**Fundamentals of Food Process Engineering**
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**Lecture - 45**
**Mechanical Separation Techniques ( Contd.)**

Hello everyone, welcome to the NPTEL online certification course on Fundamentals of Food Process Engineering. We were discussing about the Mechanical Separation. Mechanical Separation Techniques and we will continue with that topic today also. So, by now we have discussed about the sedimentation then filtration and today we will start floatation.

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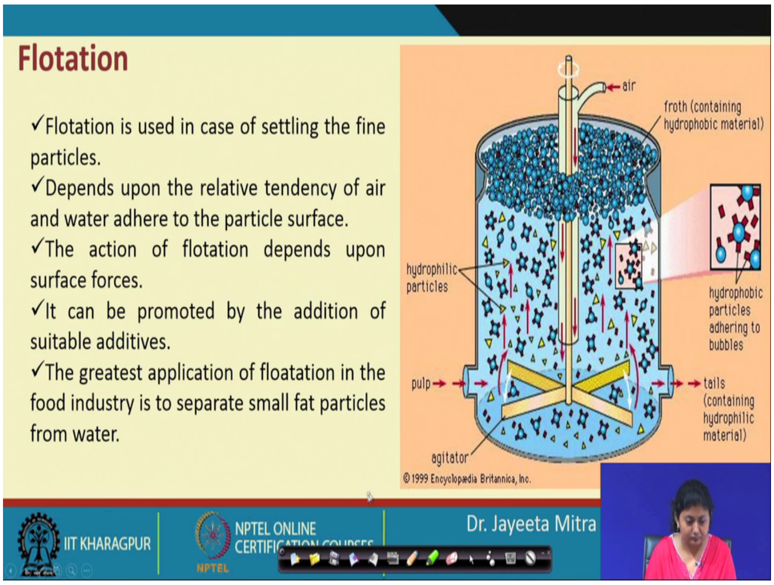


So, floatation is used in case of settling the fine particle. So, what happen then we use this there is a kind of an agitator. We will learn this in much more detail the agitation process and mixing process because we have a chapter in this course that we will cover now, I mean next to this. So, there are different particles and different density of the particles will be there. So, some will be you know coming at if we try to have some agitation there so some will be floating at the top. And because of the difference in the in the density it will be easy to separate the lighter and the heavier particles.

So, depends upon the relative tendency of air and water, adhere to the particle surface that is that is one point. And the action of floatation depends upon the surface forces. So, it can be promoted by addition of the suitable additives. So, sometime we give some kind of additives which will adhere to the particle surface and they will add to them and either they will increase the homogeneity or they may decrease in may work in reverse way. So, the application of floatation in the food industry is to separate the small fat particles from the water.

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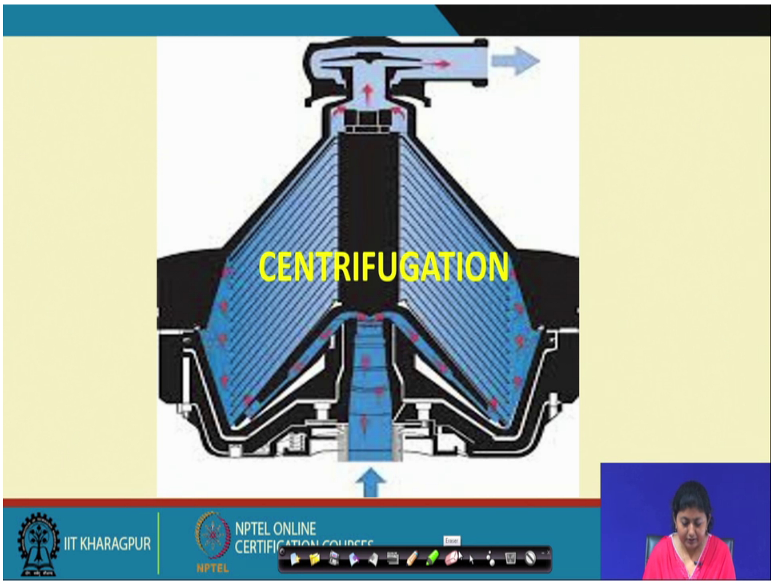


Next is centrifugation which is a mechanical separation operation and this is how diagram of a typical centrifuge is look like. Whereas, many plates are there and when the liquid enters from the bottom it will try to, you know thrown towards the channels the different channels and eventually passed the length and it will go to the peripheral distance. And this speed will govern also based on the you know as the mass of the particle because if it is a heavier particle that will be get the more higher amount of the centrifugal force and they will you know thrown towards the outward direction. And those are the heavier that will be in the near to the central section. Those will be lighter that will be near to the central section, heavier will be thrown towards the periphery.

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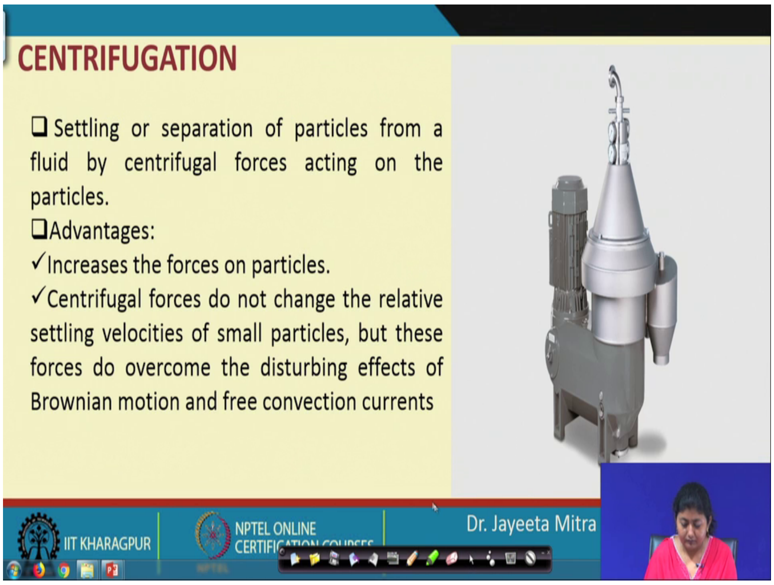


Now, settling or separation of particle from a fluid by centrifugal force acting on the particle. So, this is the basis of the centrifugation or centrifugal separation, that we separate the particle from fluid by applying centrifugal forces on the particle. So, the lab scale system looks like this where we throw the material and it will come down you know from and an incline fashion. And eventually the separation of the heavier and lighter particle will be there.

So, advantages that it increases the forces on the particle. For example, if we try to separate the particle by sedimentation there only the gravitational force is applied, but here because of the centrifugal force much more forces occurring on the particle as we have mentioned that when we do centrifugal filtration then also it is very effective separation is possible. Centrifugal forces do not change the relative settling velocity of small particles, but these forces do overcome the disturbing effect of the Brownian motion and the free convection current, that prevails in the system.

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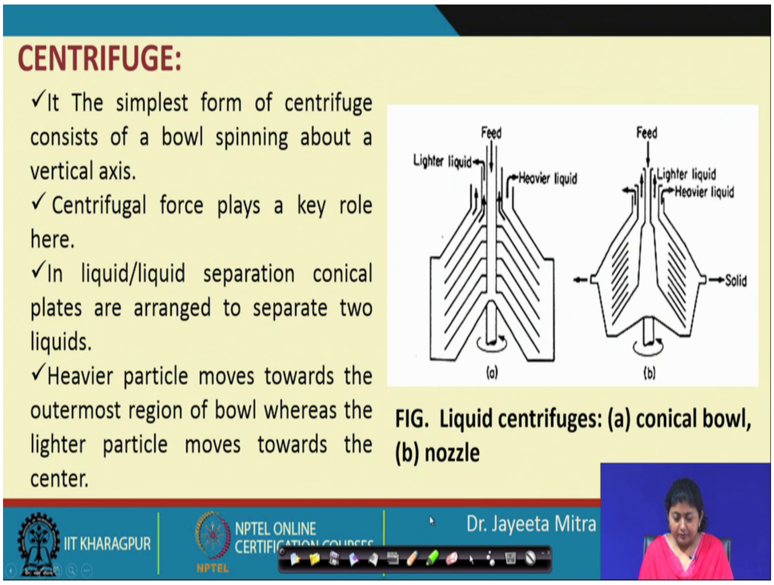


So, the simplest form of centrifuge consists of a bowl spinning about a vertical axis. There is a bowl which is spinning about a vertical axis, centrifugal force play a key role here. The liquid liquid separation conical plates are arranged to separate the two liquid. There are conical plates which are you know used to separate the two liquid of different density. Heavier particle moves towards the outermost region of the bowl whereas, the lighter particle moves towards the center.

So, we can see here either of this kind or this kind, we can see when we have two different liquid we have a slanting plate or the conical plates start from the feed feeding section. So, when this feeding will be done this is directly you know send towards this, the feed is directly sending the material because of the centrifugal force it is rotating and the material will be thrown towards the outward direction. And the heavier will be deposited here and the lighter will be near the central section

Similarly, if the slurry is of liquid and the solid particle; then the dimensions will be like this. Solid particle will be thrown out and towards the periphery because they are heavy compare to the liquid and the solids are collected. Whereas, the lighter liquid and heavier liquid those have different channels. Lighter being closer to the centre and the liquid far towards the peripheral zone, that is the heavier liquid.

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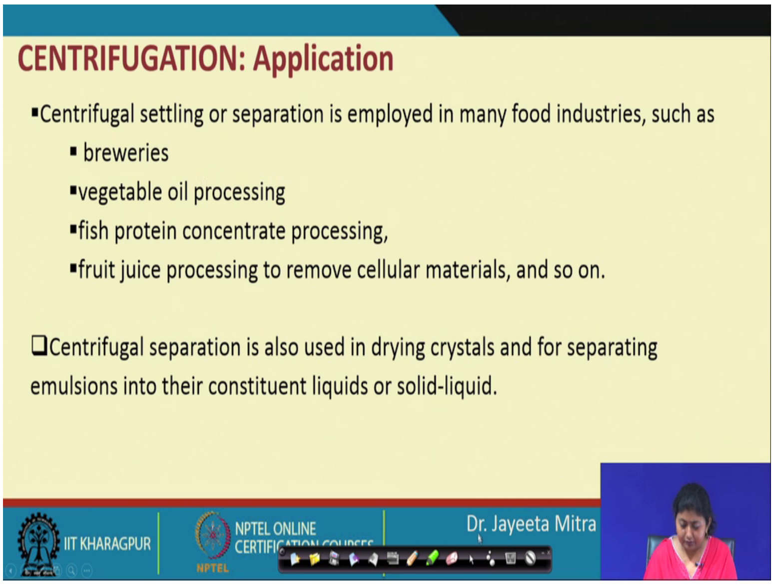


So, application if we see the centrifugal settling or separation is employed in many food industries. For example, brewery vegetable oil processing, then fish protein concentrate processing, fruit juice processing to remove the cellular material, etcetera. Centrifugal separation is used in drying crystal and for separating the emulsion into their constituent liquid or solid and liquid. So, if then emulsion is given to us and we want to separate the components we can go for the liquid liquid separation if the if the liquid. For example, if the emulsion is of some fat and the water like that or solid liquid separation also it is effectively used.

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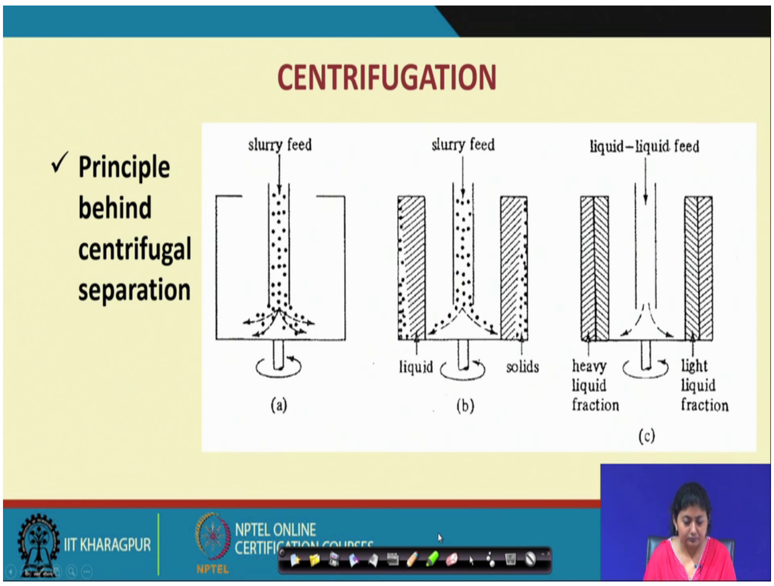

So, when we send the slurry to the you know the central inlet section of the of the feed inlet section of the bowl so that time there is an opening and from that it is spreading around the central rotating shaft. And as it enters into the centrifugal you know the zone of centrifugal action, it will have that particular force because of its mass and as the mass varies the force it is you know perceiving or the force acting upon it will also vary. So, based on that we can see that if it operates for certain time; we can clearly find the solid particles will be thrown towards the peripheral zone and the liquid will be in the inner side.

And initially we may get some mixing layer or such that. But if we run it for a more longer time we can get very easily the clear differentiation line between the particle and the liquid. Also we can get the heavy and light liquid the two different density liquid. And with time we can get clearly different zone because there is a distinct difference in the density of these two liquid that we are separating. So, very well the there will be two channel in a different location one is closer to the closer to the central section and another is the towards the periphery. So, by that we can separate the two different density liquids by centrifugal separation.

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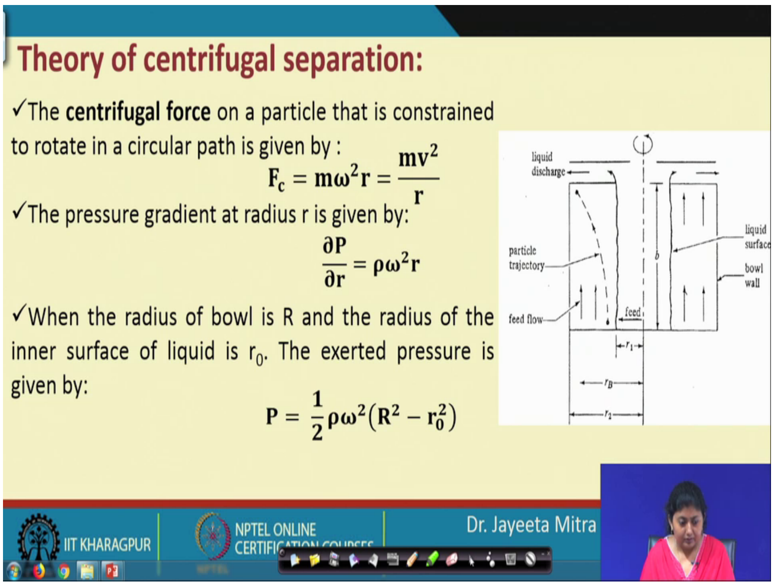


Now, the theory of centrifugal separation if we look into; the centrifugal force on a particle that is constrained to rotate in a circular path is given by F c that is equal to m omega square r. So, the force on a particle the centrifugal force on a particle the centrifugal force on a particle of mass m, which is constrained to rotate in a circular path and it is rotating at a particular velocity angular velocity that is omega. So, m omega square r omega equal to v by r; so, we can write v square by r square into r. So, m v square by r; so that is the centrifugal force.

Now, the pressure gradient at radius r is given by; if at a distance r we consider at a distance r we get consider at a distance r. And let us say here we are interested in calculating delta P. So, delta P by del r; if we take very small gaps. So, the pressure difference will be P 1 minus P 2 at this zone across the distance dr across the distance dr del r. So, the pressure gradient at radius r will be del P by del r equal to rho into omega square into r.

So, when the radius of the bowl is capital R and the radius of the inner surface of the liquid is r 0. So, this inner surface of the wall this is r 0 if it is and the outer surface if it is capital R. So, we can write that the pressure force will be half rho omega square into R square minus r 0 square capital R square minus r 0 square. So, that this we are getting from this equation delta P equal to rho omega square r into dr. So, for the whole zone the dr this has been indicated. So, half of rho omega square capital R square minus r 0 square, this we have got.

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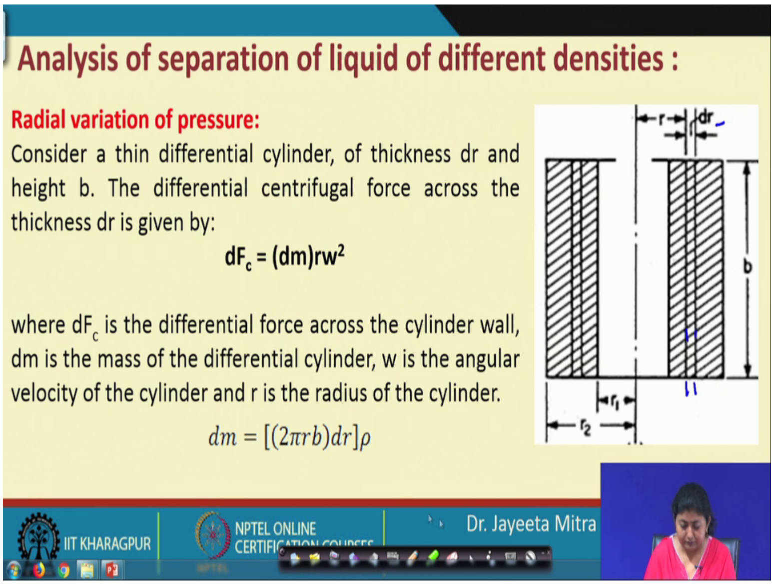


Now, again if we take the, you know radial variation of the pressure. We can calculate in this way that consider a thin differential cylinder, so we have considered thin differential cylinder. And this thickness is dr as we have mentioned and the height is b or h whatever we can take. So, the differential centrifugal force across this thickness dr that can be given as dF c not equal to dm into r omega square. So, dF c is the differential force across the cylinder wall.

Now, dm is the mass of the differential cylinder, w is the angular velocity of the cylinder and r is the radius of the cylinder. So, here dm will be the volume into density, so volume is at r distance or 2 pi r dr into b that is the height into rho.

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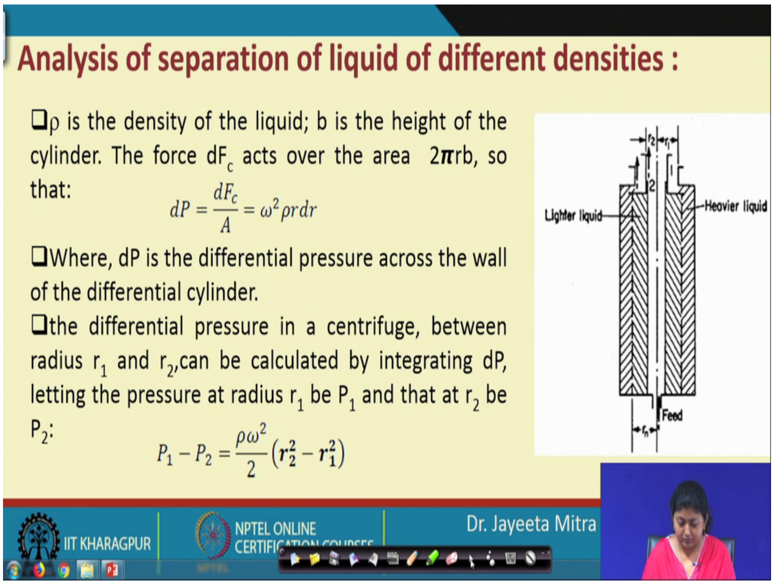


So, rho is the density of the liquid and b is the height of the cylinder, the force d F c acts over the area 2 pi r b. 2 pi r b across that area it is acting. So, we can write dP that we have calculated there. Now we have writing dP in terms of d F c by A dF c is the total force by A, so omega square into rho into r dr So, dP is the differential pressure across the wall that we have calculated for differential cylinder.

So, similarly now the differential pressure in a centrifuge between r 1 the radius r 1 and r 2; r 1 and r 2. This can be calculated by integrating dP and letting the pressure at the radius r 1 be P 1 and at r 2 will be P 2. So, if this is like that so, we can calculate the differential the delta P or the difference in the pressure as P 1 minus P 2 that is rho omega square by 2 into r 2 square minus r 1 square.

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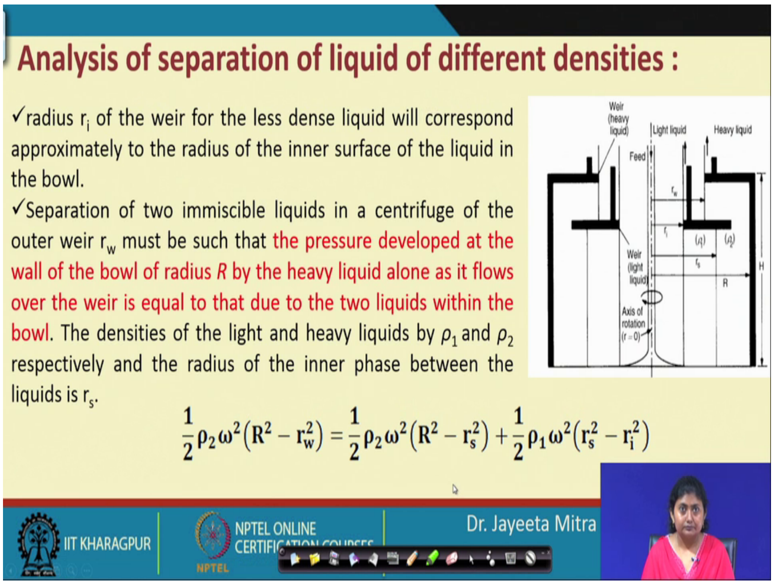


Now, again if you see, that two different liquid we want to separate in a disk bowl centrifuge. So, in that case the geometry can be written like this, if there is there is two channel, when we feed the liquid from the bottom and it is coming in the in the zone of centrifugal force and it is try to have the have the heavier particle towards the periphery. So, the heavier particle will occupy this zone, and the lighter particle will have in this section.

So, then what will happen we have two channel, from one channel the heavier particle will go out. And the other channel from which you know this lighter liquid will go out. So, radius r i here this is the radius r i this is r i of the wear for the less dense liquid. So, here from here the less dense liquid or light liquid is coming out. So, this is the radius of that wear and we will correspond approximately to the radius of the inner surface because this at the surface only the lighter liquid will be there.

So, it correspond to the inner surface of the liquid in the bowl. So, because it is rotating continuously so it has a tendency to move towards the peripheral direction. So, that is why there is a inner you know empty spaces will be will be at the at the center and then it will you know start filling towards the peripheral layer. So, separation of two immiscible liquid if you want the in a centrifuge. So, it will happen at the outer wear will be considered as r w. The distance of the outer wear through which the heavy liquid will pass that is r w. So, the condition must be such that the pressure develop at the wall of the bowl, that is here the pressure develop at the wall of the bowl of radius r.

The pressure develop at the wall of the bowl of radius r by the heavy liquid alone as it flows over the wall is equal to the pressure due to the two liquids within the bowl. So, the density of the light and the heavy liquid is defined as rho 1 and rho 2, light is rho 1 and heavy is rho 2 respectively and the radius of the inner phase between the liquid. So, the two liquids is there, the lighter and the heavier. So, the interface that is the inner phase of the liquid and that is r s. So then we can write that the force that.

So, here the pressure difference that we have calculated that will be equated in this way that is whatever the force generated on the wall because of the heavier will be equal to the total pressure of the heavier and the lighter on the in the bowl. So, half rho 2; that is density of the heavier particle density of the heavier particle into omega square that is angular rotation square into R square minus r w. So, that is defining the heavier particle heavier particle. So, this is the pressure develop at the heavier particle and this 1 half of rho 2 omega square R square minus r s. So, this is R square minus r s. So, this is for the heavier particle and this is for the lighter r s minus r i square into rho 1 into omega square by 2 this is for the lighter particle.

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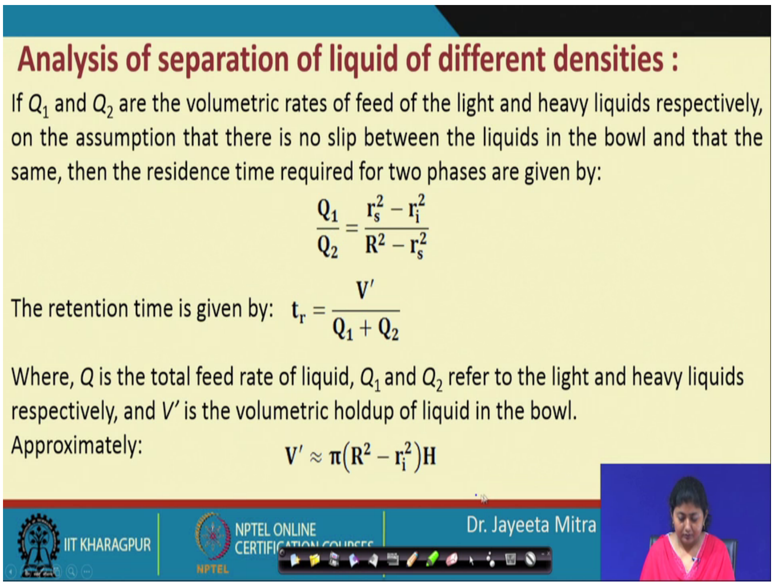


Another thing we can do is if we know that Q 1 and Q 2 which are the volumetric rate of feed of the light and heavy liquid respectively. So, volumetric this Q 1 and Q 2 these are the volumetric rate of feed of the light and heavy liquid respectively. And, on the assumption that, there is no slip between the liquids in the bowl; so this is our assumption that between the two layers that is no slip and also not with the liquid and the bowl.

So, the residence time required for two phases are given by Q 1 by Q 2 that is equal to r s square minus r i square divided by capital R square minus r s square. So, this will be the condition where r s we know this is the distance of the interphase between heavier and the lighter r i is the inner surface of the lighter and capital R is the inner surface of the outer surface of the heavier particle or you can say the radius of the bowl

Then the retention time is given by this expression. We have now Q1 by Q2 that is equal to r s square minus r i square by capital R square minus r s square. And retention time will be t that is equal to V dash by Q1 plus Q 2. So, Q 1 which is the volumetric feed rate of the light and Q 2 volumetric feed rate of the heavy; we add them together Q 1 plus Q 2 and use it here in this equation. So, t that is equal to V dash by this.

So, V dash is the volume, volumetric hold up, of the liquid in the bowl this we have already mention. So, V dash that will be pi into R capital R is the outer diameter outer radius of the heavy liquid side. So, or we can say the radius of the bowl. So, R square minus r i square into H or we can take b because we have taken the thickness as b. So, b or h other thing we can take so that is the volume.

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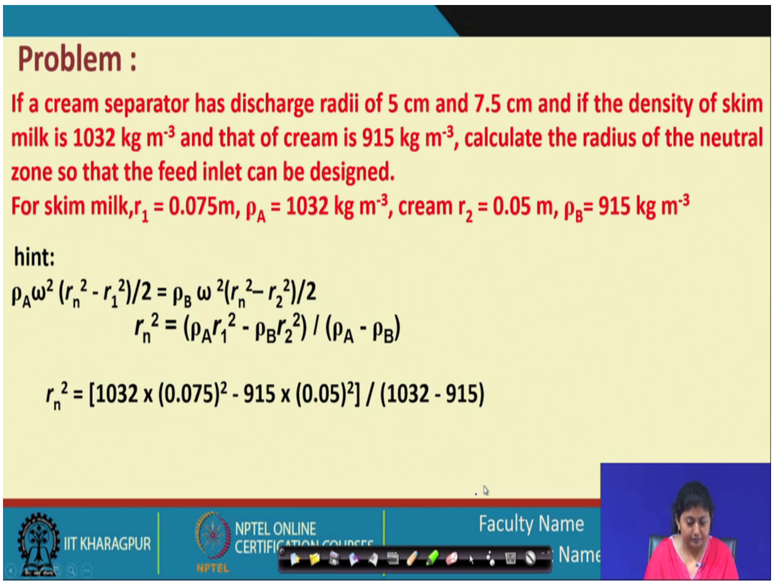

Now, we can see one problem that if a cream separator has discharge radii of 5 centimetre and 7.5 centimetre. So, we have r i the inner layer of the lighter particle and the inner layer of the heavier particle that is 7.5 centimetre. And if the density of the skim milk is 1032 kg per meter cube. And the density of the density of the cream is 915 kg per meter cube. Calculate the radius of the neutral zone so that the feed inlet can be designed. So, neutral zone means where these two you know the in between the lighter and heavier where the separation has been takes place; so, that we need to find.

So, the parameter is given r 1 is given, rho A the density of the heavier and the density of the lighter both are given. So, we use that equation that is rho a into omega square r n square minus r 1 square by 2. And here also rho b into omega square r n square minus r 2 square by 2 r n is that that we need to find, that is the neutral radius and r 1 is given r 2 is given both rho A and rho B is given.

So, we can very well calculate this because omega is cancelled out. So, here with this value we can very well calculate the value of r n. So, r n square first we will get and then we will calculate the value of r n. So, that will be the radius of the neutral zone.

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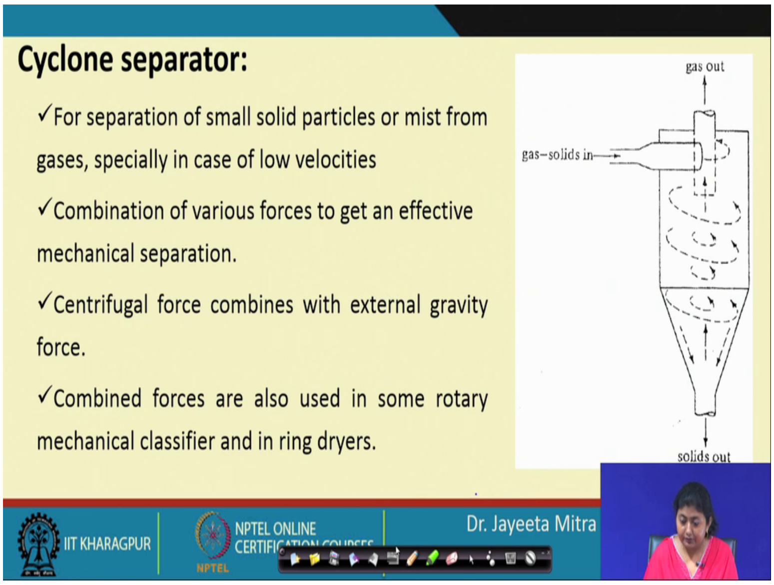


Now, the next next term mechanical separation technique is based on the cyclone separator. So, in the cyclone separator what happens is that; for separation of very small solid particle or mist from the gases specially in case of the low velocity gases we used to employ a cyclone separator. So, the gas solid mixture is coming into from a tangential inlet or entry and as it comes towards the centre this generate a swirl or a circular motion and because of that because of that centrifugal force and it comes to the solid will then come to the bottom. There is a conical section they will hit there and try to come to the outer outward directed section which is which is the outlet or solid collection section.

However, some particle, which are very very fine particle cannot be separated because those will be carried away with the exit air. So, let see this in a bit detail so, cyclone separator is a combination of various forces to get an effective mechanical separation. Here we apply a combination of many forces to get an effective separation. Centrifugal force combined with external gravity force, so this centrifugal force when it comes to the bottom there also gravity force will also act on the particle and thereby it is very effective method. Combine forces are also used in some rotary mechanical classifier and in ring dryers.

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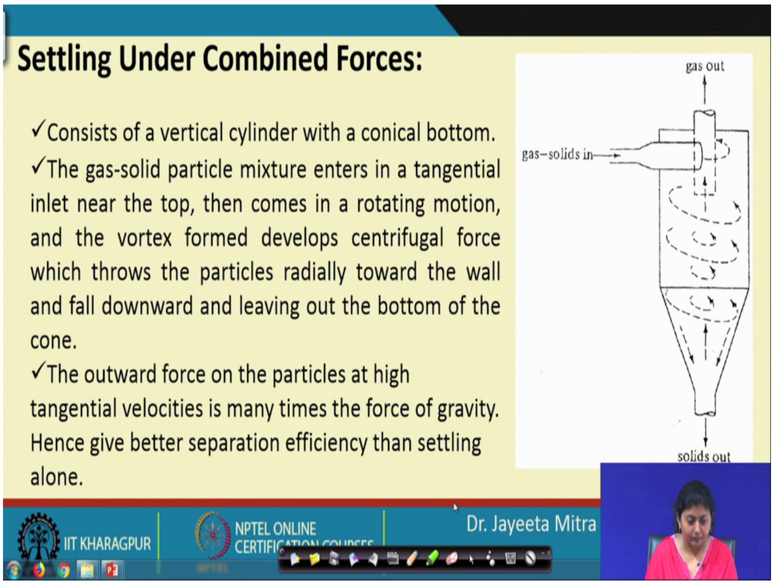


Now, it is basically consist of a vertical cylinder the cyclone separator is consist of a this vertical cylinder and a conical bottom the gas solid particle mixture that enters in a tangential inlet near at the top section. Then comes in a rotating motion so, then this motion is being generated. And the vortex form develop a centrifugal force because here the vortex will form after this small section or very small amount of barrel kind of portion is there beyond that there is a empty space. There is no proper channel the air will develop vortex and swirl and then it will come to the bottom. So, vortex form and develop the centrifugal force which throw the particle radially outward.

So, all the particle will be thrown radially outward and fall downward because when they will be thrown out based on their different you know the heavier or lighter particle or depending on their mass they will be hit the hit the body eventually. And they will come in the downward direction because of gravity. So, first of all the heavier particle will come very easily and then the comfortably finer particle will come out. The outward force on the particle at high tangential velocity is many times the force of gravity. Hence gives better separation efficiency than the settling alone.

So, when this way settling can also happen from the, we have mentioned that from the airstream fine particle separation can be done by settling also. But if you do settling there is only gravitational force is acting, but if you try to separate the dust particle from the air by using the centrifugal separation. Here centrifugal force is also acting in addition to the gravity so, it is much much higher than the, you know gravity gravitational force. So, thereby it gives us very effective separation.

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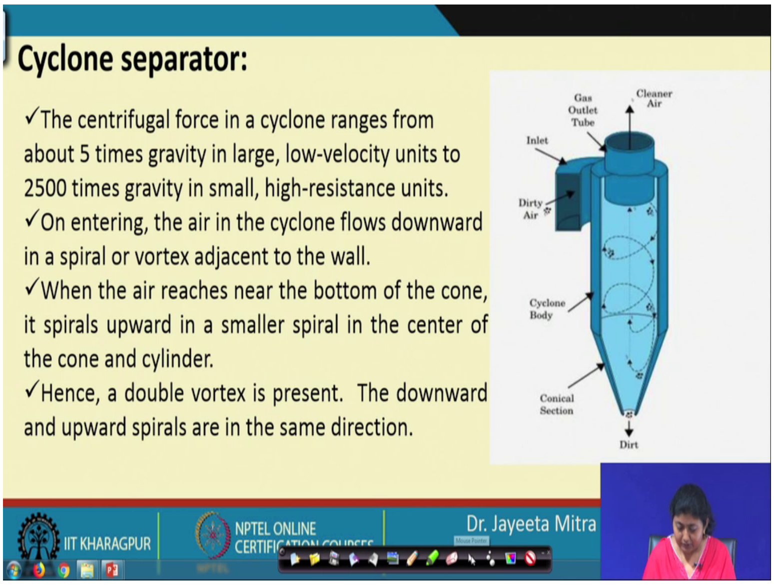


Now, we can see the cyclone separator; so this is the inlet of it now the geometry of inlet may be of round shape or you know rectangular shape that depends and from based on this we can calculate also the flow rate of the inlet air, the air which comes into the inner side. Now it is enter into a tangential direction and it comes it generates the centrifugal force as it enters into the cyclone barrel and develop that vortex which will eventually come down, but since there is the again an open portion at the top. So, because of that it will have the, air will be suck through the central section towards the upper direction and with that some fine particle may also come out.

So, the centrifugal force in a cyclone ranges from as I said that about 5 times a gravity and low velocity units to 2500 times gravity in the small high resistance unit. So, 5 times for the large unit and large low velocity unit and 2500 times in small high resistance unit. On entering the air in the cyclone flows downward in a spiral or vortex adjacent to the wall as it has been seen here.

When the air reaches near the bottom of the cone so, it spirals upward as we as we have seen then as it reaches at the bottom it spiral upward in the centre of the cone; in the centre of the cone and also the centre of the cylinder hence a double vortex is present. So, one which is while the airstream is coming down and the other one which is much smaller that is at the center that is centrally located. But those are happening in the same direction so the direction of the both the swill will be similar. So, this will be more clear we have one more picture.

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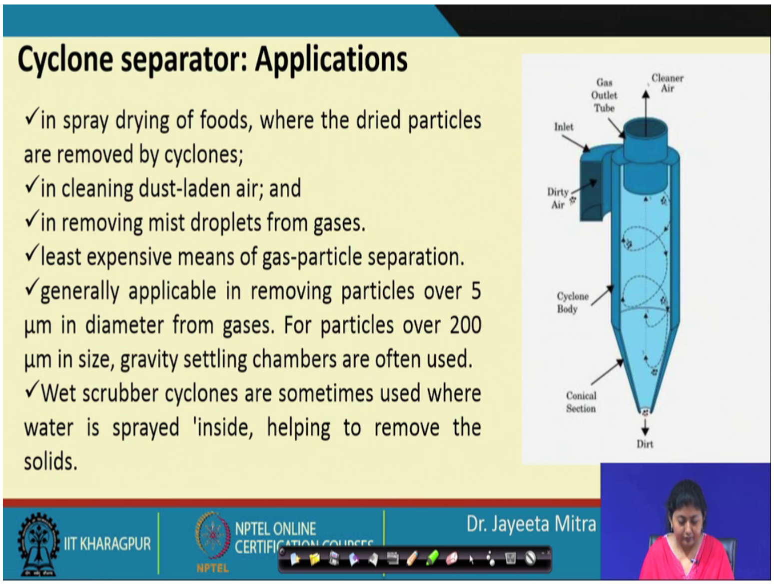


So, we have use this kind of cyclone separator in case of spray drying of food where the dried particle are removed by the cyclone. So, in cleaning dust laden air these are the application, because when we dried the spray drying. That the chamber is of this kind of a shape where very high this section is there, I mean the barrel section is there and then there is a small conical portion.

So, we want that a the particle in case of the spray drying it should hit the wall and before it is heating it should dry completely. Now when it has to be collected at the bottom and the air that we pass through this the whole drying chamber that is being sucked through the one arrangement is there and while sucking the air out we pass it through a cyclone separator. So that any remaining fine particles that may go out with the airstream with the exit airstream will be collected at the bottom of the cyclone separator.

Also in cleaning of the dust laden air the cyclone separator is used. In removing the mist droplets from the gases there also cyclone separator is used. And these are least expensive means of gas particle separation generally applicable in removing particles over 5 micrometer in diameter from gases, for particles over 200 micrometer in size gravity settling chambers are often used. And then wet scrubber cyclones are sometime use while where water is sprayed inside helping to remove the solid. So, in that case wet scrubber cyclones are used.

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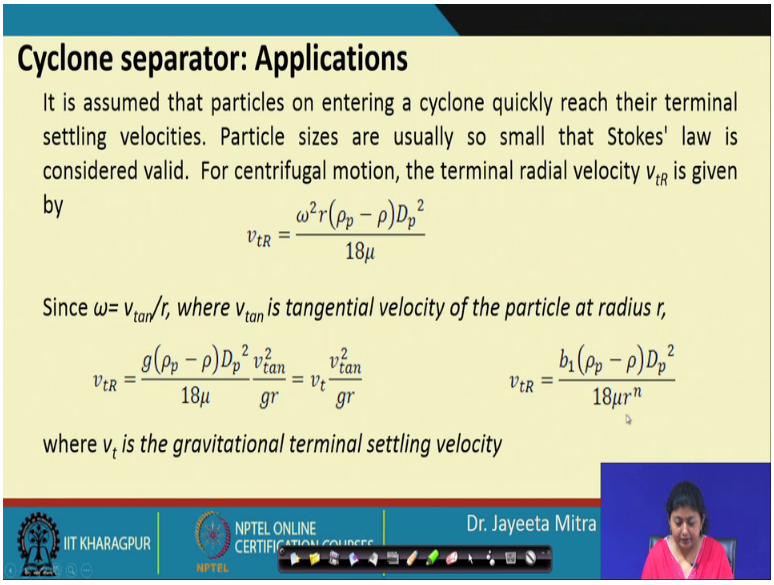


Now, then we need to see that how we can calculate the terminal velocity in case of a centrifugal sorry cyclone separator. So, it is assumed that the particle on entering a cyclone quickly reach their terminal settling velocity. So, if the particle they will enter tangentially and they will enter tangentially. And they will come into the, you know the terminal settling velocity quickly reach the terminal settling velocity.

So, particle size are usually so, small that stokes law is considered valid and for that centrifugal motion the terminal radial velocity v tR is given by this equation because here also we are considering this as the centrifugal motion will be applicable and considering that we can write v tR; that is the terminal velocity terminal settling velocity that equal to omega square r into rho P minus rho by 18 mu into D p square.

So, omega equal to tangential velocity v tan by r because here we have the tangential velocity with which the particle or an air particle laden air has been entered. So, omega is equal to v tan by r v tan is the tangential velocity of the particle at radius r. So, therefore, we can write here v tR that is equal to g into rho P minus rho into Dp square by 18 mu into v tan square g into r. That means, both the side numerator and denominator we have multiplied by g and we have this omega square by r that we have replaced with v tan square by r.

So, what we are getting that v t this when the gravity settling takes place. So, g into rho P minus rho into Dp square by 18 mu this expression that we have derived from the gravity force and equating gravity force with the buoyancy and the drag so, using that we can write it as v t into v tan square by gr. So, the tangential velocity with which it has entered and then the settling velocity vt divided by g into r. Where vt is the gravitational terminal settling velocity. So, v tR we can write as b one into rho p minus rho into Dp square by eighteen mu r to the power n.

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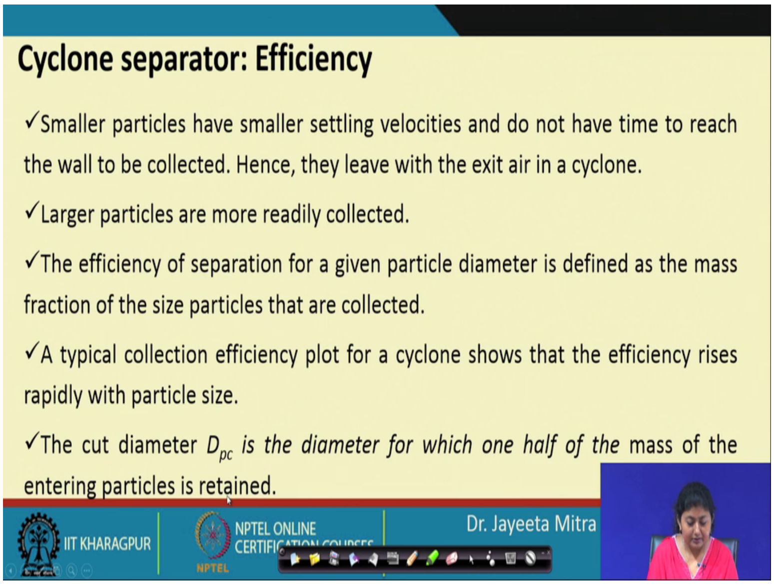

So, that way we can also express. Now efficiency if we you know try to look into the parameter based on what the efficiency of the cyclone separator will change. So, smaller particle have smaller settling velocity and do not have time to reach the wall to be collected. So, because we have we know that the smaller particle will have a small settling velocity. And because of that since there is you know we have we have introduced here a term like b 1 into rho p minus rho into D p square by 18 mu r to the power n so. So that those two parameter b 1 and r n that has been taken for this because there is lot many variation of the you know particle sizes. And we will see that how we can use them.

So, smaller particles since they have a small settling velocity, they do not have time to reach the wall for to be collected. And they have they go with the exit air that is coming out at the top of the cyclone separator. So, larger particle are more readily collected so efficiency will be; obviously, better for the larger particles compare to the various fine particles. And you might have seen that in some cases, when we use the cyclone separator for you know separating the particle from the air in case of spray dryer kind of thing we also provide a bag filter kind of so that will eventually you know filter those particle that cannot be even separated by cyclone separator.

So, the efficiency of separation for a given particle diameter is defined as the mass fraction of the size particles that are collected, the efficiency of separation for a given particle diameter. For example, a particle diameter D c which is given. So, for that efficiency will defined as the mass fraction of the size particles those are collected at the bottom. So, a typical collection efficiency plot for a cyclone shows that, the efficiency rises rapidly with particle size. So, if particle size increases the separation efficiency will also increase. So, the diameter we say that the cut diameter; that means, the extent to which it can separate easily the cut diameter is the diameter for which one half of the mass of the entering particle is retained.

So, that is all about the cyclone separator and we have covered almost all the mechanical separation techniques. For example, we have done the screening, filtration, then different kind of filtration, then sedimentation and settling then centrifugal separation and cyclone separation. So, in the next class we will move on to a different topic or a different chapter.

Thank you.