Air Pollution and Control
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Lecture 42
Air Pollution Control Devices- Part - 1

Hello, friends. You may recall last time we discussed about introductory part of air pollution control. Today we will discuss about air pollution control devices. And within that, first of all we will discuss like how to control particulate matters.

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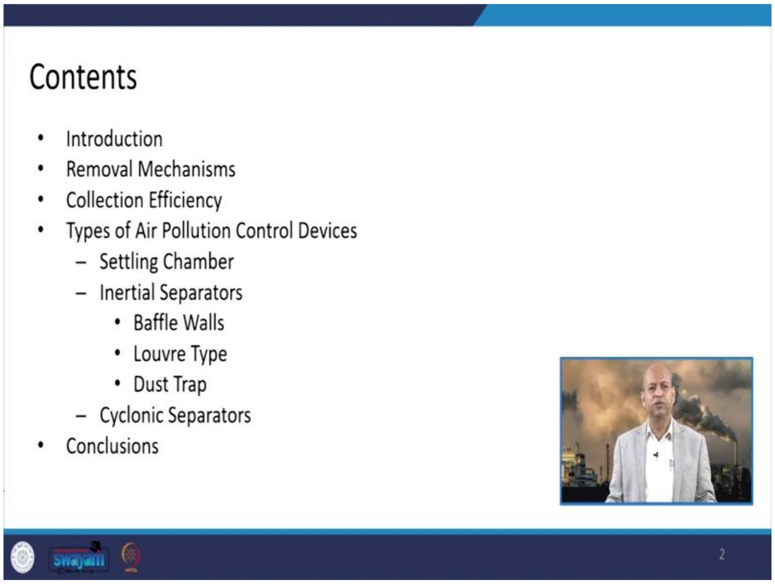

So, in this lecture after introduction we will see these removal mechanisms, collection efficiency related issues, then types of air pollution control devices, for example, settling chamber or inertial separators like baffle walls related or louver type or dust trap kind of devices, separators, cyclonic separators and then we will conclude. And after in next lecture again we will continue, how to control the air pollution through these controlling devices. Well, so, in introduction, we can say that this control of their pollution is very important. And in a most effective way, if you want to control the pollution then it is better to control at the source itself.

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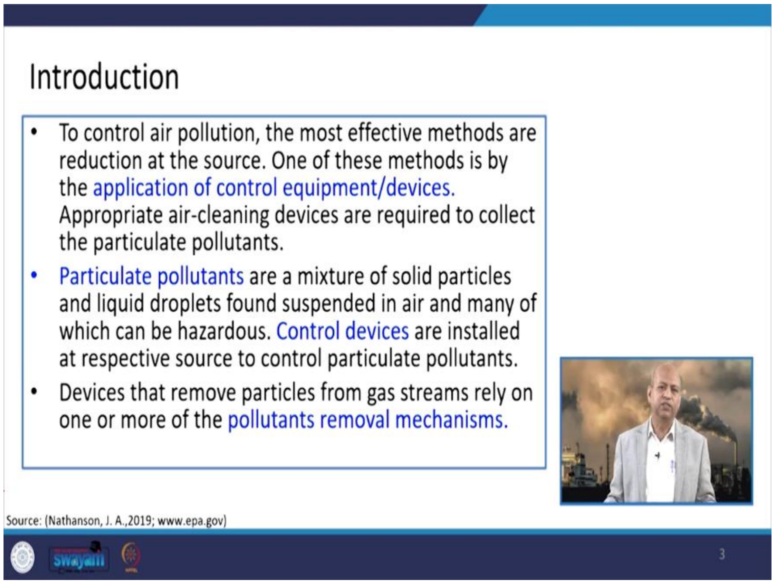

And one of these methods which are prominent or effective to control the air pollution emissions is by the application of control equipment or devices at the source itself. And appropriate air cleaning devices are required to collect the particulate pollutants, because whenever there are a number of pollutants are emitted. So, as per the nature of the pollutant, whether it is particulate pollutant or gaseous pollutant we have to install some equipment or controlling devices.

So, today we will discuss about particulate pollutants, concentration, reduction or control of the particulate pollutant emissions basically. So, we will see how particulate matters of different sizes or different densities we can control. So, these control devices we will focus only on particulate matter concentration or collection basically.

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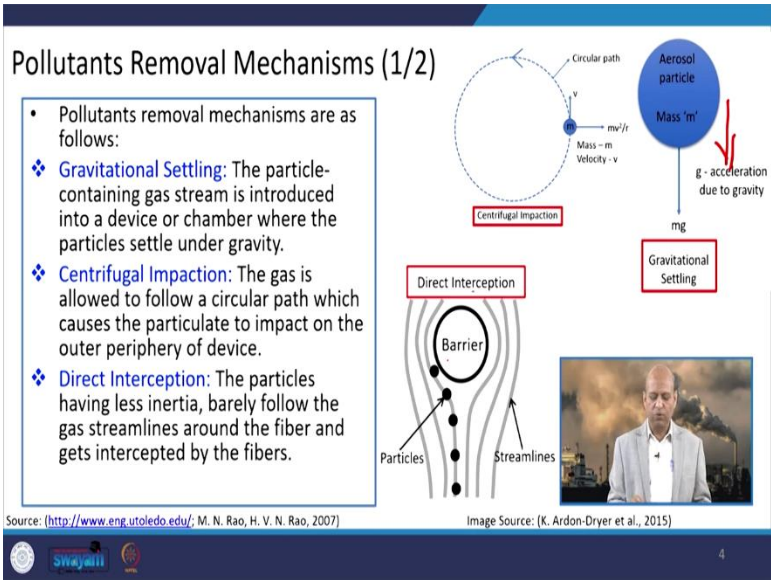

So, if you talk about like different pollutants removal mechanisms which are used for removal of these particulate pollutants, then basically we list like gravitational settling or centrifugal impaction or direct interception those kinds of things. So, in gravitational settling basically only the gravity, it acts like there is a mass of the aerosol or particles so gravity pulls and it settles down because of simple gravity. Then we can also mimic this pulling force or gravitational force by creating centrifugal force.

So, if you rotate by some device, the particulate matter, then there will be centrifugal force and it will strike to some surface and then there it will lose the velocity and it will be collected or we can also do like impaction through barriers, whenever we change the course or this direction of the flow, then what happens like these particles which are having mass so because of this momentum, they just go in a straight line. They do not quickly change the path right like the guests. So, they will have the tendency of striking to the particular that barrier and then again they can lose the velocity and they can be trapped or collected.

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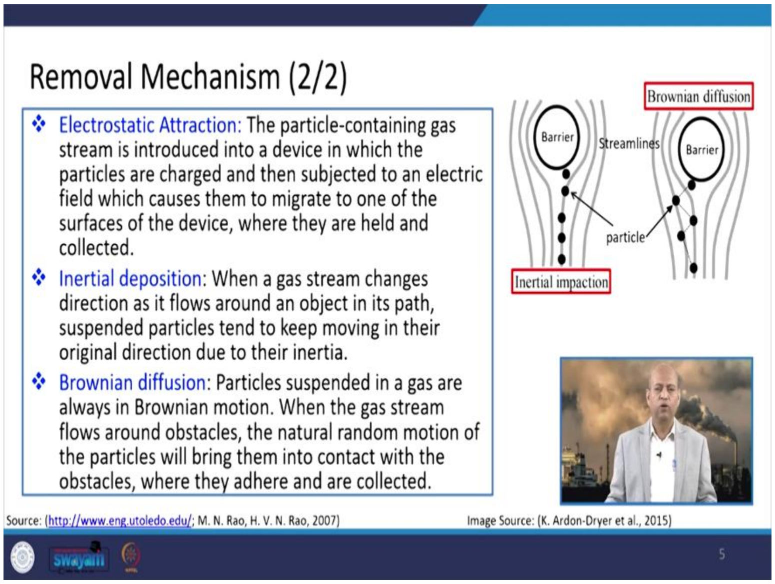

Then there may be another way like electrostatic attraction. Electrostatic attraction force is created by kind of ionization. So, we have different kinds of field, we have particles pass through so they get charged, and then on the opposite charge there is one device where they are collected, then they lose again the velocity and slides down. Inertial deposition can be there as these baffling kind of things maybe there or Brownian diffusion. So, ultimately, they get attached to some surface and slide down or get collected at the hopper at the bottom.

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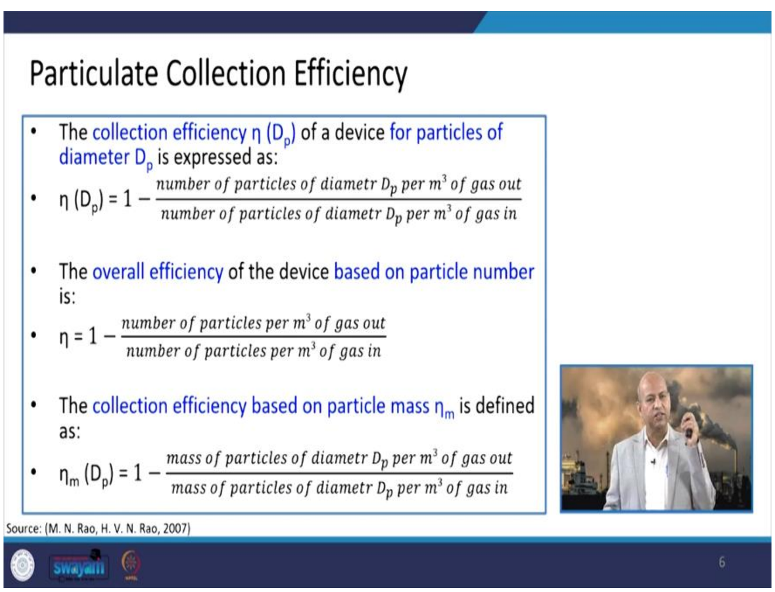

So, if we want to collect, then as an engineer we also want to know what the efficiency of collection is. So, in a general we can say, like this efficiency related to a particular, let us say, diameter particle D_p, if we want to calculate the collection efficiency of particulate pollution of the diameter D_p, then 1 minus number of particles of that diameter D_p only per cubic meter of the gas going out divided by the number of particles of diameter D_p only per cubic meter in the flow gas coming in. So, that is the simple relationship.

$$\eta\ (D_p) = 1 - \frac{number\ of\ particles\ of\ diametr\ D_p\ per\ m3\ of\ gas\ out}{number\ of\ particles\ of\ diametr\ D_p\ per\ m3\ of\ gas\ in}$$

$$\eta = 1 - \frac{number\ of\ particles\ per\ m3\ of\ gas\ out}{number\ of\ particles\ per\ m3\ of\ gas\ in}$$

$$\eta_m\ (D_p) = 1 - \frac{mass\ of\ particles\ of\ diametr\ D_p\ per\ m3\ of\ gas\ out}{mass\ of\ particles\ of\ diametr\ D_p\ per\ m3\ of\ gas\ in}$$

If you want to just the overall efficiency then rather than this particular diameter we consider number of all the particles. So, number of all the particles going out per cubic meter remember this and number of particles coming in so that division deducted from the 1 so that is the particular efficiency of overall efficiency.

If you want to see the collection efficiency based on particulate mass, this eta m (η_m) mass related, then it can be defined it like, defined like mass of particles of diameter D_p per cubic meter of gas going out divided by the mass of particles of diameter D_p per cubic meter of gas which is coming in that device. So, that is overall efficiency related relationship which we generally use, because it will be used later on to calculate the efficiency that is why we discussed just now about this.

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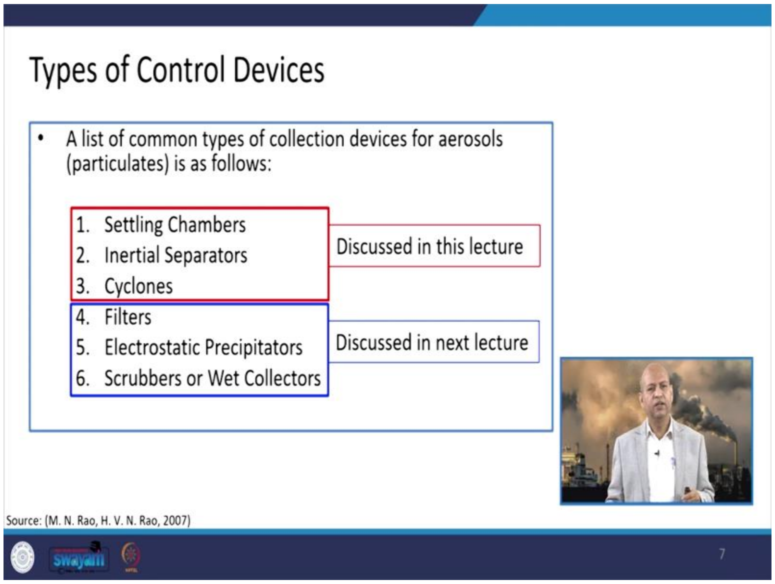

Then if we talk what kind of devices are there which are available in industrial pollution control, so the list of common types of these air pollution control devices or collection devices of aerosols or particulate matter is like settling chambers or inertial separators or cyclones. These three types of devices we will discuss today. Then there are like bag house filters or filters, fabric filters, electrostatic precipitators or scrubbers or wet collectors they are known as we will discuss in the next lecture.

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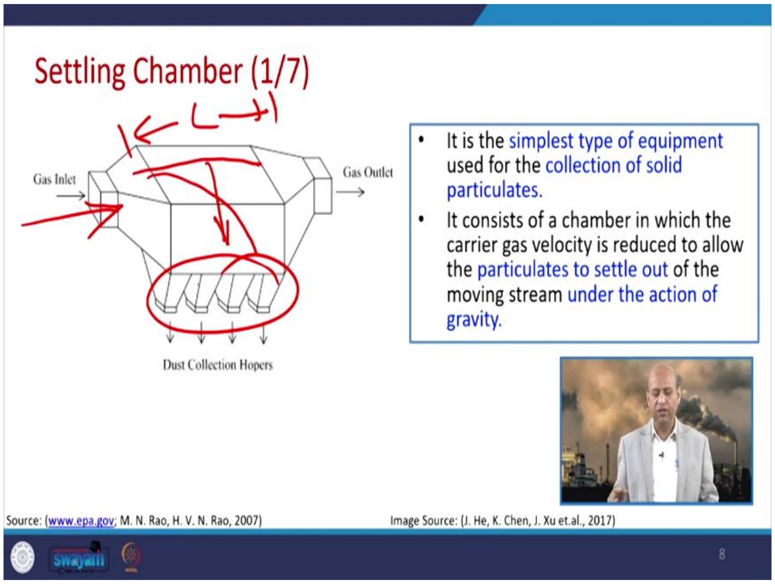

So, if we start our discussion on settling chamber that is the simplest device. Basically, this is simple chamber, length, width, height, so this kind of device. So, there is inlet, gas, lead and by pollutants goes into this and it comes out of this particular outlet. So, there is a distance this length L, this has to be traveled by this gas particles, particles are there in the dirty gas and this particle has the mass so it has tendency due to gravity to go down.

So, when it travels to this distance this should be of such a speed or velocity that these particles comes down before going out through the outlet that is the fundamental thing very simple understanding we have to develop that it should be removed only then it will come down and we will remove from the hopper.

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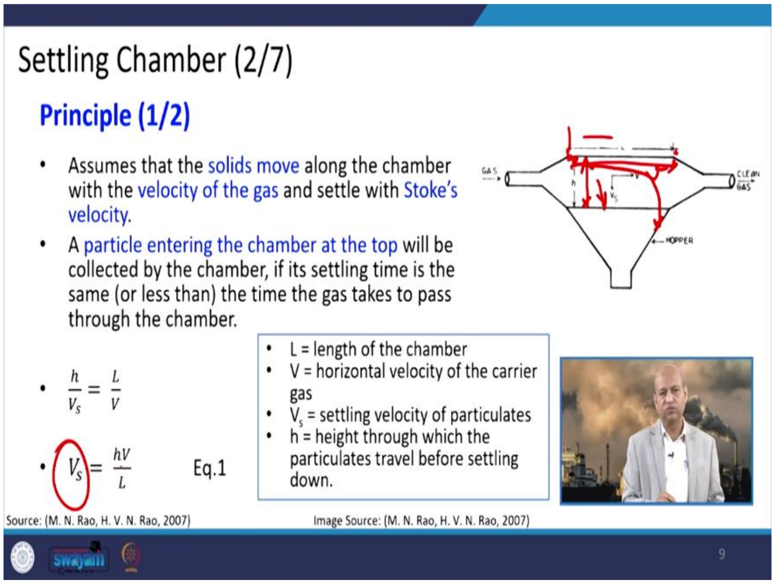

So, this is the chamber, settling chamber of the length L and height h and this gas which is full of these particulate matters is going inside and this velocity of the gas is V simple V. And the Stoke's velocity of the particles, which takes it down is Vs. So, this Vs should be says that with this Vs this height will be traveled, this length of the height. For that particle this path is of the length height and this gas the path is length L. So, with V when this particle comes to this stage, this should basically come down.

$$\frac{h}{V_s} = \frac{L}{V}$$

So, that h divided by Vs equals L divided by V. So, the time taken by one particle which it travels from this point to this in the horizontal direction, in vertical direction it should have the velocity of Vs and it should come down. So, that particular diameter of the particle we have to design for that how this Vs can be achieved so that it does not go out with the dirty gas rather it comes down. And this L is length of the chamber as you know, V is the horizontal velocity of the carrier gas and Vs settling velocity of particles and h is the height through which this particulate matter travels following the Stoke's velocity. So, this Vs is nothing but this hV divided by L. So, that way we can calculate the velocity.

$$V_s = \frac{hV}{L}$$

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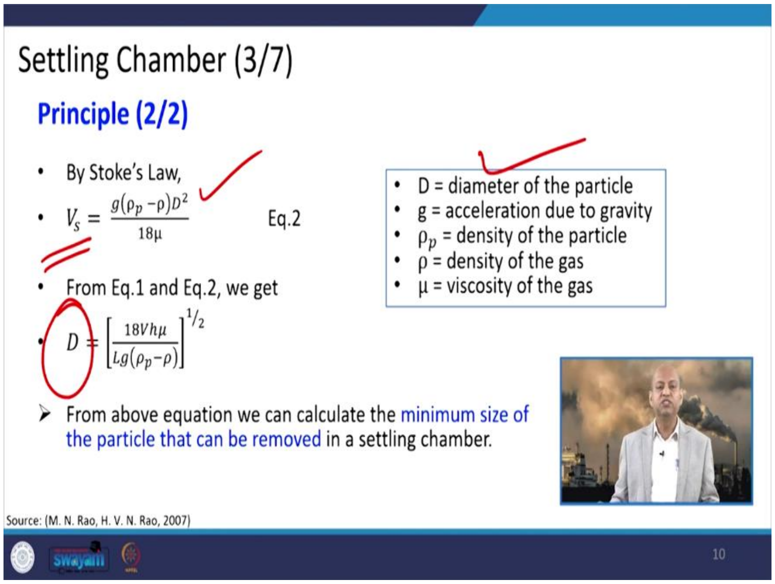

This Stoke's law you can represent it by this Vs g into rho p (ρ_p) minus rho D square divided by 18 mu. So, D is the diameter of the particle, g is acceleration due to gravity as you know, rho p (ρ_p) is the density of the particles and rho (ρ) is the density of the gas carrier, mu is viscosity of the gas. So, when we determine D using this equation, so you can just play with it and the square root of 18V h mu ($18Vh\mu$) divided by L into g rho p (ρ_p) minus rho (ρ). So, that way this is the diameter which is basically the minimum size of the particle which can be removed in a settling chamber.

$$V_s = \frac{g(\rho_p - \rho)D^2}{18\mu}$$

$$D = \left[\frac{18Vh\mu}{Lg(\rho_p - \rho)}\right]^{1/2}$$

So, this will decide that this will be the minimum of size. Beyond that size they will have more than Vs. So, they will automatically come down. But this is the minimum size of the particle which will be removed almost completely. So, that will be the design parameter for settling chambers, like particulate matter of different size exist in the exhaust gas. So, we have to design the settling chamber to remove these particles which are mostly coarser particles, coarse sized particles and these are used for cleaning of the gas when it is passed through other instruments. So, that on those instruments load is less in comparison.

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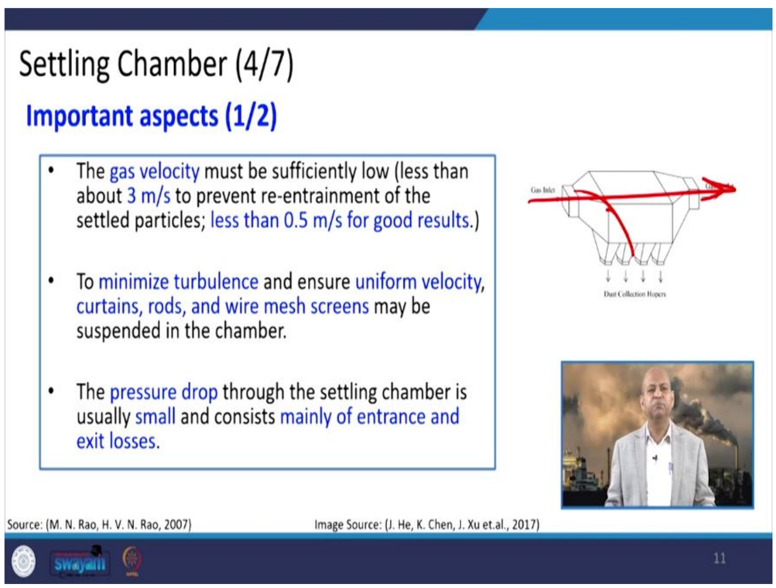

Then there are certain important aspects. So, like for example, the gas velocity must be sufficiently low. If it is more, if it is speedy, then short circuiting will be there and gas will directly pass through this taking the pollutants out. So, that is not effective. We want to calculate those particles. So, this gas velocity must be slow or it should not be more than 3 meter per second (m/s) and so that it can, otherwise it is speedy, it will short circuit as well as resuspension of the dust particles may also occur because of this high speed so that we have to avoid. Less than 0.5 meter per second is the velocity which gives very good results. So, 0.5 to 3 meter per second we have to maintain it.

Then to minimize the turbulence and ensure uniform velocity sometimes curtains or rods or wire mesh those kinds of things can be applied by suspension so that this inertia kind of things occur. And the pressure drop through the settling chamber is usually small, not most, not much and consists mainly of entrance and the exit losses only. So, that way it is very simple way.

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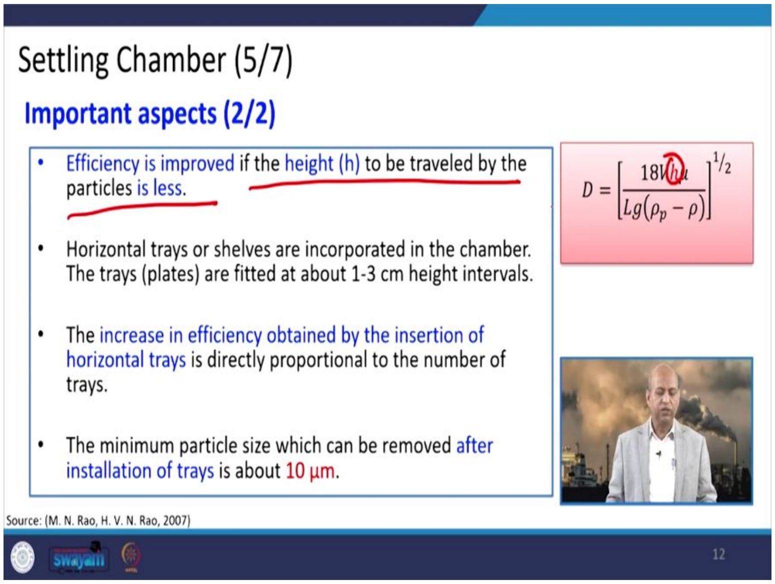

Then if we talk about the efficiency then it can be improved by the height, improved in the terms of height as traveled by the, this particle. When efficiency is improved if the height traveled by the particle is less, otherwise there are other problems. So, this is less. So, diameter related to height can be calculated. Horizontal trays or shelves can be incorporated to reduce this height part, otherwise there will be large height. So, you can install more horizontal plates so that effective height can be reduced for several diameter particles.

And to this increase in efficiency obtained by these insertion of horizontal trays directly proportional to the number of trays, basically that efficiency can be covered by the number of trays. And the minimum particle size which can be removed after installation of these trays can be up to 10 micrometer, otherwise, generally it removes up to 40 micrometer or so. But by these manipulation of this settling chamber through horizontal trays etc. you can improve the efficiency in terms of the size of the particle so that you can remove even fine particles up to 10 micrometer which is PM_{10} or RSPM, respirable suspended particulate matter.

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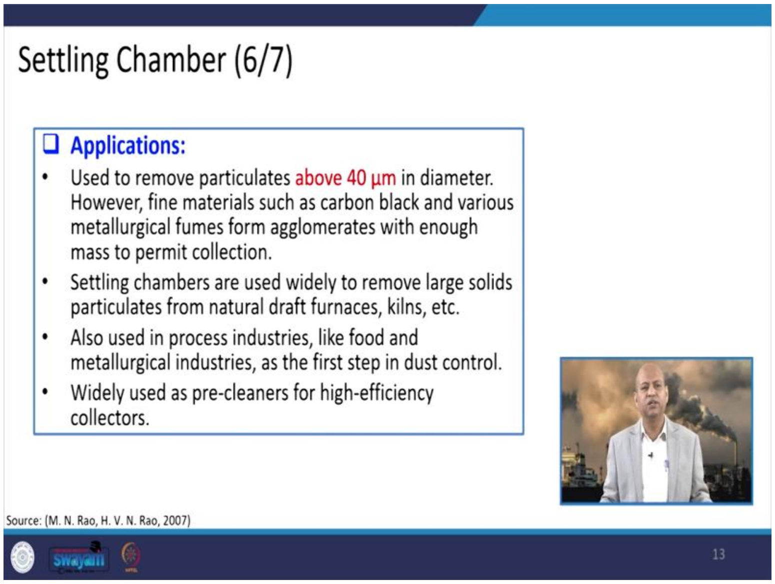

So, this is used for removing the particulate matters of size equal to or more than 40 micrometer. For that, it is very good. And if you want to reduce further then you have to apply certain those original trays etc. Then these settling chambers are used widely to remove large solid particulate matters from natural draft furnaces, kilns, etc. And also, it is used in process industries like food and metallurgical industries as the first step to dust control, so that the load on the secondary device can be reduced significantly and it is widely used as pre-cleaners for high efficiency collectors.

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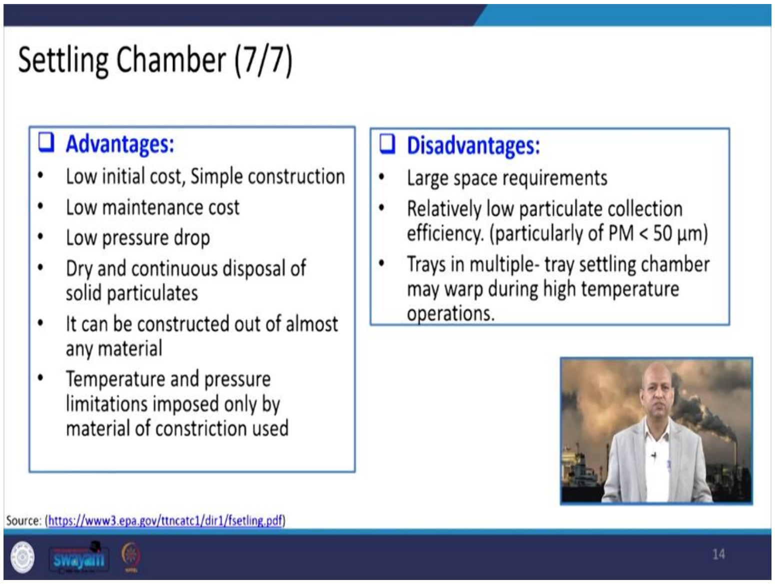

Then there are advantages and disadvantages. In advantages that it is low initial cost, simple construction. The construction is very simple kind of chamber you can divide. But in terms of disadvantage it requires large space. So, in countryside it can be okay fine, but in urban areas it is difficult because land cost is much more.

When we go for another additional advantages that it requires very low maintenance, because there are no moving parts etc., low pressure drop is there, then dry and continuous disposal of solid particles can be achieved by these settling chambers and it can be constructed out of almost any material whether you construct by simple chamber of some metal or even bricks etc. that is also possible. Temperature and pressure limitations imposed only by material of the construction use. So, that way you can also control of which high temperature if you want to use then accordingly material of those valves can be used.

If you talk about the disadvantages, it requires large space. So, the land should be cheap in that particular location, otherwise it is not advisable. Then relatively low particles collection efficiency like beyond 40 micrometer or 50 micrometer if it is less than that then it is difficult to trap them unless we provide those horizontal trays etc. It is good for 40 or 50 micrometer. Then trays in multiple tray settling chambers may warp during high temperature. They can undulate. They can get D shaped kind of things. So, those are the issues with this settling chamber.

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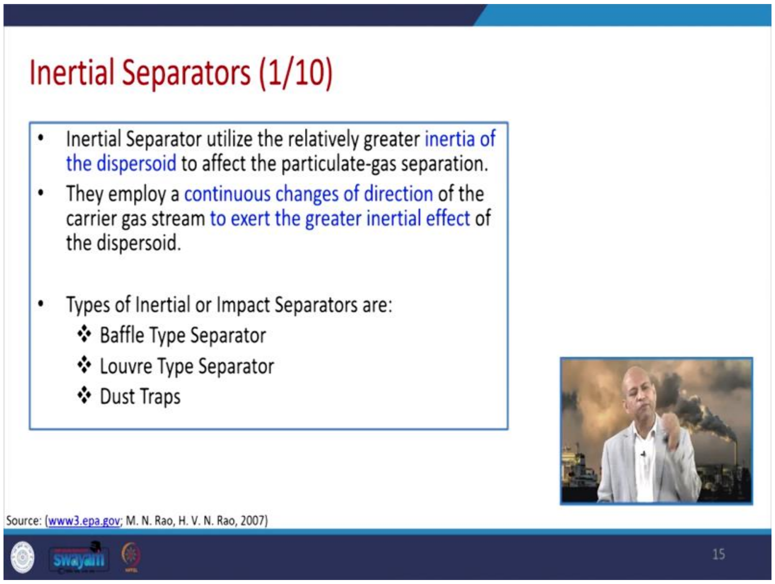

Then we come to another device which is known as inertial separators. So, these inertial separators basically utilize the relatively greater inertia of the, these dispersoids, those fine particles to affect the particulate gas separation. And they employ continuous changes of the direction of the carrier gas stream to exert the greater inertial effect on the dispersoid or particles, because impact will be more if we changed its direction, we provide some baffle walls or those kinds of things. So, the types of inertial or impact separators can be like baffle type separators or louver type separators or dust traps.

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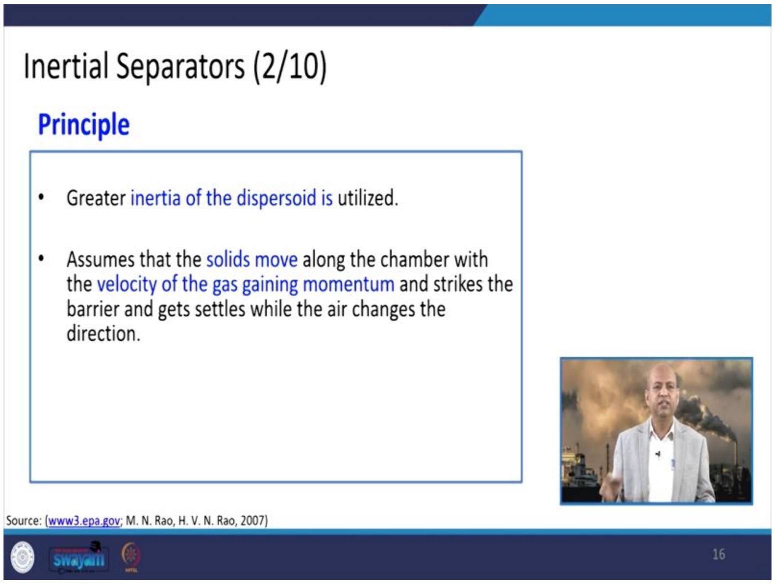

So, the principle, basically the inertia related, inertia when you change the direction by baffles etc. inertia occurs and they strike to the surface then they lose the velocity and slide down. And we, these solid moves along the chamber with the velocity of the gas gaining momentum and it strikes at the barrier and get settles down when air changes the direction because of losing the velocity.

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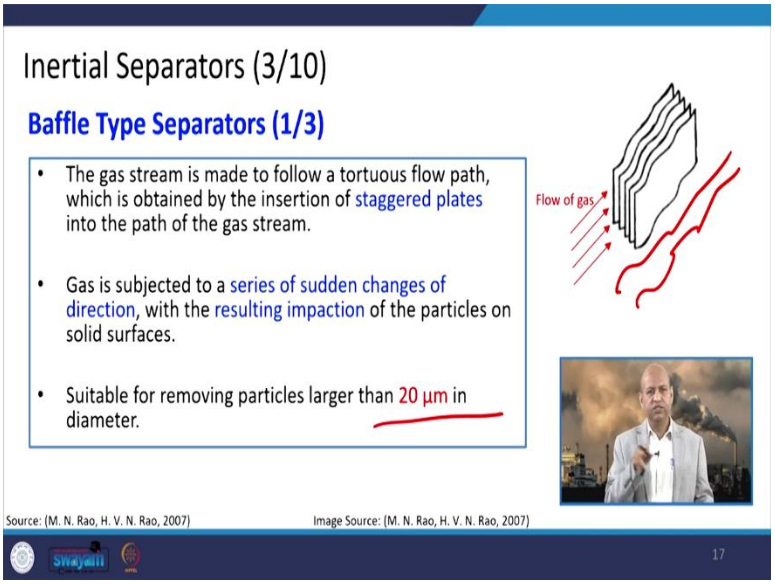

When we talk about baffle type separators, these kind of deformed kind of valves we take so the direction changes continuously and the suitable for removing particles larger than 20 micrometer in diameter. So, that way it is better if we compare with the settling chamber. So, certain change direction is to be ensured by these staggering kind of plates etc.

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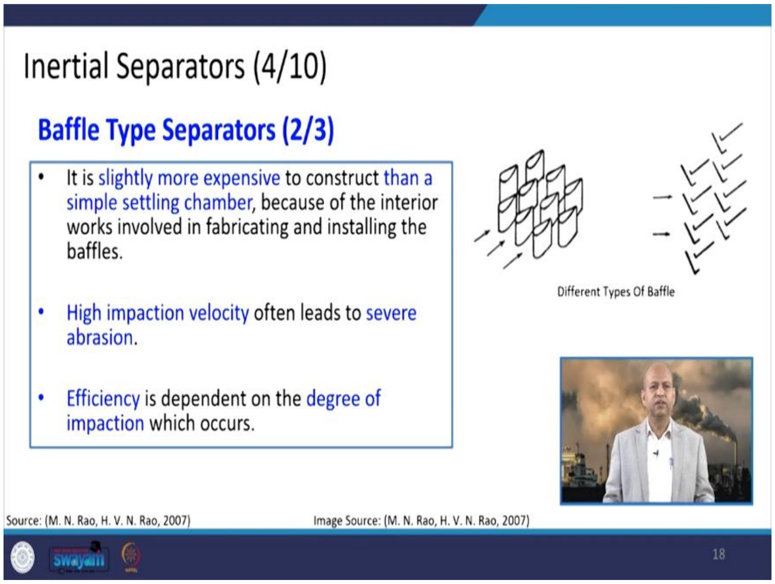

Whenever this high impaction velocity often leads to severe abrasion, so those are the issues basically. Efficiency is dependent on degree of impaction which occurs. So, those things we have to ensure if we want to remove more particles.

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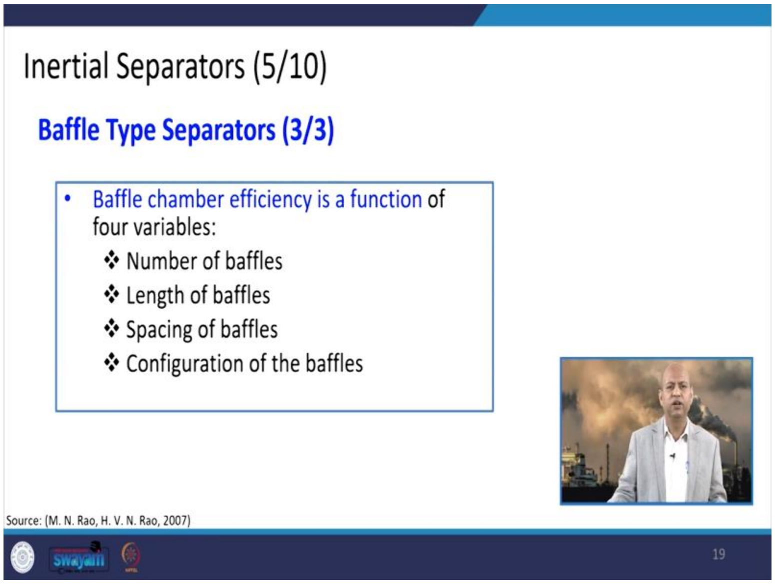

And these baffle chamber efficiency is a function of four variables basically, like number of papers we have provided, length of the baffle, spacing of the baffle, configuration of the baffles, the types etc. So, these things will influence the separation of the particles basically.

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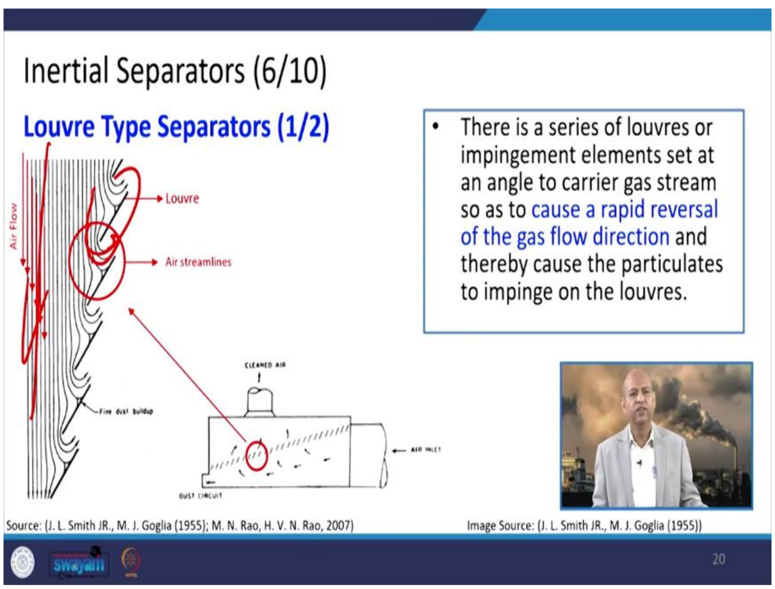

You can see like this louver type of separators where these kind of louvers are installed. So, that there is the change of the velocity, like air is going like this, but nearer to these kind of insertions this air changes its velocity and then this it causes rapid reversal of the gas flow direction and thereby it causes the particulate matter to impinge on the louvers and lose the velocity and get down in the hoppers basically. So, these type of, louver type of separators can operate at the velocity of like 12 to 15 meter per second at the inlet. So, that way you can have more efficiency. And its efficiency depends upon like closer spacing of these louvers which we have seen in the, these kind of configurations.

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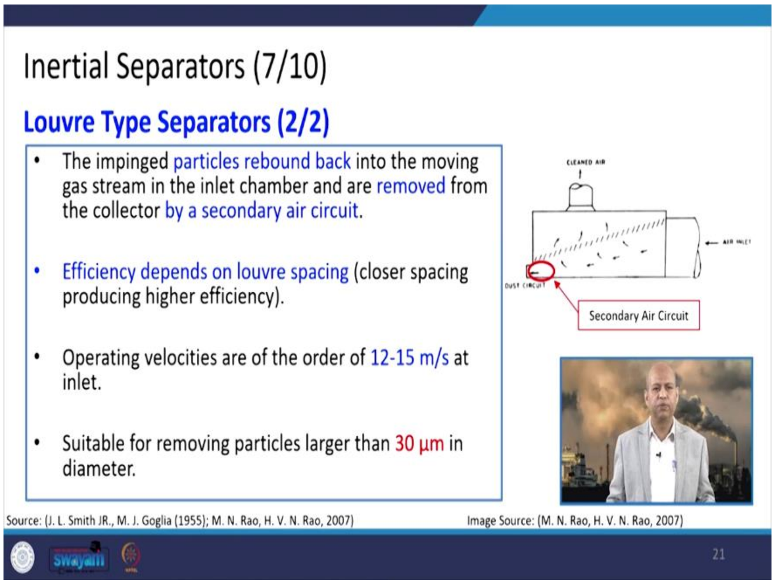

And it is suitable for removing particles larger than 30 micrometer. So, that way again it is better than the settling chambers, but baffle walls are better than these.

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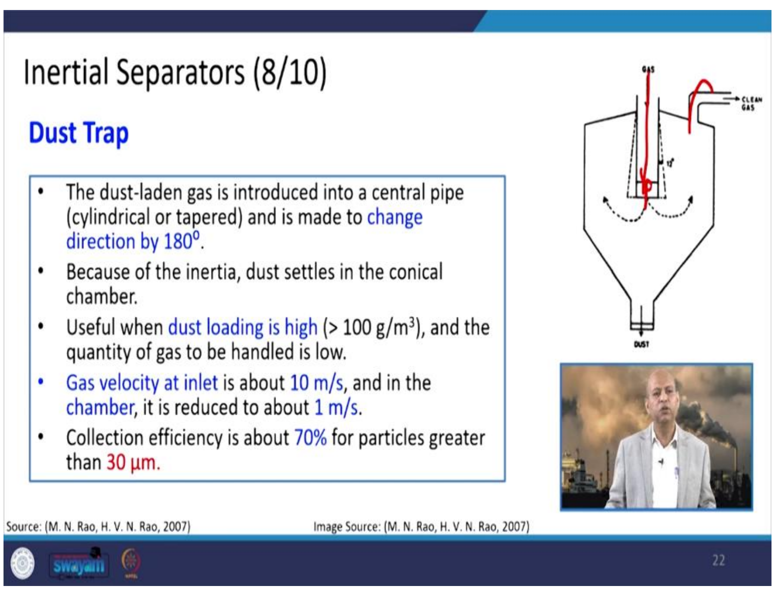

Then if we talk about the dust trap, like gas comes down and then it changed direction because the outlet is above so it will go 180°. So, in this change of the direction it again have this tendency of striking to the walls and losing the velocity and getting down and it is useful for dust loading when it is very high like 100 gram per cubic meter or so. And this gas velocity at the inlet is like 10 meter per second in the chamber and it is reduced about 1 meter per second afterwards. Then again collection efficiency is about 70 percent of the particles greater than 30 micrometer. So, it is comparable with those earlier one.

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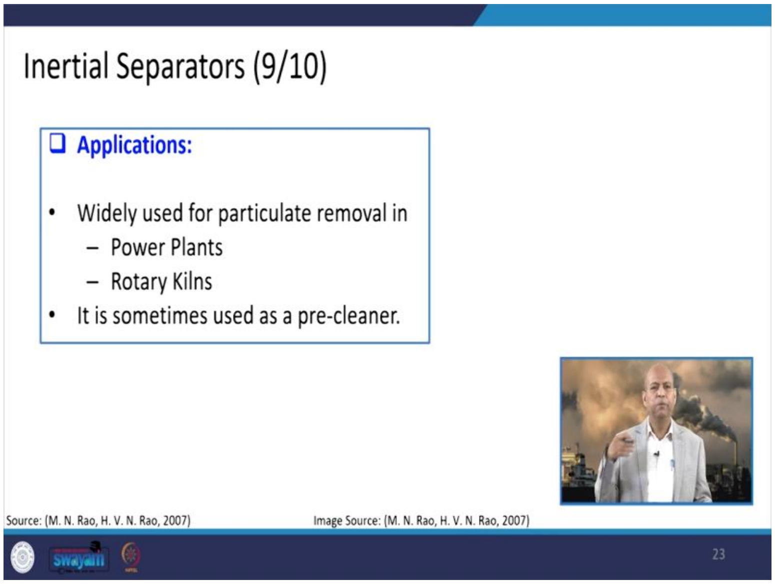

Then the applications of these inertial separators can be widely it can be applied to the particulate matters removal like in power plants or rotary kilns or it is sometimes used as the pre-cleaner as settling chambers also use so that way also these are devices which can be used for pre-cleaner before better devices like ESP etc.

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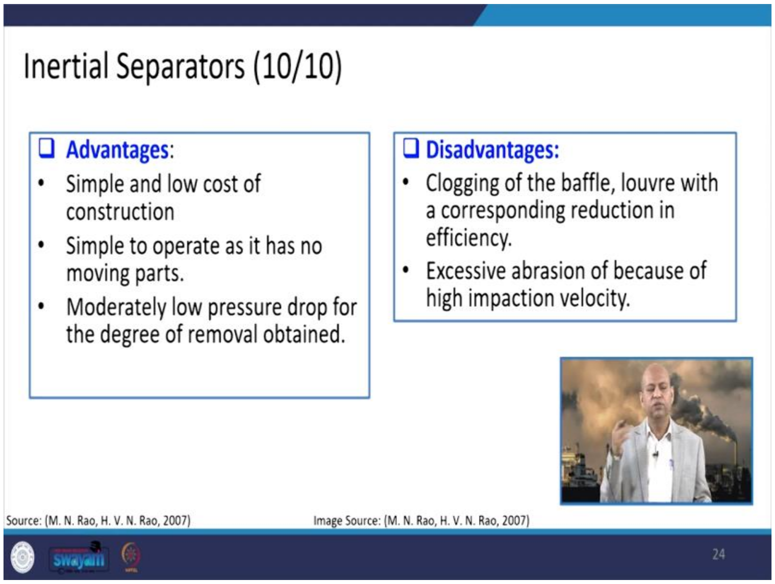

Then advantages and disadvantages if you want to discuss about inertial separators then advantages are like it is again simple low-cost device and construction is also very easy, simple to operate as it has no moving parts, then moderately low pressure drop for the degree of removal obtained. But there are disadvantages like clogging of the baffle was louver with the corresponding reduction in efficiency occurs after some time. So, you have to clean that after some time. Then excessive abrasion because of high impaction velocity also occurs. So, maybe you have to change those baffle walls or louver kind of structures.

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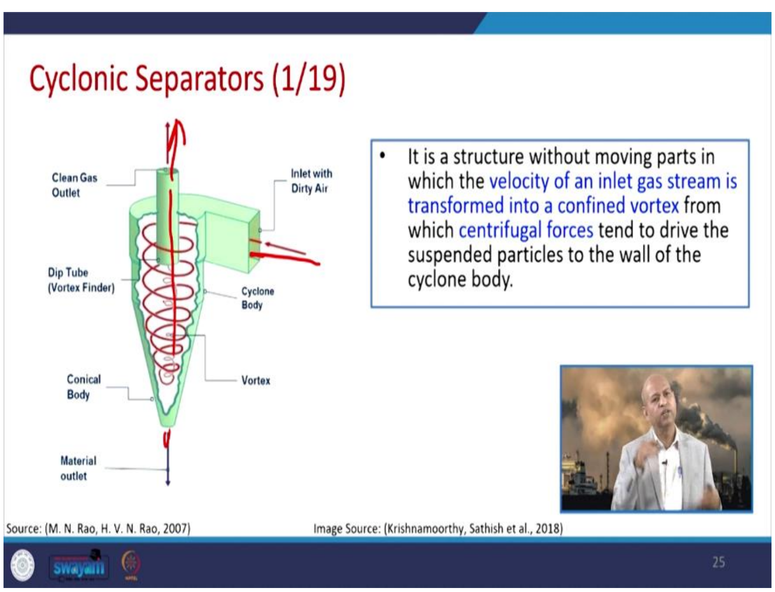

Now, we come to the cyclonic separators. So, in cyclonic separators basically it is nothing but a structure without moving parts in which the velocity of an inlet gas stream is transformed into a confined vortex that circular motion from which centrifugal forces tend to drive the suspended particles to the wall of the cyclone body. So, like for example, this inlet is there and this gas goes downwards basically, it goes downwards in circular motion.

So, in circular motion because of centrifugal force and tangential force it restricts to the wall and loses its velocity and gets down to a hopper. Then when it goes up, because outlet is in this direction, so it goes up again, in circular motion it goes, there also again it is trapped and whatever remaining particles, smaller particles, they can be again give their velocity to zero and come down so that way cyclonic separators work.

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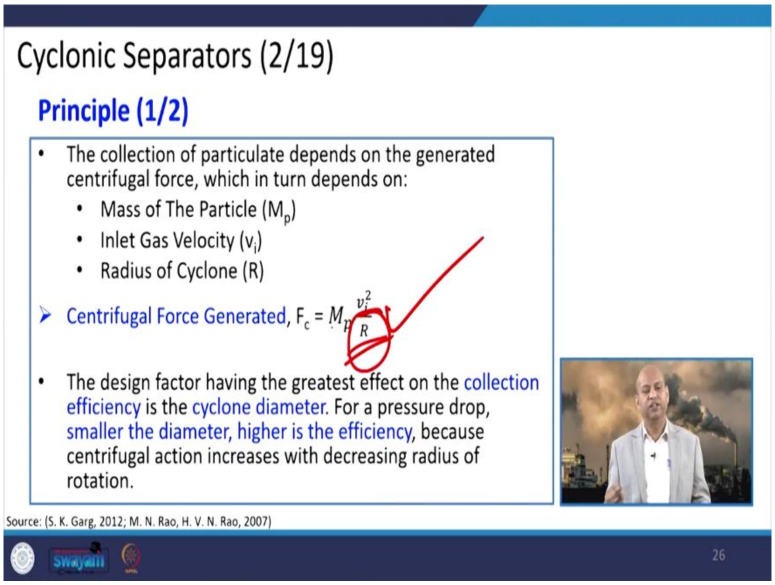

So, its principle basically have influence of the mass of the particles, inlet gas velocity or radius of the cyclone, because the centrifugal force generated is like this Mp into vi square upon R, where mass of the particle is Mp and the radius of cyclone is R and the inlet gas velocity is the vi. So, this particular relationship will work to get the particle separate from the cyclonic separators. And the design factor having the greatest effect on the collection efficiency is the cyclone diameter basically, this radius. For a pressure drop, smaller the diameter higher the efficiency, because centrifugal action increases with the decreasing radius of the rotation because it is in the denominator. So, that is the very simple thing.

$F_c = M_p \frac{v_i^2}{R}$

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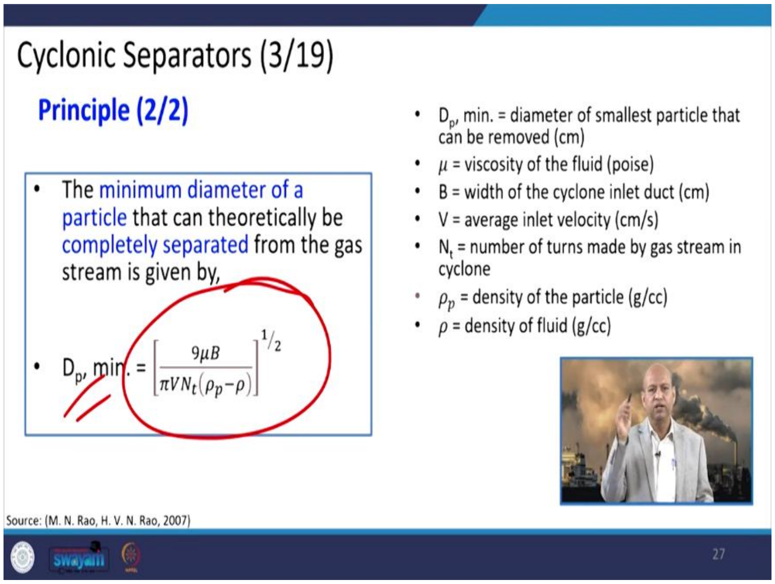

The principle is again the minimum diameter, if you want to calculate for a particle that can theoretically be removed completely from the cyclonic separator then this is the relationship Dp can be calculated by this equation, 9 mu B ($9\mu B$) divided by pi V Nt rho p minus rho [$\pi V N\_t\ (\rho\_p - \rho)$], where Dp is the minimum diameter of the smallest particle which can be removed by this particular mechanism, mu is the viscosity of the fluid that is the gas or so, and the B width of the cyclone inlet duct when it is coming and then the V is the average inlet velocity, Nt is the number of turns made by gas stream in the cyclone when it comes down and go up, so rho p (ρ_p), density of the particle so is the density of the fluid.

$$D_p, \text{min.} = \left[\frac{9\mu B}{\pi V N_t(\rho_p-\rho)}\right]^{1/2}$$

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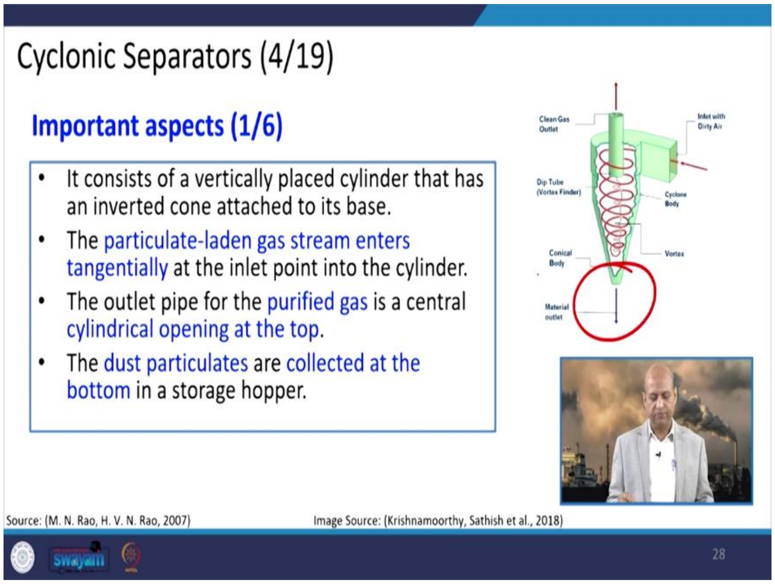

Important aspects like it consists of vertically placed cylindrical apparatus that has an inverted cone kind of attached to the base. And the particulate laden gas stream enters tangentially, at the inlet point here and then it goes down. And the dust particles are collected at the bottom in the storage hopper.

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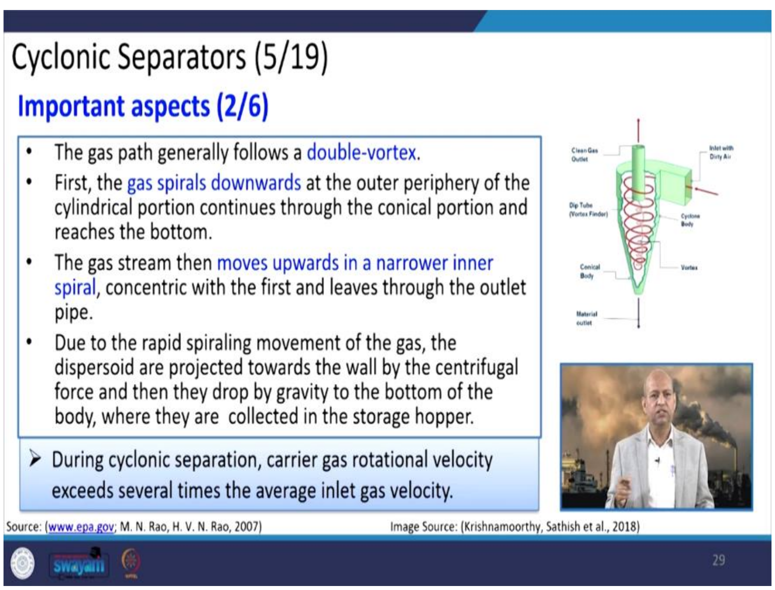

The gas path generally follows a double vortex. Once it comes down then it goes up inside. So, double part is there. So, that way there is a possibility of collection of smaller particles also. During cyclonic separation carrier gas rotationally rotational velocity exceeds several times the average inlet gas velocity. So, that is the very important point for removal of these particles.

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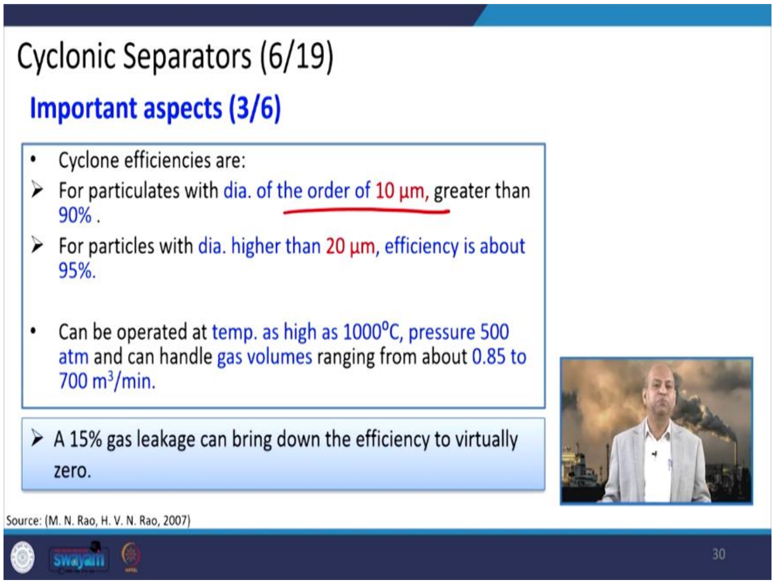

So, cyclone efficiencies are like for particulates of the order of 10 micrometer also greater than 90 percent. A particles are of the size of 20 micrometer or so, then efficiency further increases 95 percent. So, coarser particles naturally mass is more, removal efficiency is more. And it can be operated at the high temperature like 1000 degrees Celsius, pressure of the 500 atmospheric pressure. It can handle gas volumes ranging from 0.85 to 700 cubic meter per meter minute. So, means good flow rate can we handled. A 15 percent gas leakage can bring down the efficiency to virtually zero. So, the leakage should not be there that is very important aspect in this case. So, wherever leakage it should be handled properly and promptly, otherwise efficiency will be drastically reduced.

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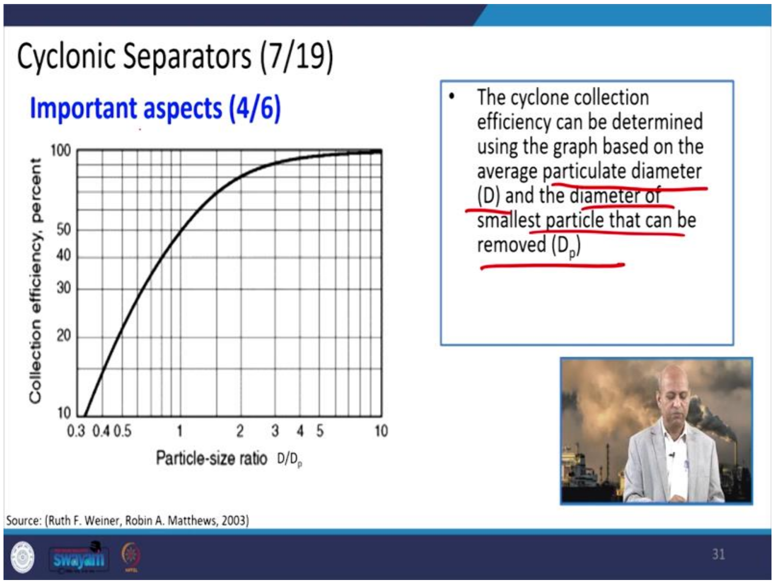

In this graph the efficiency, collection efficiency depending upon the size of the ratio of the particle, this D and D, particulate diameter D and diameter of smallest particle that can be removed D_p. So, if it is like 10 up to 100 it can be removed. So, the ratio and you can decide the efficiency.

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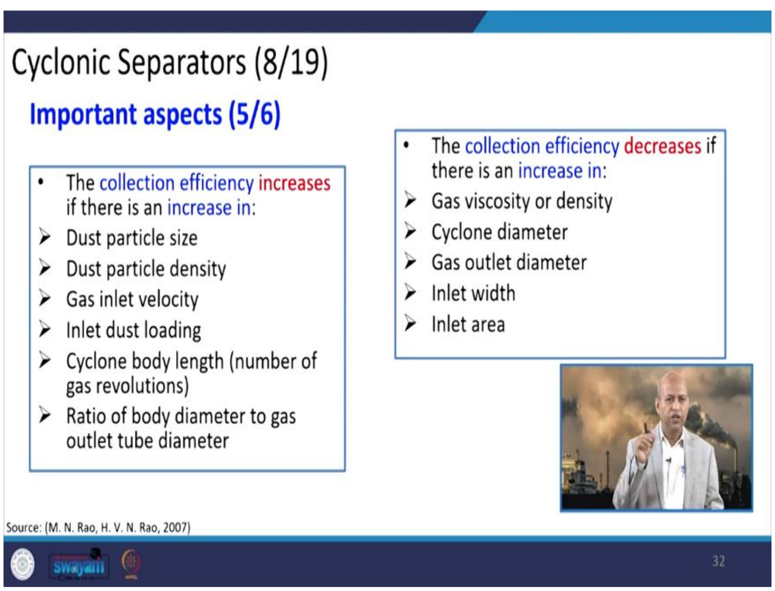

Well, the important aspects like the collection efficiency increases, if there is an increase in like dust particle size or dust particle density or gas inlet velocity or inlet dust loading or cyclone body length, number of gas revolutions because it will ensure more gas revolutions, then ratio of the body diameter to the gas outlet tube diameter. And the collection efficiency decreases with the gas viscosity or density or cyclone diameter or gas outlet diameter, inlet width or inlet area. So, these very kind of thumb rules. These aspects can be observed or taken care when we want to design cyclonic separators.

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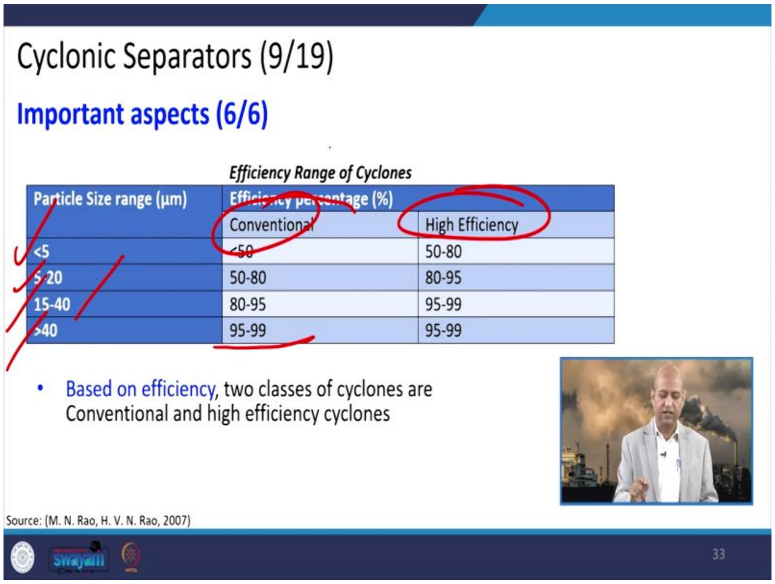

And then another set of important aspects are there like different size of the particles are there, less than 5 micrometer or 5 to 10, 15 to 40, more than 40. Efficiency, conventional and high efficiency kind of separators maybe there. So, in conventional like less than 5, less than 50 percent efficiency is there, high efficiency can ensure 50 to 80 also. And like 40 micrometer or so, 95 to 99 in conventional and in high efficiency also. So, that is the limit up to the 40, otherwise the basic thing is difference in this 5, 20 and 15, 40 that is the efficiency difference. And based on the efficiency, two classes of cyclones have been categorized like conventional and high efficiency.

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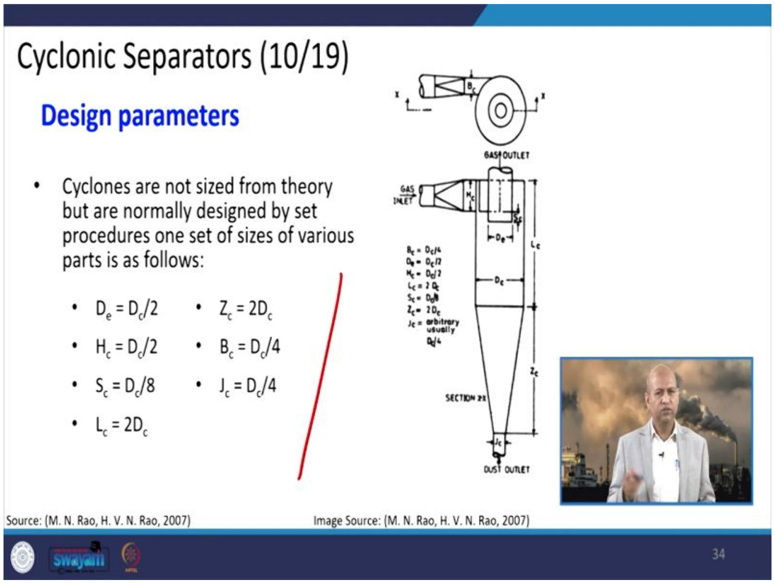

If you want to see the design parameters basically, based on several design exercises or practices or observations there are certain relationship, empirical relationships which have been decided like this De equals Dc upon 2, Zc equal equals Dc upon 2. So, these are the dimensions in this cyclonic separator cross section and those particular relationships are taken into consideration when we design so that become better or efficient way of designing.

- $D_e = D_c/2$
- $H_c = D_c/2$
- $S_c = D_c/8$
- $L_c = 2D_c$
- $Z_c = 2D_c$
- $B_c = D_c/4$
- $J_c = D_c/4$

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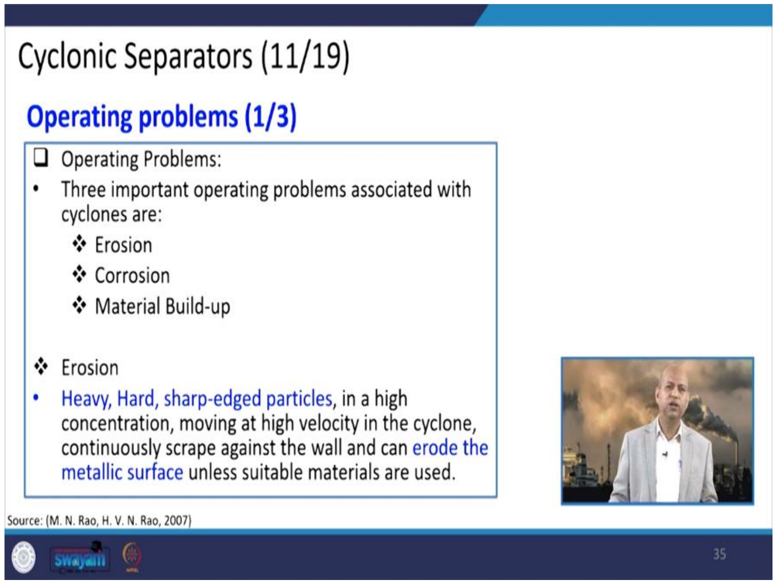

Well, operating problems are there, like it can eroded by particulate matter because it strikes to the surfaces, corrosion maybe there if those gas, carrier gas is having like acidic content like SO_2 etc. then material build-up can be there at the inlet, outlet or some surfaces also. So, at some surfaces sometimes people use those kind of like rim kind of thing and it can be removed, otherwise regular cleaning is needed.

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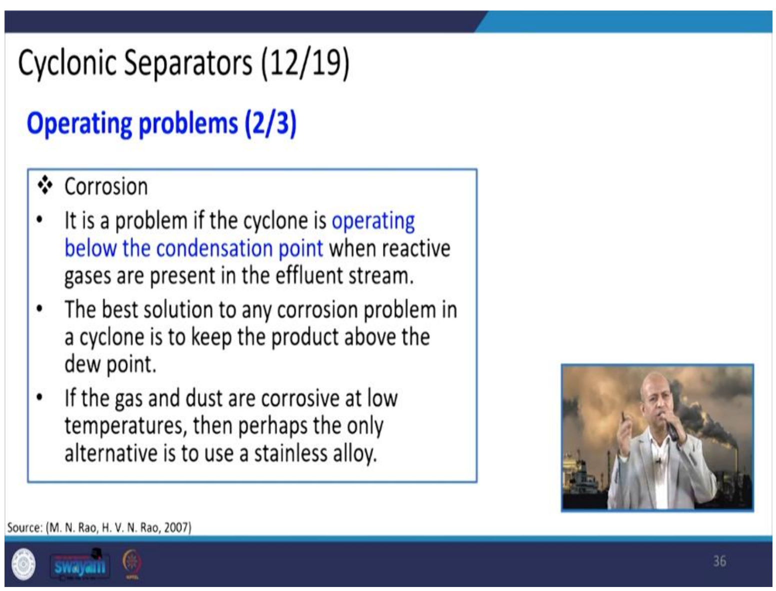

And corrosion-related means the carrier gas is taken into at the temperature where dew point is not achieved only then it would be better, otherwise corrosion problem may be there.

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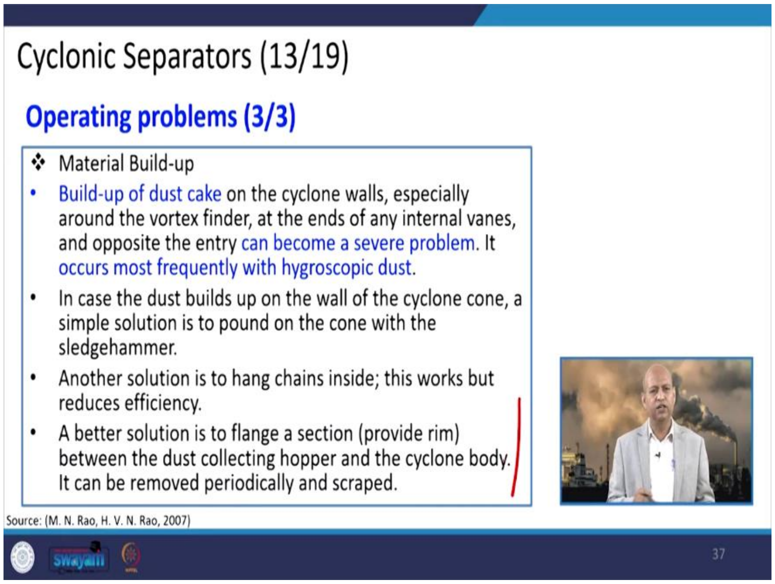

And metal build-up can be taken into consideration and it can be removed by this rim provision or by regular cleaning.

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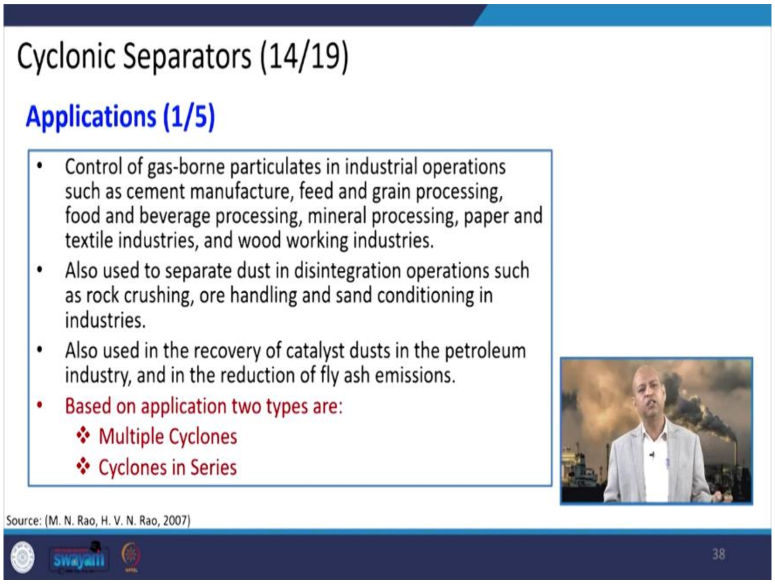

Well, applications can be there in many cases, like it can be used as the multiple cyclones or cyclones in series depending upon what kind of pollution load is there.

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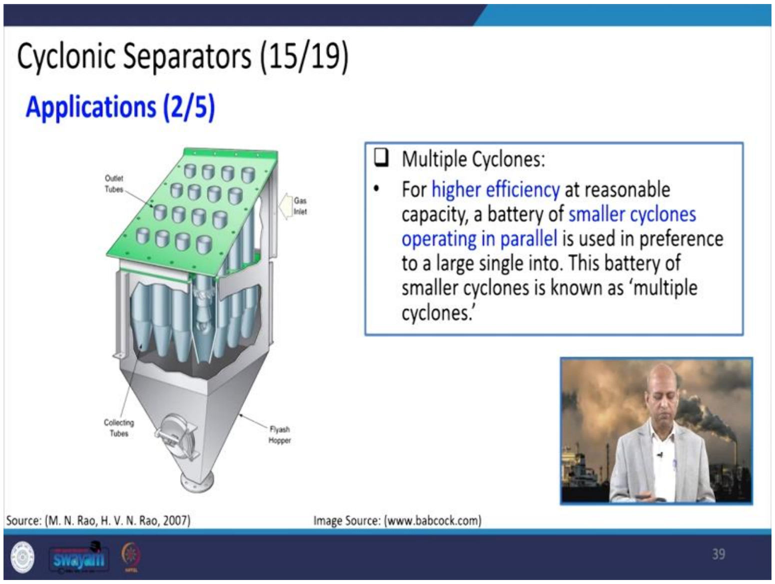

For example, to increase the efficiency in row and parallel rows as well as this kind of system maybe there where smaller cyclones can be put together and multiple cyclones we can call it so that more cyclones are available to remove the particles.

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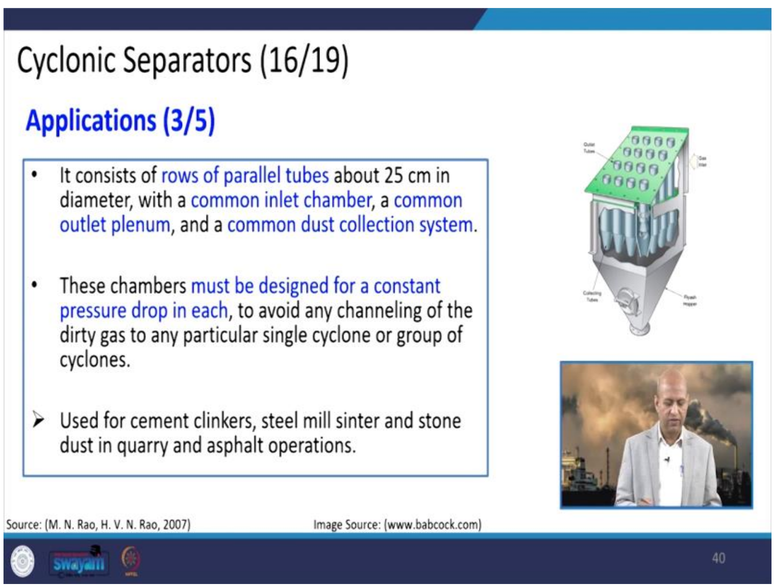

Well, this can consist of different rows two or more and depending upon their distance and collection efficiency can be calculated.

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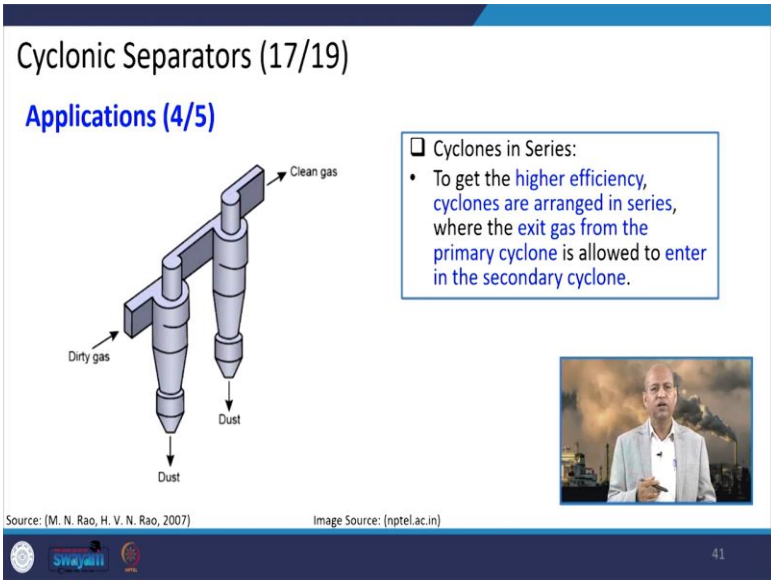

If we go into series only one after one then dirty gas goes to one particular this separator then cleaner gas goes to another separator that way you can ensure very high efficiency or very clean gas at the outlet depending upon how many cyclone separators you have installed in series basically.

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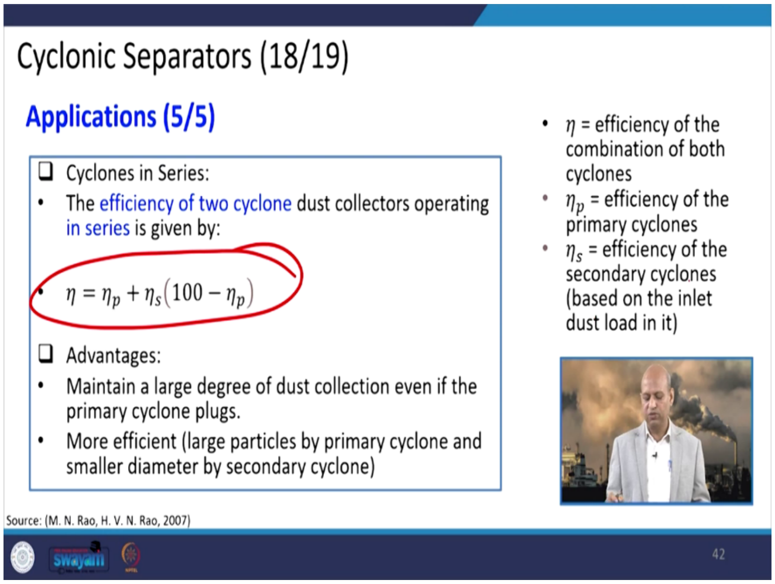

So, if you want to calculate the efficiency in cyclones installed in series, then this is the simple formula like eta equals eta p plus this eta s 100 minus np [$\eta = \eta\_p + \eta\_s\ (100 - \eta\_p\ )$]. So, this is basically this eta (η) efficiency of the combination of both the cyclones, eta p (η_p) is efficiency of the primary cyclone that is initially, then efficiency of the secondary cyclone based on the inlet dust load in it so that can be used.

$$\eta = \eta_p + \eta_s(100 - \eta_p)$$

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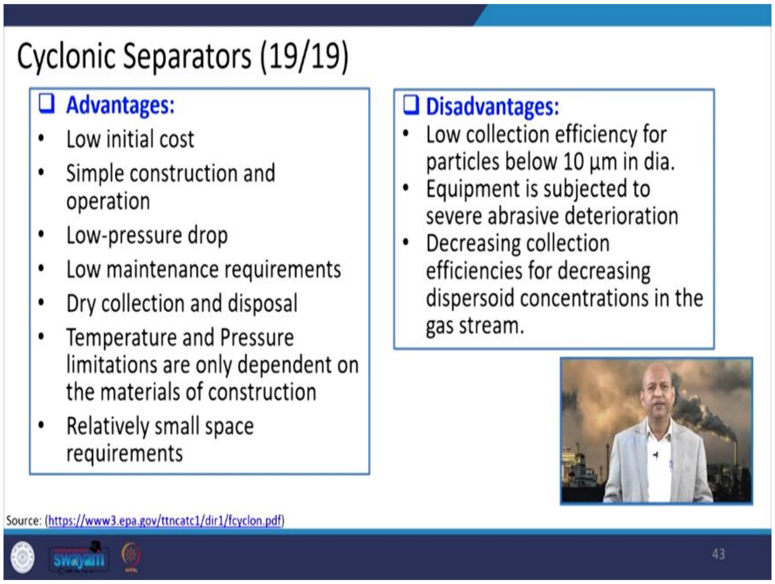

Then advantages are like low cost, initial low cost, simple construction and operation, low pressure drop or low maintenance requirement, dry collection and disposal is very easy, temperature and pressure limitations are only dependent on the materials of the construction. So, that way you can have different kinds of metal if there are issues with the temperature. Relatively small space required, because vertical you can design it. So, horizontal space may not be a big problem which is a problem in the settling chamber.

Disadvantages like low collection efficiency for particles below 10 micrometer in diameter, equipment is subject to the severe abrasive deterioration and depending upon the particle size, its sharpness etc. then decreasing collection efficiency for decreasing dispersoid concentration in the gas system. So, those are the issues of the disadvantages.

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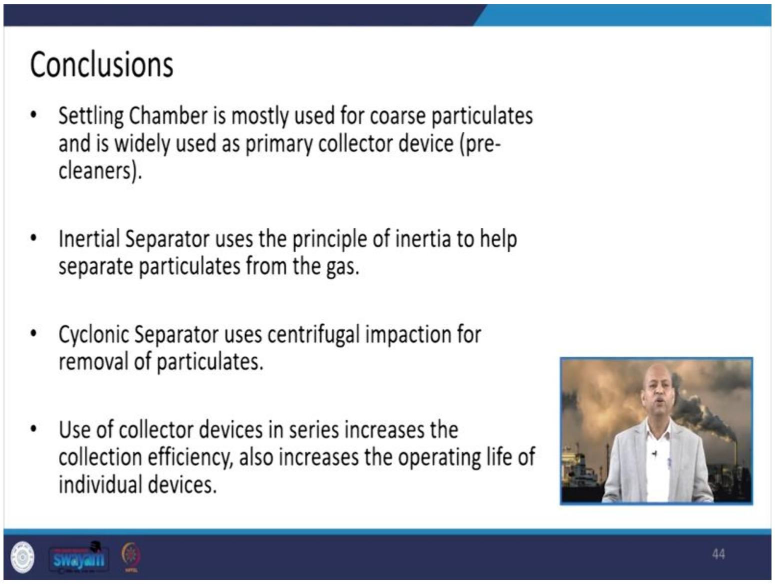

Well, so, overall, we can say that the settling chamber is mostly used for coarser particles because it is very simple device. It works on gravitational force. So, there is no other external forces we are using. So, only coarse particles can be removed very efficiently and it is used that is why for primary collector devices before some other devices are placed.

Then inertial separator uses the principle of inertia as we have seen to help separate particulate from the gas. And cyclonic separators basically use this centrifugal impaction because of centrifugal force to remove the particulate matter.

And the use of collector devices in series increases the collection efficiency. It also increases the operational life of the individual devices. If some devices more problematic at the primary stage you can remove it, replace it so that you can increase the life of the other devices which are on the downward side. So, this is all for today's lecture on particulate matter collection devices. We will continue this lecture of air pollution control devices.

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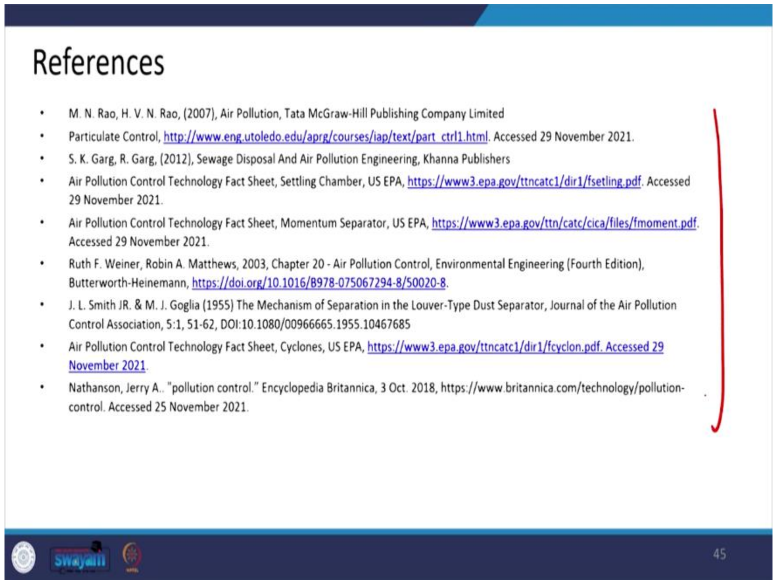

So, these are the references for additional information. And thank you for your kind attention. See you again in the next lecture. Thanks again.