

Lec 23: Particulate Matter Separation by Gravity Settling Chamber

Hello everybody, welcome to this massive open online course on solid-fluid operations. So, we are discussing about the particulate matter separation by different techniques. This lecture we will try to learn something about the how to separate that particulate matter by gravity settling chamber. And here we will discuss that very fine particles whenever it will be suspending in air or open atmosphere or that is coming out from that industry as an effluent from the chimney or outlet of that particular process unit. So, those particulate material, those have the size very fine that means micron size, micron in range you can say. So, those particles actually is regarded as pollutant, okay.

So those pollutants, how it can be separated, those are actually to be discussed here and there are several methods to separate those particles. I think we have discussed also in the previous lectures that there are several methods are available to separate those particles. One of the method that we have discussed that the screening method but those screening operation is basically applicable for coarse- particles whereas the fine particles those are suspending in the atmosphere or it is coming out from the outlet of that particular process unit in industry. In that case how those solid particles to be separated, for them you will see that several techniques like that gravity chamber, electrostatic precipitator, bag filter, even you will say that other methods like plate and filter and press processes or plate filter or membrane technology, those are actually being used in industry to separate those particles either from air or you can separate it from the solution in a slurry, solution of solution or slurry you can say.

So in that case you have to know that what type of materials or what are the size of that materials to be there in that slurry or in a solution or in atmosphere. You will see that this particulate matter based on the size those are very fine, it is called as pollutant in atmosphere which will be consisting of a mixture of solid and liquid or you can say that solid liquid in mixture, there itself you will see that particles will be of different type like some will be inorganic, some will be organics that will be suspended in air or liquid or in a mixture of air and liquid. So in that case the particulate matters are mainly the products of combustion and aerosols nucleation. So these are the techniques by which that particulate matters is coming out from the industry like in combustion system, in fluidized bed reactor that we are discussing. In industry where that in power plant that burning of coal will produce that steam or gaseous product from that gaseous product or steam that power or electricity generated.

So there when that coal will be burnt there you will see that very fine particulate matters will be coming out that is as a ash you can say also. So those are very fine, those you will see that floating or it will be coming out from the outlet, they are from the chimney, those will be going to that atmosphere as a carbonaceous particle or some other small fine particles there. So in that case you will see that those particles to be segregated by a certain means. Also you will see that in atmosphere, open atmosphere generally you will see that when very fine droplet of water that is inorganic substances of that droplet it will be that

suspending in the air or very fine particles which will be suspending in the air that will be called as aerosols. So that aerosols also it will be formed by nucleation and it will be suspending in the atmosphere.

So from the combustion and also that aerosol nucleation whenever particulate matter it will be coming out to the open atmosphere you will see that those particles to be you know separated. So in industrial sector they are you will see that they are responsible to separate all those particles otherwise those particles if we inhale you will see that all those particles will be coming to our lungs and then it will be harmful for our breathing system and also other diseases will generated there. So in that case those to be separated and you will see that generally in atmosphere there are very fine particles generally around 2.5 micron in size. So it will be regarded or called as that particulate matter 2.

5 it is denoted by this PM 2.5 that means your particulate matter of size around 2.5 micrometer. And the aerosol commonly refers to the particulate or air mixture there so those also are very harmful for our health so those to be also segregated or separated by different means. Now in this case what are the basic principle to remove all those particulate matter? So in that case there are different types of devices are basically designed based on particulate principle basically on the principle that a gas stream which actually contains that particles are very fine in size that will be passed through a region where the particles are acted on by external force and hence because of that driving force by that external force the particles will be separated from that mixture of that stream that contains that particulate matter.

So basically a design of a device that will be done for that separation of particulate particles where that external force will be applied to pass that particle laden air stream through that equipment and whenever it will pass through that equipment there will be a certain governing mechanism based on which that particulate matter can be separated from the particle laden stream. So that mechanism either maybe based on that particle size either maybe based on that characteristics of the particle like the properties of the particle either it will be that magnetic in nature or that ionic in nature or other properties will have that materials or not or you can make this particle particulate material into a certain property oriented material so that those property oriented materials can be segregated from that air stream. So these are the mechanism basic mechanism you will see that based on that mechanism there are several equipment or devices are designed to separate those particles. So when that acted upon by external forces on these particles you will see that the particles acquire a velocity component there inside the equipment that will be in a particular direction that will be different from that of a gas stream. So whenever the particle laden gas will be passed through that equipment the particles will acquire a certain velocity component by that external force in the direction that will be different from that mainstream of the particle laden gas stream or other stream.

So in this way that particles can be separated. Now to get this velocity component by that

external force. So this is one mechanism another mechanism to change the direction of the particle materials based on that size that is by gravity force. Also the direction of that particulate material can be changed by its property like that if you see it is ionic then you will see that some provision will be made if it is anionic then some cathode or anode electrode will be placed or devised in such a way that those negative ion particles will be going to the cathode like positive ion electrode. Whereas negative ion based particles will go to the that in the positive electrode.

So in this way you will see that there will be a change of direction of that particles from the mainstream based on their property as well as this gravitational force or particle size or other external forces. So in order to design a separation device based on particulate separation by external forces one must be able to compute the motion of a particle under such circumstances. So this is the principle of that particulate material removal. Now in this case you have to remember some important points for design of that equipment which is called that emission control system. You will see that design of a particulate emission control system is generally based on knowledge of 4 items like that particulate concentration is one of the component of that in the stream which is to be cleaned and also the gas flow rate this is very important and the size distribution of the particles which is to be removed and the final allowable particulate emission rate.

So these are the 4 components which is to be considered for design of that emission control system. So other than these points of course you will see that total cost of the construction, size of the collector, operational factors to be also considered. Now what are those total cost of construction? You will see that total cost of construction actually depending on the volumetric flow rate of the gas which is to be cleaned. So it is directly proportional to the volumetric flow rate of the gas. Also size of the collector, it is also directly proportional to the volumetric flow rate of the gas which is to be cleaned and other operational factors like what will be the pressure drop of that equipment whenever it will be operated, what will be the power consumption, what is the power required for that, that will come from that frictional pressure resistance which is exhibited by that equipment when it will be run.

And then you will see that other important points that you have to remember that quantity of liquid which is needed, either liquid or gas stream, you will see that it is basically special cases for the wet scrubbing system. You will see that in some cases you will see that some particulate materials to be separated from the open atmosphere just by flowing it through a dispersed phase of droplet. That means from one position that liquid will be spread, that liquid will be in such a such compound that which will be having that adsorption capability of those particulate materials. So that liquid as a solvent to be spread inside a device where you will see that particulate laden gas system to be passed through that devices counter-currently so that whenever that droplet of that solvent will come into contact with that particulate laden gaseous stream, those particulate materials will try to attach on the surface of the solvent droplet or liquid droplet on which it will be adsorbed or attached. So

in this way that particulate matter can be separated.

So for that you have to know how much amount or what will be the flow rate of that you know liquid which will be spread as a droplet for that scrub scrubbing system. So these are the operational factors, okay? So main factor that total cost of the construction which will be actually affecting which will be affected by volumetric flow rate of the gas or liquid and also you will see that pressure drop also that what will be the power consumption for that operation. So these all are to be considered for the design of emission control system for separation of the particulate material. Now we are talking about that different mechanism by which that particulate matter is to be separated by that special devices which is actually designed based on that principle of that particulate matter movement or the properties of the particle or you can say that other driving forces on the particulate matter. So in that case one mechanism it is called sedimentation.

So here in this case the devices which are being designed to separate those particulate materials from the gas stream rely on one or more of the following physical mechanism. One is called sedimentation, another is called you will see that electrostatic or that it is called electrostatic precipitator; you will see that membrane separator; you will see that there will be it is called that also it is called lip filter process also you can say that it will be that another special design that of magnetic induction precipitator like that. So there are different mechanism, mainly that four mechanisms are there sedimentation, migration of charged particles in an electric field and then inertial deposition and then also Brownian diffusion. So these are main broad classification of that mechanism of that separation of that particulate matter. So in this case first of all we will say that sedimentation, this is basically that particles containing gas streams is introduced into a device or chamber where the particles settled under gravity to the floor of the chamber and devices of this type are called settling chambers.

We will come to that point in details of that settling chambers. And then another mechanism it is called the migration of charged particles in an electric field. So, that particle laden gas stream is introduced into a device in which the particles are charged and then subjected to an electric field. In this case that resulting electrostatic force on the particles causes them to migrate to one of the surfaces of the device where they are held and collected. So in this case you will see that whenever particle laden gas stream to be passed to the devices those particles will be ionized first.

After that those ionized particles it will be change its direction to the anode or cathode which is actually made a provision just by in presence of electric field. So because of that you will see that the ionized particles to be shifted to that you know cathode or anode based on that what type of ionic particles to be produced. So this is the main mechanism. So it is called that migration of charged particles in an electric field. This is one mechanism and this type of devices are called electrostatic precipitators.

Then third one is called inertial deposition. So in this case you will see that that particle laden gas stream change the change the direction as it flows around an object in its path. So in its path there will be some object which will be changing its direction and there you will see that suspended particles tend to keep moving in their original direction due to their inertia. So particle laden gas it will be passed through the devices where you will see there will be some obstruction to be made in front of that or you will see that in the path of that particle laden gas. So whenever that particles will be get obstruction or resisted by that obstruction mechanical devices or you can say mechanical provision there itself you will see that particles will be stopped its flow and it will be go downward along the side of that mechanical provision.

Whereas the gas will not be moving downward that will be changes direction you know in other way. So in this way particles would change its direction in one way and another way that gas would be passing away. So in that case the particulate materials will be collected in the devices based on this principle include like cyclones or scrubbers and filters like that. So you will see that membrane there you will see that membrane you will see that when that particle laden liquid it will be passed through that membrane. Membrane is basically the porous media through which that particle laden liquid or gas will be passed through and they are based on that pore size of that membrane the particulate materials will be start or it will be separated in one end of this membrane whereas through that pore the liquid will be passed through.

So based on that particle size and pore size of that membrane particles will retain in one side of the membrane whereas the liquid will be passing through that membrane. So in this way that particles will get that resistance to flow based on their size and it will be retained in one end other whereas liquid which will be you know passing through that pores and then the separation will happen. So this is called inertia deposition mechanism. So in this case we can say that there are several other devices are being designed to separate those particulate materials from the air stream or liquid stream those are called cyclones, scrubbers and filters like that. Then another mechanism it is called Brownian diffusion.

In this case particles suspended in a gas are always in Brownian motion that we know like open atmosphere. When the gas stream flows around obstacles the natural random motion of the particles will bring them into contact with the obstacles where they adhere and are collected. So in this case this is the particulate materials will be adhere on the surface of the solid which is made provision to get obstruction of that materials onto the surface and then it is attached. So because we know that the Brownian motion is more pronounced the smaller the particles we expect that devices based on diffusion as the suspension mechanism will be most effective for small particles. So in this case particle size will be very very fine.

So in that case due to their Brownian motion whenever that particles will come in contact with that surfaces on which that particles will be adsorbed or you can say that attached on

the surface. So based on that principles the device will be designed. So it is called Brownian diffusion based on which that particle materials, particulate materials will be separated on the surface. That surface may be that made more effective to attach those particles based on the you know properties of the surface. Now which surface will have the more tendency to attach those particulate materials.

So in that way those surface can be modified either chemically or physically there. So the key parameter that influences the choice of which device to employ in a particular case is the particle diameter that is dP. So dP is one of the important criteria based on which you can select what type of device you can use for separation of those particle or specific particles to separate. So, we are having different that type of equipment or devices those are commonly used in industry for separation of the particulate material. Those are called settling or gravity chamber, electrostatic precipitators, cyclone filters, wet scrubbers or devices.

Even in industry some you will see that that will be that bag filter or leaf filter is what it is called. Now whenever you are going to assess those equipment by which that particulate materials to be separated you have to what would be the collection or removal efficiency of the equipment. So how to assess, how to estimate that you have to know. So collection efficiency generally denoted by eta which is a function of particle diameter of a device for particles of diameter dP that can be defined by this equation. This is basically 1 minus number of particles of diameter dP per meter cube of gas out divided by number of particles of diameter dP per meter cube of gas in.

Here the Equation

$$\eta(d_p) = 1 - \frac{\text{number of particles of diameter } d_p \text{ per } m^3 \text{ of gas out}}{\text{number of particles of diameter } d_p \text{ per } m^3 \text{ of gas in}}$$

as 1 minus number of particles per meter cube of gas out by number of particles per meter cube of gas in.

Here the Equation

$$\eta_{ov} = 1 - \frac{\text{number of particles per } m^3 \text{ of gas out}}{\text{number of particles per } m^3 \text{ of gas in}}$$

So in this way you can say that what would be the overall efficiency can be calculated. Now if you are having that in the outlet or inlet there will be a certain distribution of the particle particulate materials which is coming into the devices and which is also coming out from the devices you will see there will be a certain range of particles in that inlet and outlet. So there will be some distribution of that particulate materials. So based on that particulate material distribution or size distribution this efficiency also can be expressed in terms of that particle size distribution function at the inlet and outlet sides of the devices.

So this efficiency can be defined based on that particle size distribution as like this here. Here it will be that 0 to infinity it is defined as the eta in dP that means here what will be the efficiency of that devices at its inlet condition based on that particle size distribution whose function is ni in dP and minus eta out dP into d dP divided by 0 to infinity ni dP d dP.

Here the Equation

$$\eta = \frac{\int_0^{\infty} [\eta_{in}(d_p) - \eta_{out}(d_p)] dd_p}{\int_0^{\infty} \eta_{in}(d_p) dd_p}$$

$$= 1 - \frac{\int_0^{\infty} \eta_{out}(d_p) dd_p}{\int_0^{\infty} \eta_{in}(d_p) dd_p}$$

So this is actually based on that that efficiency at the inlet and efficiency at the outlet efficiency at the inlet. So we can write here that 1 minus 0 to infinity eta out dP d dP by 0 to infinity eta in dP d dP. So this from this equation number 3 you can calculate what will be the efficiency of that devices based on that particle size distribution.

Now the definition of overall efficiency above is based on particle number. The overall efficiency can be defined based on the other particle properties such as surface area and the volume or mass. For example the collection efficiency based on the particle mass that is eta m you can say that so eta m dP that will be equal to 1 minus mass of particles of diameter dP per meter cube of gas out divided by mass of particles of diameter dP per meter cube of gas in.

Here the Equation

$$\eta_m(d_p) = 1 - \frac{\text{mass of particles of diameter } d_p \text{ per } m^3 \text{ of gas out}}{\text{mass of particles of diameter } d_p \text{ per } m^3 \text{ of gas in}}$$

And then overall efficiency again based on that mass of the particles can be expressed by this equation number 5.

Here the Equation

$$\eta_m = \frac{\int_0^{\infty} \left[\left(\frac{\pi}{6} \right) \rho_p d_p^3 \eta_{in}(d_p) - \left(\frac{\pi}{6} \right) \rho_p d_p^3 \eta_{out}(d_p) \right] dd_p}{\int_0^{\infty} \left(\frac{\pi}{6} \right) \rho_p d_p^3 \eta_{in}(d_p) dd_p} = 1 - \frac{\int_0^{\infty} \eta_{out}(d_p) dd_p}{\int_0^{\infty} d_p^3 \eta_{in}(d_p) dd_p}$$

Then another important point that you have to remember sometimes the collection efficiency the efficiency of the equipment can also be referred by other times other terms like that penetration grade efficiency like this.

In this case the term that is sometimes used to express collection efficiency is called the penetration. In this case the penetration based on particle mass is just P_m that will be equal to $1 - \eta_m$ and other terms that are used for this quantity are the grade efficiency or the fractional efficiency and the penetration is based on the amount of emitted rather than captured. So, you have to remember that the penetration can be defined on the basis of particle number also. So, it will be P_n is equal to $1 - \eta_n$ based on that number distribution. So, it will be $1 - \eta_n$ at the point here η_n is equal to 0.

5 where that efficiency will be 0.5 is called the cut size or the cut diameter. So, the particle diameter at which that you can get that efficiency of the devices it will be called as cut diameter. So, these terms also you have to remember. Then coming to the point that settling or gravity chambers by which you are able to separate those particulate materials based on that gravitational force. So, this is basically a very simple and large box through which the effluent gas stream will be passed and you will see that there the particles in the stream will be settled to the floor of that gravity chamber here, okay? By gravity action and here in this case that you will see that whenever that particle lead and gas will be coming through this chamber that is large size the particles will be you know flowing very laminar condition and during that laminar condition those particles will have that higher gravity will be coming down in this chamber whereas other particles will flow because of that inertia effect and those will be separated in other chamber based on that its particle size.

So, if you have that particle size higher it will have that higher gravity whereas the lower particle size will give you the lower gravity and because of that lower gravity the finer particles relatively finer particles will go ahead compared to that its position leaving the other bigger size particles and it will be separated based on this. So, in this way this gravity chamber is being used to segregate those particles based on their size and this size will give you the gravity force and based on that gravity force difference those particles will be separated in a different location where you will see there will be certain degree of inertia will be applied here, okay? So, in this case you can separate these particles but there will be some limitation in this case, in this case the removal of particles larger than about 50 microns you know is possible whereas less than 50 microns it is very tough to get the separation. And you will see that settling chambers also will have some advantage here in this case it is very simple construction and low cost and in this case you will have that small pressure drops their energy consumption will be less than the main disadvantage of the settling chamber is that large space is required to separate those particles. And basic idealized flow situations will give you that difference in that operation of this settling chambers. So the some that settling chambers will operate based on that laminar flow, some settling chamber will operate as a plug flow where velocity will be uniform across the cross-section where there will be no vertical mixing of that particles inside the chamber and also there will be some settling chamber where plug flow with complete vertical mixing of that particles will be there. So these three categories can be assessed of those settling chamber based on which that settling chamber working.

If we talk about that laminar flow settling chamber there you will see that the particles will be flowing with a velocity which will have that velocity profile almost parabolic in type and such flow would only be realized when that Reynolds number will be below that for transition to turbulent flow. So in this case of laminar flow you will see that the time required for a particle of height y here as shown in the picture above the floor of the chamber to settle it will be as y by u_t . So that means y by u_t , y is the height of the chamber. So what will be the time required for that particle of height y above this floor of this chamber to settle that will be calculated as what is the distance it will be travelled to come to this bottom of this chamber at the velocity u_t . u_t is basically the terminal velocity of that particle.

So the time required to settle down to this bottom of this chamber will be equal to y by u_t . So where u_t is the particle settling velocity or terminal velocity. Now in this case how will you calculate the collection efficiency of this settling chamber. So it will be $\eta(d_p)$ that is defined by $\frac{3\beta}{2\alpha}$.

Here the Equations

$$\eta(d_p) = \frac{3\beta}{2\alpha} = \frac{u_t L}{u H}$$

What is beta? Beta is defined as $\frac{2}{3} u_t \bar{u}$ and alpha is $\frac{H}{L}$ and u_t is that means terminal velocity at this laminar condition.

Here the Equation(s)

$$\beta = \frac{2}{3} u_t \bar{u}$$

$$\alpha = \frac{H}{L}$$

$$u_t = \frac{\rho_p g d_p^2}{18 \mu}$$

velocity or terminal velocity of the particle which is basically a function of size of the particles and also length of the chamber also what will be the average velocity by which that particles will be flowing through the chamber. If you allow that particle laden gas stream at a particle volumetric flow rate then you have to divide that volumetric flow rate by the cross sectional area of this settling chamber. Then you will have that average velocity of the flow of that particle laden gas stream through the chamber. So all those parameter will give you that collection efficiency by this definition as given in equation number 6 along with that terms which is defined in equation number 7, 8 and 9 respectively.

Here the Equations

$$\beta = 2 \frac{u_t}{\bar{u}}$$

$$\alpha = \frac{H}{L}$$

$$u_t = \rho_p g \frac{d_p^2}{18 \mu}$$

So here we can have that the terminal velocity, average gas velocity, height of the chamber, length of the chamber, particle density, particle size and viscosity of the gas stream which will affect that collection efficiency.

Let us do an example for this here. Consider a settling chamber for which height is 0.1 meter and l is equal to 10 meter, length is 10 meter where the gas system is flowing with an average velocity 0.1 meter per second and particle density is given 1 gram per centimeter cube at 298 Kelvin temperature viscosity is 1.8×10^{-4} gram centimeter inverse second inverse.

The kinematic viscosity of the air is 0.015 centimeter square per second. Under these conditions the Reynolds number for the channel flow is found to be 667.0 so that the laminar flow conditions will prevail. Now in this case after substitution of those parameters in the efficiency equation we can have 0.

0.3024 dP square, here dP is unknown to you. So this efficiency will be depending on that particle diameter provided that other parameters is known to you. And in this case the dP will be in micrometer. So thus for this particular conditions the collection efficiency will be changing with respect to particle diameter. So how it can be then calculated if you substitute the value of dP, different value of particle size then you will get different efficiency. So here if we increase the particle size you will see that efficiency of the settling chamber will increase.

So that settling chamber will give you the better efficiency if your size of the particles will be higher. Then coming to that another condition, flow condition of that settling chamber it is called plug flow condition where you will see that there will be no particle mixing of the particles and the particles will be distributed uniformly across the entrance to the chamber. And in that case the collection efficiency is then just as per that laminar condition you can say it will be $u_t L$ divided by $\bar{u} H$

Here the Equation

$$\eta(d_p) = \frac{u_t L}{\bar{u} H}$$

almost the same way that you are having in your laminar condition. So the same as that laminar flow settling chamber it will work because in this case the parabolic velocity profile

case even though the particle falls across the streamlines with different velocities the particles are simply falling across the streamlines with the mean velocity of the flow. That is why the plug flow settling chamber will be working as per the principle of laminar flow settling chamber.

Then coming to that turbulent flow condition of that settling chamber. In this case the flow in a rectangular channel like settling chamber can be assumed to be turbulent if the Reynolds number will be greater than 4000. Here Reynolds number will be based on that chamber dimensions, chamber hydraulic radius. So here this Reynolds number is defined as $4 R_s \bar{u} \rho / \mu$

Here the Equation

$$Re_c = \frac{4r_H \bar{u} \rho}{\mu}$$

here R_s is basically that hydraulic radius, hydraulic radius will be defined as by this equation 12 here r_H is equal to hW divided by 2 into $h + W$,

$$r_H = \frac{HW}{[2(H + W)]}$$

H is the height of the chamber cross section and then width of the chamber is W . Now if that duct or chamber contains N horizontal plates each space receives a volumetric flow of Q by N and has its height of h by N .

In this case there will be a negligible effect of plate thickness. In that case the Reynolds number for that flow in each space can be defined by this equation number 13 here that will be $2 Q \rho / \mu$ into $h + NW$.

Here the Equation

$$Re_c = \frac{2Q\rho}{\mu(H + NW)}$$

Here N is the number of horizontal plates. So there that chamber inside it there will be a number of N number of horizontal plates to be placed. you will see that there are N number of space through which that particulate and gas will be passing through. So in that case that average velocity it will be divided for that each space that will be as Q by N and also height also will be divided into its N number of plates that means h by N and then Reynolds number will be defined accordingly.

In this case the collection efficiency of a settling chamber of N number of plates for turbulent condition where velocity will be very high. So in this case you will see that eta dP will be is equal to 1 minus N by N 0 here.

Here the Equation

$$\eta(d_p) = 1 - \frac{N}{N_0}$$

$$= 1 - \exp\left(-\frac{u_t L}{\bar{u} H}\right)$$

$$\eta(d_p) = 1 - \exp\left(\frac{LW\rho_p g d_p^2}{18\mu Q}\right)$$

N will be the number of concentration of particles in the diameter range dP plus d dP here, here number of particles and N 0 will be is equal to what number of concentration at the entrance to the chamber. So here this N please do not be confused with that N in the previous slides we described that is number of plates here this N is number of concentration of particles here, number concentration of particles in the chamber based on that diameter range of dP plus d dP and N 0 is the number concentration at the entrance to the chamber.

So based on this we can have 1 minus exponent of minus ut L by U bar H. So one can express this collection efficiency in terms of particle diameter for Stokes flow settling condition there itself then eta dP will be is equal to 1 minus exponent of ut you just substitute the value of ut that means settling velocity of the particles there and also what will be the average velocity of that particles inside the chamber according to that you can have this efficiency of the chamber. So if you are having that one chamber only then N will be is equal to 1 whereas if you are having number of plates there inside then you have to divide that Q by Q by N and also H should be H by N that you have to consider here. So Q is the volumetric flow rate of gas through the chamber and W is the width of the chamber.

Here the Equation

$$Q = \bar{u}HW$$

So in this way you can assess or you can estimate what will be the collection efficiency of the settling chamber. Now this you will see that this efficiency of that settling chamber based on that three flow conditions either there will be complete mixing with plug flow, vertical mixing with plug flow or no mixing with plug flow.

So in that case how that efficiency of that settling chamber will be changing? Generally you will see that the S shape profile will give you for that settling chamber for its efficiency

based on this parameter here root over U_{TL} by U_H there. So this efficiency how it will be changing? You will see that in the diagram it is shown that or in this graph it is shown that how that efficiency of that settling chamber will be changing and it will give you that also as a certain degree of mixing how that efficiency will be changing with respect to this parameter. So once this parameter what will be the efficiency you can easily calculate from this graph. Let us do an example based on this theory. Now in this case you have to determine the length of a settling chamber which is required to achieve 90 percent efficiency for 50 micrometer particles of a density 2 gram per centimeter cube from an air stream of 1 meter cube per second at 298 K at 1 atmosphere.

The chamber is to be 1 meter wide and 1 meter high. The kinematic viscosity of the air is given 0.015 centimeter square per second. So based on this you have to calculate what will be the length of the settling chamber to require or to achieve this 90 percent efficiency of that equipment for separation of that 50 micrometer particles of density 2 gram per centimeter cube. So in this case what you have to do? First of all you have to calculate that Galileo number. So this Galileo number will be based on function of Reynolds number and drag coefficient and it is defined like this here it is shown in the slide to be $4G d_P^3 \rho$ into ρ_P minus ρ by $3 \mu^2$.

G is the gravitational acceleration, d_P is the particle diameter, ρ is the density of the fluid and ρ_P is the particle density and μ is the viscosity of the fluid and it is a function of drag coefficient and Reynolds number square. I think we have discussed this in where we have discussed about that settling velocity for multiple particles there. So in that case you have to calculate first Galileo number and then what is the terminal velocity of that particle those also will be coming as a function of that Reynolds number here and then you will see that from the graph of this C_d into r^2 versus this Reynolds number you will see this type of graph you can expect for this particular problem this profile if you change that Reynolds number this Galileo number will be changing. That means here the C_d into r^2 will be changing with respect to Reynolds number.

So at this 12.1 value from this graph what will be the Reynolds number here it is coming around 1.10 and from this Reynolds number you will be able to calculate what will be the terminal velocity by this equation. So this terminal velocity is coming 33 centimeter per second then from equation number 14 that we have given earlier, you have to calculate what will be the length of that chamber. So for this you have to calculate again from this equation U_t you have to calculate \bar{U} that means average gas velocity and also what is the efficiency. Efficiency is given to you that is 90 percent, S is given to you and what will be that \bar{U} .

Now from this efficiency that is a equation efficiency you can calculate this \bar{U} here. Once that \bar{U} you will be able to calculate that W also if it is required or W if it is given then you can easily calculate what will be the Q value. So here you will see that Q value is given to you. So how to calculate \bar{U} ? S is given to you, W is given to you. So U

bar easily you can calculate once that U bar you will be able to calculate the L from this equation once that η value is given to you that means efficiency is given back to you.

So from this equation you can simplify like this L will be equal to this this equation. So after substitution of this value of U bar H , η and U_t you can easily calculate what will be the length of that chamber it is coming 6.98 meter. So what you have done actually here first of all you have to calculate the Galileo number sorry Galileo number from this Galileo number and from this graph you will be able to calculate what will be the Reynolds number. Once that Reynolds number you will be able to calculate what will be the terminal velocity and also from the given value of Q , H and W you will be able to calculate average velocity.

Once that average velocity U bar and U_t and also H you will be able to calculate the length of this chamber from this efficiency equation. So finally it is coming 6.98. I think you understood this problem which is actually very useful for understanding this relation of efficiency of the settling chamber. So we have discussed here what is the basic principle of separation of particulate materials, what are the different mechanisms, what are the commonly used devices which are being used in industry to separate those particulate materials and also we have analyzed the efficiency of that gravity, settling chamber on which that it will be working basically in the three working or flowing condition it is working and based on which how that efficiency of that settling chamber can be calculated.

So in the next lecture we will also try to understand more about this separation of particulate material by other mechanism in a certain devices which is defined or which is designed based on that mechanism it is called cyclone separator. So we will be discussing about that cyclone separator in the next lecture. So thank you for giving attention. Have a nice day.