Air Pollution and Control
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Lecture 43
Air Pollution Control Devices: Part – 2

Hello, friends. So, these days we are discussing about Air Pollution Control devices. In the part 1 we discussed about particulate matter control devices. And part two is also related to particulate matter control devices like fabric filters, electrostatic precipitators, scrubbers or wet collectors and then we will conclude.

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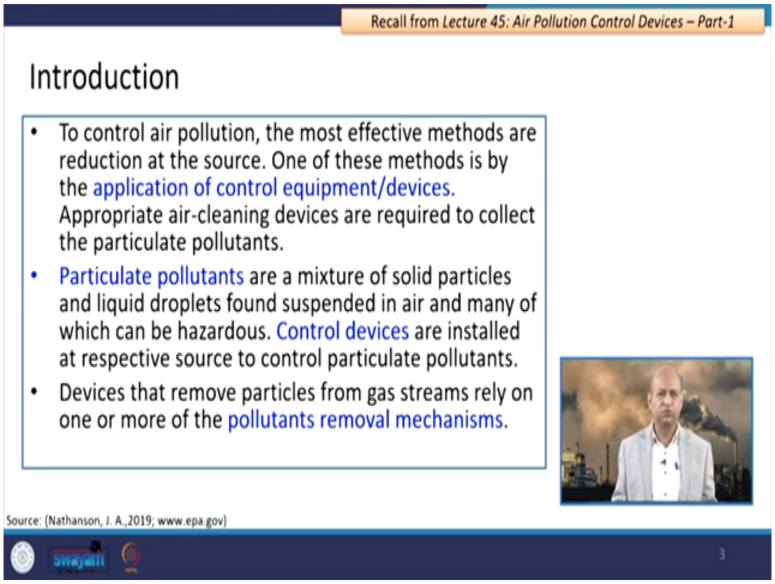

So, if you recall the last lecture like what is the way of controlling air pollution and we kind of agreed or concluded that the most effective method for reduction of pollution or controlling air pollution is reducing it at the source or controlling it at the source itself. And there are several devices which can be used for controlling air pollution at the source basically.

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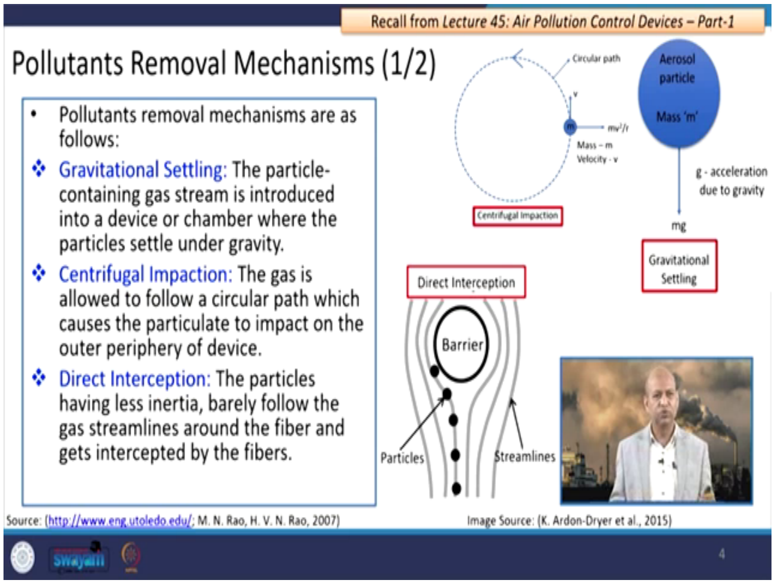

And these control devices are based on different principles which we go one by one and different mechanism like gravitational settling, in this, the particles when they contain gas or aerosol particles. So, mixed, mixture of, it is introduced into a device or a chamber where the particles can settle down with the force of gravity.

And in centrifugal impaction basically the gas is allowed to follow a circular path and which causes a particulate matter to impact on the outer periphery of the device and lose the velocity due to the centrifugal force. They go outside and impact on the wall and then slide down to get collected into the hopper. Then direct interception can also be there, like the particles having less inertia, like barely follow the gas stream lines around the fiber and gets into intercepted by the fibers itself those kinds of interception occurs.

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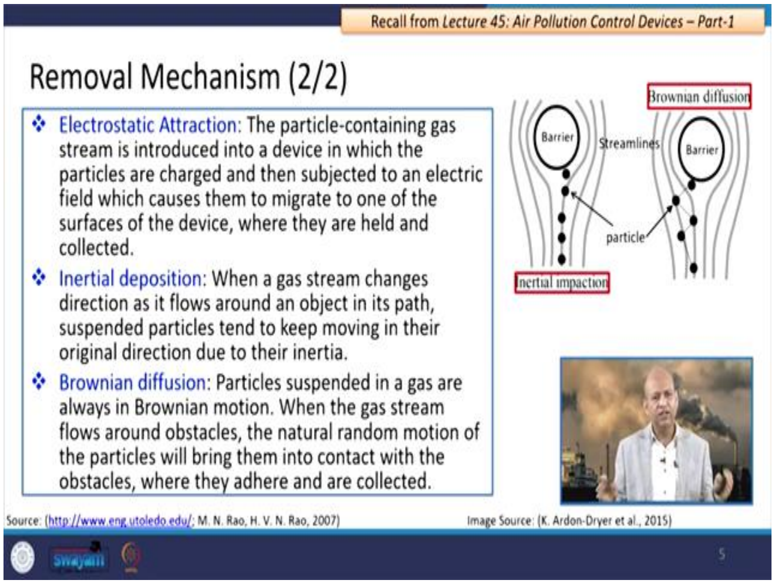

Electrostatic attraction is also one way of controlling these air pollutants or collecting these air pollutants of particulate nature. The particles containing gas stream is introduced into a device in which the particles are charged and then they are subjected to an electric field which is causing them to migrate from one of the surface of the device to another surface where the opposite charges are there then they lose the charge and again slide down and get collected into the bottom hopper.

Then there is one mechanism like inertial deposition in which gas stream changes direction as it flows around an object in the path and suspended particles tend to keep moving in the same direction and they strike to, with the inertia strike to the that particular object and again lose the velocity. Then there is Brownian diffusion also, like particles they are suspended in the gas and they always in Brownian motion. They go from one direction to another. And in that movement, they again get impacted on the surface and then get reduced to the, like velocity get reduced to the 0 and then they slide down.

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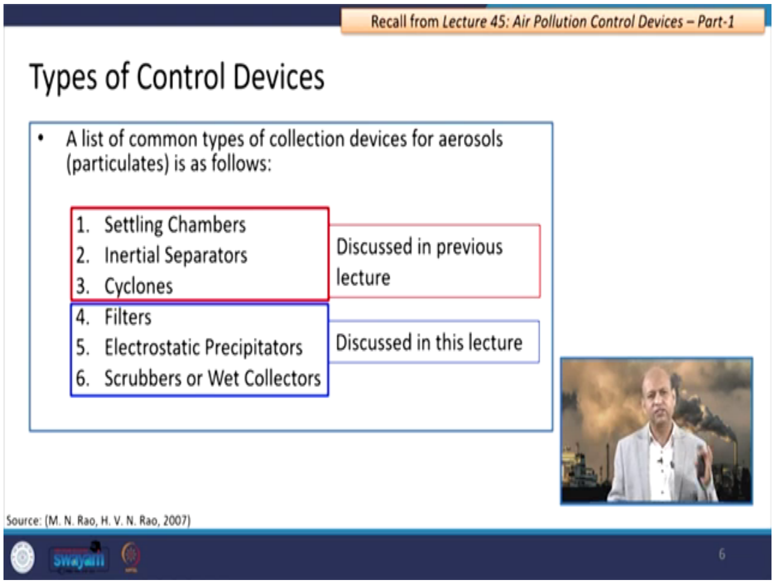

So, in that way, we have discussed three devices like settling chambers or inertial separators and cyclones in the last lecture. Today, we will cover filters, electrostatic precipitators and scrubbers or wet collectors.

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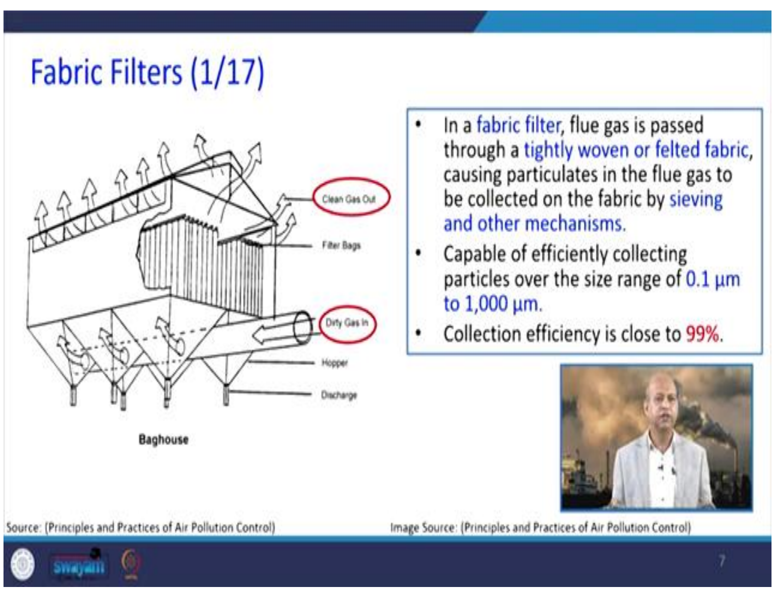

So, when we go to the fabric filters basically, in fabric filter this flue gas which is containing particulate matter is passed through a tightly woven or like cloth or fabric bag or something like that, that causes particles in the flue gas to collected on the fabric by like sieving kind of thing, because it passed through the pores and then it gets attached to those surfaces. And these are capable of efficiently collecting these particles over the size range of 0.1 micrometer to 1000 micrometer. So, very good range is there for fabric filters. They are very good devices in fact to control or to capture very small particles and even large particles. So, that way it is very good. And then a collection efficiency is also very high, like 99 percent of the particles can get collected by these fabric filters.

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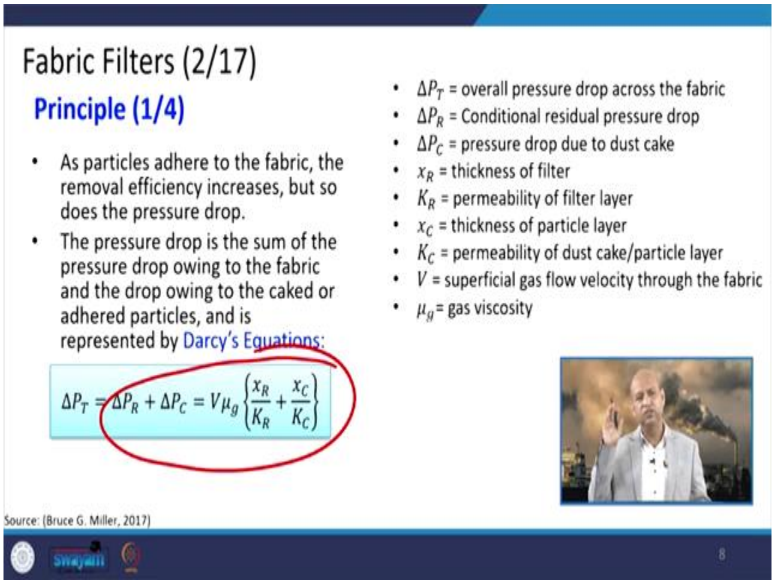

Now, if we talk about the principle how does fabric filters operate, then basically we should know about the concept of like overall pressure drop. When something is coming then they pass through some inertia or some kind of obstacle, then they loses this force or pressure. So, overall pressure drop is causing in the, across the fabric filter that we should know. Then this conditional residual pressure drop delta PR (ΔP_R) that is also to be known. Then pressure drop due to dust cake, cake means the dust particles which will get collected on the surface. So ultimately, they will form some layer or we call it cake. So, that because of that also pressure drop will be there.

The thickness of the filter that fabric baghouse filter and then permeability of the filter layer, thickness of particle layer which will deposit over the period of time and permeability of that dashed cake or the particle layer that should be known and superficial gas velocity through the fabric filter when gas is passing through with certain velocity and gas velocity that this gas viscosity mu g (μ_g) that should also be known in addition to the gas velocity. So, those things these all parameters can be put in this equation and we can get this delta PT (ΔP_T) that is the overall pressure drop by using these particular values.

$$\Delta P_T = \Delta P_R + \Delta P_C = V\mu_g \left\{\frac{x_R}{K_R} + \frac{x_C}{K_C}\right\}$$

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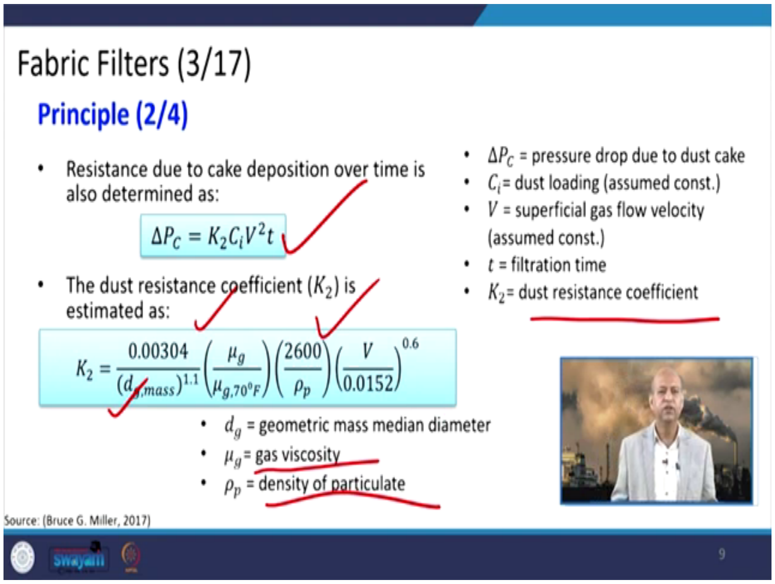

Well, when we talk about like resistance due to cake deposition that can be calculated further with this empirical relationship and where K_2 is basically dust resistance coefficient that is also calculated by this empirical relationship which has density of the particulate, gas viscosity, then d_g is there this geometric mass median diameter, because particles are of different sizes. So, we calculate the mean or median diameter of the, those particles that is to be used for this calculation purpose.

$$K_2 = \frac{0.00304}{(d_{g,mass})^{1.1}}\left(\frac{\mu_g}{\mu_{g,70^0F}}\right)\left(\frac{2600}{\rho_p}\right)\left(\frac{V}{0.0152}\right)^{0.6}$$

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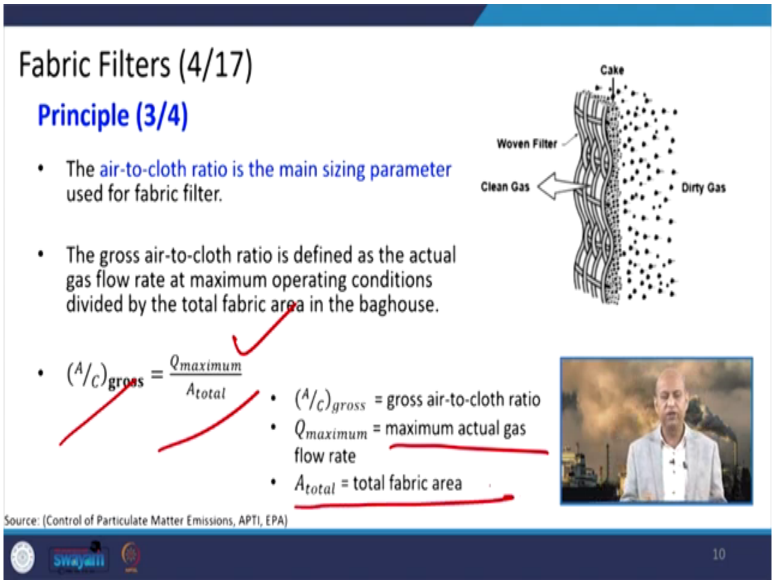

Then, when we talk about like air-to-cloth ratio that is also very important governing factor for efficiency of collection of particles through fabric filters. So, this is basically you can call like this is ratio which is defined as the actual gas flow rate at the maximum operating conditions divided by the total fabric area in the baghouse. So, that is the air cloth ratio which is a parameter and this is air cloth ratio the gross is $Q_{maximum}$ divided by A_{total}.

$$(A/C)_{gross} = \frac{Q_{maximum}}{A_{total}}$$

So, A, this gross of the air to cloth ratio is calculated by this particular relationship where $Q_{maximum}$ is maximum actual gas flow rate, the actual gas flow rate of the maximum value because it may fluctuate. So, the maximum value we will take. And the A_{total} fabric area, the complete fabric area through which this gas will pass so that area has to be taken, means including the pores.

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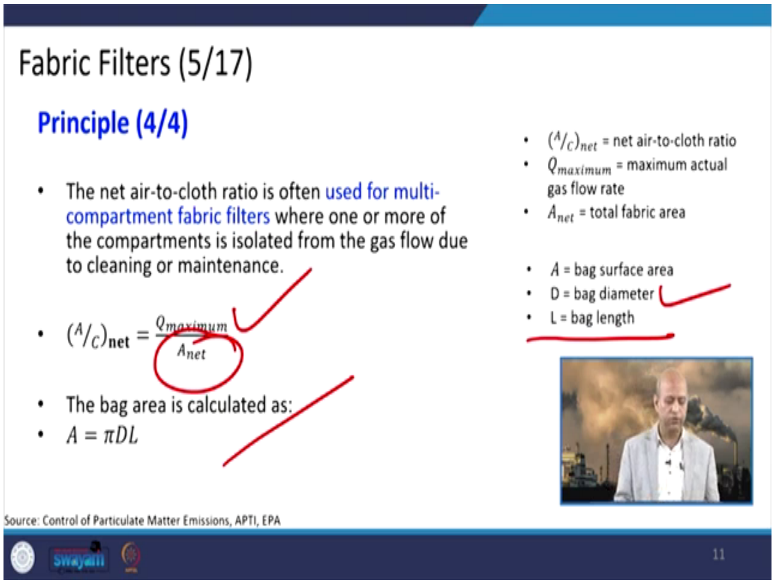

Well, then there is another concept of the net air-to-cloth ratio and this is basically defined like in multi compartment fabric filters, where one or more of the compartment is isolated from the gas flow due to like cleaning purpose or maintenance purpose. So, there may be multi filters or bag filters. So, one can be for maintenance purpose, others may be in operation. So, in that case this net A / C, air cloth ratio in terms of net, so that is $Q_{maximum}$ divided by A_{net}. Earlier we used A_{total}, total area, now this is the net area which is in operation and in A total basically we are, we use all kinds of these cloth area. So, in this, this bag area is calculated by pi DL(πDL), where D is the bag diameter and L is the bag length and A is the bag surface area. So, this is the relationship which is used for calculation of this air-to-cloth ratio of the net, not the total. Total was earlier one.

$$(A/C)_{\boldsymbol{net}} = \frac{Q_{maximum}}{A_{net}}$$

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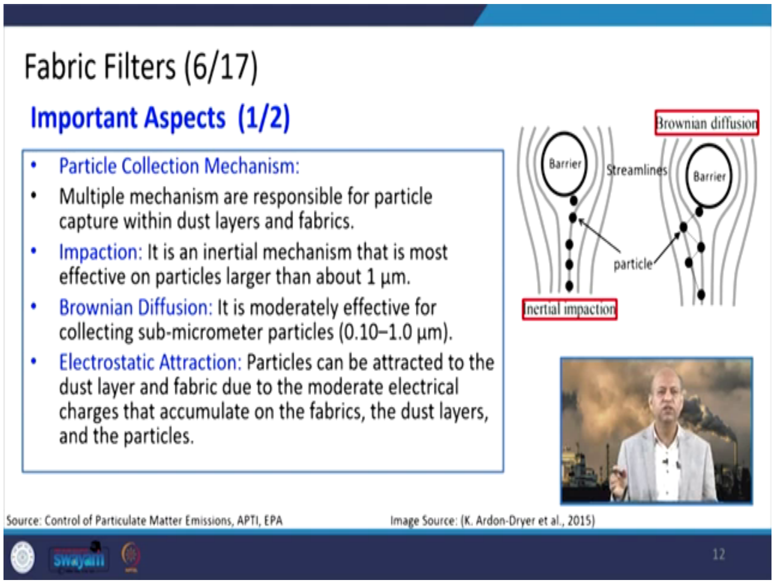

Now, there are different important aspects in filter, this fabric filter operation, like particle collection mechanism is important in the sense that these multiple mechanisms are responsible for particle capture with the dust layers and fabrics like impaction, Brownian diffusion, electrostatic attraction. So, those things are important aspects basically.

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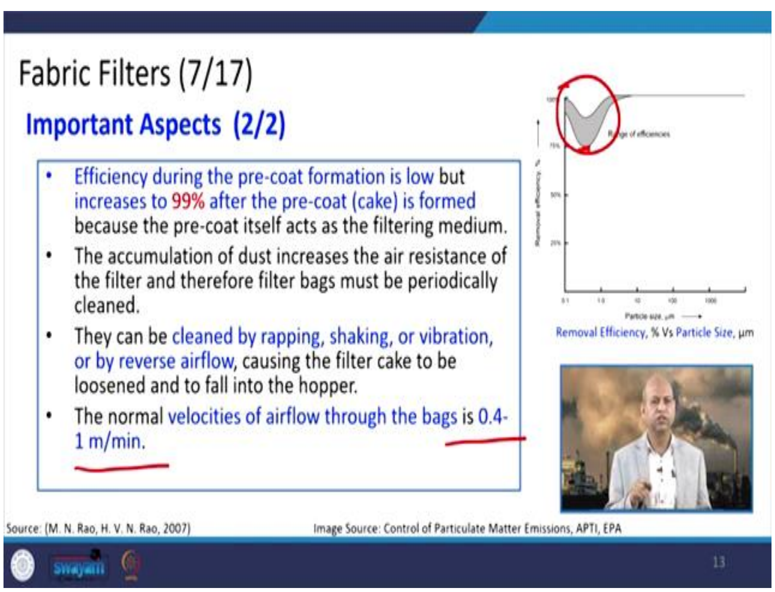

And then if we talk about the efficiency during this pre-coat formation that is before cake formation of the particle layer formation on the bag, so then it is less efficiency, but after this layer is formed, then efficiency increases, because then more it is like pore is less in size or less area is available to go through the empty area. So, the efficiency increases basically when this pre-coat, in comparison to the pre-coat there is this dust increases and that air resistance increases because of less pore size. So, the cake information is also important in this case basically.

And this normal velocities of airflow through bag is 0.4 to 1 meter per minute. So, that kind of velocity has to be there, otherwise like particle size and this removal efficiency that can vary basically for different sizes, but this kind of drop is there for some particle size which can be again overcome when cake formation is there. Those particles this like 0.1 to 10 so their efficiency is less initial stages, but after cake formation the removal can be better.

So, in continuation to the important aspects we also consider like pre-coat formation. Before this cake formation is there efficiency is less especially in the range of these particles 0.1 to 10 micrometer. When this coat formation or cake formation is there, then resistance is more for passing the air and then the efficiency again increases and this like, for example, it is around 75, then it becomes like maybe 85 or 90 or something like that. So, that way the efficiency increases after this cake formation. And the normal velocities of the airflow through these bags has to be like 0.4 to 1 meter per minute. So, that way we can collect a lot of particulate matter with good efficiency.

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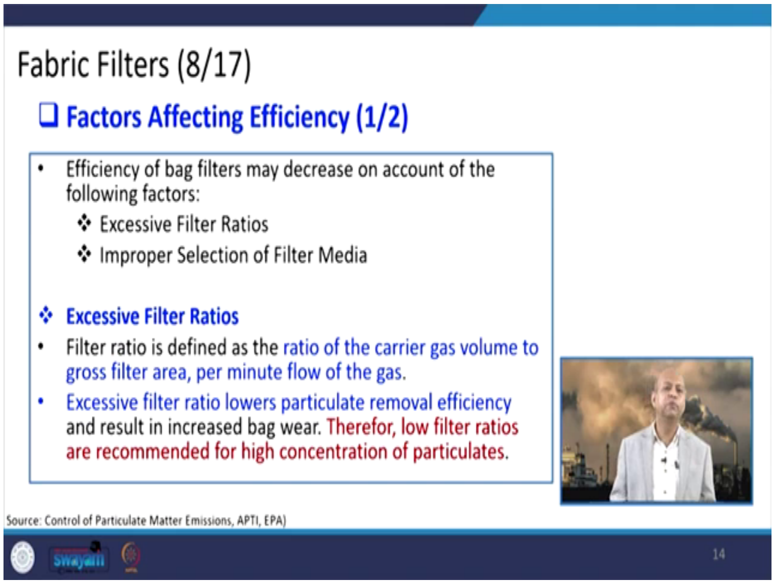

Then if we talk about like efficiency of bag filters, how they decrease or increase, so they may decrease on account of following factors like excessive filter ratios or improper selection of the filter media. So, those could be the reason basically. When we talk about excessive filter ratios, basically this filter ratio is defined like carrier gas volume to the gross filter area per minute flow of the gas. And this excessive filter ratio lowers particulate removal efficiency and result in increasing the bag wear and tear. So, that way life of the bag also is reduced. Therefore, low filter ratios are recommended for high concentration of particulate matter to be removed.

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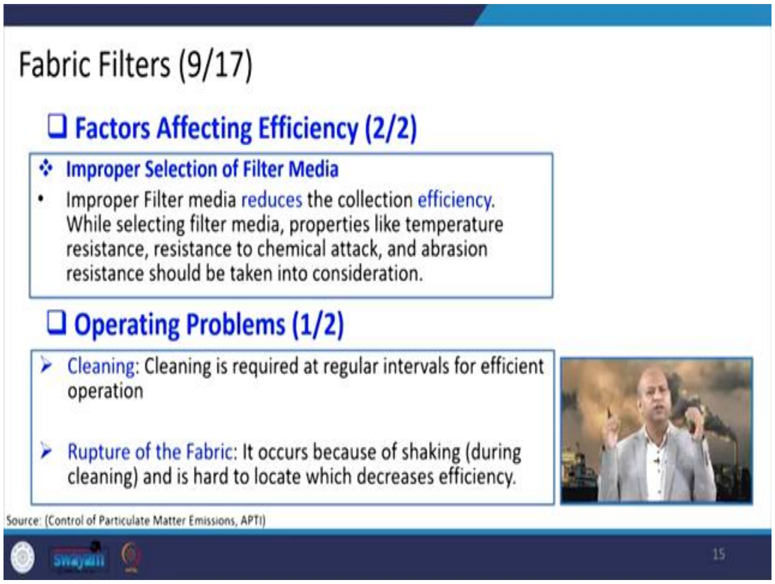

Then we talk about like improper selection of filter media. So, improper filter media can reduce the collection efficiency also. While selecting filter media, properties like temperature resistance means because the guests these emissions could be of different temperature basically. So, what is the range, which range of the temperature this filter media can afford, so that has to be taken into account. Then resistance to chemical attacks, because some gases may be of acidic nature like SO_2 etc. maybe, dew point is achieved then the sulfuric acid formation maybe there because of moisture etc. and this can attack the filter media if it is not resistant to chemical attacks. Then abrasion resistance or all these kinds of things should be taken into consideration basically.

When we talk about operating problems, means operational problems, then cleaning, rupture of the fabric. So, cleaning is required because otherwise when these pores are packed, then pressure drop increases very high and efficiency decreases. So, regular cleaning has to be there. Then rupture of fabric can be there because of shaking during the cleaning process. So, it is very difficult to locate that rupture and it can decrease the efficiency very significantly.

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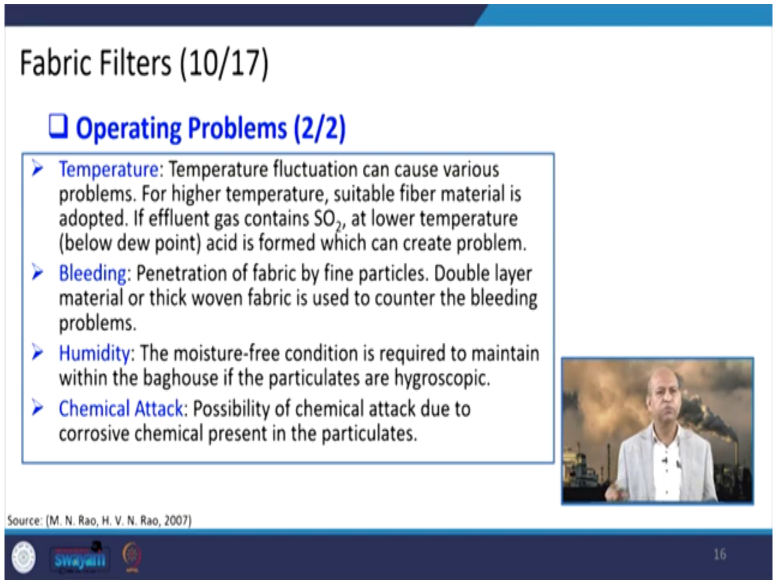

Then temperature also, like if temperature fluctuation is there and very high temperature occurs maybe fire can also can be caught by the filter media if it is not a very high temperature resistant. Bleeding like penetration of fabric by some fine particles. Double layer material or thick woven fabric is used to counter these bleeding problems.

Humidity can be there like moisture free condition is required for maintaining good efficiency within the baghouse, otherwise particulate matters of hygroscopic nature they will catch the moisture and they will deposit to the pores. It will be difficult to take them out and the efficiency or the removal efficiency and this pressure drop will increase and efficiency will decrease. Chemical attack, the possibility of chemical attack due to corrosive chemical present in the particulate matter and gas can be there.

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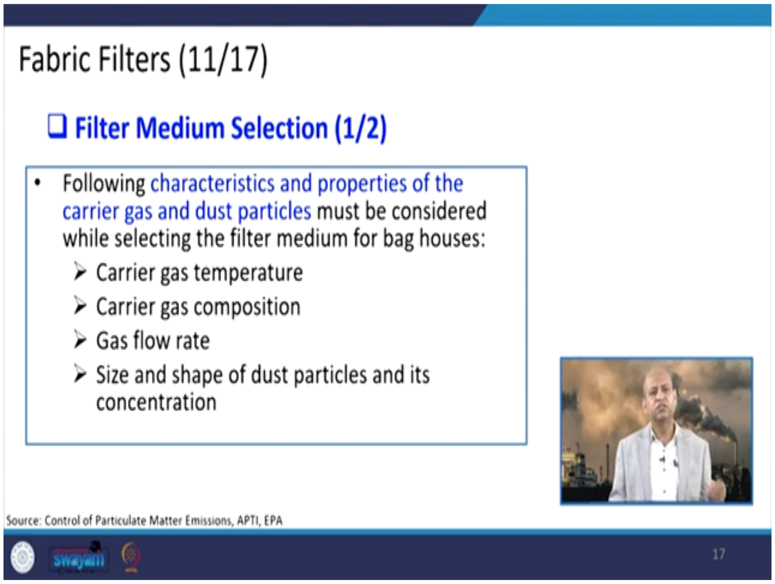

Then if we talk about like different characteristics which are important, different properties of the filter media, which are important for these baghouse filter or fabric filters these are like carrier gas temperature, carrier gas composition of SO_2 etc. there then we have to take care those kind of filter media we have to select which can resist the chemical attacks, gas flow rate, size and shape of the dust particles and its concentration because accordingly the pore size will vary, efficiency of removal vary, all these things will vary.

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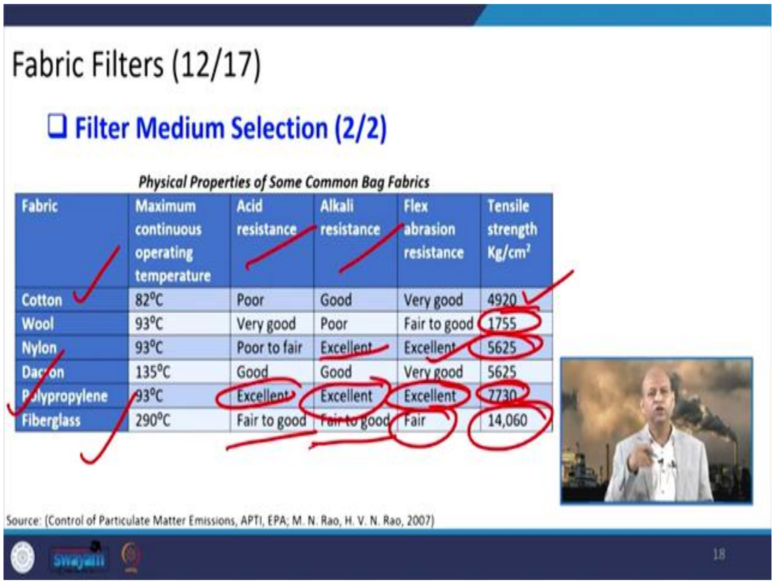

Fabric	Maximum continuous operating temperature	Acid resistance	Alkali resistance	Flex abrasion resistance	Tensile strength Kg/cm²
Cotton	82°C	Poor	Good	Very good	4920
Wool	93°C	Very good	Poor	Fair to good	1755
Nylon	93°C	Poor to fair	Excellent	Excellent	5625
Dacron	135°C	Good	Good	Very good	5625
Polypropylene	93°C	Excellent	Excellent	Excellent	7730
Fiberglass	290°C	Fair to good	Fair to good	Fair	14,060

So, if we see this table, this gives the physical properties of some common baghouse fabrics like cotton. Cotton is there then the maximum continuous operating temperature could be 82 degrees Celsius. Beyond that fire will be there. So, we cannot increase the temperature beyond 80 or 82 degree Celsius. Acid resistance is poor for cotton. They can attack by resist, acidic component of the gases and their life will be very less. Alkaline resistance is good for the cloth, this cotton. And then flex abrasion resistance is very good in that sense. And tensile strength is around 4900 kilogram per square centimeter. This is better than the wool.

But wool's temperature resistance is better 10 degree Celsius. It is wool is good for acidic resistance, then it is fair to good for these abrasion resistance, but this tensile strength is like only 1755 much less than the cotton one. Nylon has similar properties as wool when temperature is taken into consideration, but acid resistance is not so good in comparison to the wool or then alkali resistance is excellent and this abrasion resistance is also very nice and this tensile strength is better than the wool and is even better than the cotton.

Then other metals are there. The best one is fiberglass which is having very high temperature resistance like up to 290 degrees Celsius it can resist. And, but acid resistance fair to good basically. It is not excellent like polypropylene. So, it is fair to good. Similarly, alkali resistance is also fair to good and flex abrasion resistance is fair not excellent. This polypropylene has excellent properties for abrasion and resistance to acidic and alkaline components and tensile strength is maximum for this fiberglass. But second best is this polypropylene material.

So, means depending upon which industry is there, what kind of gas it is coming, what is the composition of the gas, what is the temperature, what kind of resistance we need depending upon that we can choose which fabric we should be using in that baghouse filter basically.

Then if we talk about like types of the fabric filters, then there are numerous types like envelope type fabric filter can be there. It is in the form of cloth envelope supported on a wireless screen frame and the individual units range from around 0.6 to 1 meter wide and 3 to 5 centimeter thick. And gas is introduced on the outside of the each envelope and this passes through the fabric into that frame of the unit and then it goes out of the collector. And then, but it is not suitable for very fine particles. It is good for coarse particles.

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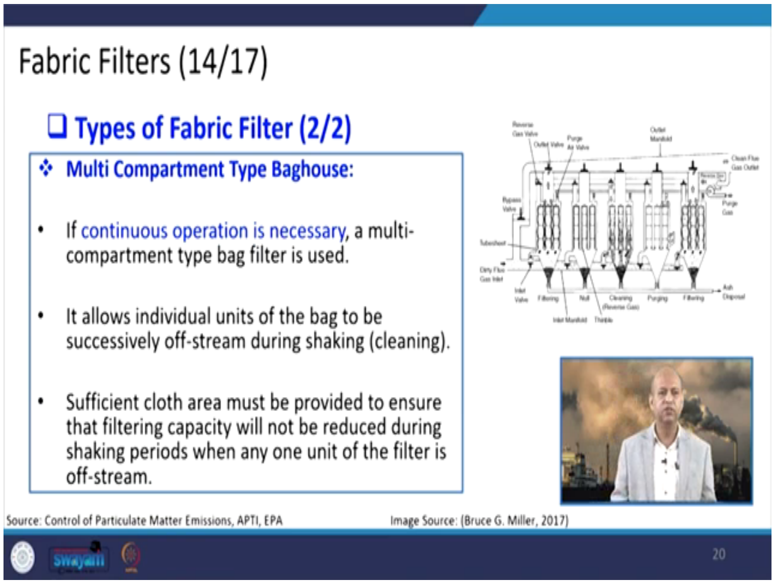

Then there may be multi-compartment type baghouse filters also where different compartments are there like 1, 2, 3, 4, 5. And for, continuous operation is necessary then these kinds of arrangements are very good because if one compartment is under maintenance then other compartments will continue to work. So, those kinds of things can be there. And then shaking, cleaning are needed for time to time. So, some compartments will not be in operation, but other compartments may be in the operation.

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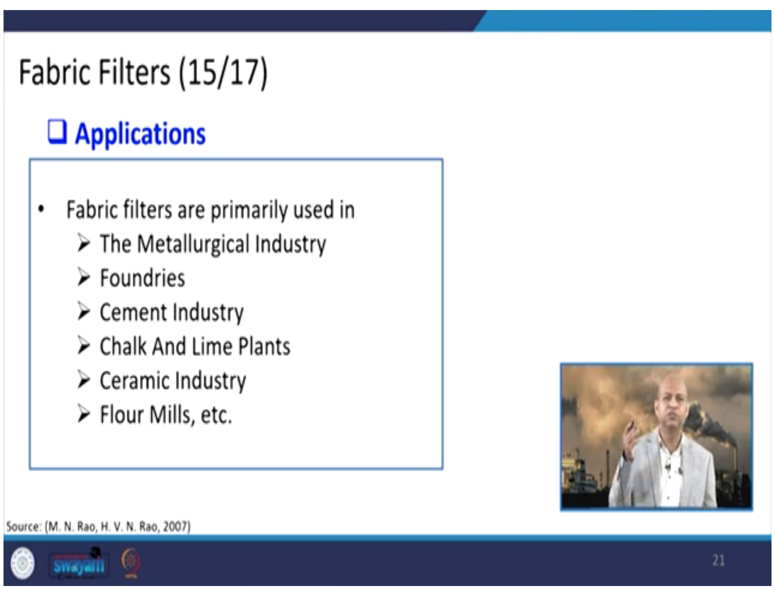

Then if we talk about like applications where they are good these fabric filters, so we can see into metallurgical industries or foundries or cement industries, even chalk and lime plants or ceramic industries, then flour mills etc. So, those are the kinds of industries where these fabric filters are mostly used.

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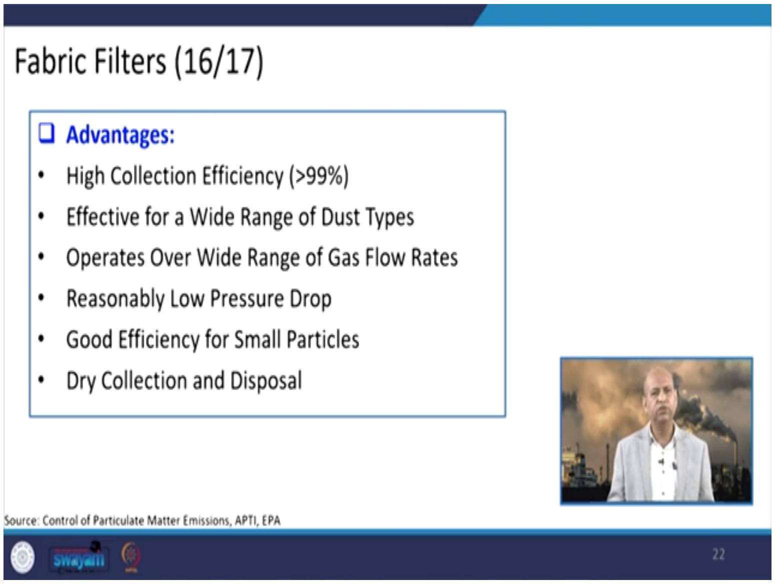

And the advantage is if we talk about then they are having high collection efficiency even more than 99 percent of particles can be collected by fabric filters. And these are effective for a wide range of dust types and this can operate over wide range of gas flow rates also. So, fluctuation it can also afford to resist. Then reasonable low-pressure drop is there. It is not very high pressure drop like other kind of devices have. Good efficiency to small particles also depending upon the pore size and then this flow rate etc. Dry collection and disposal is very good in that sense.

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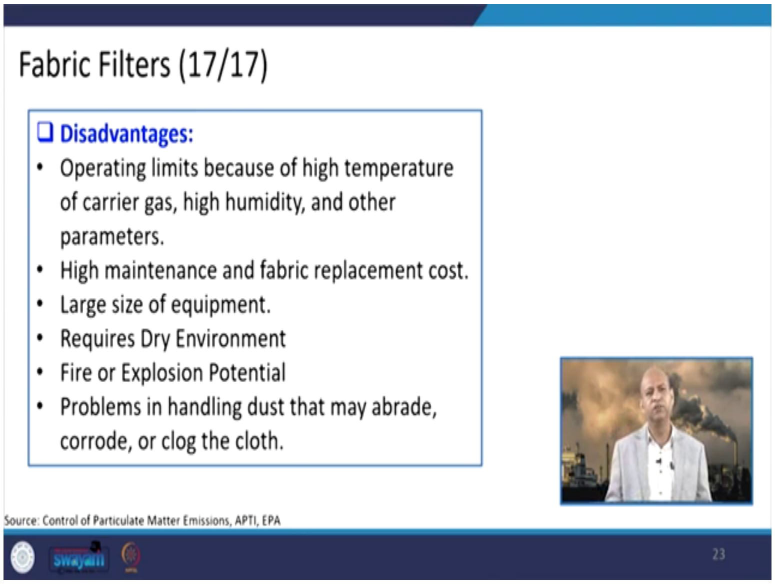

But there are some disadvantages also. Like there are limitations in terms of high temperature of carrier gas or high humidity and other parameters because it cannot afford, otherwise very high temperature can generate some fire related hazards, high humidity can very tight cakes may be formed and it is difficult to remove them so efficiency decreases. High maintenance and fabric replacements cost can be there. Large size of equipment is needed for, depending upon their flow rate. Then it requires dry environment basically. Moisture is not good for fabric filters.

And fire or explosion potential can be there depending upon the temperature. Problems in handling dust that may like corrosion kind of thing or clogging the cloth. So, those kind of problems are there. It is not free from problems. But if we can get rid of this with highly skilled people and if we have a lot of good money to operate, then this is a good suggestion to go for fabric filter depending upon if there is no very high hot gases there.

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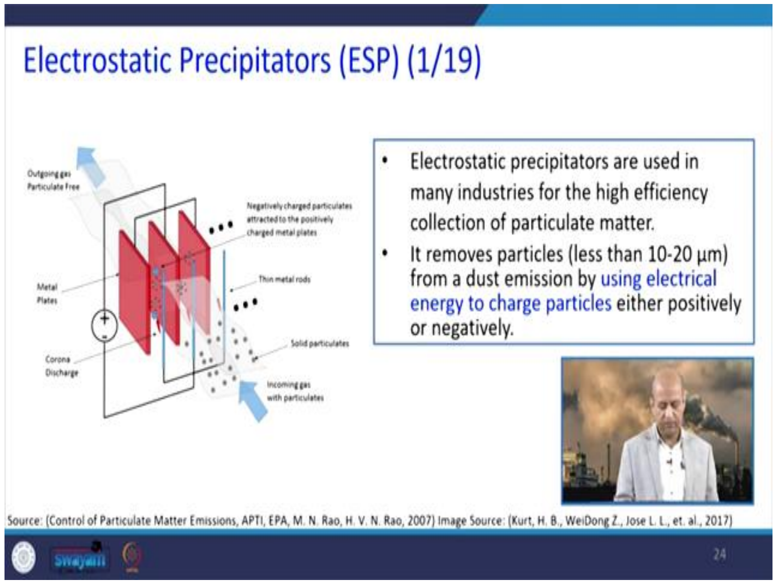

Now, if we talk about electrostatic precipitators, because fabric filters is a different device, electro precipitator is different device. So, if you talk about the electrostatic precipitators, they are used in mainly like industries of very high efficiency collection of particulate matter. We will see that they are very costly to install, but their efficiency is very good. It can remove particles even less than 10 to 20 micrometer from a dust emission using electrical energy to charge particles and then go for the other kinds of charge of the plates where they are deposited because of opposite charge basically. So, one plate is there, through which particles go through and they get charged into that particular kind of electric charge and then they move towards the opposite charge plate where they lose their charge.

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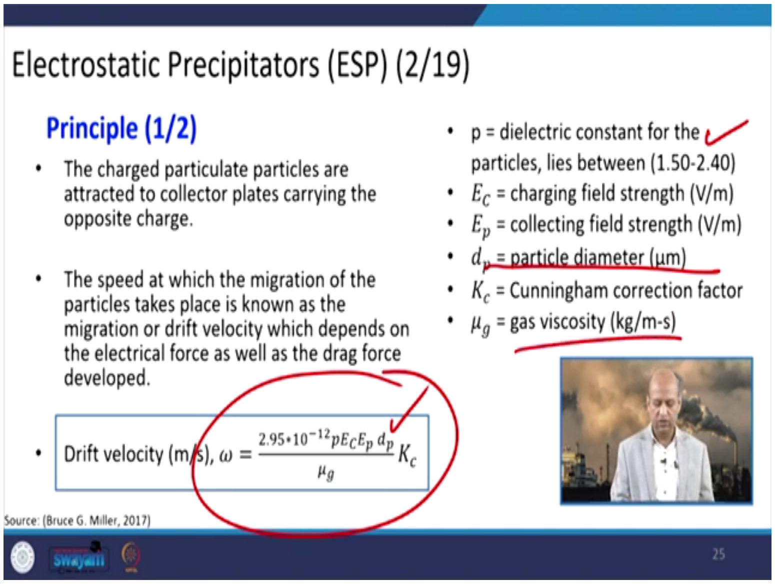

So, the charged particulate particles are attracted to the collector plates basically carrying the opposite charge. And the speed at which they migrate from this charging plates to the collector plate can be known as the drift velocity basically, and this can be calculated by this particular empirical relationship where we know like this dielectric constant for the particles which is between 1.5 to 2.4 and then this E_c charging field is strength is there, E_p collecting field strength is there, d_p is particle diameter this one and the K_c is correction factor, mu g is gas velocity, so, all these, sorry, gas viscosity. So, all these parameters are used for calculating the drift velocity.

Drift velocity (m/s), $\omega = \frac{2.95\text{x}10^{-12} p E_C E_p \, d_p}{\mu_g} K_c$

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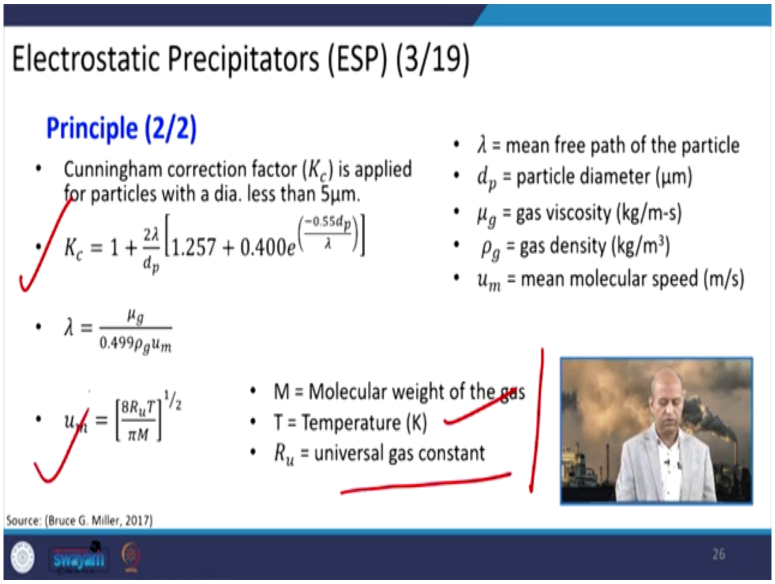

And so these parameters as we have seen these are calculated by another set of empirical relationship where the meaning of different parameters are given like free path of the particle, mean free path, particle diameter, viscosity and gas density, mean molecule speed, all these, then molecular weight of the gas, temperature in Kelvin and the universal gas constant is also used for calculation of this mu m (u_m).

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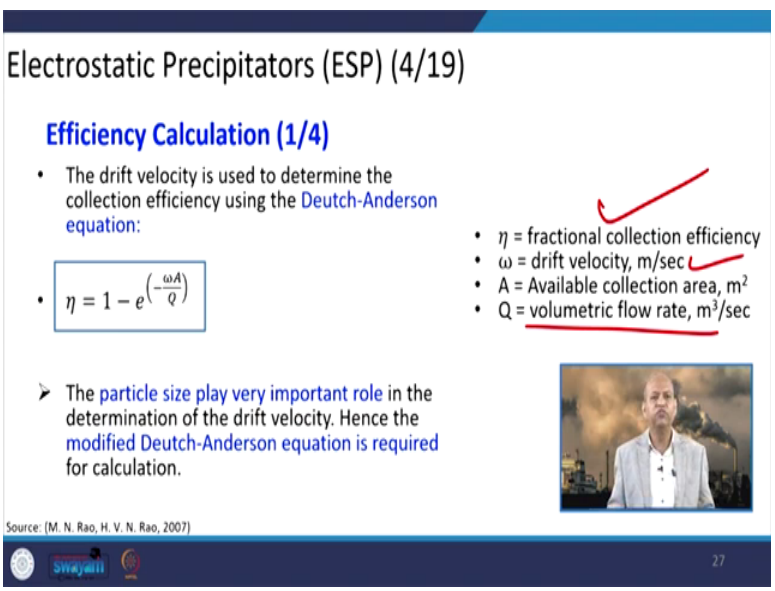

Then if we talk about efficiency of the collection, so that can be calculated by this formula eta equals 1 minus e to the power of minus this omega A upon Q. So, this omega (ω) is drift velocity and eta (η) is fractional collection efficiency, A is the available collection area of the plates basically, if it is plate, if it is circular cylinder then we can calculate the surface area basically, volumetric flow rate Q is there. So, the particle size basically play a very important role in the determination of drift velocity as we have seen earlier and has the modified this Deutch-Anderson equation is required for calculations.

$$\eta = 1 - e^{\left(-\frac{\omega A}{Q}\right)}$$

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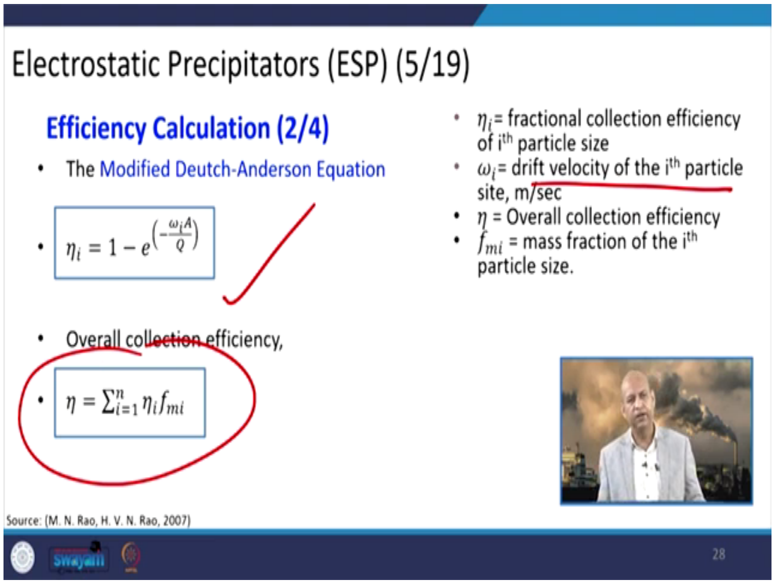

And then this is the modified the equation where you can use this omega (ω_i), this is the drift velocity of the i[th] particle. So, different particle related calculations can be there and then we can do integration. So, overall collection efficiency is there. This integration can be there for different type of particles and you can get the net collection efficiency.

$$\eta_i = 1 - e^{\left(-\frac{\omega_i A}{Q}\right)}$$

$$\eta = \sum_{i=1}^{n} \eta_i f_{mi}$$

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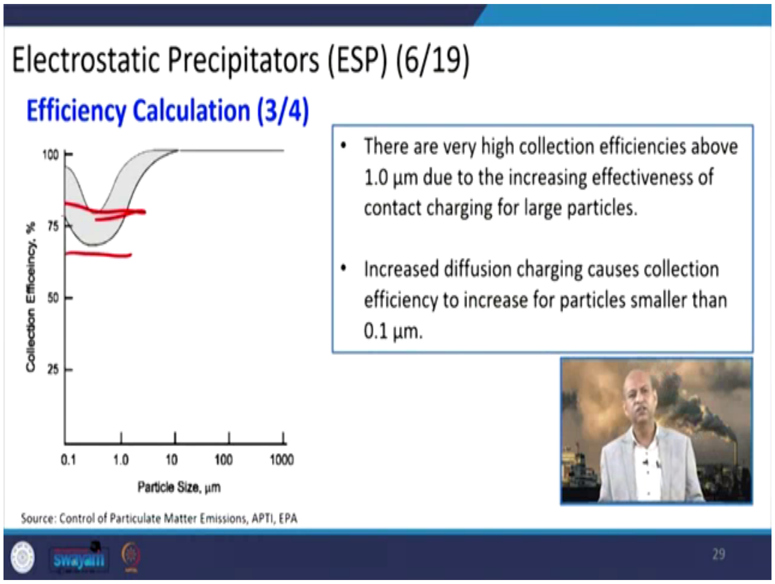

Again, if we see like efficiency, so different particle size, collection efficiency is there and there are very high collection efficiency above 1 micrometer of the size of the particles when we talk about these electrostatic precipitators, but the increased diffusion charging causes collection efficiency to increase for particles smaller than even 0.1 micrometer. So, that kind of efficiency also increases here as we have seen in the bagfilter or fabric filter kind of devices.

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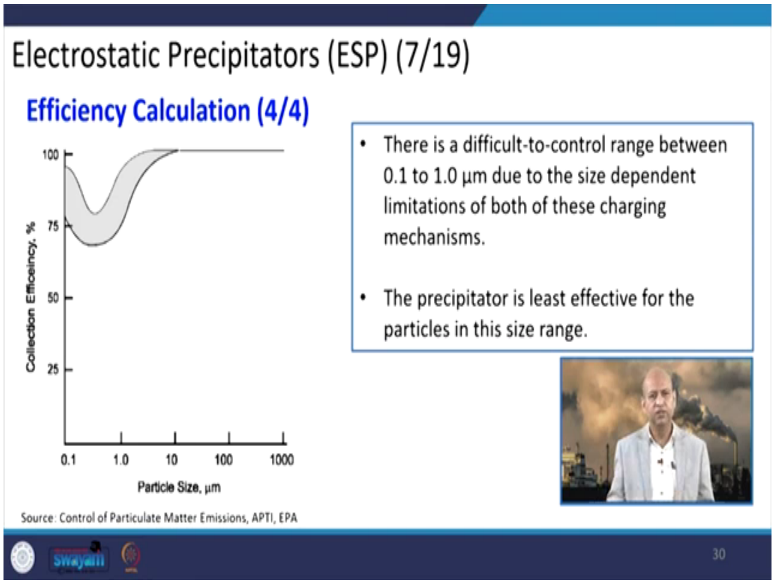

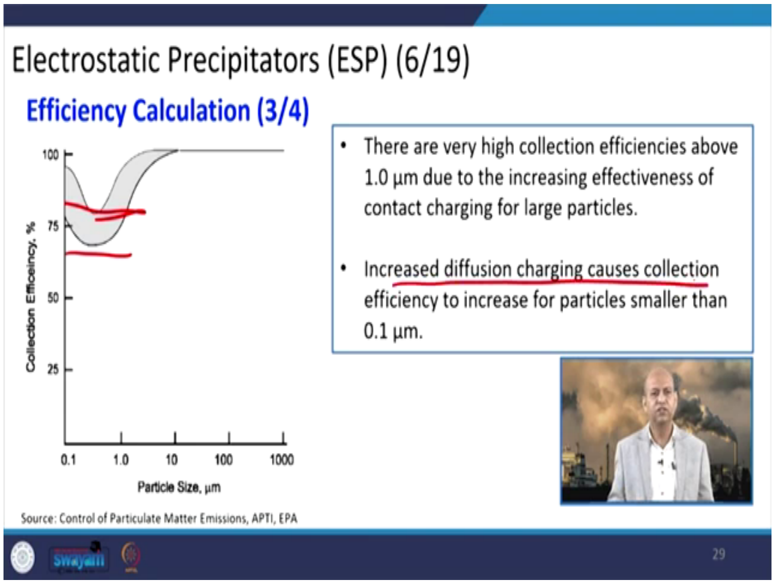

Well, there is difficult-to-control range between this 0.1 to 1 micrometer due to the size dependent limitations. So, these precipitators are least effective when, for this particular size range. But as we have seen little bit improvement can be there depending upon this diffusion charging kind of phenomena.

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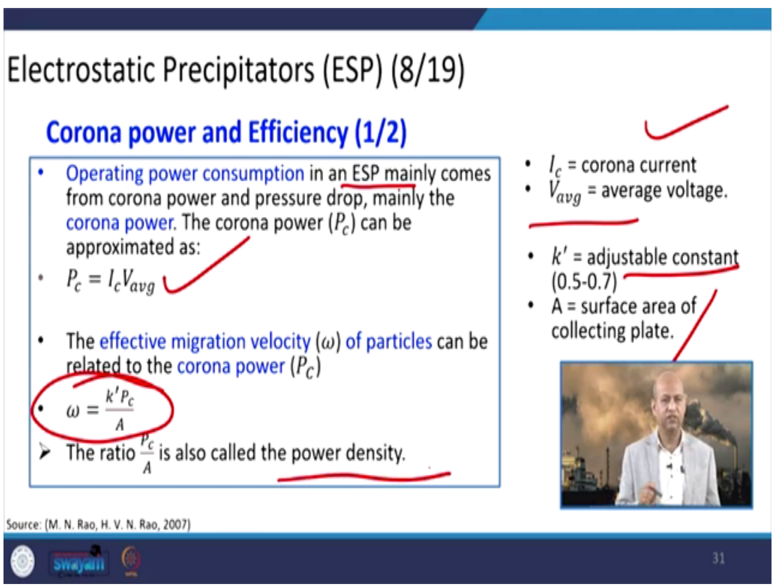

When we talk about like corona power and efficiency, so you see this is operating power consumption in electrostatic precipitator which comes from the corona power where this some blue light is there where this passes through gas and particles pass through we call it corona. So, this corona power can be calculated by this particular relationship where I_c is corona current and this V average is average voltage basically. So, this adjustable constant is there, surface area of the collecting plate is there. So, you can calculate this omega k dash P_c divided by A and this ratio P_c by A is called power density here in this particular relationship.

$$P_c = I_c V_{avg}$$

$$\omega = \frac{k' P_c}{A}$$

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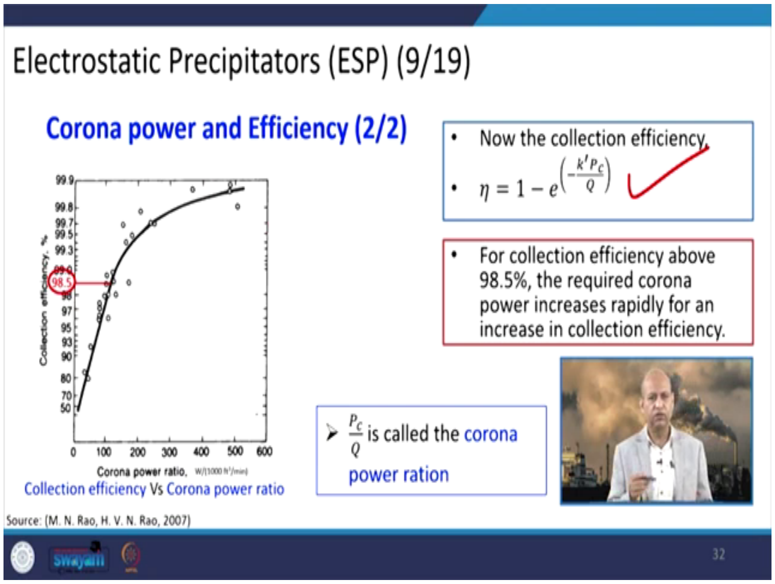

When we see this corona power ratio and collection efficiency, there is one good range we are 98.5 percent efficiency can be achieved. So, with this relationship we can calculate the, this net collection efficiency and as it is given in this particular figure that the collection efficiency above 98.5 percent this required corona power increases rapidly for an increase in collection efficiency. So, up to this it goes very rapidly, but after that it is slightly slow.

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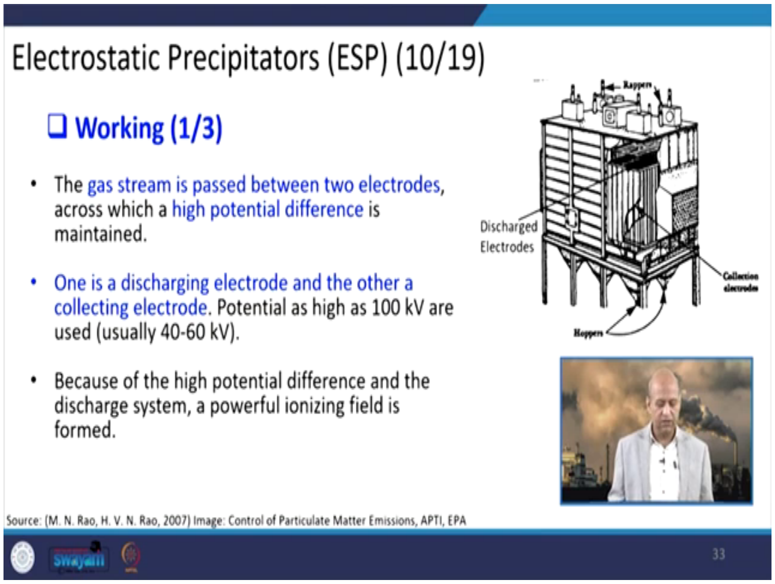

So, if you talk about like working, how does it work basically, so the gas stream is passed between two electrodes across with a high potential difference is maintained between those two electrodes, one is a discharging electrode and the other is collecting electrode where these particles go and lose their charges and the potential as high as 100 kilo volt are used. Usually 40 to 60 kilo voltage, the voltage there, but 100 can also be there. Because of the high potential difference and the discharge system, a powerful ionizing field is formed where these particles get ionized basically.

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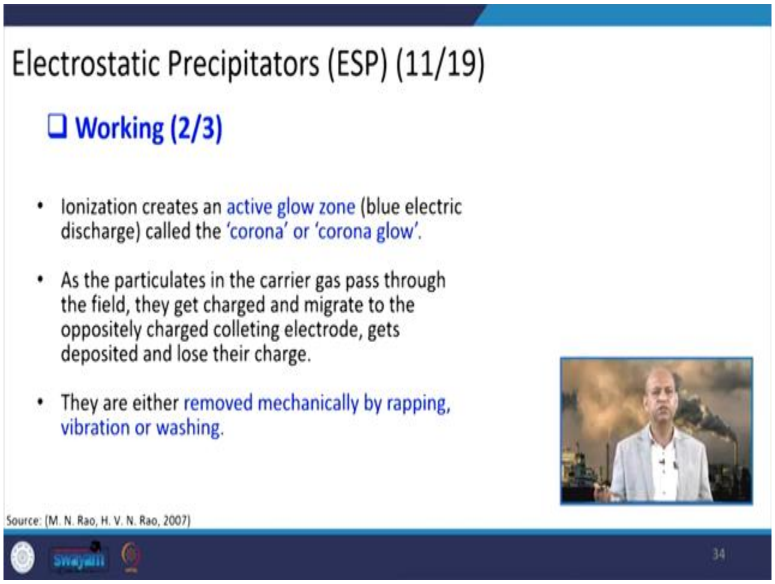

So, ionization creates an active glow zone like blue electric discharge, that is why we call it discharging zone and this is called the corona or corona glow. So, as the particulate matters pass through this carrier gas with the particles when it pass through this particular field, they get charged, these particles get charged and then it goes to the collecting electrode where they lose the charge basically and slide down to the bottom where hopper is there and it is removed periodically.

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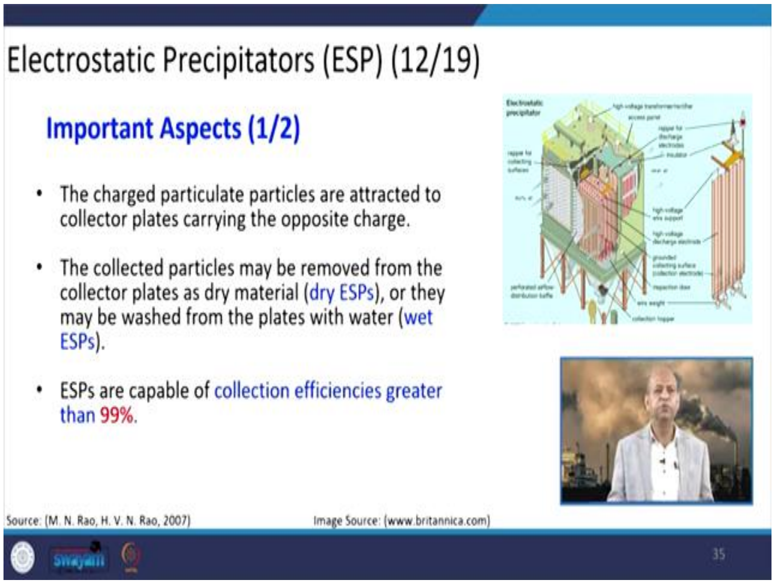

There are some important aspects, for example, the charged particles are attracted to collector plates carrying the opposite charge. The collected particles may be removed from the collector plates and this dry material that is dry ESPs or they may be washed from the plates with water wet ESPs. So, two kind of ESPs maybe there, dry electrostatic precipitators or wet electrostatic precipitator depending upon how we remove the particles. So, these ESPs are capable of correction efficiencies greater than 99 percent, even 99.9 percent sometimes those kind of efficiency can be achieved by electrostatic precipitators.

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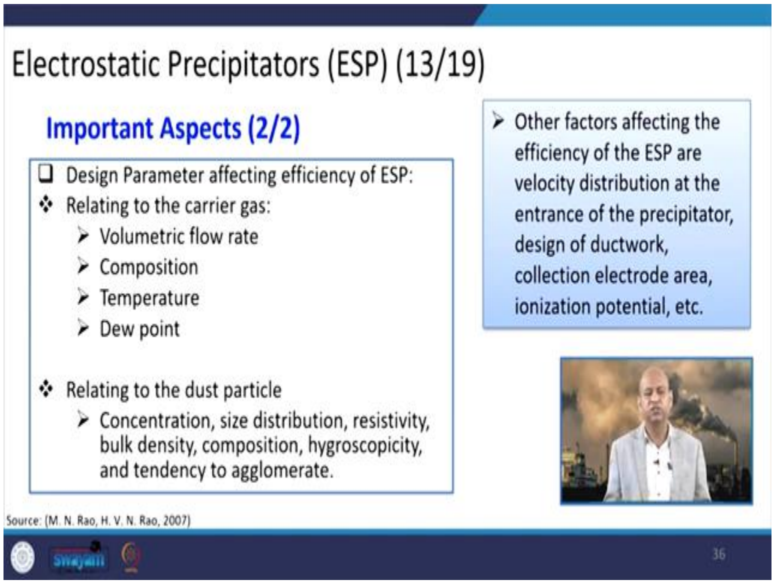

And the design parameters which affect the efficiency of ESP are like volumetric flow rate, composition of the gas and particles, temperature, dew point. If dew point is there, then some acidic formation is there. They can attack the plates etc. Then there are like relating to the dust particles, for example, concentration or size distribution of the particles, resistivity, then the bulk density and composition or hygroscopic nature like moisture can be contained or tendency to agglomeration those kind of things are there.

Other factors affecting the efficiency of ESP are like velocity distribution at the entrance of the, this precipitator, then design of this dock work and collection electrode areas and ionization related potential those kinds of issues can be there which are important when we do design of the electrostatic precipitators.

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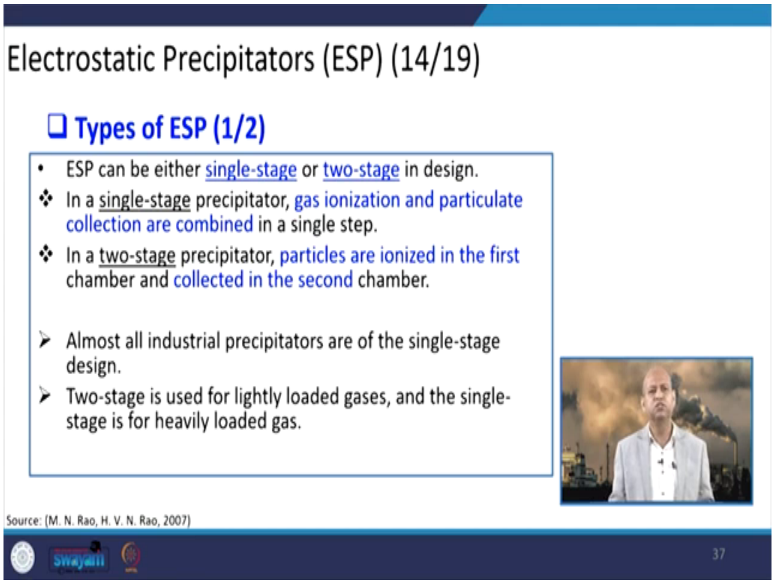

And these can be either single-stage type or two-stage type basically. In a single-stage type precipitator and this gas ionization of the particulate matter and collection are combined with single, within the single chamber. At one corner it goes, another corner they get collected and goes down. In two-stage one chamber is for like this kind of ionization of the particles, other is for this collection or deposition of the particles. And almost all industrial precipitators are of the single-stage design basically. Two-stage is used for like lightly loaded gases and the single-stage is for heavily loaded gases. So, those are the basically differences.

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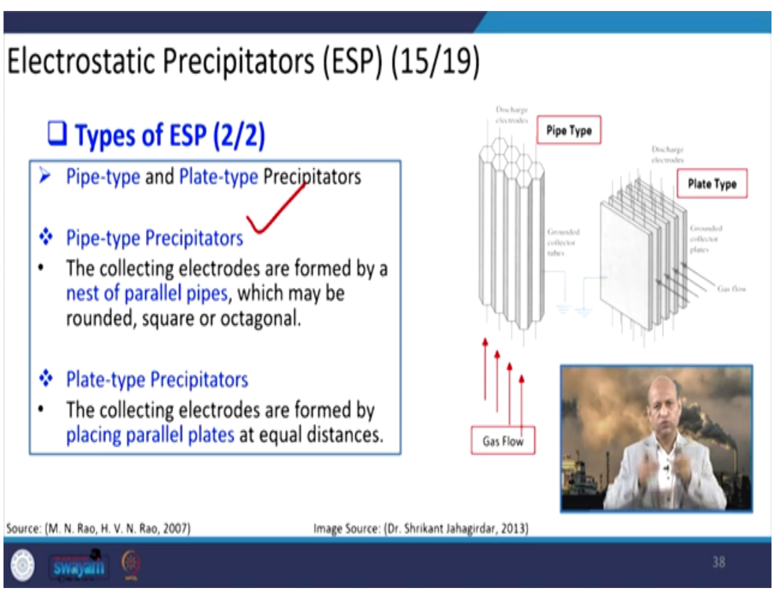

Then different types are also in terms of their shape like pipe types can be there these kind of formation maybe there, different pipes, gas passes through these pipes and then up to their wall they trapped and then go down, then these may be plates type. So, different kind of shape may be there. So, the collecting electrodes are formed by a nest in parallel pipes in the pipe type precipitators which may be rounded or square or octagonal in shape basically. So, there may be long pipes of different shapes. Plate type are like they are in parallel. They are parallel plates which are at equal distances they are kept and accordingly that gas laden with particles are passed through those openings.

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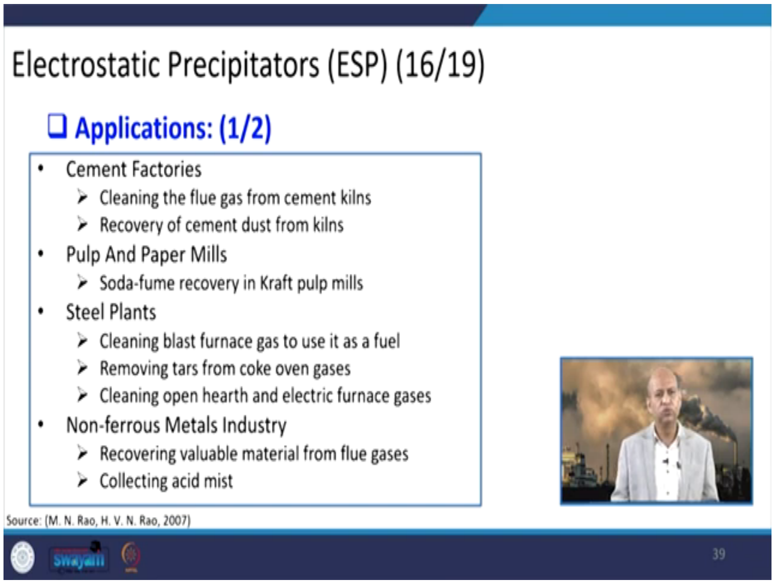

Well, when we talk about applications, so they are very popular in industries like cement factories, cleaning the flue gas from cement kilns or recovery of the cement dust from the kilns those kinds of things can be done by these ESPs. Pulp and paper mills or soda fume recovery in craft pulp mills again ESPs are very good. Steel plants where cleaning blast furnace gas to use it as a fuel. So, fuel recovery is done by ESPs. Removing these tars from coke over gases or play these cleaning open hearth and electric furnace gases that can be done by ESPs also. Non-ferrous and metal industries also use in a significant manner or large manner these ESPs.

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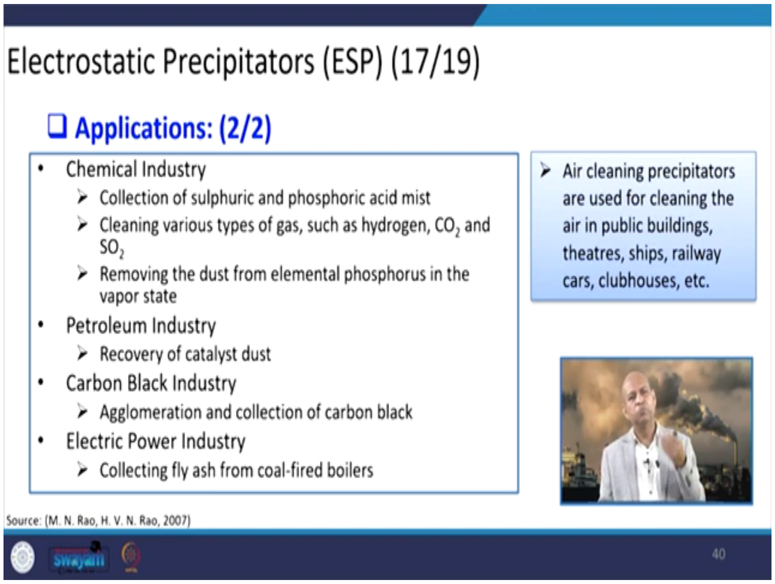

Chemical industries, petroleum industries, carbon black industry or electric power industries all these industries are using these ESPs in a popular way.

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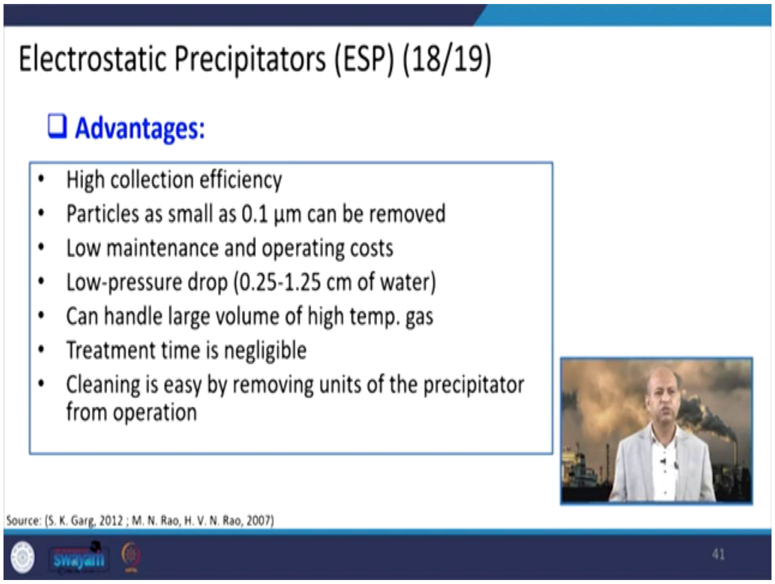

When we talk about the advantages then high collection efficiency is one of the big advantage of this ESP. And, even 0.1 micrometer can be removed. So, this is great range in that sense. Low maintenance and operating cost or low pressure drop and then it can be handling large volumes of the gases basically even up to high temperature, treatment time is negligible, very quickly it removes basically, cleaning is easy by removing units of the precipitator from operation.

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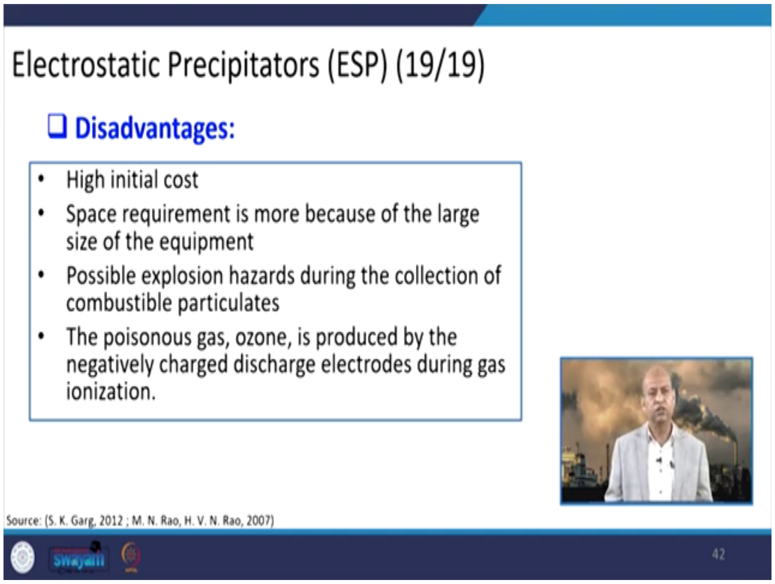

But there are disadvantages or limitations because initial cost is very high. So, those industries which do not have good funds for that, they cannot afford this kind of device. Space requirement is also more because of the large size of the equipment and the possible explosion hazard can be there, collection of combustible particulates can be there because of this ionization and sometimes ozone is formed in that. So, these kind of problems maybe there. Poisonous gas, ozone is produced by the negatively charged discharge electrodes during the gas ionization. So, very skilled person must be there to handle it or to operate it.

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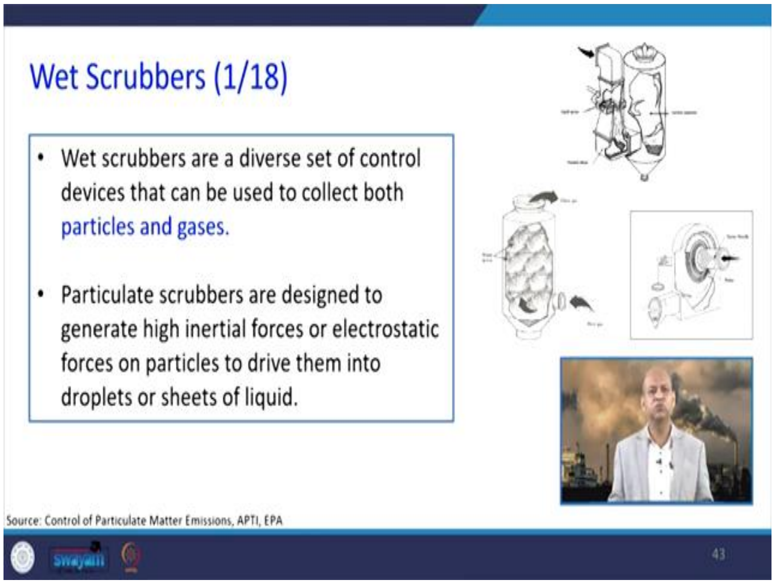

Now, we talk about the wet scrubbers. This is third kind of device in today's lecture basically. So, these are the devices or scrubbers which are diverse set of control devices which can be used for collecting both particulate matters as well as gases. So, particulate scrubbers are designed to generate high inertial forces or electrostatic forces or particles to drive them into some kind of droplets or sheets of the liquid where liquid is dropping in a kind of sheet so they can get attached to this and removed.

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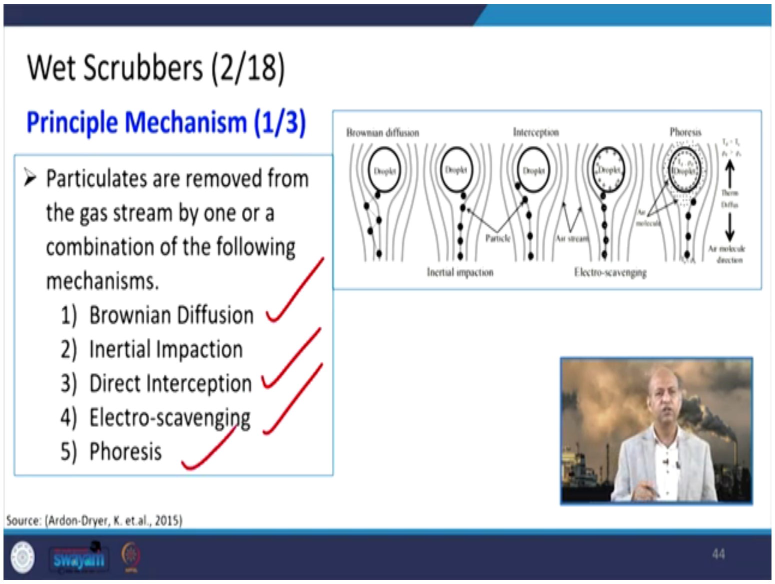

And the principal if you talk, then there are these certain mechanism like Brownian diffusion, inertial impaction, direct interception, electro-scavenging and phoresies. All these kind of mechanism can be used for wet scrubbers basically.

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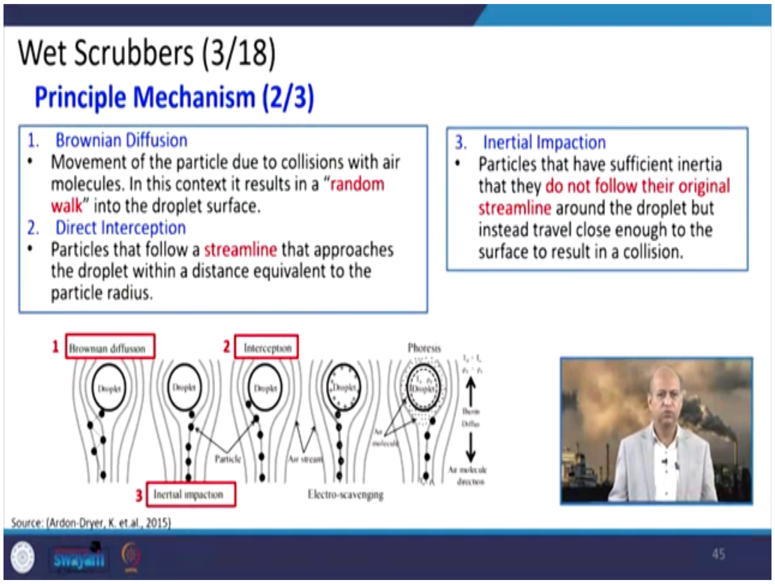

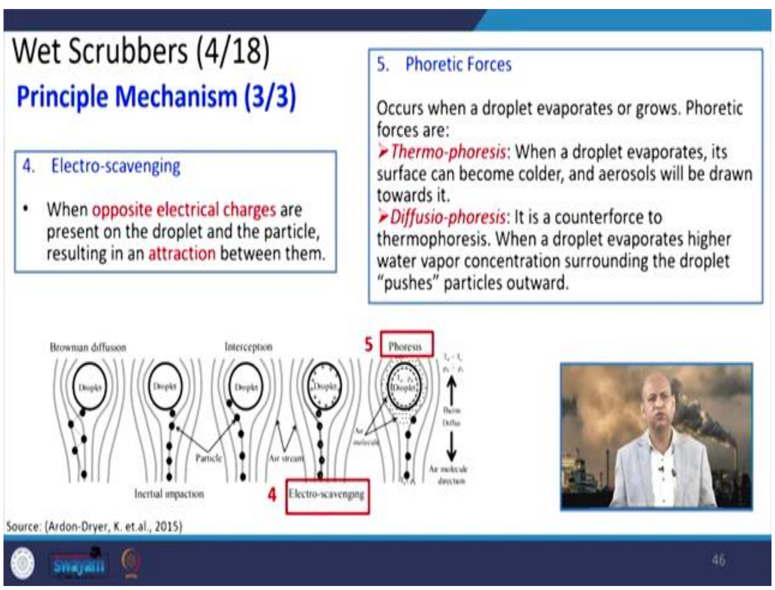

So, these are like random which we have seen in earlier also Brownian diffusion, direct interception, depending upon where you are targeting that particular stream. So, these kinds of mechanisms are used very frequently.

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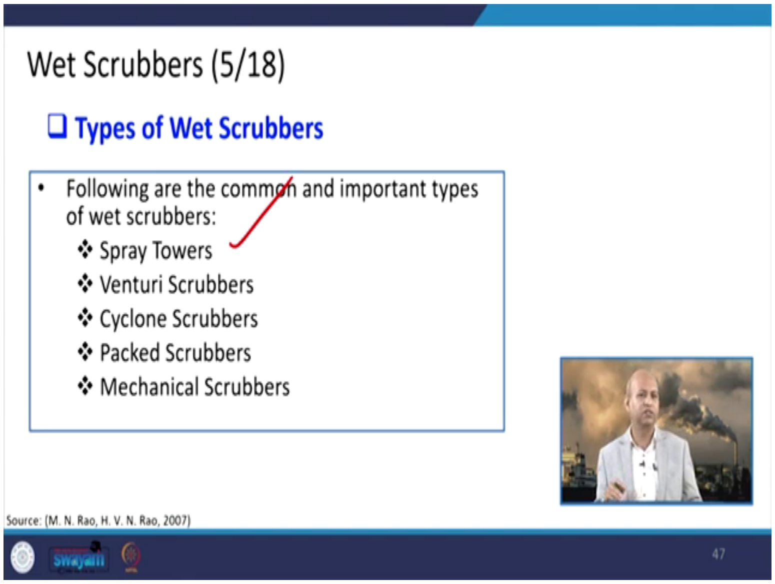

If you talk about different types of wet scrubbers then there can be like spray towers or venturi scrubbers or cyclone scrubbers or packed discoverers or mechanical scrubbers.

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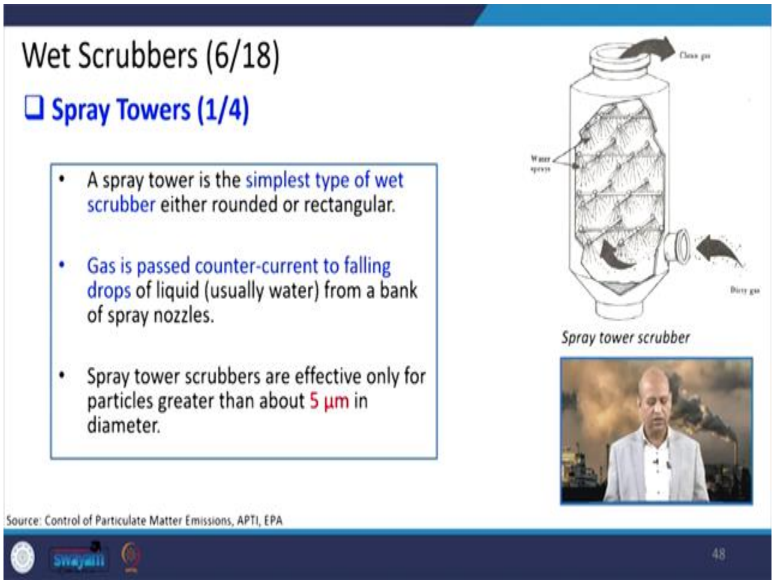

So, if you go one by one in spray towers this kind of tower is there and spray means some water spray can be there or some solution can be sprayed depending upon what kind of gases are there, what kind of removal efficiency is needed. So, this is the device which is known as spray tower scrubber. And it can effectively remove particles even greater than 5 micrometer in size, up to 5 micrometer size it can remove.

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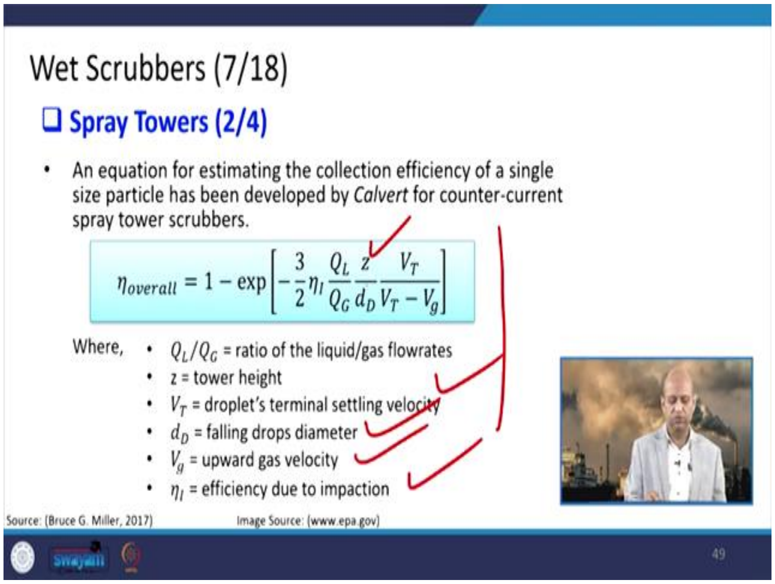

This is the overall efficiency which is calculated this relationship for spray towers, where this tower height z and then droplet's terminal settling velocity, then falling drops diameter, the upward gas velocity, efficiency due to impaction all these parameters are used on right side in the empirical relationship.

$$\eta_{overall} = 1 - exp\left[-\frac{3}{2}\eta_I \frac{Q_L}{Q_G}\frac{z}{d_D}\frac{V_T}{V_T - V_g}\right]$$

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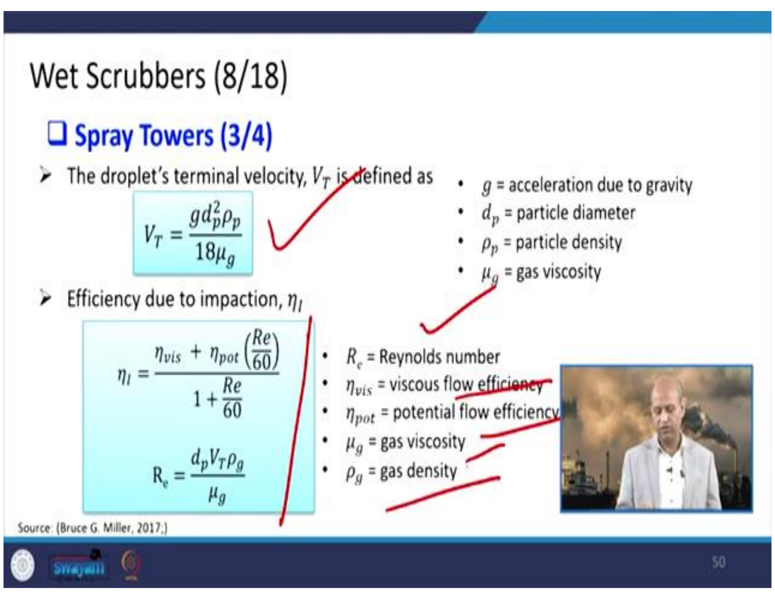

Then you know terminal velocity how to calculate. Earlier we have seen in case of that settling chamber also. And the efficiency of impaction can be calculated by Reynolds number, viscous flow efficiency, potential flow efficiency, gas viscosity, gas density. All these kinds of parameters are used in this empirical relationship.

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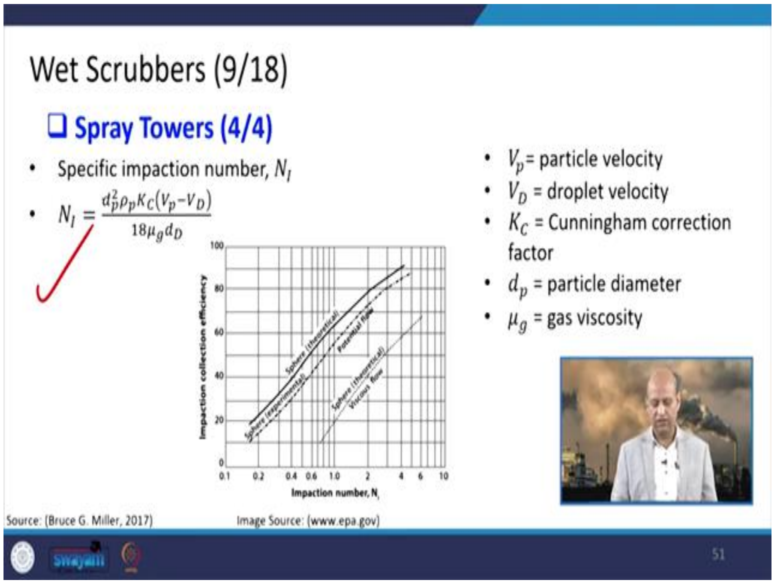

And then, specific impaction number is calculated by this kind of relationship or graphs or charts. So, you put those values and you can get this N_1 that is the specific impaction number.

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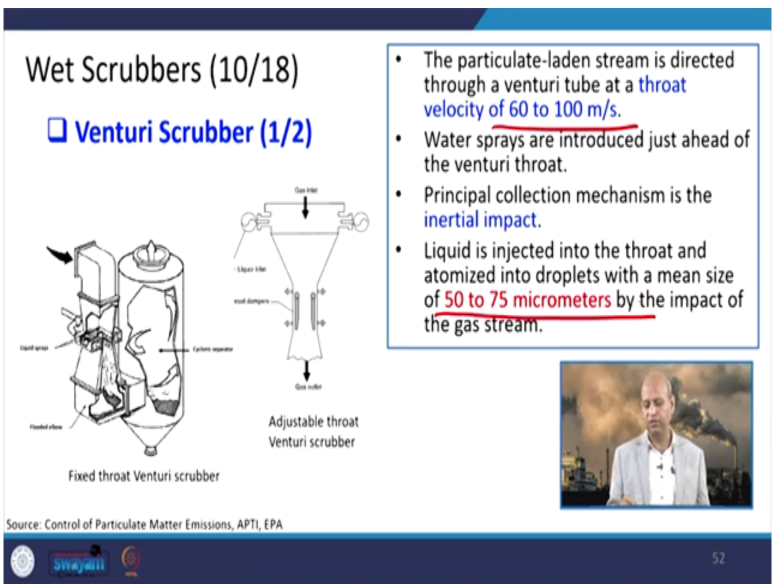

When we talk about different scrubber like venturi scrubber, then there we use very narrow throat to push liquid, these particles with high speed and at the same time liquid also after certain distance so this velocity like 60 to 100 meter per second very high velocity through the throat. And water sprays are introduced just ahead of the venturi throat. So, this inertial impaction is occurred and that can remove these particles and this mean size like 50 to 75 micrometer particle of the size particles can get removed very easily.

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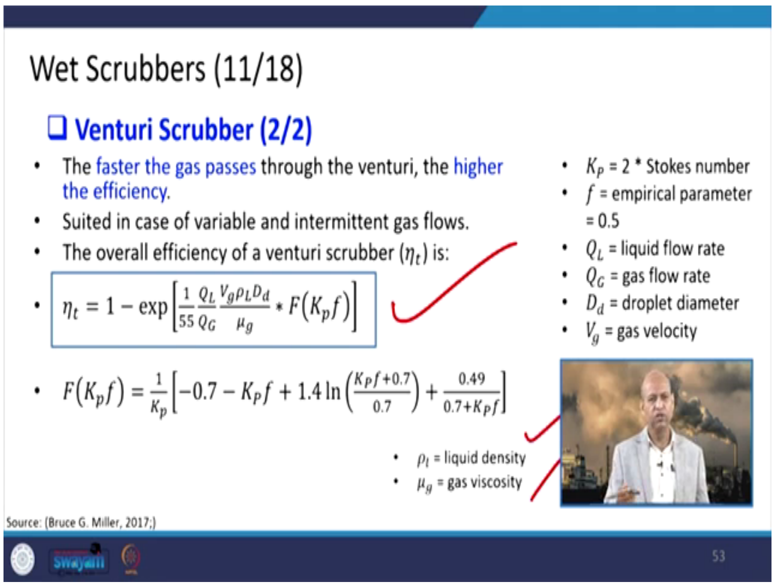

These are the empirical relationships for calculation of efficiencies. Again, this liquid density, gas viscosity all those parameters are used basically.

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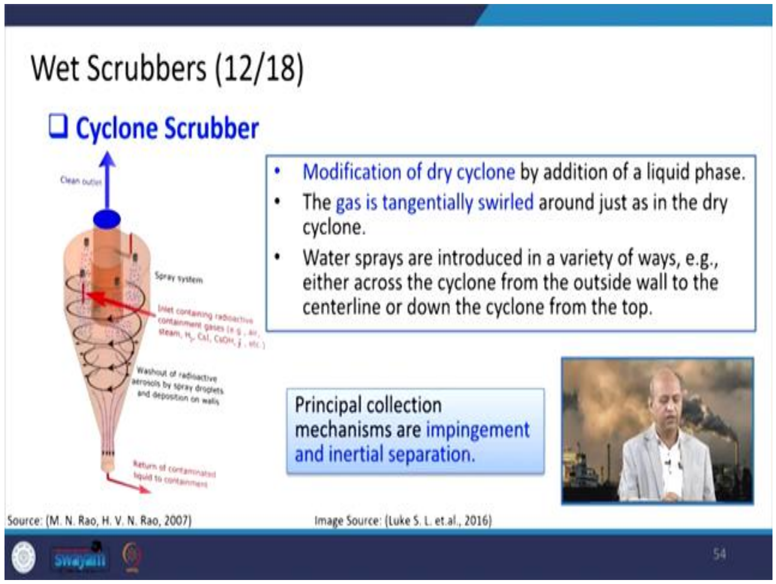

When we talk about cyclone scrubbers then there is modification like we have dry cyclones for particulate matter, in this some liquid is also sprayed. This water spray can be in this tube when gas goes up or it can be at the side also depending upon which kind of design you are taking into account. So, for impingement and the inertial separation these kind of mechanism are used with cyclone scrubbers.

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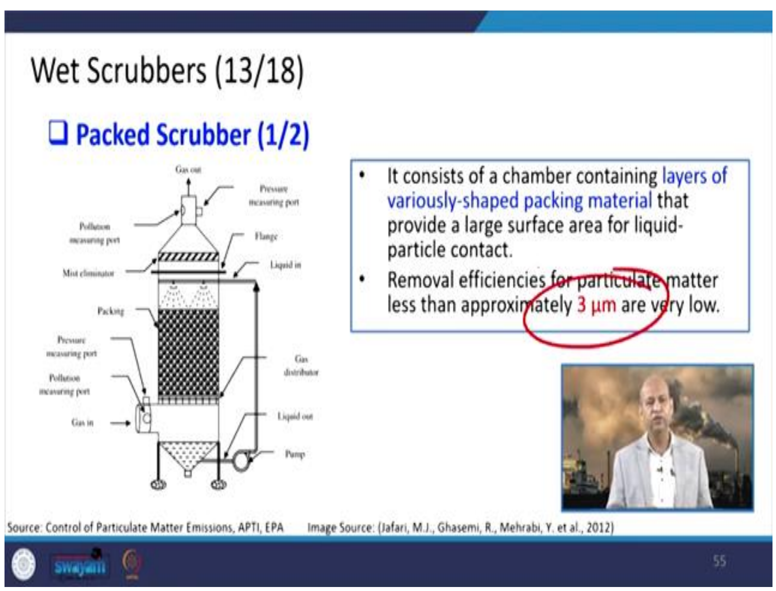

Packed scrubbers are using some sort of materials to provide large surface area where the particles can get attached as well as spray is also there of the solution. So, the packed material must be there and it can remove up to 3 micrometer of the particles.

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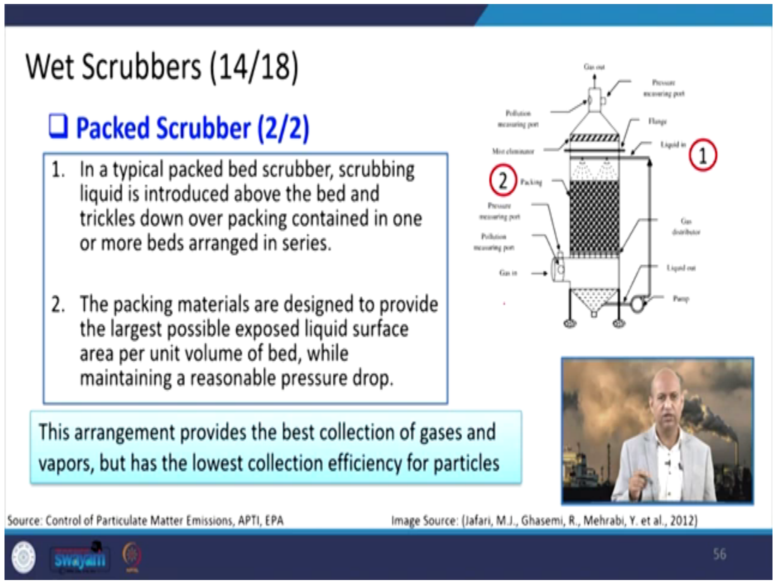

And this packing material here and liquid is taken into like a spray. So, this arrangement provides the best collection of gases and vapors and lowest collection efficiency for particles basically. So, they are more into removal of the gaseous emissions basically.

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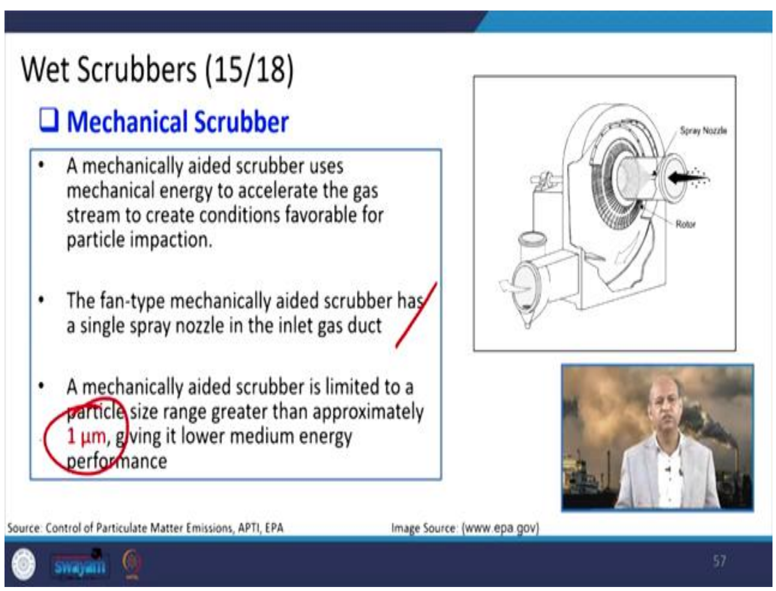

When we talk about mechanical scrubbers, so these are mechanically aided scrubber, basically. Spray nozzle can be there and this fan-type mechanically aided scrubber can be there. So, efficiency is increased in that sense and it can go up to 1 micrometer size to remove the particles.

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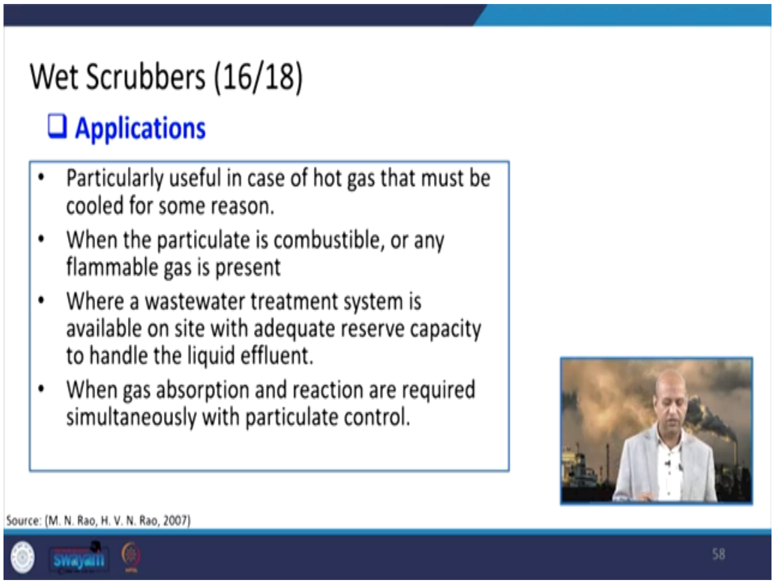

Well, applications of wet scrubbers are like it is useful for both gas as well as particulate removal. And it must be cooled for some reason so then scrubbers are needed not other kind of devices. So, that way scrubbers are good for that purpose where hot gases are there and we need to damp on its temperature before removal of other particulate matter or gases. When the particulate is combustible or any flammable gas is present then also wet scrubbers are better because they will not have this fire related problem.

Where a wastewater treatment system is available on site with adequate reserve capacity to handle the liquid effluent, otherwise we will have to have this wastewater treatment plant because wet scrubbers are producing wastewater basically. So, air pollution is converted into wastewater. When gas absorption and reactions are required simultaneously with particulate control, so those where applications are more popular.

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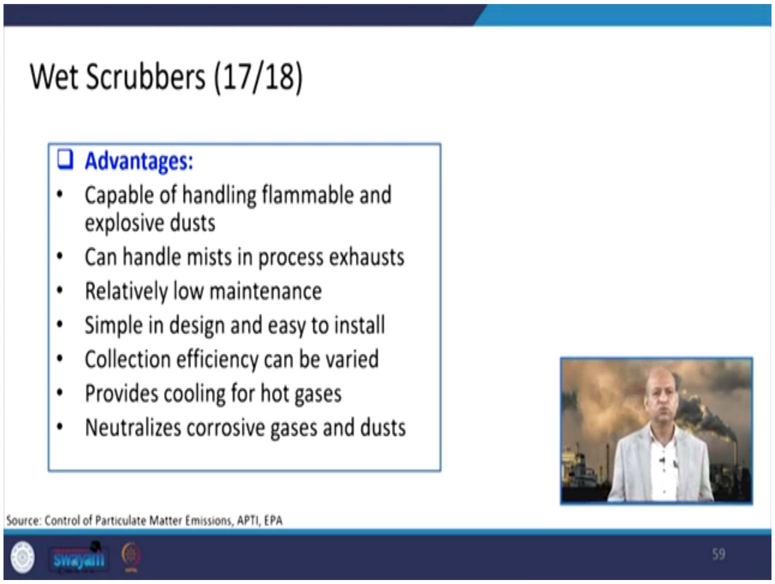

Then there are advantages like it can be capable for handling flammable and explosive dusts because wet scrubber is there water and those kind of things. It can handle mist and in the process of exhaust. Then relatively low maintenance is required. Simple in design and easy to install. Collection efficiency can be varied depending upon different size and nature of the particle. Provides cooking for hot gases, so neutralizes corrosive gases and dust, so those kind of advantages are there.

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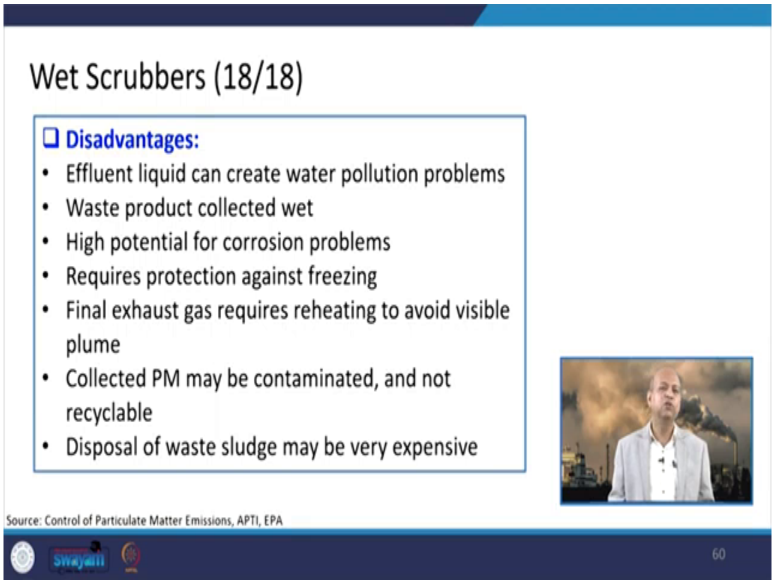

But of course, limitations are also there, like effluent liquid can be in the form of some water pollution. So, another problem has been created. So, we have to deal with it. Waste product collected like in wet, nor dry. So, handling is difficult. Dry, it is very easy to handle. You can just go and dump it somewhere or you can use in some other form. High potential for corrosion problems can be there, because this moisture and acidic gases are there.

It requires protection against freezing because water is there so in very cold regions it is difficult to run. Final exhaust gas requires reheating to avoid visible plumes, otherwise even if water vapor is coming out people think its lot of pollution, perception can be there. Collected particulate matter maybe contaminated and not recyclable, dry could be better. Disposal of waste sludge maybe very expensive. So that way means it can be costly affair after all.

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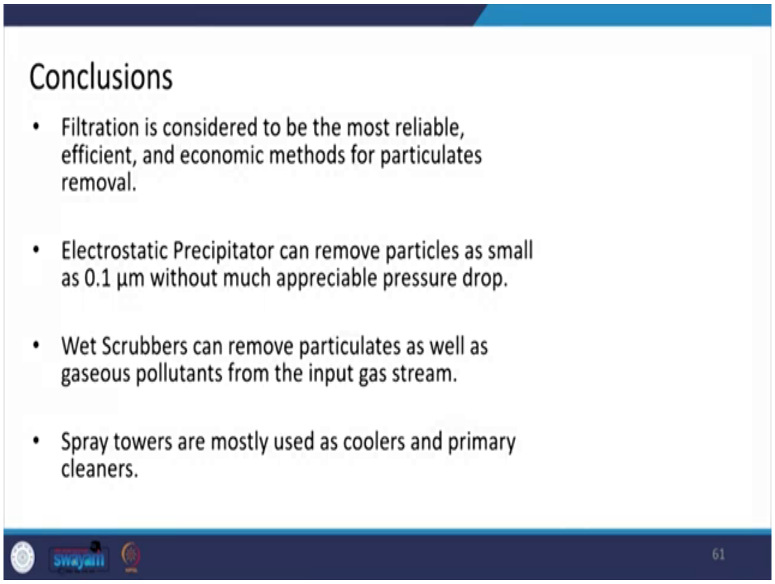

So, overall, now we can conclude that this filtration is considered to be most reliable and efficient and economic methods for particulates removal. An electrostatic precipitator is one of the best devices to remove even up to the small, very small size of 0.1 micrometer size particulate matter without significant drop in the pressure. And wet scrubbers can remove both gas as well as particulate matter basically. Spray towers are mostly used as coolers and primary cleaners. So that way different devices are available. And according to the different situations we can recommend what is the optimum or the best possible device to remove the particulate matter.

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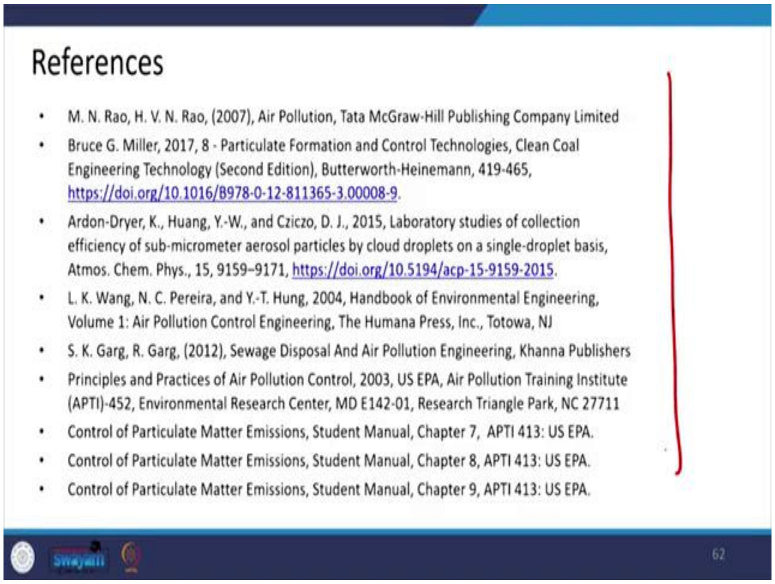

So, this is all for today. Thank you for your kind attention. These are the references for your additional reading. Thanks again. See you in the next lecture. Thank you.