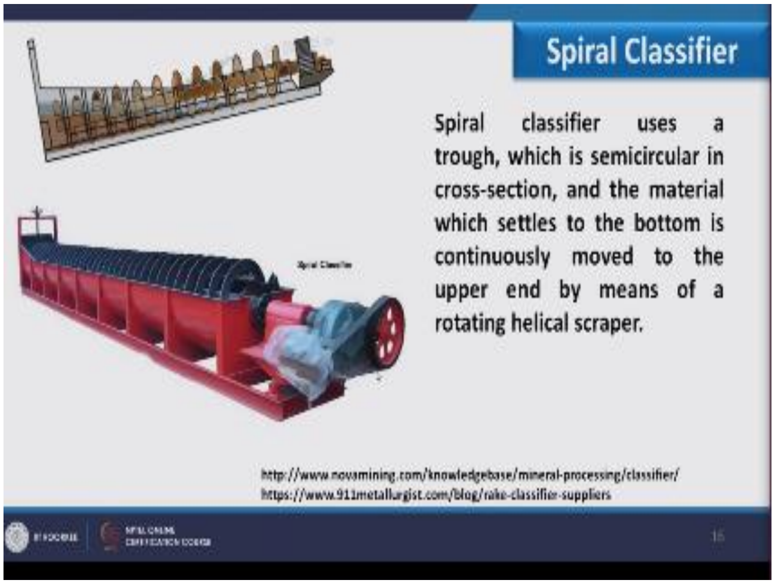

This is the photographic view of this, if you want to study about spiral classifier mode then you can visit these two links, and last equipment we have the bowl classifier. Now the picture shows that it has the huge

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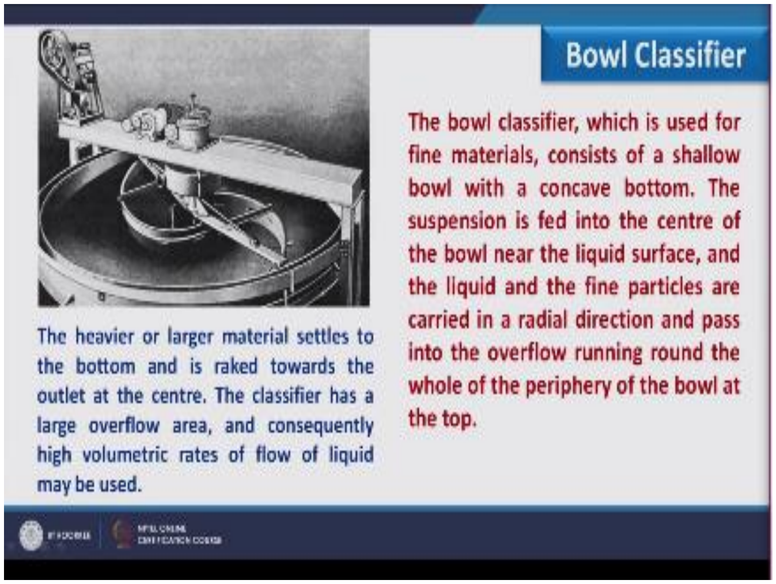

Cylinder so it has structure like bowl, so why we call it bowl classifier, you see the, it is basically cylinder as far as its periphery is concerned and at the bottom it has concave structure so that is why we call it bowl classifier. So bowl classifier which is used for fine particle consist of shallow bowl with the concave bottom. The suspension is fed into the centre of the bowl and liquid and the fine particle which are carried when it comes out from the center it is carried in a radial direction and move on to the surface of the bowl.

Now what happens when after sometime when settling takes place so coarser particle will be settled down at the bottom of the bowl, however final particle which are suspended over here they are collected in the ring which are available at the periphery, that you can see in this section the fine particles are collected. So the heavier or large material settles to the bottom and is raked towards the outlet at the center.

However fine particle is collected in the chambers which are at the periphery of the bowl. So the classifier has large overflow area and consequently high volumetric rate flow of liquid maybe used. So that is the functioning of bowl classifier it is used to separate fine particle and coarser are collected at the bottom of the bowl. In this part of this lecture we have covered the concept classification as well as equipment related to this and next we will solve some of the problem on classification and we will discuss jigging, so that is all for now, thank you.

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