Basic Environment Engineering and Pollution Abatement
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Lecture 22
Air Pollution Control 2

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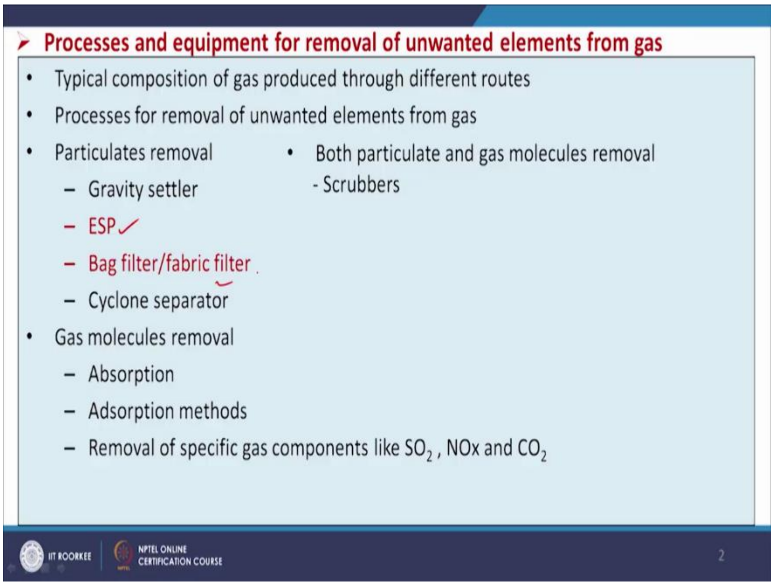

Hello everyone. Now, we will discuss on the topic Air Pollution Control part 2. In this class, we will be focusing on electrostatic precipitator and fabric filter.

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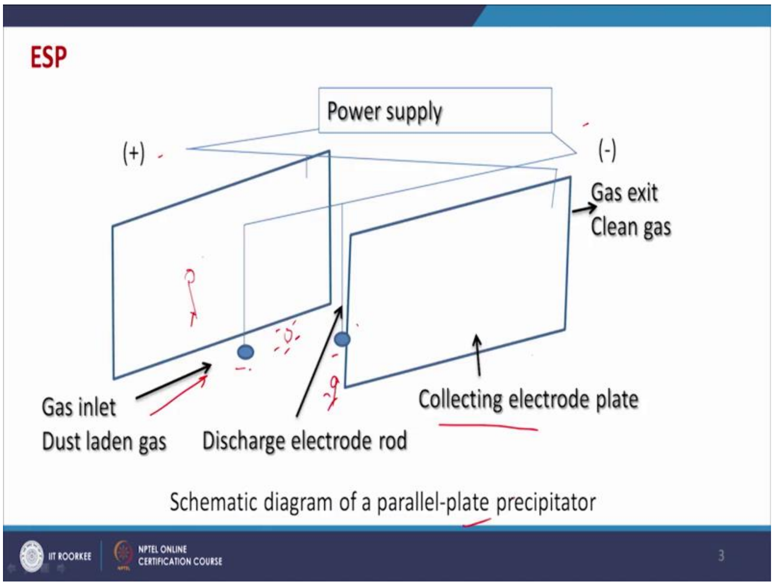

Now, we will see what electrostatic precipitators are. As you know, the particles are normally having negative charge. So, if we can create some electrical field through which the particle leaden gas is moving, so in that case, the negatively charged surface of the particles will help to move it towards the positively charged collectors.

So, the particles can be collected, so, ESP is basically used to remove the particulates from gas stream by this mechanism. Now, let us see this figure. So, here we have shown these two plates, so, these two plates are collecting electrode plate and these are another electrode. So, this usually, this is connected to negative sides and these are two positive sides.

So, these are the anode and these are the cathodes, due to the use of these two types of electrode there will be some current into the circuit or if we connect some current to the circuit, so, one electric field will be generated in between these two plates, and now we are sending the gas. So, gas inlet will be having the particulates.

So, these particulates will be having some say negative charge at its surface. So, these are positively charged these two plates are so it will be moving towards this collection and it will be collected. So, once this negatively charged particles is moving and getting arrested by this, so, it will fall. Similarly, any particle can move these directions also. So, then that will also be fall. So, this is the mechanism of the collection of the particles.

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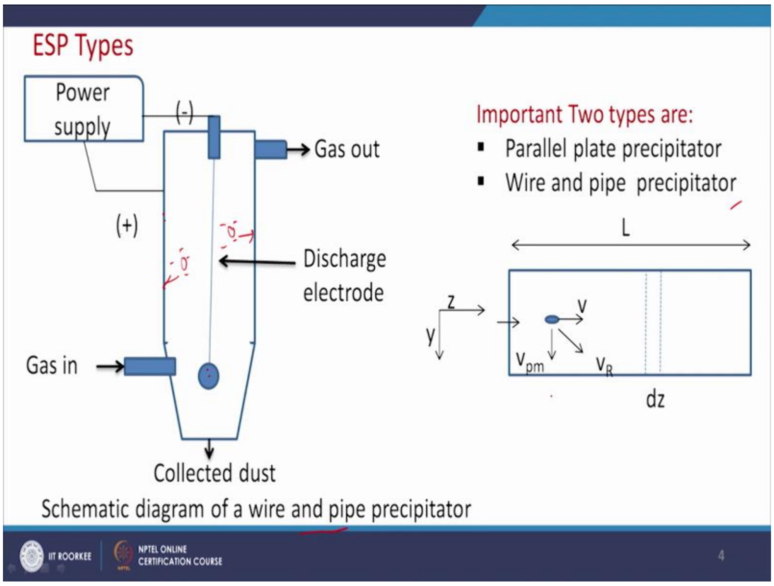

Now, this is for parallel plate precipitator. There may be different geometry this can be a wire and pipe precipitator. So, here say this is our pipe, tubular pipe. So, here we are, it is positively charged. So, this surface will collect the particles and inside we have put 1 wire an adding some electrode that is anode, and this is our cathode. If we supply electricity, then there will be some electrical and then particles which are negatively charged those will be moving towards the surface and will be collected, so the same mechanism here also.

Now, if we see this particle, so, there are basically two types of forces, one is your gravitational forces and another is these electrical forces which you are getting. So, parallel plate precipitator and wire and pipe precipitator, in both cases, the similar type of phenomena we will be getting only the difference in the geometry.

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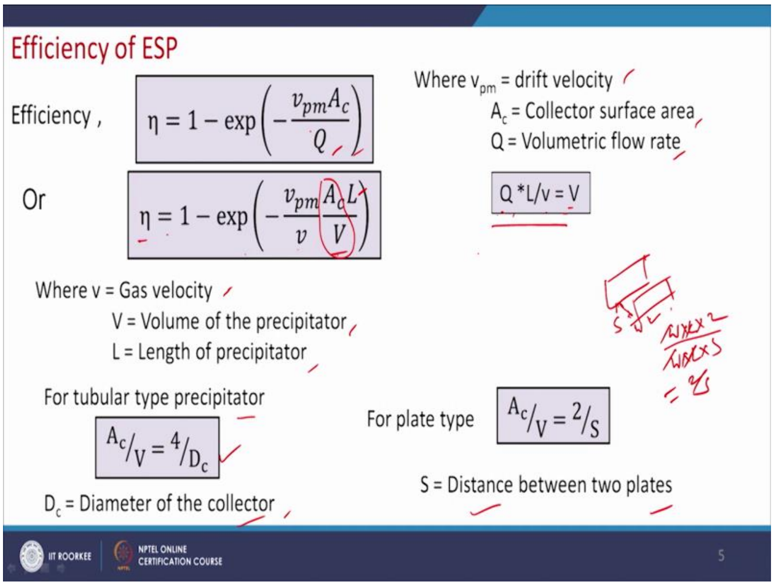

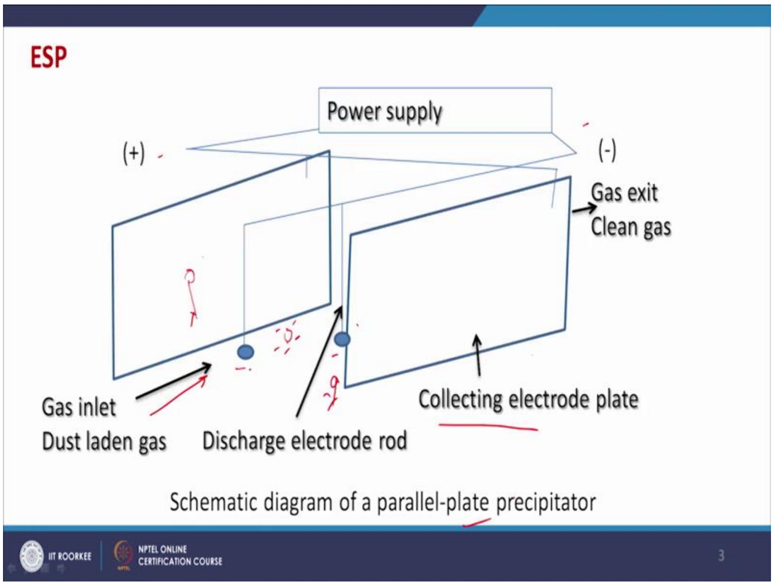

So, then how can we define the collection efficiency, in such case the collection efficiency

$$\eta = 1 - \exp\left(-\frac{v_{pm}A_c}{Q}\right)$$

Where, v_{pm} is drift velocity and Ac is the collector surface area and Q is the volumetric flow rate. Now,

Q*L/v = V.

V is equal to the volume of the precipitator, L is the length of the precipitator and v is the gas velocity. If we see this figure, v is the gas velocity, so, length is the precipitator.

Now, by using this expression, by replacing this Q that is when the volumetric gas velocity volumetric gas flow rate, we may not be able to measure every time. So, we can convert it in terms of some known parameter that is volume of the precipitator and length of the precipitator. These are the your design parameter of this, the geometry of this precipitator, so easy to calculate and use the formula for competition purpose.

$$\eta = 1 - \exp\left(-\frac{v_{pm}}{v}\frac{A_c L}{V}\right)$$

Now, Ac/V, this is another term is coming that is equal to surface area by volume of the collector, for tubular type precipitator

$A_c/V = 4/D_C$

where D_C is the diameter of the collector

For plate type precipitator

$A_c/V = 2/S$

where S is the distance between two plates, say we have two plates here. So, this plate and this plate both will be collecting.

So, L*H = S so, 2*A*A. So, 2AC and volume will be that A^2*S the distance between two plates. So, we will having say this is one plate and this is another plate, so in between the distance is equal to S. So, if it has L and this W is our width. So, the area we are getting W *L *2, that is equal to *W*L*S.

So, that is equal to WW LL cancel. So, 2/S we will be getting here supplied type S equal to distance between two plates and Ac/V=2S. So, by putting this parameter now, we can calculate the value of efficiency for the collection, but the drift velocity will be depending on many factors.

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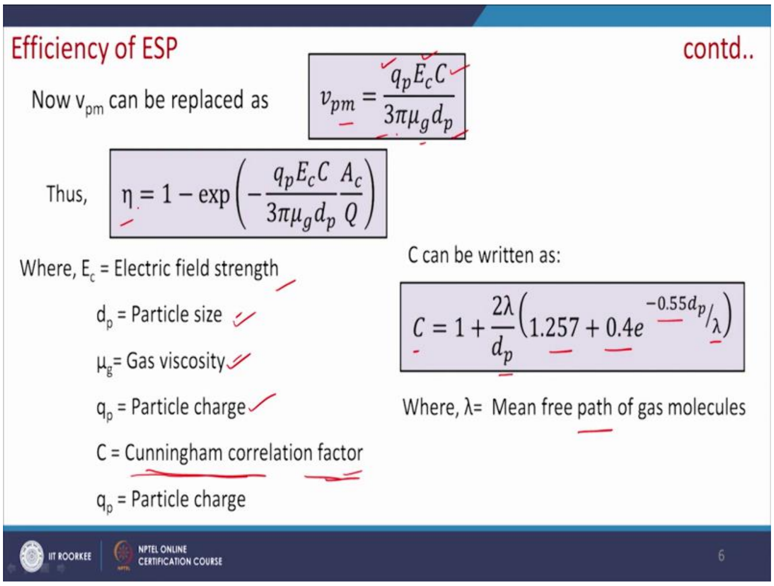

So, that will it depending on the particle size, gas viscosity, particle charge and another constant that is Cunningham correlation factor. So, how this is, so,

$$v_{pm} = \frac{q_p E_c C}{3\pi\mu_g d_p}$$

Where this E_c is nothing but the electric field strength and C is the Cunningham correlation factor and µg gas viscosity and d_p is the particle size. So, that we can calculate the v_{pm}.

Now, this C is Cunningham correlation factor that also depends upon the nature of the gas. So, this can be calculated as

$$C = 1 + \frac{2\lambda}{d_p}\left(1.257 + 0.4e^{-0.55 d_p/\lambda}\right)$$

So, this λ is the mean free path of gas molecules. So, that is why depending upon the type of gas the C value will depend, so, it is very clear that efficiency value depends upon many factors including the nature of the gas.

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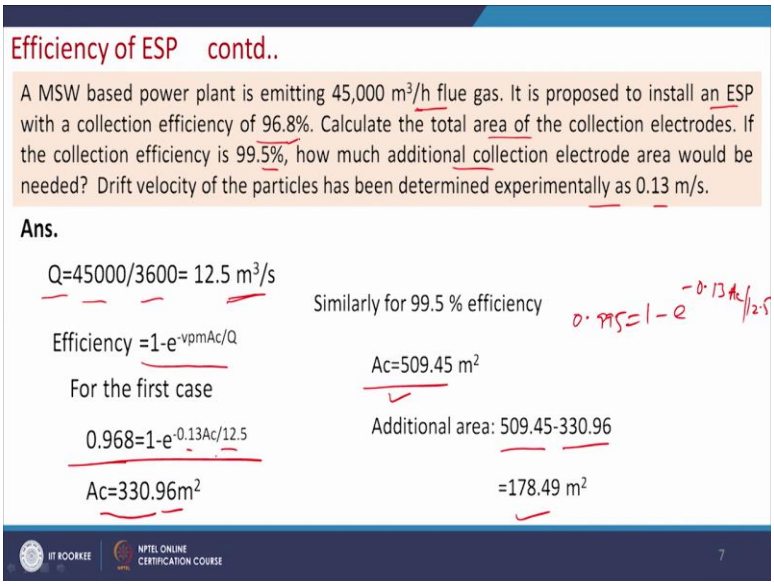

Now, let us see a numerical problem, MSW based power plant is emitting 45,000-m^3/h flue gas. It is proposed to install an ESP with a collection efficiency of 96.8 %. Calculate the total area of the collection electrodes, if the collection efficiency is 99.5 %, how much additional collection electrode area would be needed? Drift velocity of the particles has been determined experimentally at 0.13 m/s. So, drift velocity is already given. So, we do not need to calculate it from other parameters.

So, here the volumetric flow rate (Q) = 45,000- m^3/h = 45000/3600= 12.5 m^3/s

Efficiency $=1-e^{-vpmAc/Q}$

For the first case

$0.968=1-e^{-0.13Ac/12.5}$

$Ac=330.96m^2$

So, this is for the first case, in the second case, our efficiency is more so, certainly the area requirement will be different. More area is required because collection efficiency is more. So the same expressions we will be using.

Similarly for 99.5 % efficiency

$Ac=509.45\ m^2$

Additional area: 509.45-330.96

$=178.49\ m^2$

So, that way we can find out the area which has to be increased to increase the efficiency, collection efficiency from 96.8 % to 99.5 %.

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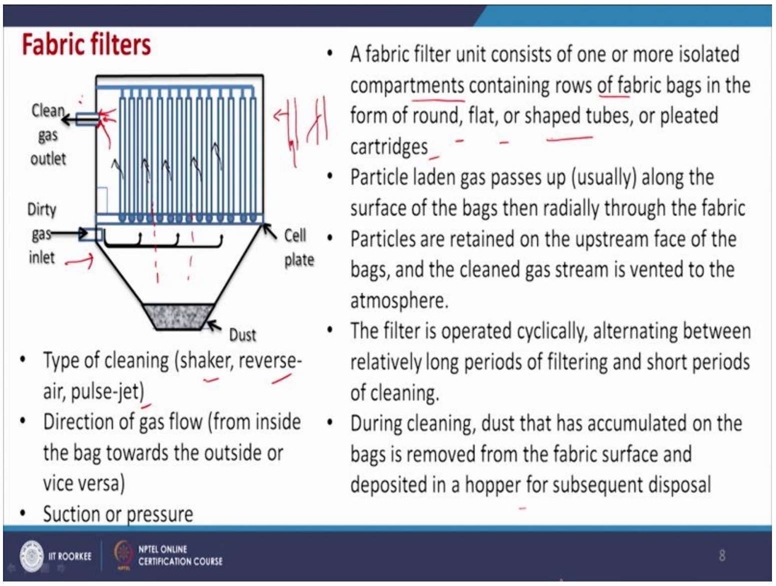

Now, we will discuss the fabric filters. So, you see this figure shows us the operation of fabric filters. So, here this is our dirty gas it is coming in and there are a number of stand we can see, these are the cages and these cage is covered by the fabrics or the bags. So, then this particulate matter leaden gas is coming here that is a dirty gas and it will be passing through the fabrics basically, there is one blower at the top. So, some suction is there.

So, which gas is coming, it will be forced to go through the pores of it there may be two types of arrangement, so we can have the cage like this. So, this cage maybe air pass through this and the cloth will be at the outside of it and air may pass again through it or another type of arrangement may also be possible that is from this the gas is going so, that way also it is possible.

So, here, if gas gets entry here, so it will be going out from this and that will be going out so that due to the blower which is working at the top of this. So that way the fabric filters work. So, a fabric filter unit consists of one or more isolated compartments containing rows of fabric bags that is shown here in this figure, in the form of round, flat or shaped tubes or pleated cartridges.

So, different types of arrangement can be used in this case and particle laden gas passes up along the surface. So, gas is going along the surface of the bags when radially through the fabric then particles are retained on the upstream phase of the bags and the cleaned gas stream is vented to the atmosphere just which we have discussed. The filter is operated cyclically, alternating between relatively long periods of filtering and short periods of cleaning, so there is some off time and on time, long on time and small off time that is there.

During cleaning dust that has accumulated on the bags is removed from the fabric surface and deposited in a hopper for subsequent disposal. So, particles are deposited on the surface of it. Then when we are cleaning these dusts are being collected it falls and then it is collected.

So, this is the mechanism of the fabric filter. And the type of cleaning maybe either shaker cleaning or reverse air or pulse jet cleaning. And direction of gas flow maybe from inside the bag towards the outside or the vice versa just we have discussed, and suction or pressure both arrangement are there so suction are the when it is going for cleaning and where will, it is working in normal operation and during cleaning the pressure can be applied.

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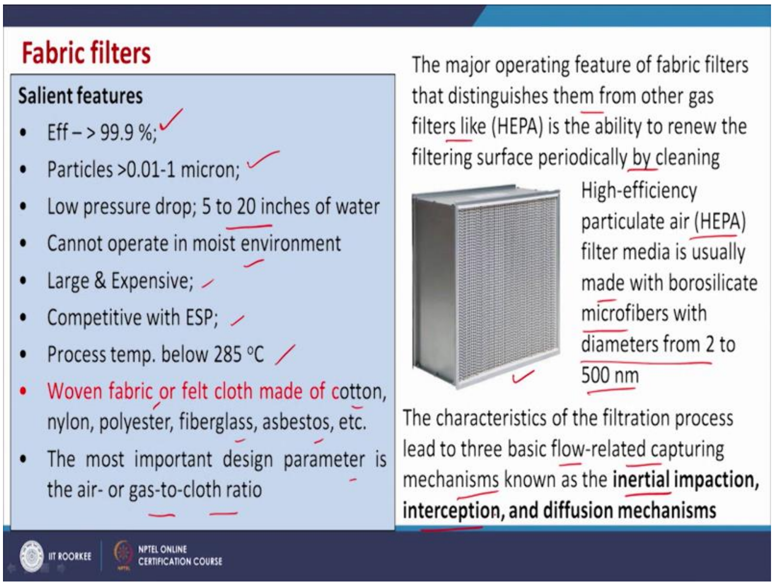

So, the salient features of these fabric filters are it is highly efficient 99.9 % or more than that efficiency is possible. It can be suitable for smaller particles also that particle size greater than 0.01 to 1 micron. Where the in case of settling we had seen that gravity settler it is more than 50 micron, but here it is 0.01 to 1 micron particle size can be separated and low pressure drop 5 to 20 inches of water.

It has some disadvantages also, like it cannot operate in moist environment and it is relatively larger volume and expensive bags like the fabrics are expensive and it is competitive with electrostatic precipitator and temperature normally below 285 °C. And when we use the fabrics, those fabrics or maybe woven fabric woven or it is felt cloth made of cotton, nylon, polyester, fiberglass, asbestos, etc.

And the most important design parameter is air or gas to cloth ratio, air to cloth ratio or gas to cloth ratio. And the major operating feature of fabric filters that distinguishes them from other gas filters like say HEPA filter, so, is the ability to renew the filtering surface periodically by cleaning, that is it can be operated continuously. But HEPA and other types of filters may be working for certain time and then it has to be discarded if we had the HEPA filter his shown.

So, High Efficiency Particulate Air that is HEPA, High Efficiency Particulate Air filter, media is usually made with borosilicate microfibers with a diameters of 2 to 500 nm. And both in case of these type of filters or fabric filters or HEPA filters or bag filters. So, we have fibres those are responsible for the separation of the particles.

So, the characteristics of the filtration process lead to these fabric flow related capturing mechanisms known as the inertial impaction and then interceptions and diffusion. So, then three major types of mechanisms are there, which are responsible for the collection of the particles in this type of device. And now we will see those different types of mechanisms.

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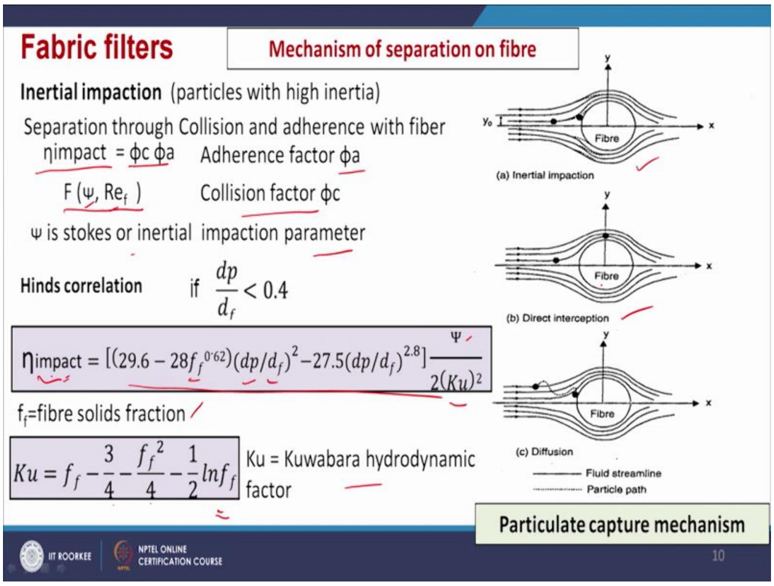

Here this figure shows us your inertial impaction and this is your diffusion this one and direct interception. So, direct interceptions here inertial inception, you see in the case of direct interceptions the particles is coming here, but in case of inertial impaction the separation through collision and adherence with fibres.

So, collision and adherence and here it is adherence and we are seeing and in case of diffusion the density or concentration gradient will also responsible for the movement of the particle when it is outside then it is going to the inside, but here the particle is already in the inside. So, that way the mechanism is different, so the separation through inertial impaction, we can calculate the efficiency that is efficiency impaction

η impact = ϕc ϕa,

ϕa that is adherence factor and collision factor ϕc.

So, theta c theta a and these are the factor of fibre Reynolds number and Ψ. So it is the Stokes or inertial impaction parameter. And this is your function of this what are those exact expression, exact expressions are like this. So, Ψ through impaction, efficiency for the collection through impaction that is equal to this expression, we can calculate.

$$\eta impact = [(29.6 - 28 ff 0.62)(dp/df)^2 - 27.5(dp/df)^{2.8}]\frac{\Psi}{2(Ku)2}$$

Here we see that, these are related with dp particle diameter and df fibre diameter and Ψ and Ku and f_f also. f_f is fibres solid fraction and Ku is Kuwabara hydrodynamic factor. So, these are we are getting and

$$K_u = f_f - \frac{3}{4} - \frac{f_f^2}{4} - \frac{1}{2}\ln f_f$$

So, these are the different expressions which are available to calculate the value of efficiency due to impaction.

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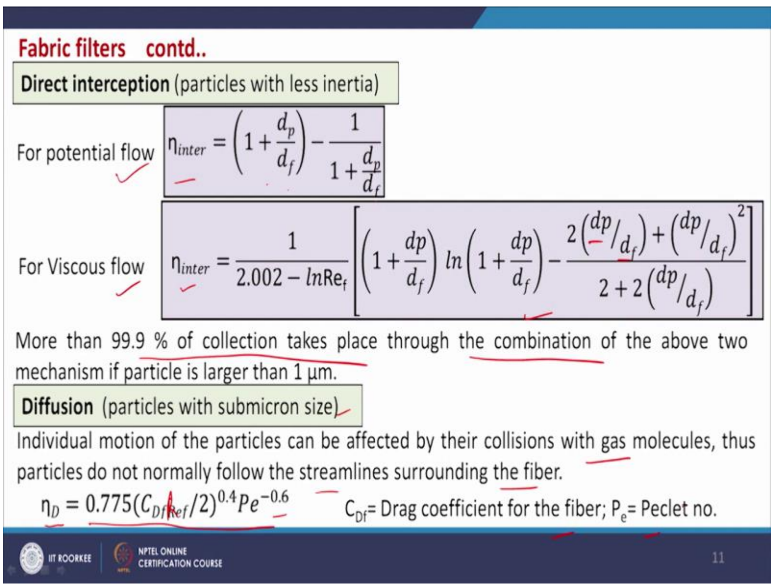

Now, for direct interception the formula we can use that is equal to

$$\eta inter = \left(1 + \frac{dp}{df}\right) - \frac{1}{1 + \frac{dp}{df}}$$

that is for potential flow laminar flow and for viscous flow we are getting that is efficiency for interception

$$\eta inter = \frac{1}{2.002 - \ln Ref}\left[\left(1 + \frac{dp}{df}\right)\ln\left(1 + \frac{dp}{df}\right) - \frac{2\left(^{dp}/_{df}\right) + \left(^{dp}/_{df}\right)^2}{2 + 2\left(^{dp}/_{df}\right)}\right]$$

So, again this is also dependent on dp and df.

So, mostly 99.9 % of collection takes place through the combination of these two methods or mechanisms and diffusion also when the particle size is very, very small that sub-micron particle, so, that will also be diffused as I shown in the previous slide that is from outer to inner side.

So, that diffusional motion of the particles can be affected by their collisions with gas molecules. Thus, particles do not normally follow the streamlines surrounding the fibre and efficiency for diffusion can be calculated by these expressions

$$\eta_D = 0.775[(C_{Df\ Ref}/2)]^{0.4} Pe^{-0.6}$$

So, CDf is drag coefficient for the fibre and pe is equal to peclet number.

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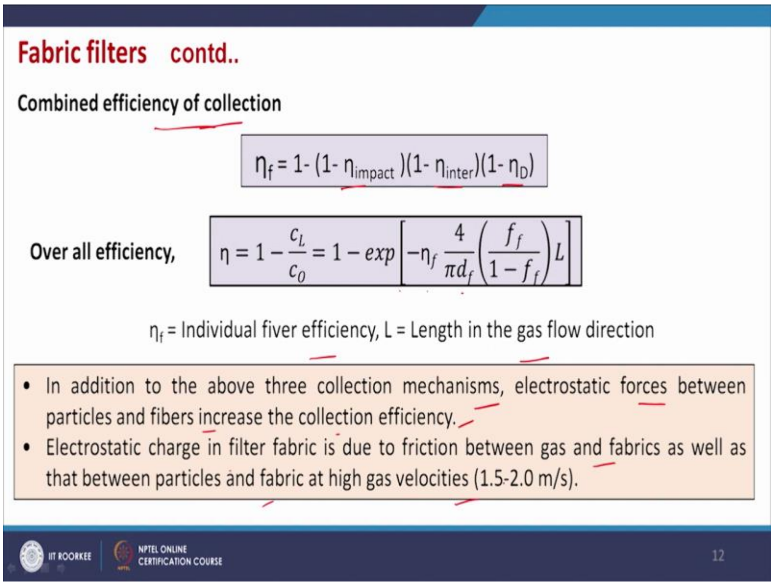

So, for combined efficiency

$\eta_f = 1- (1- \eta_{impact})(1- \eta_{inter})(1- \eta_D)$

This is for 1 fabrics. So, 1 fibre this will be the combined efficiency, but if we have number of fibres, then overall efficiency

$$\eta = 1 - \frac{C_L}{C_o} = 1 - \exp\left[-\eta f \, \frac{4}{\pi df}\left(\frac{ff}{1 - ff}\right) L\right]$$

So, that will be used to calculate the actual efficiency for the overall case.

So, C_L final concentration of the particle, and C_O is the initial concentration of the particle. L where η_f is the individual of fibre efficiency, L is the length in gas flow direction.

So, in addition to the above three collection mechanisms electrostatic forces between particles and fibres increase the collection efficiency and electrostatic charge in filter fabric is due to friction between gas and fabrics as well as that between particles and fabric at high gas velocities that is 1.5 to 2 m/s.

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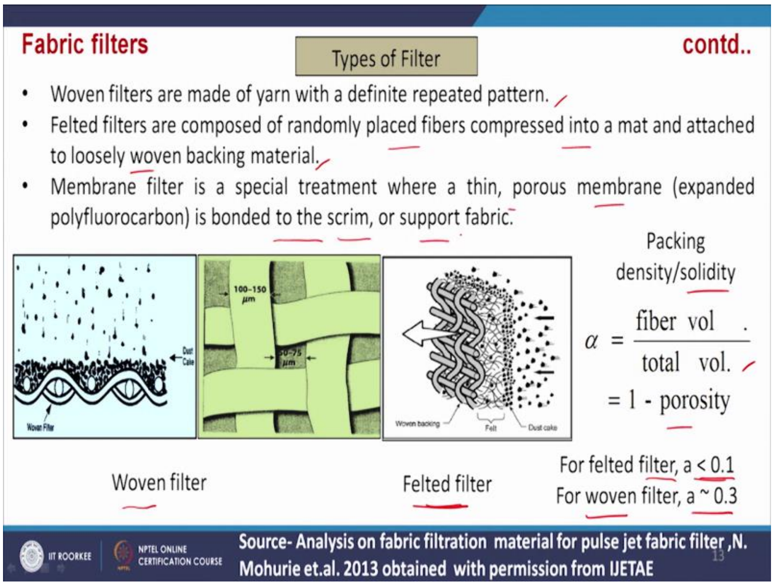

Now, we will see different types of filters and fabrics which are used in this type of filter. So, here you see the fibres are either woven or it is felted fibre. So, this it is very clear that in case of woven filtere, the volume of this fibre is much more than in case of filtered filter. So, the packing density is one parameter through which we can quantify the quality of these type of filters, so that packing density or solidity that is defined as

α = fibre volume/ total volume

α = 1- porosity.

So, for filtered filter this is less than 0.1. However, for woven filter, this is around 0.3. So, woven filters are made of yarn with a definite repetitive pattern. And felted filters are composed of randomly placed fibres compressed into a mat and attached to loosely woven backing material. Membrane filter is special treatment where a thin porous membrane expanded poly fluorocarbon is bonded to the scrim or support fabric. So, these are the different types of fabrics or patterns or processes which are used. And now, we can see the performance of different types of fabrics which have been used in real field.

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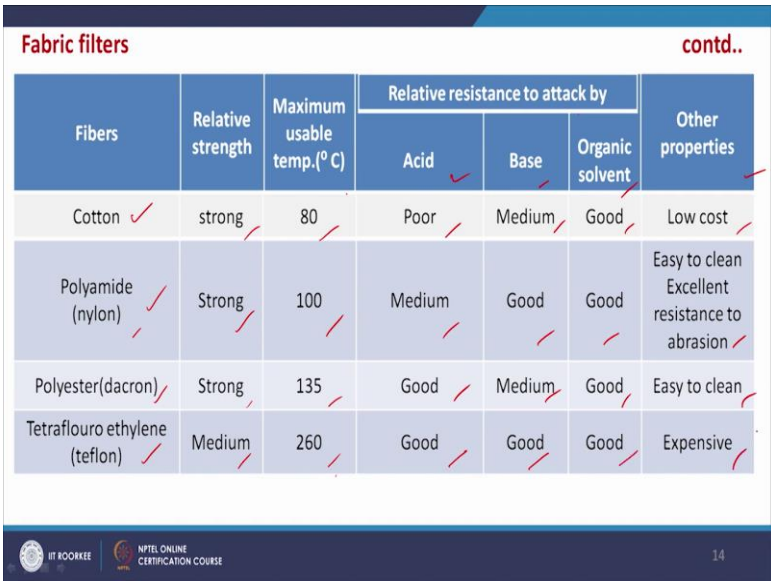

Fabric filters contd..

Fibers	Relative strength	Maximum usable temp.(° C)	Relative resistance to attack by			Other properties
			Acid	Base	Organic solvent	
Cotton	strong	80	Poor	Medium	Good	Low cost
Polyamide (nylon)	Strong	100	Medium	Good	Good	Easy to clean Excellent resistance to abrasion
Polyester(dacron)	Strong	135	Good	Medium	Good	Easy to clean
Tetraflouro ethylene (teflon)	Medium	260	Good	Good	Good	Expensive

So, different fibres there is a cotton, polyamide, polyester tetrafluoroethylene and if we see that they are relative strength, and then maximum usable temperature and relative resistance to attack by acid base, an organic solvent also provided and other properties are also provided.

So, for cotton you see, relative strength is strong, but maximum usable temperature 80 °C and for acid it is relative resistance is poor, for bass medium and organic solvent it is good and other properties it is of low cost. Similarly for nylon. So, relative strength is strong. So, here maximum temperature is 100 °C.

And acid resistance is medium, base is good and organic solvent is good and easy to clean, excellent resistance to abrasion. And your polyester again it is strong strength 135 °C. It can be used and it has good acid resistance, base resistance and good organic solvent resistance and easy to clean also.

So, tetrafluoroethylene it is also relative strength your medium and it can be applied up to 260 °C and it is good acid resistance, good base resistance and good organic solvent resistance, but this is expensive.

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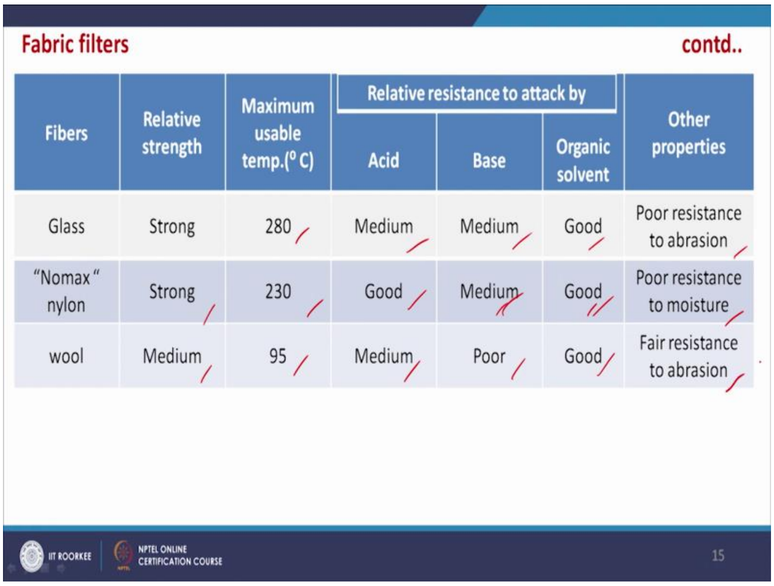
Fabric filters contd..

Fibers	Relative strength	Maximum usable temp.(° C)	Relative resistance to attack by			Other properties
			Acid	Base	Organic solvent	
Glass	Strong	280	Medium	Medium	Good	Poor resistance to abrasion
"Nomax" nylon	Strong	230	Good	Medium	Good	Poor resistance to moisture
wool	Medium	95	Medium	Poor	Good	Fair resistance to abrasion

Other are glass and Nomax nylon and wool, so you see a glass is strong relative strength, maximum usable temperature 280 ºC, relative resistance medium, base strength medium and organic solvents strength also good and it is poor resistance to abrasion and Nomex nylon, it is strong relative strenght and maximum usable temperature 230 ºC, it is good acid strength, medium base strength and acid resistance medium base resistance and good organic solvent resistance and this is poor resistance to moisture.

And for wool, it is medium relative strength, maximum usable temperature 95 ºC and acid resistance medium base resistance poor and organic solvent resistance good with fair resistance to abrasion it has.

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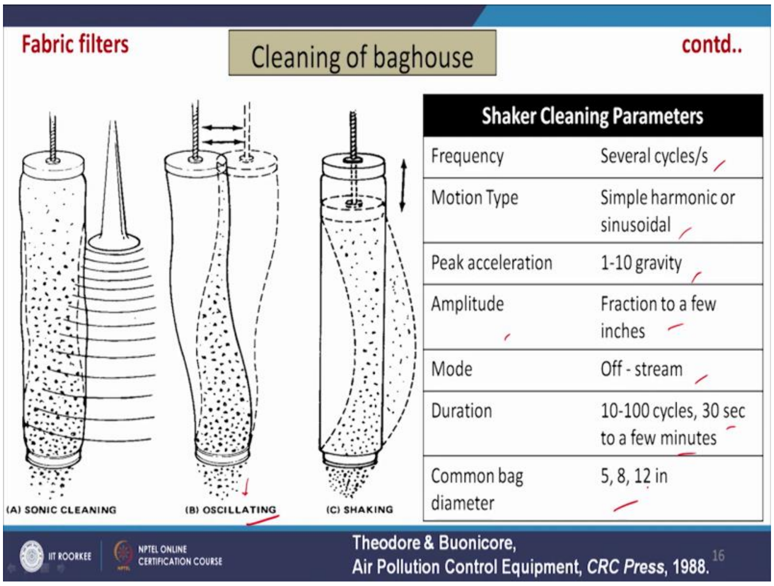

So, these are the different fibres which can be used and depending upon our need, we can select any one for our application. Now we will discuss on the cleaning aspect how the fibres or fabrics can be cleaned when say we are attending certain pressure drop, then we need to clean it. So, there are basically three types of cleaning methods you have discussed, one is your shaking, then other is your reverse air and another your impulse air.

So, now here you see we have a bag. So, particles are attached to the surface outer surface of it, then if we can create some disturbances so that is using ultrasonic or to the sonication. So, then there will be disturbances and it will be shaked and the deposited particles will fall. So, that is one way, other way we can make some arrangement for oscillations like see these type of oscillations if we make some oscillation, so, there will be the cloth will disturb and particles which are deposited on it will settle.

Or we can arrange some shaking like say this is vertical direction, we can put some mechanical arrangements so it will be shake and cage will be deformed to some extent. And in that case the particles which are associated this outer side of the fibres or the fabrics will be separated.

So, this is the shaker cleaning mechanism and here frequency several cycles per second and motion type simple harmonic or sinusoidal and peak acceleration 1 to 10 gravity and then amplitude fraction to a few inches and then mode upstream and duration 10 to 100 cycles 30 second to few minutes and common back diameter is 5, 8 and 12 inch.

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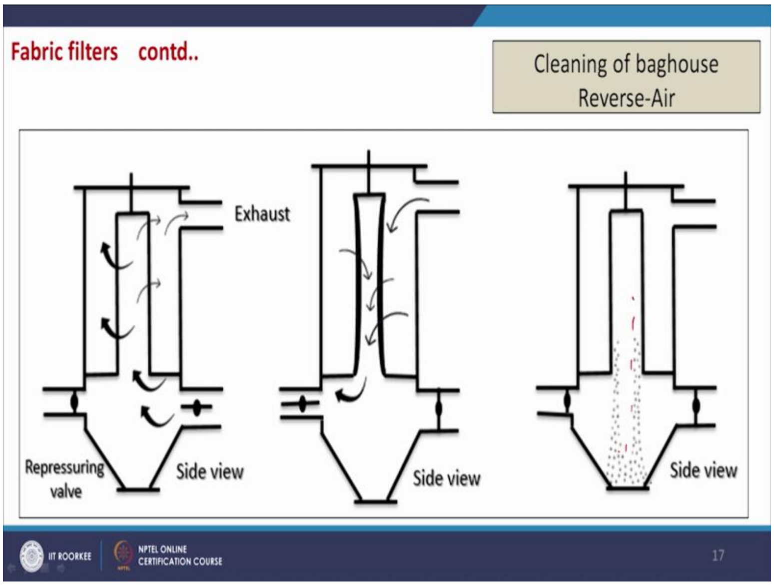

And here this is your reverse air, so here in normal conditions. So, if air goes through this in the reverse air the air will go into opposite direction. So, this is the mechanism and, in that case, also it will be having the particles which are deposited that will be opposite flow it is getting so, that will be settled.

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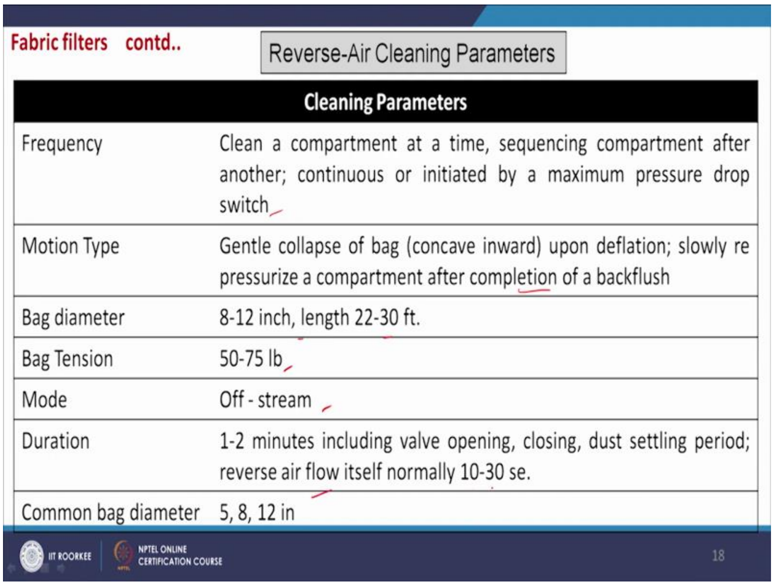

So, this is one reverse air mechanism through which is this can be cleaning can be done and frequency air clean a compartment at a time, sequencing compartment after another continuous or initiated by a maximum pressure drop switch and motion type it is gentle collapse of bag upon deflation slowly re-pressurize a compartment after completion of a back flush and bag diameter 8 to 10 inch lengths 20 to 30 feet and back tension 50 to 75 pound and mode off-stream direction 1 to 2 minutes including wave opening, including valve opening closing, dust settling period, reverse airflow itself normally 10 to 30 second and common bag diameter 5, 8 and 12 inch.

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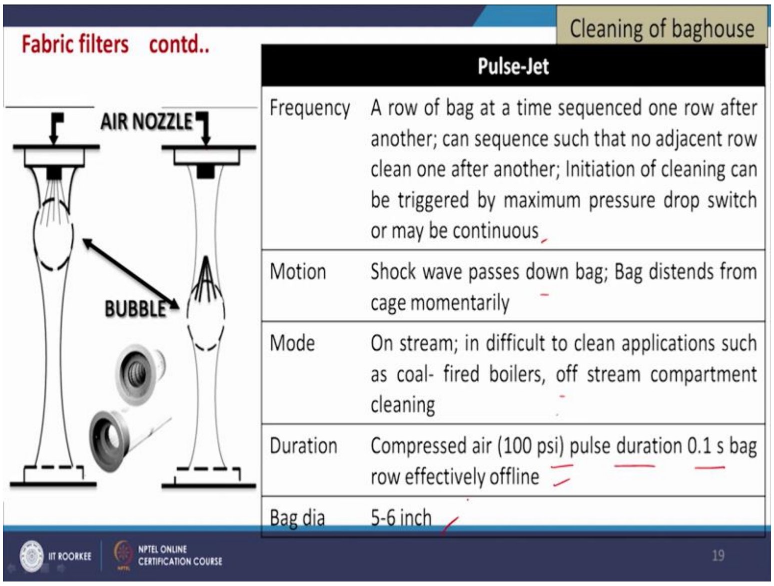

And you see here the pulse jet. So, pulse jet we are providing air with a very small duration inside the bag. So, there are some on off time there is a on of controllers So, when there is an instrumental air, so that instrumental air will give some air inside this bag. So, this through this air nozzle and this this will be air bubble will create and it will disturb the particulates which are associated with the fibres or the fabrics from its outer surface. So, the particles will fall.

So, this is the mechanism so, here also has some characteristics like say frequency a row of bag at a time sequence one row after another; can sequence such that no adjacent row clean one after another; initiations of cleaning can be triggered by maximum pressure drop switch or maybe continuous.

And motion, shock wave passes down back, back distance from cage momentarily and mode on stream in difficult to clean applications such as coal fired boilers, off stream compartment cleaning. Duration compressed air that is 100 psi, pulse duration 0.1 second bag row effectively offline. And then bag dia 5 to 6 inch. So, these are the different methods which are used for the cleaning of the bag. Out of these, the last one pulse jet, is used in many cases in the industry.

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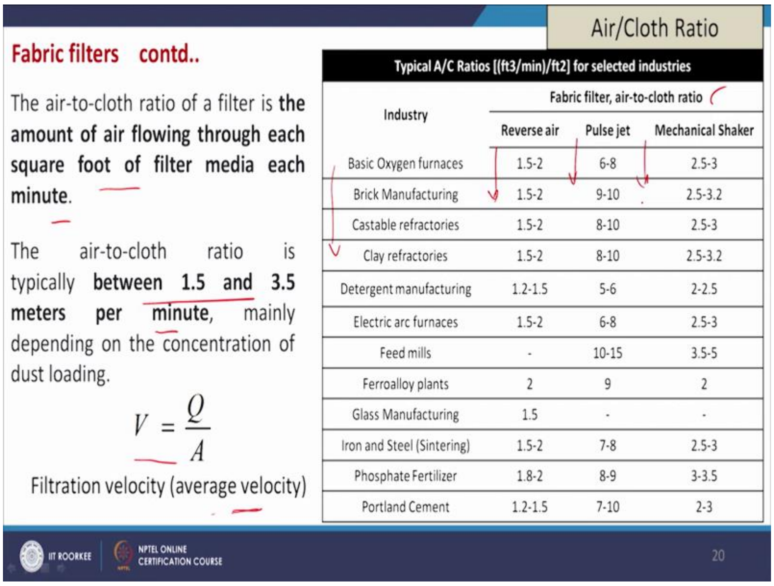

Industry	Fabric filter, air-to-cloth ratio		
	Reverse air	Pulse jet	Mechanical Shaker
Basic Oxygen furnaces	1.5-2	6-8	2.5-3
Brick Manufacturing	1.5-2	9-10	2.5-3.2
Castable refractories	1.5-2	8-10	2.5-3
Clay refractories	1.5-2	8-10	2.5-3.2
Detergent manufacturing	1.2-1.5	5-6	2-2.5
Electric arc furnaces	1.5-2	6-8	2.5-3
Feed mills	-	10-15	3.5-5
Ferroalloy plants	2	9	2
Glass Manufacturing	1.5	-	-
Iron and Steel (Sintering)	1.5-2	7-8	2.5-3
Phosphate Fertilizer	1.8-2	8-9	3-3.5
Portland Cement	1.2-1.5	7-10	2-3

And the last we will discuss the air or gas to cloth ratio. So, the air to loth ratio of a filter is the amount of air flowing through each square foot of filter media per minute. So, the air to cloth ratio is typically between 1.5 and 3.5 meters per minute, mainly depending on the concentration of dust loading. This meter means meter cube per meter square that is why it is meter. So, then we are getting the $V = Q/A$

So, filtration velocity, or we know this is the average velocity. So, this table gives us some data on air to cloth ratio for different types of clothes, you see different types of industries where these bag filters are used and different types of cleaning purpose cleaning method. So, reverse air, pulse jet and mechanical shaker, so, in these cases air to clot ratio is also provided.

So, when we will be in need to design a particular filter unit or say fabric filter or bag filter for a specific application. All this information will help us to decide its size and to decide its fabric to decide its operating conditions like air to cloth ratio, etc. So, up to this in this class, thank you very much for your patience.