Lec 24: Particle Separation by Cyclone and Centrifuge

Hello everybody. Welcome to this massive open online course on solid-fluid operations. So as we are talking about the particle separation by different mechanism and their respective equipment, how those equipment can be designed and what are the governing equation to calculate the efficiency of that equipment for the separation of the particulate matter. And in the previous lecture we were discussing about that how that particulate material can be separated by gravity settling chamber. Here another mechanism in this lecture we will be discussing and this mechanism is called that particle separation by cyclone and centrifuge. How that cyclone and centrifuge actually working for the separation of the particulate materials will be discussed in this lecture.

So if we talk about that cyclone separator for separation of the particles, you will see that this cyclone separator utilize the centrifugal force that created by the spinning gas stream. Here in this slides it is shown that animation there how that particles are being separated just by spinning that particle laden gas versus stream in this system. And there particles is acted on by a centrifugal force of measurement like this if you have that particle mass and its velocity at this radial direction and what radius of curvature this involve to rotate or centrifuge that if and if it is denoted by small r then this centrifugal force can be calculated by this equation that is called mp v theta square by r. So a particle is acted on by this centrifugal force of mp v theta square by r and the gas whatever it is float is supposed to flow that curved geometry of that system through that curved geometry that particles would be acting upon to get that centrifugal force and whenever that centrifugal force of particles will be effective on that particle you will see that particles will thrust on that wall of that centrifugal separator that is called cyclone separator and when it will thrust on that wall you will see that it will reduce its movement or you can say that it will diminish its flow on the surface just by getting that obstruction and after getting that obstruction you will see that particles will go downward as per their gravity.

So the gas flow is supposed to follow that curved geometry and during that geometry you will see that the inertia of the particles causes them to move towards the outer well outer wall where they collide and collected on the surface of the wall. So here in this cyclone separator it is shown that the dusty air will be inlet into the cyclone separator and then it is getting that inertia particles that which causes to move towards the outer wall of the cyclone and then after getting that change of that inertia at the wall the particles will fall down due to their gravity effect. So this is the basic mechanism of cyclone separator. Also you will see that at a typical value of that radial velocity that is around see that 10 meter per second or the radius of 0.5 meter the force will be around the 20.

4 times that of gravity on the same particle. So in that case the gas stream may execute that several complete turns as it moves from one end of the device to the other. So in that case the length of the body of the cyclone will be related through the gas flow rate to number of turns which will be executed by the gas stream. So in this case the design problem sometimes will be posed in terms of that computing the number of turns that takes by that

gaseous stream and also the particles which is coming with that gaseous streams and that actually give you the effective predicted value or calculated value of that efficiency of that equipment and that efficiency can be regarded as a collection efficiency. So in that case it will be required to interior surface be smooth to get that smooth surface so that the collected particles may slide easily down the wall as per that gravity.

So this is the case so here we can say that there will be certain factor that will affect on that efficiency of that cyclone separator to separate those particles. Especially that geometry is one of the important factor and then also you can say that the particle size, that all particle size cannot be separated by this cyclone separator. You will see that there will be certain range of that particle size to be separated where that the inertia will be produced by that cyclic turn of that gaseous streams. Whenever that inertia will be that diminishes on the surface by heating or just by colliding with that particles that wall then those will be falling downward as per gravity. So in this case that particle size also one of the important whether this inertia will be more enough to that gravity force or not.

So whenever it will be turning up in the centrifugal action so in that case that gravity force will not be that higher compared to that inertia force initially. After that getting stuck on the wall of course that gravity force will be acting on the particle to slide down alongside of the wall. Now you will see that whenever we are talking about the design of that cyclone separator there are basic three types of that cyclone separator will be designed. And in this case some will be called that reverse flow cyclones some will be called as straight through flow cyclones. And also another important design specifically that is impeller based cyclone separator will be there.

So in this case we can say that in case of reverse flow cyclones the particles are actually forced to wall by centrifugal force and then fall down the wall due to gravity. At the bottom of that cyclone you will see that the gas flow reverse to form an inner core that leaves at the top of the unit. And the gas is introduced down the axis of the cyclone. So this is very important that whenever we are talking about that reverse flow cyclones. So in this case you will see that gas flow will be reversed to that direction of the particulate and gas stream.

So clean gas will be reversely flow in the cyclone. So here you will see that in the diagram it is shown that the red line it shows that that due to this centrifugal force action that the direction of this gaseous stream with particle how it will be directing and then after separation of those particles you will see that the clean gas will be passing through the core region of this cyclone separator. So here you will see that the clean gas will be reversely flow compared to that dirty air here. So this is the basic concept that particles are forced to wall by centrifugal force and then fall down the wall due to the gravity and at the bottom of that cyclone the gas flow reverse to form an inner core that is inner core here this is inner core that leaves at the top of the unit. So this is the basic principle of reverse flow cyclones.

Whereas straight through cyclone you will see that the inner vortex of air that leaves at the bottom instead of leaves at the top. So in this case here reverse direction will not happen. So the safe advantage of this unit that it will give you that low pressure drop and high volumetric flow rates. Whereas impeller type collectors or separators there in this case gaseous enter normal to many plated impeller you can say that and are swept out by the impeller that around its circumference as shown in the picture here. Surroundings the circumference you will see that particles will be moving downward and this particles will be thrown into an annular slot that around the periphery of that devices.

And then the principle advantage of this unit is that this actually unit is very compact in nature you can say that all the accessories to be designed in such way that it will be give you that compact design of this separator. And then before assessing that that cyclone separator for its particular size of that particles to be separated. In this case you have to assess those that particle separation based on its that efficiency of that cyclone. Now to define that collection efficiency consider a particle that entering the cyclone as shown in the figure here at r is equal to r 3 at any position you will see that if particles here in this cyclone separator inside the cyclone separator. Here you will see that this is the schematic of this cyclone separator or you can say that some view the top view of this cyclone separator and half of this cyclone separator the top view we can show here.

So, at a r radial position at r is equal to r 3 here suppose this particle is there. So, in this case we can say that at this r is equal to r 3 the particles will strikes the wall at theta is equal to theta f where is that theta here theta is equal to theta f this is the theta here. So, at r so this is the r position here and theta how does it make that angle here at any r position here. So, the particles velocity component at this location anywhere suppose here if I consider the particle hits outer wall at this position at theta is equal to theta f. So, in this case what are the basic components of that velocity of these particles.

Then you can say that there will be two components at this that will be one is the v theta and another one will be your v r. So, the radial velocity component is the terminal velocity of the particle when acted on by the centrifugal force f c. So, here on this particles there will be a force acting that is called a centrifugal force. So, this centrifugal force will be having two components because of this one is radial component of this velocity of this particle and also theta component of this particle velocity. So, in this way that particles will be moving inside the and after that you have to assess what will be the radial velocity that radial velocity can be calculated by this equation 1 it is given here is basically that this is the terminal velocity based on this centrifugal force.
Here the Equation(s)

$$v_r = \frac{F_c}{3\pi\mu d_p}$$

$$v_\theta = u = \frac{Q}{Wr(\ln r_2 / r_1)}$$

$$F_c = \frac{m_p v_\theta^2}{r} = \frac{\pi}{6}\rho_p d_p^3 \frac{v_\theta^2}{r} = \frac{\pi}{6}\rho_p d_p^3 \frac{Q^2}{r^3 W^2 (\ln r_2 / r_1)^2}$$

$$v_r = \frac{\rho_p Q^2 d_p^2}{18\mu r^3 W^2 (\ln r_2 / r_1)^2}$$

So, it is f c is equal to v r into 3 pi mu d p s this is your terminal velocity. So, v theta v r can be calculated from this centrifugal force and v theta is basically the actual that radial velocity here in this case. So, that can be calculated from this volumetric flow rate and also it is cross sectional area. So, based on which you will see that we can get this v theta after derivation from its geometry we are having this equation number 2 that is q by w r into ln r 2 by r 1. What is that r 2 and r 1? r 2 is that your outer diameter outer radius of this centrifugal separator and this here this is the inner core radius of this centrifugal separator.

And then you will see that that f c that f c how you can calculate this f c. So, f c will be equal to m p into v theta square by r and this is basically what pi by 6 rho p d p cube this is the mass of that particle and v theta square by r there that is theta component velocity at the radial direction and also you can say that you will see that after substitution of this v r and v theta here basically that v theta so we can get this equation number 3. And in this case v r also can be calculated after substitution of this velocity of centrifugal sorry value of centrifugal force from this equation number 3 then we are getting this v r that is radial velocity here. So, w is here width d p is the particle diameter u is the velocity and q is the volumetric flow rate and rho p is called that density of the particle. So, in this case we can say that the particles will be having the radial component of v r as rho p q square d p square by 18 mu r cube w square into ln r 2 by r 1 whole square whereas v theta will be as per equation number 2.

So, from this velocity component and what will be the that centrifugal force that also can be calculated based on this equation number 3. After that you can calculate what will be the trajectory of a particle in the cyclone and in this case you have to calculate what will be the distance that is travelled in the theta direction in a time interval d t. So, for a certain time you are going to operate this cyclone let it be considered here as time is d t. So, for that time interval in the theta direction how much distance that particles can be particles can be moved or particles is moving there. So, it will be v theta into d t this is basically r into d theta also the distance the particle moves in the r direction in time d t that will be is equal to d r is equal to v r d t.

Here the Equation

$$\frac{rd\theta}{dr} = \frac{v_\theta}{v_r}$$

Then over a time interval d t r d theta by v theta that will be is equal to d r by v r. So, this is the from geometry you can easily obtain and also from this relation we can have this equation here r d theta by d r that will be is equal to v theta by v r. Thus by dividing that v theta and v r we are getting this equation number 4. And then we can represent this equation number 4 as by d theta by d r that will be is equal to as shown in the equation number 5. So, if the particle enters the device at r is equal to r 3 and hits the outer wall at theta is equal to theta f then after integration of this equation number 5 we can have this theta f is equal to 9 mu w ln into r 2 by r 1 divided by rho p into r 3 by r 1.
Here the Equation(s)

$$\frac{d\theta}{dr} = \frac{18\mu W \ln(r_2/r_1)r}{\rho_p Q d_p^2}$$

$$\theta_f = \frac{9\mu W \ln(r_2/r_1)}{\rho_p Q d_p^2}\left(r_2^2 - r_3^2\right)$$

So, Q into d p square into r 2 square minus r 3 square. Here r 3 here as shown in the picture what is the r 3 and what is the r 2 it is shown in the diagram here and then r 3 will be from this equation number 6 can be obtained and which can be represented by equation number 7 as like this.

Here the Equation

$$r_3 = \left[r_2^2 - \frac{\rho_p Q d_p^2 \theta_f}{9\mu W \ln(r_2/r_1)} \right]^{1/2}$$

So here basically we can say that this r 3 distance whenever the particles will be initially at this position at r 3 so that r 3 can be calculated based on that geometry of this cyclone separator and also other physical properties and also geometry of the cyclone. So, here how that r 2 and r 3 at a position of that particles from its that outer wall or outer wall diameter or radius how it will be related that can be obtained by this equation number 7. And then after getting this r 3 value at a particular time at what position that particles will be there and what is the r 3 value if we know this from this r 2 r 3 and r 1 and r 2 we will be able to calculate what will be the collector efficiency or separator efficiency or it is called collection efficiency.
Here the Equation

$$\eta = \frac{r_2 - r_3}{r_2 - r_1}$$

$$\eta(d_p) = \frac{1 - \left[1 - \frac{\rho_p Q d_p^2 \theta_f}{9\mu W r_2^2 \ln(r_2/r_1)}\right]^{1/2}}{1 - r_1/r_2}$$

If the entering particle concentration and gas velocity are uniform across the cross section then ideal case we can say that the collection efficiency can be represented by the fraction of the particles in the entering flow that the outer wall before theta is equal to theta f. So, at theta is equal to theta f what will be the efficiency that will be depending on the time whereas before that theta is equal to theta f at a particular location initially you will see that when that particles in the entering flow entering flow what will be the fraction of that particles that fraction will give you that efficiency of that collection. So in that case that efficiency can be related to that geometry at position of that particles as well as other geometry of the system. So, that can be expressed by this equation number 8. So, eta will be is equal to r 2 minus r 3 divided by r 2 minus r 1.

So, if we substitute the value of r 2 r 3 and r 1 r 3 already we obtained by equation number 7 here. So, in this case if we substitute this r 3 value here. So, eta can be calculated or it can be simplified which can be represented by this equation number 9 after simplification you will get this and from this equation 9 you can easily calculate what will be the collection efficiency. Now this collection efficiency that depends on that geometry of the system and also you will see that there will be a particle size, particle density and flow rate of the gas also at what position that particles there that also will be affecting on this efficiency of the collection. Suppose that you are getting that 100 percent efficiency in your ideal case.

So, the particles will be located at what position that means at what value of theta or you can say that at what value of r 3 that particles will be positioned so that their efficiency of the collection will be 100 percent. So, in that case we can calculate it from this equation number 9. So, there if we substitute that eta will be is equal to 1 that means 100 percent efficiency and then r 3 will be is equal to r 1.

Here the Equation

$$\theta_f = \frac{9\mu W \ln(r_2/r_1)}{\rho_p Q d_p^2}\left(r_2^2 - r_1^2\right)$$

$$\frac{F_c}{F_g} = \frac{Q^2}{g r^3 W^2 \ln(r_2/r_1)^2}$$

$$F_c / F_g >> 1$$

$$F_g = (\pi/6)\rho_p d_p^3 g$$

So in that case theta f can be calculated from equation number 9 as here it will be as 9 mu W ln r 2 by r 1 divided by rho p q dp square into r 2 square minus r 1 square. So, at this theta f value you can get ideal cyclone separator which give you that 100 percent efficiency for separation of the particles that means all the particles will be separated by this cyclone separator for a particular operating condition and that condition that theta f will be is equal to this as per equation number 10.

Now if we consider that at this 100 percent efficient system of the cyclone separator, so what will be the centrifugal force and if we compare with the gravitational force then we can have this factor of this centrifugal force in terms of the gravitational force. So, that ratio that centrifugal force to the gravitational force can be obtained from this equation number 11. So, after simplification of this substitution of f c and f g value at this 100 percent efficient condition we are having this the ratio of the centrifugal force to the gravitational force. So, from this ratio you can say whether it will be greater than 1 or less than 1. If suppose this f c by f g is more than 1 then you can say that the centrifugal force will be more effective compared to the gravitational force there.

So, that is why you can say that particles will be having the enough rotational speed or you can say that having enough inertia so that it will thrust on the wall and after reversing that thrust the gravitational force will be acting on the particle. So, in that case the centrifugal force also to be designed or to be normalized in such way that what will be the material strength of that wall that also to be considered there. Also that what will be the smoothness factor of that wall that also important. So, accordingly that centrifugal force to be designed based on that gravitational force. So, based on these ratio you have to design that system you have to design that system where you have to maintain that f c will be far more than gravitational force.

Now coming to that another point that what are the factors basically effect on that cyclone collection efficiency. One is told that particle size another will be that particle density that particle density and what will be the inlet gas velocity, cyclone body length, number of gas revolutions is important and smoothness of the cyclone wall. Also you will see that other factors like what is the diameter of that cyclone and also what will be the gas outlet duct diameter that means through which that gas will be entering to that cyclone what will be the cross sectional area of that duct or what will be the hydraulic radius or hydraulic diameter of that duct that should be known and that will effect on that collection efficiency. Also what will be the gas inlet area that is basically coming as that whether it is cross sectional area or whether it is a hydraulic diameter to be considered for that getting for that gas outlet area or not that depends on that whether it will be cylindrical in shape or that channel type or you can say that rectangular shape of that inlet. So, based on who is that you have to calculate the hydraulic diameter and based on who is you have to calculate what will be the area.

If it is cylindrical simply that that cross sectional area you can calculate if you are having that rectangular cross section then you have to consider their hydraulic diameter or simply that what will be the perimeter and or also you can say that width and breadth of that duct or that rectangular cross section. Now all those factors how it will be effecting on that collection efficiency. You will see that this collection efficiency will be increased with increasing particle size with increasing particle density with increasing inlet gas velocity with increasing cyclone body length with increasing number of gas revolutions with increasing smoothness of the cyclone wall. Also this collection efficiency will be depending on the cyclone diameter gas outlet duct diameter even gas inlet duct diameter or area. So, in that case collection efficiency would be decreasing if you increase that cyclone diameter if you increase the gas outlet duct diameter or if you increase the gas inlet area.

So, these are the some factors which will be taken care for the design of that cyclone separator. So, here you will see that the design of a cyclone separator that will represent a you know compromise version among collection efficiency pressure drop and size based you know design. So, in that case higher efficiency required you will see that higher pressure drop for a particular that cyclone separator. In that case of course that inlet gas velocity will be more higher because your higher pressure will be required there and in that case larger sizes that means here you will see that sometimes you have to increase the body length of that cyclone separator. So, to get that higher efficiency of that cyclone separator you have to increase the body length of that cyclone and also you have to increase the pressure drop just by increasing the inlet gas velocity.

Also there will be a certain limit of that gas pressure drop to be followed that also depends on that capacity of that cyclone separator also load also you can say that material strength. So, cyclone pressure drops generally to be maintained or you can say that followed within a certain range it is generally 250 to 4000 Pascal there. And then there was a certain standard cyclone design based on which you can procure that cyclone separator for your application. So, in this case optimum dimensions required to specify a tangential entry reverse flow cyclone which are shown in this diagram. In this case you will see that number of revolution that will be followed just by gauging that what actually flow rate of the gas will be there, how that gas will be making that outer vortex that will be solved based on that efficiency and also other physical and geometrical variables.

So, in that case number of revolutions that the gas makes in the outer vortex can be approximated by equation number 13.

Here the Equation

$$n_r = \frac{1}{H_c}\left(L_c + \frac{Z_c}{2}\right)$$

So, where the dimensions are shown in the figure. So, here you will see that cyclone dimensions that its optimal operating condition you can say you can design in such a way that standard design of that cyclone separator would be like this. Here BC as shown in the picture the BC will be is equal to DC by 4, where this is the diameter of this cyclone body here and you will see that BC is basically that entry duct length here. So, it will be DC by 4 and DE here you will see that core region through which that gas will be coming out from that cyclone separator the diameter is DE that will be is equal to DC by 2 and AC that AC is basically what that here this entry of this duct that is height of this entry region of the duct it will be DC by 2 and LC is the length of this body of this the cyclone separator it will be two times of that diameter of that cyclone and SC is shown here SC here this is the length SC this portion which part of this that central core up to depth which depth it will be kept inside that cyclone separator.

So, it will be SC which will be one-eighth of DC and ZC is basically that conical region of that cyclone part the length is ZC it is generally twice of that diameter of this cyclone and ZC is the outlet duct of that particle that will be basically one-fourth of that DC. So, this is the standard dimensions of the cyclones and also you can assess this cyclone efficiency based on some empirical correlations that empirical correlations are developed based on that experimental data and here this case Leith and Leach 1972 they have suggested one empirical equation for the prediction of collection efficiency of this cyclone separator and they have done or they have suggested this correlation based on the velocity profile in a cyclone. In that case they considered that the particles should not that adhere strictly to the ideal form of that cyclone. So, in that case that particles may not be having that ideally separated in well form that means here you can say that the particles would not be having that uniformly mixed inside the separator or there will be no that certain fashion or flow pattern of that particles inside the cyclone separator there will be a random motion there will be no uniform distribution of that particles inside the bed. So, that is why based on that experimental data they have developed this semi empirical equation it is not that from that basic mass balance or energy balance equation here.

So, they have considered that the general form of the velocity profile inside the you know cyclone that will be is equal to u theta into R to the power n that will be is equal to constant.

Here the Equation

$$u_\theta r^n = \text{Constant}$$

Here n is a constant here some coefficient that may be vary according to that operating condition and according to this condition and after derivation here it is not given this derivation. So, they finally obtain this final form of efficiency equation as an empirical form as eta into dp that will be is equal to 1 minus exponent of minus m into dp to the power n. Here this capital N is basically 1 by 1, 1 plus n.

This n is basically a coefficient which depends on that some operating condition like you know temperature of the system at which temperature this operation will be done and also what will be the diameter of that cyclone that also effect on this coefficient n.

So, that diameter of this cyclone will affect that velocity profile inside the cyclone. That is why they have considered that this u theta into R to the power n should be constant where n will be as a function of dc and temperature. So, from equation number 7 you can get this value of coefficient n. And also another important factor is called m. This m is also that empirical constant here is given in equation number 15.

Here the Equations

$$\eta(d_p) = 1 - \exp\left[-Md_p^N\right]$$

$$N = 1/(n+1)$$

$$n = 1 - (1 - 0.67D_c^{0.14})\left(\frac{T}{283}\right)^{0.3}$$

$$M = 2\left[\frac{KQ}{D_c^3}\frac{\rho_p(n+1)}{18\mu}\right]^{N/2}$$

And this factor also depending on that operating condition like what will be the flow rate, what will be the diameter of this cyclone, what will be the density of the particle and also what will be the effective viscosity of that particle laden gas that is entering to the cyclone. And also it depends on that empirical constant that is coefficient small n here as given in equation number 17. So, you will see that this empirical equation of this you know collection efficiency depending on that physical property as well as geometry of the cyclones. So, once that geometry and operating conditions you will be able to calculate from this equation what will be the collection efficiency. Let us do an example from this theory of that collection efficiency of the cyclone.

So, in this case consider a cyclone having W that will be equal to 4 meter and Q volumetric flow rate of the gas is 20 meter cube per second. Inner and outer radii of 0.5 meter and 1 meter respectively and an angle of turn of 12 pi. So, assume that the particle size range of interest is from 1 to 30 micrometer and that the particles have a density of 2 gram per centimeter cube. The relative dimensions of the cyclones are these given in cyclone dimensions earlier and in this case assume that temperature will be 293 K.

So, you have to calculate what will be the efficiency of the cyclones either based on that theoretical equation for the cyclone efficiency or collection efficiency or by leach and litt correlations that is given in equation number 15. So, by those two equations you will be able to calculate what will be the efficiency. Now, if you substitute the value of given parameters here in this problem, you will see that this efficiency will be depending on the particle diameter. Here particle diameter is not given to you.

Rather you can get all other parameters. So, if you substitute all other parameters except dP you will get this equation number 9 only in terms of dP along with other coefficient. Whereas numerical or empirical value of equation 15 based on the equation of 15 also it will be a function of diameter dP. So, if we calculate this efficiency by changing the diameter of the particle then what would be the actually profile of that efficiency. Now, it is shown here in this slide that if we change the particle diameter from 0 to 30 you will see that the efficiency based on that equation number 9 it will be coming as that like this. Whereas from the empirical equation you can get this efficiency like this.

So, both the cases you will see that the efficiency will be different whereas at a certain particle diameter there will be a same. So, within a certain you will see that within a certain you know range of those particle diameter you will see that the efficiency of that cyclones assessing by these two model equations will be different. So, it is better to follow that theoretical model instead of that empirical model there. So, empirical model will give you that certain fashion of that certainly you will see that after a certain particle diameter efficiency will be constant. But it is not expected because that theoretical model that always it will be a certain radial condition there is certain you know geometrical condition and also other factors energy whatever it will be there distribution inside that separator and also that you will see that uniformity of that particle movement inside the bed will be there.

So, based on those consideration of profile of that particles movement inside the bed that theoretical model as per 9 equation number 9 it will be followed. Whereas you will see if there are more than you will see that or you can say there are more variables simultaneously affecting on that efficiency of that that cyclones. So, in that case it is better to follow that empirical equations because here these empirical equations will give you the overall value. In that case just averaging of all other factors either mixing characteristics or uniformity of the particles or other properties of the particles physical property or other thermodynamic properties of the particles if they are affecting on that case. So, it will be better to use this then empirical model instead of that theoretical model.

But theoretical model sometimes it is very difficult to consider that some other operating variables. So, in that case more operating variables where there will be involving and also if it is a very complex system inside that cyclones. So, in that case empirical model will be more accurate to predict that collection efficiency. Then another one separation by centrifuge here also we will see that it uses the centrifugal force to separate particles that contained in a solution.

Here we will see the solution will be considered here. The particles are segregated depending on their size, shape, density and also the speed. The mixture is separated through spinning here. Here we will see that this animation that the solid particles will be allowed to enter to that basket spinning basket you will see that inside and the basket will be rotating at a certain rotational speed and during that rotational speed you will see that the particles will be you segregating at the wall and you will see that along the wall of that centrifuge you will see that there will be some membrane through which that liquid will be passed whereas that solid particles will retain on that membrane surface. So, during that centrifugal action you will see that liquid will be passing through that force of the membrane which is attached the side of that centrifuge whereas higher than the pore size the materials will be retained on the one side of this membrane which will be taken out from this collector. So, in this case the centrifuge also will be acting based on that centrifugal action which will be acting on the particle and it will give you that separation based on that retaining of that particles after stacking on the surface of the membrane here in the centrifuge.

Here also you will see some factors which will be influencing that centrifugation the density of both the solvent and the solution you can say which are being used along with the particles and also distance of the suspended particles displaced from their original position and also you will see the temperature of medium viscosity of medium speed of rotation of the centrifuge these are the factors that will be affecting and also the centrifuge consists of a rotor enclosed in a centrifugal separator. There you will see that there will be certain electric motor to be acted upon based on which that centrifugal action will be generated and the centrifuge uses that centrifugal force in order to differentiate between the different phases of varying densities. The centrifugal force is observed to be proportional to the rotational rate of the rotor. The centrifugal acceleration you will see that makes the suspended particles move in a tangential direction towards the outward direction there. Here in this case you will see that the technique of that centrifugation is dependent on the fact that if we turn any object at a steady angular velocity that is moving across a circular motion it is subjected to an outward directed force say F here.
Here the Equation

$$F = m\omega^2 r$$

$$G = mg$$

So what is that force centrifugal force F that will be equal to m omega square R and the gravitational force will be mg and the separation factor which can be obtained from these two force that will be regarded as S which will be basically ratio of this centrifugal force to the gravitational force and this is obtained just by dividing these two force after substitution of their values here. So finally it will be coming as u square by Rg. So this is your separation factor. So based on this separation factor you will be able to calculate what will be the separation efficiency.

Here the Equation

$$S = F / G = [m\omega^2 r]/[mg]$$
$$= \omega^2 r / g = (u/r)^2 r / g = u^2 / (rg)$$

Now let us do an example here suppose a centrifuge of diameter 0.2 meter in a pilot plant that rotates at a speed of 50 Hertz in order to achieve effective separation. If this centrifuge is scaled up to diameter of 1 meter in the chemical plant and the same separation factor is to be achieved what is this rotational speed of the scaled up centrifuge. Here you have to calculate the rotational speed of the scaled up centrifuge. So here the separation factor what is that omega square R by g. So in this case since you are scaling up this centrifuge so there you have to keep that ratio that is separation factor will be same that means ratio of centrifugal force to the gravitational force to be constant.

So in that case we can write here omega 1 square R1 that will be equal to omega 2 square into R2. So from which we can get omega 2 that will be equal to root over omega 1 square R1 by R2. Here omega is basically the rotational speed. So omega 1 it is given to you and also R1 is given to you R2 also it is given. So as per those values if you calculate you can get this omega 2 will be equal to 22.

36. So if you scale it up your rotational speed of the scaled up centrifuge will be 22.36 Rps. So I think you understood that the vertical separation by cyclone separator and centrifuge and what are their basic principle and also how to calculate the efficiency of the collection of the particles by that centrifuge as well as that cyclone separator. So we will discuss more about this particle separation by other mechanism. In the next lecture we will try to discuss about the particle separation by electrostatic precipitator. So thank you for giving attention. Have a nice day.