Technical Textiles
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Lecture – 14
Filter Fabrics (Contd.,)

Hello everyone, we will continue with the particle capture mechanisms. So, as I have mentioned in last class the there are various capture mechanisms inertial impaction, direct interception, Brownian diffusion, gravity settling and electrostatic capture.

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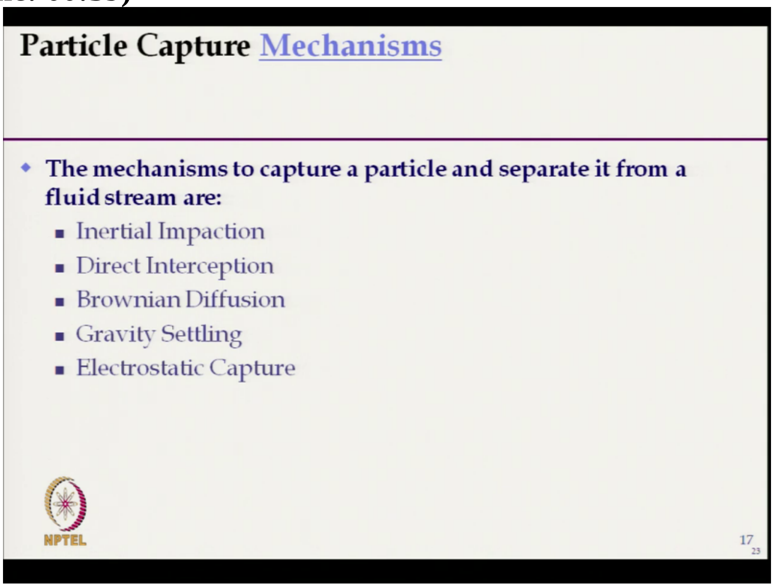

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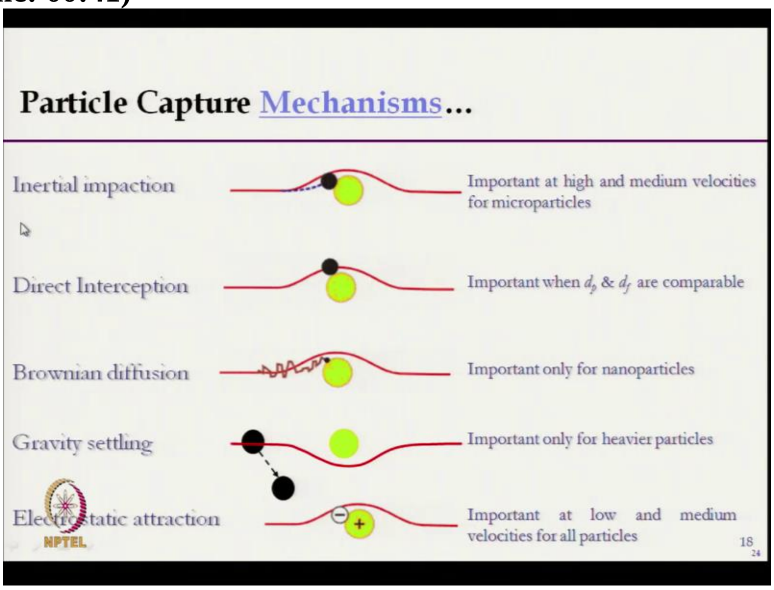

So, this is the diagram which is showing the inertial impaction. So, it means, here as I have already explained, the red path is shown the air or fluid path and this black color dot is the particle. So, due to the inertia, this particle is not following the air stream and striking the fibre and deposited at that point. Direct interception, the particle with a lower dimension lower size due to their lower inertia they can follow the path of air and get trapped inside the structure where the particle diameter is higher than the diameter of the pores.

And Brownian diffusion due to the Brownian motion the particle strikes the fibre surface and get settled on that and gravity settling here due to the mass of the particle, it gets separated from the air stream and the electrostatic attraction due to different charge the particle gets attracted by the fibre filter medium and gets separated from the air stream.

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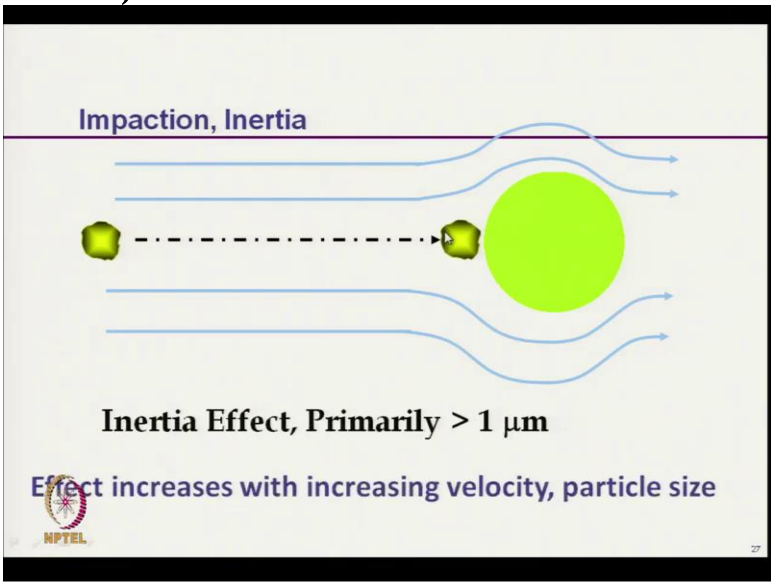

So, straining and sieving which is actually take place when the distance between the fibre that is pore size is smaller than the particle size. They get directly trapped by the filter medium. So, this type of filtration takes place for coarse filter with a larger size particle.

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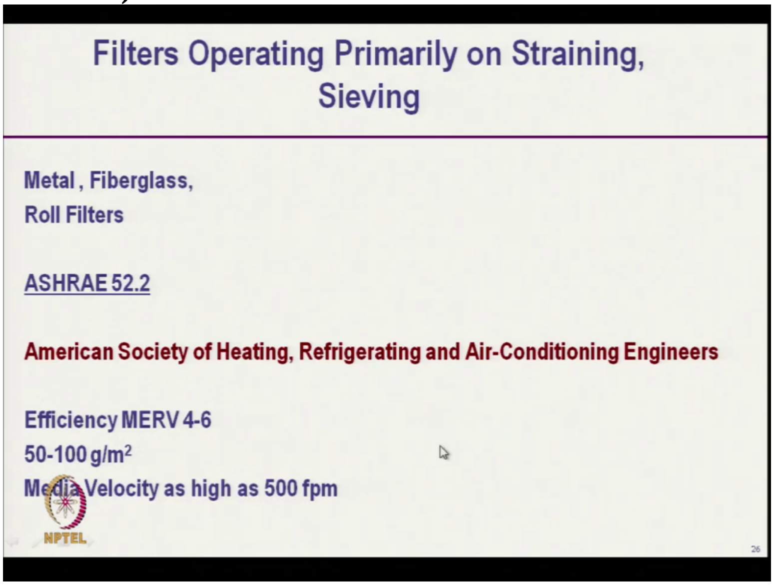

So, for metal fibreglass, roll filters are the examples of this. So, as per ASHRAE 52.5 standard, what is ASHRAE American Society of Heating, Refrigerating and Air-conditioning Engineers. This is a society which forms the standards for filters as per that standard the efficiency for this type of sieving or straining type filter is at the label of 4 to 6. That is the efficiency that means 4 to 6 lower the MERV value.

Lower will be the filtration efficiency here we require the fabric with lower GSM 50 to 100 gram per square meter and this type of filtration it can take place at very high velocity. So, if we want a coarser filter, so, that in that case we can use higher velocity, but for very fine particle filtration, we have to reduce the velocity of fluids. Impaction. So, it has directly impacted.

So, due to the inertia effect and it is primarily around 1 micron and above size particle. So, it should be more than typically 1 micron and this effect of inertial impaction increases with the increase in particle size and increase in velocity, because higher the velocity of air higher will be the inertia of that particle. So that chances of impaction will be more, and larger particle will have higher inertia.

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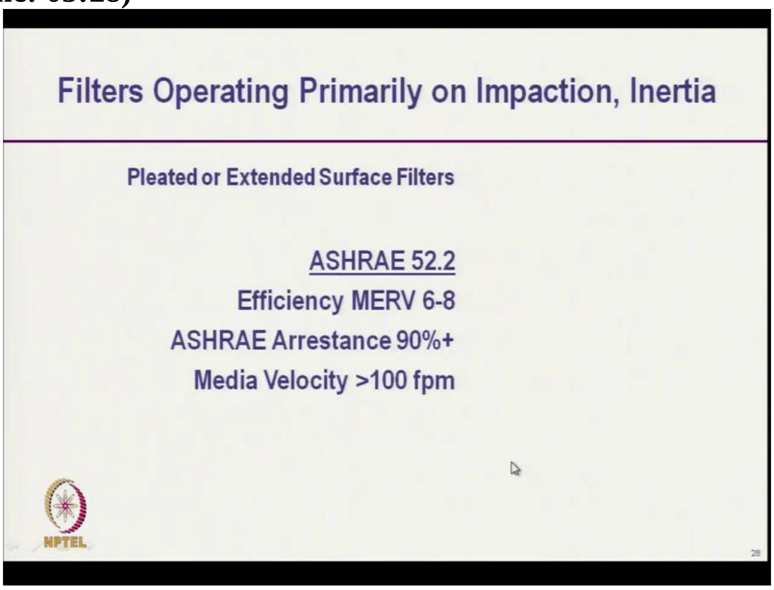

But here the efficiency is more than the straining system; it is 6 to 8, where arrestance percent 90% around 90%. And media velocity is 100 feet per minute. So, it is lower than earlier one 100 feet per minute. It is more than that. So earlier it was 500.

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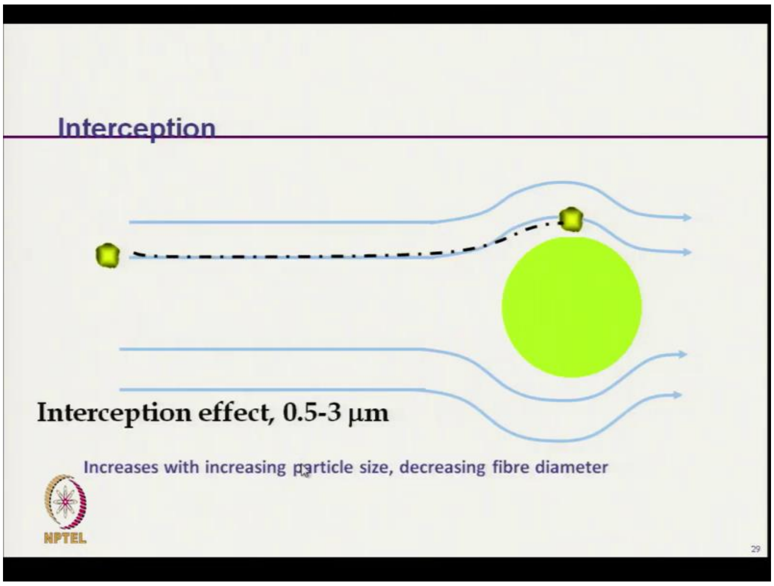

Interceptions, this is typically around 0.5 to 3 micron range, this effect interception effect increase with the increasing particle size and decreasing fibre diameter because it is interception. So, lower the fibre diameter, lower will be the fibre to fibre distance. So, that will actually enhance the interception possibility of interception as it is increasing, it increases with the increase in particle size.

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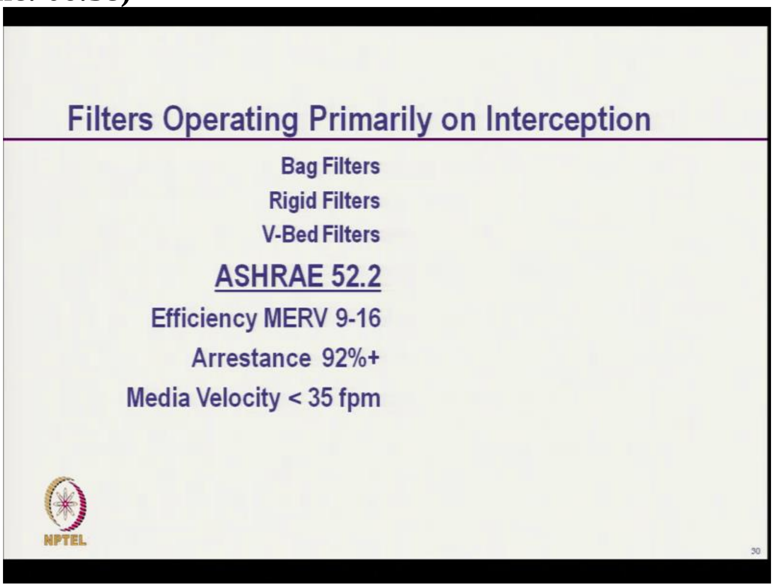

So, this principle is used in case of bag filters, rigid filters, V-Bed filters. So, these types of filters use this type of interception mechanism. So, here, efficiency it is higher than earlier it is 9 to 16 MERV value where arrestance particle arrestance is 95% and more and media velocity you can see here it is lower much lower than earlier. So, here media velocity 35 feet per minute. So, as we go on increasing the filtration efficiency, we try to increase the filtration efficiency, we have to reduce the media velocity.

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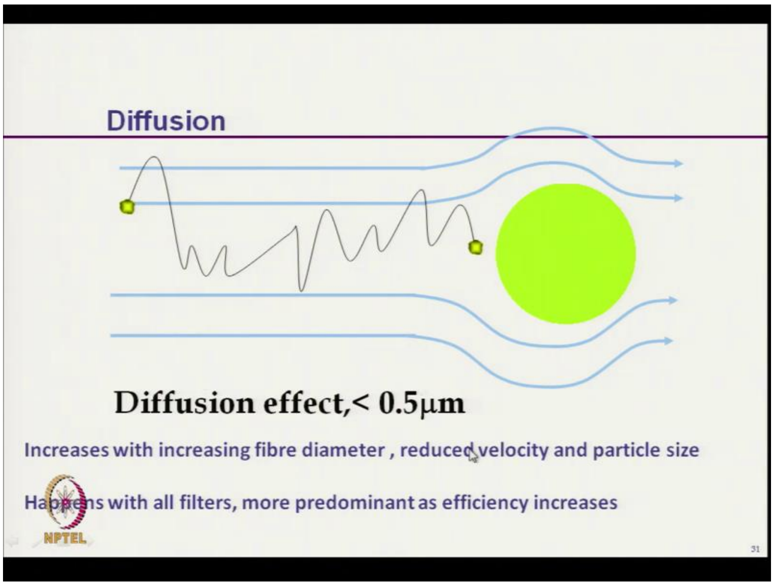

The diffusion here diffusion takes place with very small size particle less than typically 0.5 micron and this effect of diffusion it increases with increasing fibre diameter and reduced velocity and particle size. So, if the particle size reduces the Brownian motion, the Brownian diffusion will increase and higher fibre diameter means there will be a surface present where the particle can get settled and lower velocity is required as I have mentioned, because the particle the Brownian motion is maximum in case of the still air. It happens with all filters.

In any filter, it can happen, but the particle size should be low, and velocity should be low, and it is more predominant as efficiency increases. So that is why so this if the particles are less and Brownian motion if we want to impart this mechanism, we have to reduce the velocity.

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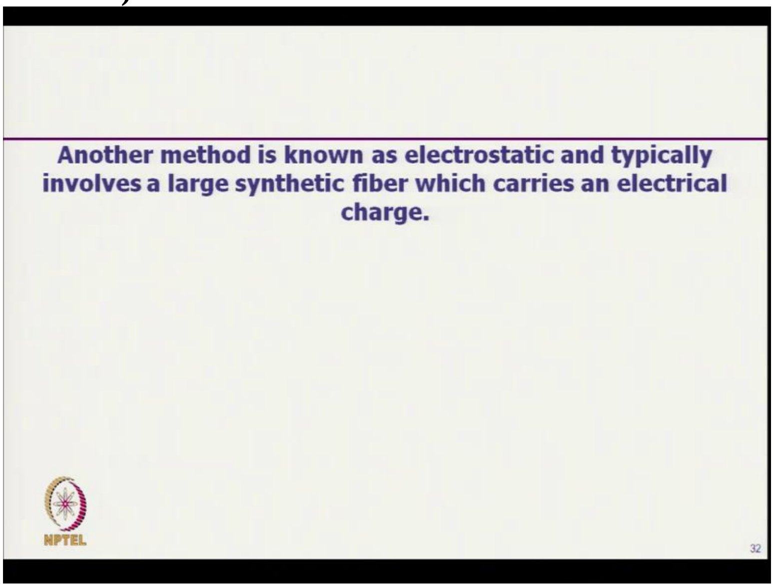

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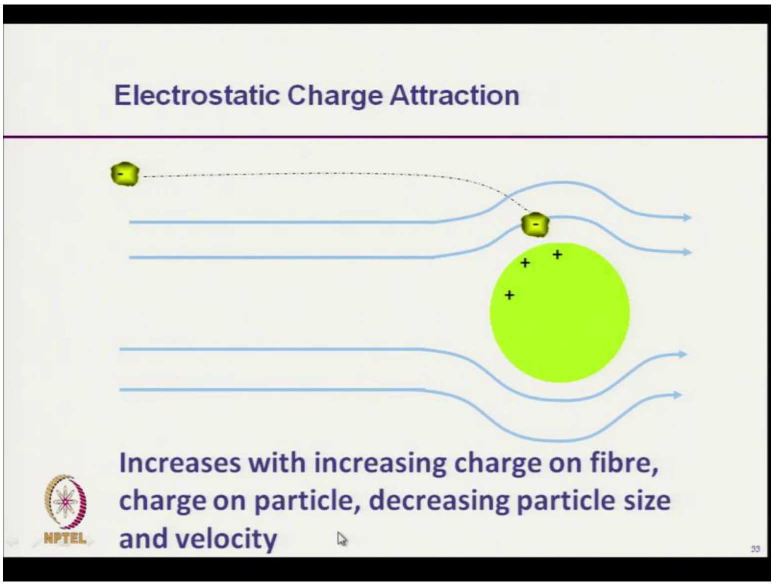

Another technique is that another mechanism is that electrostatic charges. So, the charges of attraction so, this fibre is charged with positive charge, whereas the particle with negative charge get attracted. And this effect increases with increase in charge on the fibre. If we charge the fibre with a higher amount, that will attract more and more particles also increasing the charge of particle decrease in particle size. So, if we reduce the particles at lower sized particle, the attraction force of attraction will be more and reducing velocity. So, this is actually will give best result when the particle velocity or velocity of the stream is low.

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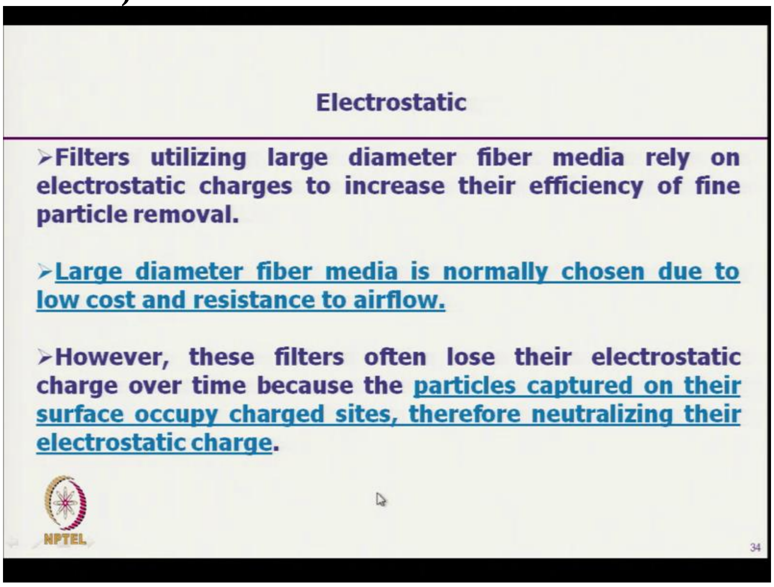

The electrostatic filter utilizes the large diameter fibre rely on electrostatic charges. So, large diameter fibres are generally charged because of the cost and the resistance to airflow. So, large diameter fibres if we use to produce a filter medium due to their open area due to their less specific surface area, the airflow will increase, but that fibre surface those fibre surfaces will actually attract the smaller particle.

However, these filters often lose their electrostatic charge over time, because of the decay and because of the continuous fibre particle deposition, that the charges on the fibre gets neutralized. The particle capture on the surface occupies charged site. Therefore, neutralizing their electrostatic charges. These are used in case of bag filter, rigid filters, pleated filters here the efficiency is at the range of 9 to 15.

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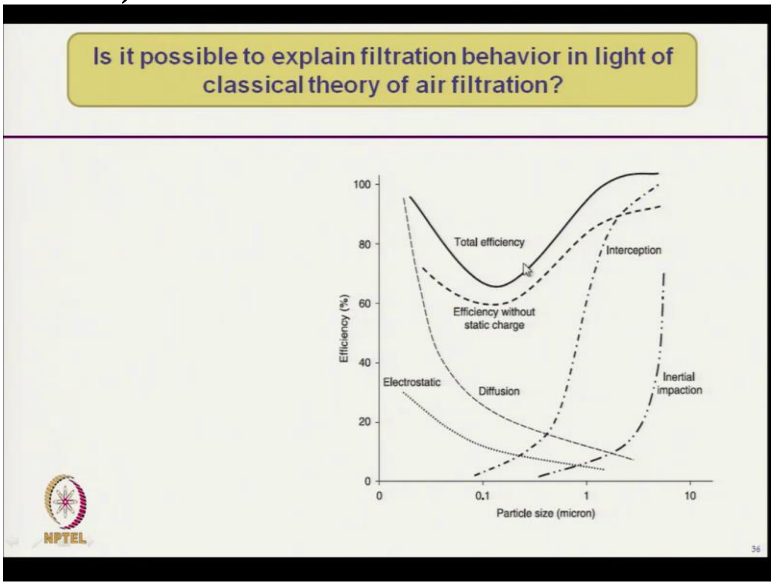

If we see the overall diagram of particle size and filtration efficiency based on different filtration mechanism, this is inertial impaction. It typically it is around say 0.5 micron and above, inertial impaction. Interception, where it starts with the lower particle size, as the particle size increases, the filtration efficiency increases. On the other hand, the diffusion it starts with a very low particle size, and as the particle size increases, the contribution of diffusion reduces. Electrostatic charge.

If we want electrostatic charge, it is okay otherwise, without electrostatic charge, typically these 3 mechanisms are important. And we must know that any particle, any dust particles present in air, it is a combination of very small particle mixture of very small particle and large particles. So, all 3 mechanisms they take place at a time, depending on the type of size, size and conditions, their proportion, their weightage may vary, but overall these 3 mechanisms are always there.

And if we take combined efficiency, the nature of curve is like this dotted line this follows dotted line that is initially at lower particle size very low particle size, the filtration efficiency is high, where the Brownian diffusion is predominant, but as we increase the particle size, it gradually reduces due to reduction in Brownian diffusion. But, after that, after certain particle size, it again increases; this is due to the inertial impaction and interception.

This is the type of typical curve and if we use the electorate filter electrostatic charge, we can have a little bit higher filtration efficiency enhanced filtration efficiency, but the typical shape of the carbon remains same.

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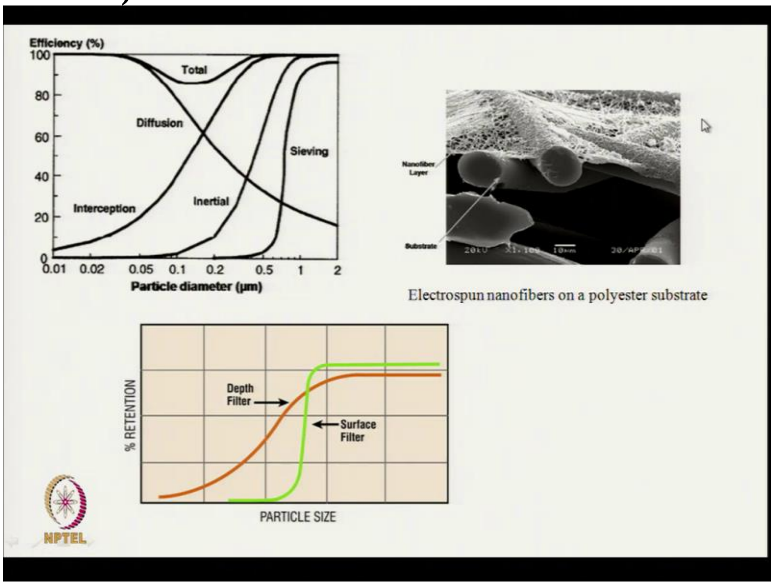

This is the type of relationship as I have already discussed and here if we see this is the retention percent in Y axis and in X axis it is a particle size. So, in case of surface filtration, these 2 curves shows a surface filtration and depth filtration, in case of surface filtration with the increase in particle size retention percent suddenly increases because of definite size of the pore.

But in case of depth filtration, with the particle size, it gradually increases. This picture show filter fabric were combined nonwoven and nano fibre waves nonwoven fabric is where nano fibre waves are deposited, this type of filters they have their own application area, special electro spun nanoweb on a polyester nonwoven substrate, they have their application area.

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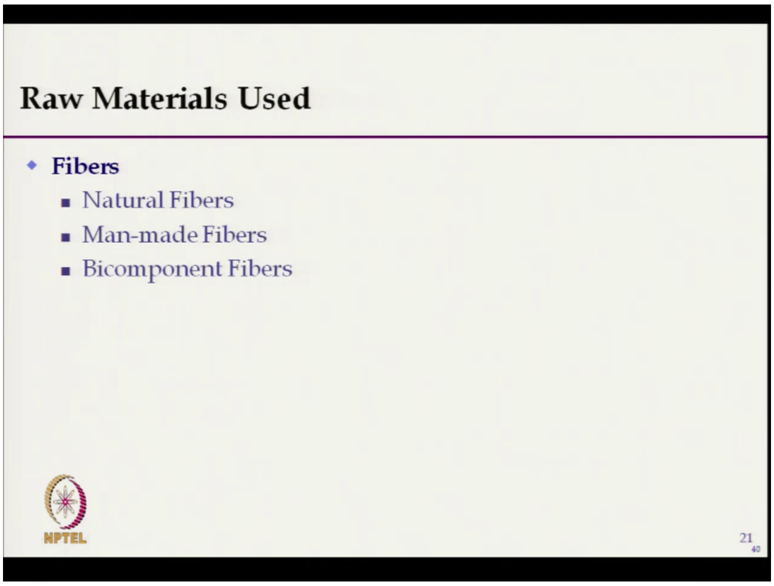

Now, what are the raw materials used in filter fabrics, so, different types of raw materials are used natural fibre and synthetic fibre they are used. So, natural fibre, synthetic fibre, manmade fibres and also bicomponent fibres are majorly used in case of air filtration. In air filtration use bicomponent fibres. So, we will discuss.

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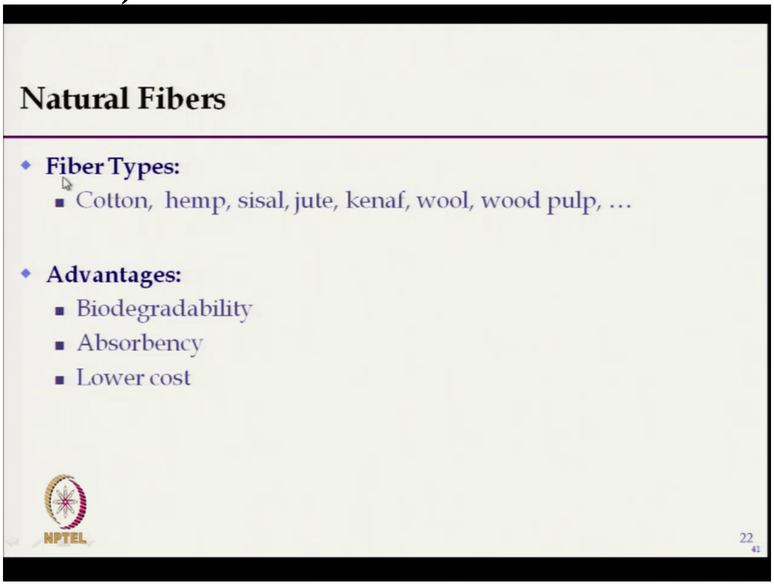

So, natural fibre cotton, hemp, sisal, jute, all these fibres are used wool, wood pulp this fibres are used in filter fabric that their advantage is that biodegradable they are absorbent their cost is low. So, due to that all this so we can use natural fibre.

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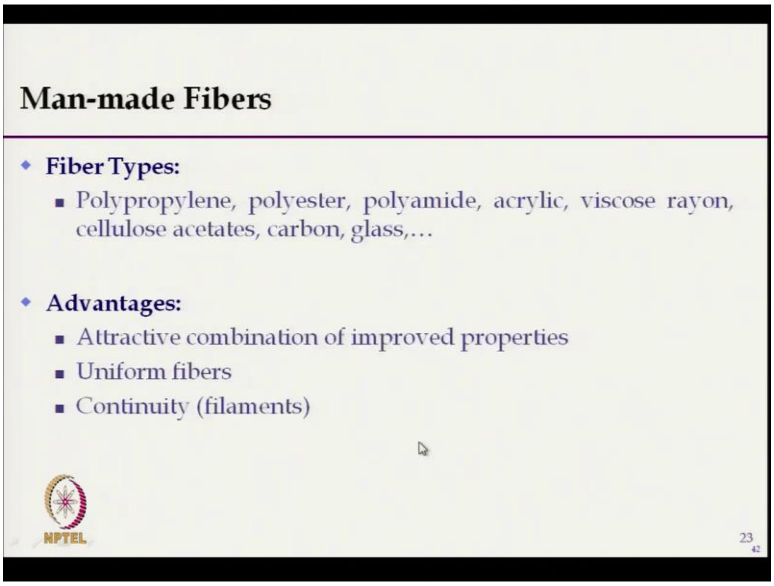

Among the manmade fibres we use polypropylene, polyester, polyamide, acrylic, viscose rayon. So, these all fibres we can use depending on the type of application. Sometimes we can use carbon or glass fibre we can also use for very high temperature filtration application. We have to use the fibre with high melting point. So, main advantages that attractive combinations are possible they have their uniform fibre dimensions. So that we can engineer the filter medium, fibre continuity is there, filaments we can use, like for mesh application we can use filaments.

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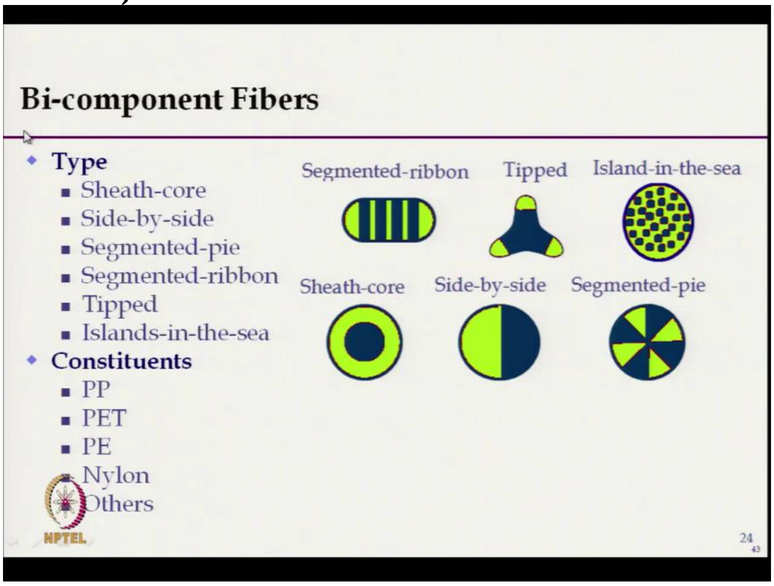

If we see the bi-component fibres, there are different types of bi-component fibres possibly where we can use polymers of 2 different melting points. So, these are like there are different types of arrangements core-sheath arrangement, side-by-side, segmented-pie, island-in-sea is very common in bi-component fibre type. So, all this like segmented, ribbon, tipped. So, these are the different shapes and their constituents are PP, PET, PE, nylon and different other fibres.

So, here one component will have the higher melting point fibre and other component will have lower melting. So, like polyester with high melting point than polypropylene. So, we can have polyester polypropylene, Island-in-sea here this dot these are polyester and the green fibres are this component is polypropylene. Now once we manufacture the nonwoven fabric out of these and after that, these fabrics are subjected to heat treatment.

Maybe by steam or superheated steam or hot air due to that the fibre or component polymer with lower melting point melts and they join each other and that forms a stable structure that stable structure, definite structure is important for and at the same time that total structure is a porous. So, stable porous medium is produced where there will be definite pore structure those pore structures will not get changed with the pressure or with during handling.

So, we will get the uniform or stable filtration characteristics from this type of bi-component fibres. So bi-component fibres are used for filter fabric because of the reason their structures are stable, and they maintain the proper airflow and they maintain the lower pressure drop during the entire lifespan. Their pressure drop does not change, but on the other hand normal nonwoven if we use during use the nonwoven gets compressed and they themselves block the pores. So, the air pressure, air pressure drop increases. So, that is why bi-component fibres are very important for air filtration application.

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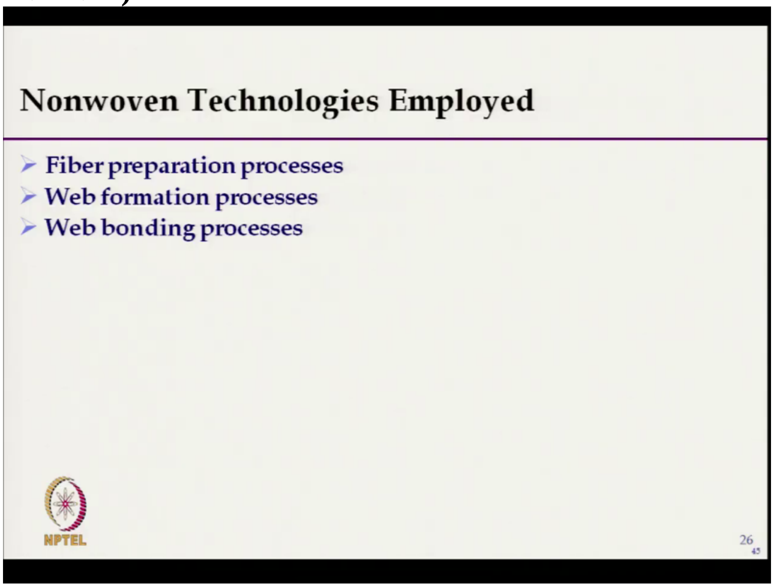

There are different nonwoven technologies used. So, in nonwoven fabric manufacturing, first fibre preparation process then web preparation and web bonding processes. Web bonding can be done by mechanical bonding or by chemical bonding. So, mechanical bonding typically it is a needle punching, chemical bonding it is adhesive bonding or thermal bonding. It is a heat calendaring process or in case of these bi-component fibres, these are bonded by thermal treatment by hot air.

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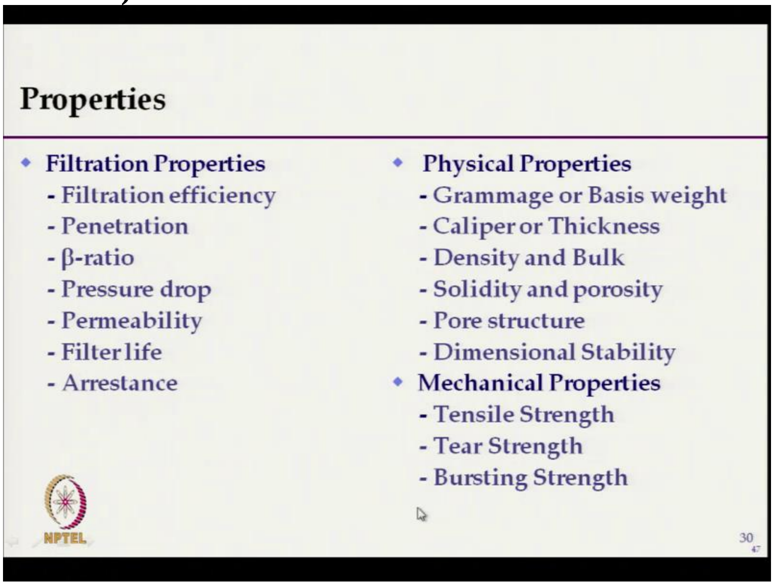

Now, coming to the properties of filter fabric, there are different properties. Properties we can actually divide into 3 distinct classifications, one is filtration related properties, then physical properties and after that, mechanical properties. All these 3 different properties are important. Among the filtration properties, the filtration efficiency, penetration, beta ratio, pressure drop, permeability, and filter life and filter arrestance.

These are the main properties related to filtration properties and physical properties are physical nature of filter fabric like thickness, density, bulk, mass per unit area, dimensional stability, pore structure. So, these are the different properties related to physical nature of the fabric and mechanical properties as we know the tensile characteristics tear and bursting, they are very important as per as performance of filter fabrics are concerned.

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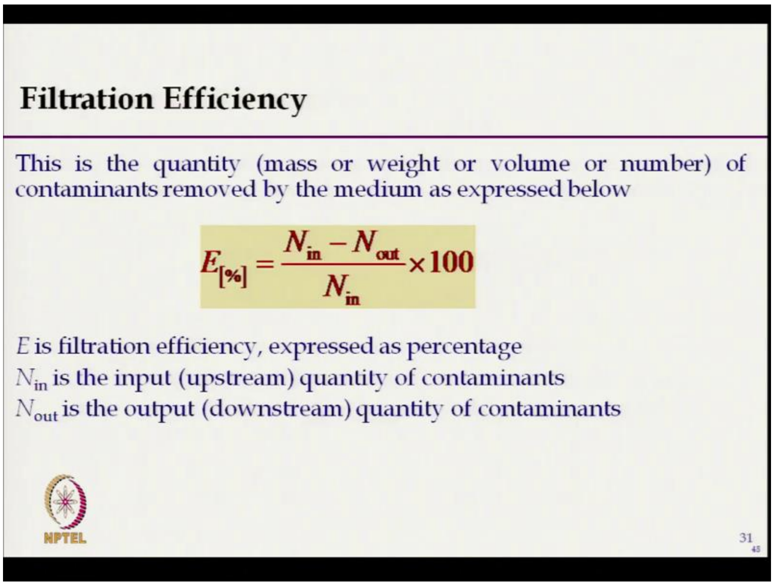

So, let us first start with the filtration related property. First it is the filtration efficiency. So, this is the quantity, quantity in terms of mass or volume or number of particles. So, quantity of contaminants removed by the filter medium, expressed in terms of percentage. So, efficiency percentage is equal to N in minus N out by N in, N is the mass, volume or number of particles in the upstream side.

And N out means number of particles or mass of particle, which are coming out from the filter media which has not been arrested by the filter medium during filtration. So, this if it is expressed in terms of percentage of the input material, so, that is filtration efficiency. Now, here in filtration efficiency if we take care of, we take into account of the mass or volume or number it can be mass or volume or number. So, if it is based on mass or whether it is based on number, it does not matter. It will we can call it as filtration efficiency.

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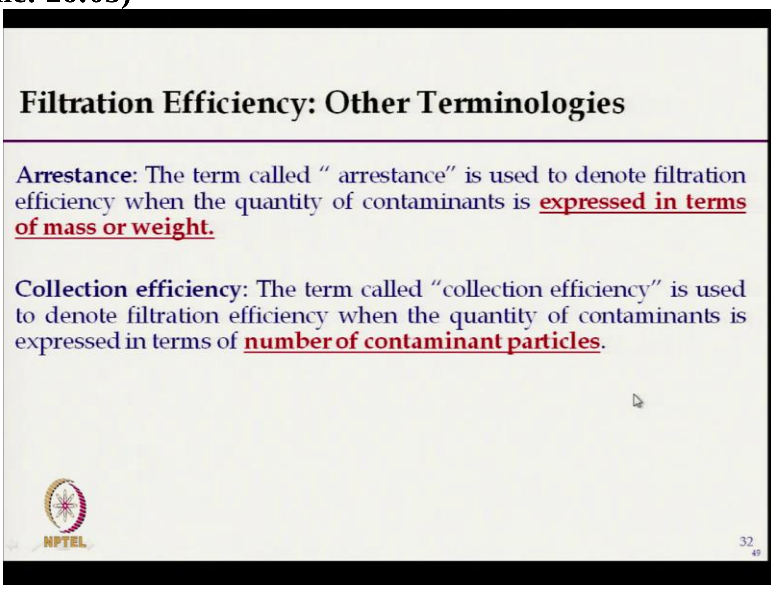

But to differentiate this filtration efficiency, we can term in 2 different ways. One is arrestance, another is collection efficiency. Arrestance is the term where we use the particles in terms of mass. When we use the particle, the mass of the particle which is entering in the upstream side and mass of particle actually, coming out from the filter medium. If we express the filtration efficiency in this term, then we will call it as arrestance.

But, if we use that term in terms of number of particles then these filtration efficiency will be called as collection efficiency. Just to differentiate the nature of measurement, we can use arrestance or collection efficiency.

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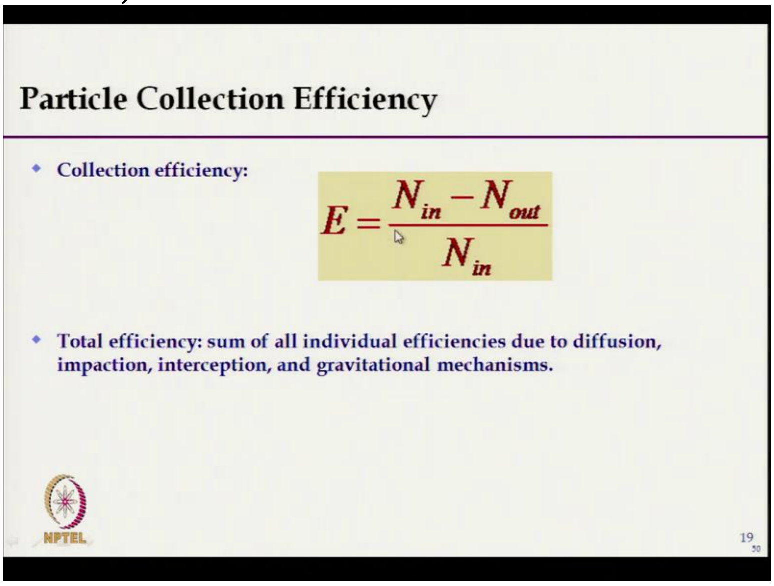

So, collection efficiency is number of particles in the upstream side and number of particle which is going out from the filter medium the difference that is the, this difference is the actual number of particles arrested by the filter medium by divided by the number of particles fed.

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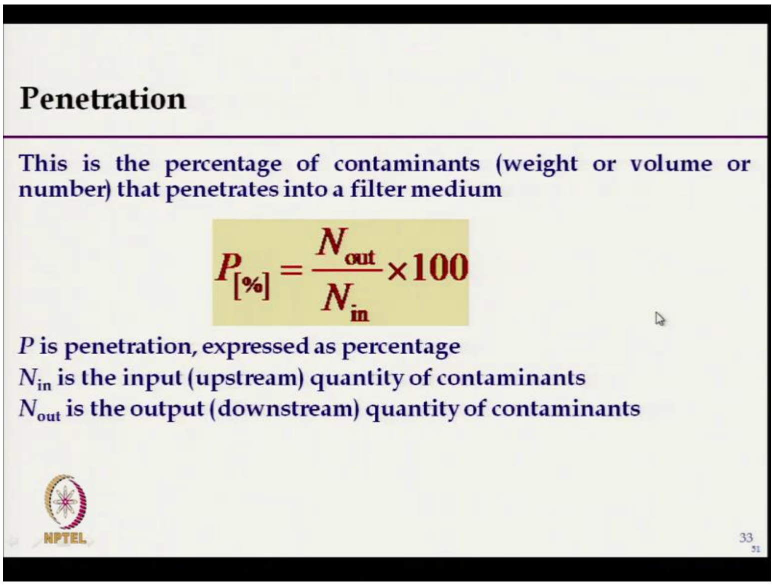

Another term, which is penetration. Penetration is again number, weight, or volume, it is a ratio of number of going out and number of fibre number of particles actually coming. So, it is feeding or number or maybe mass, mass or volume. So, we can use any of this the ratio of this 2 terms, if we use in terms of percent, then it is called penetration percent.

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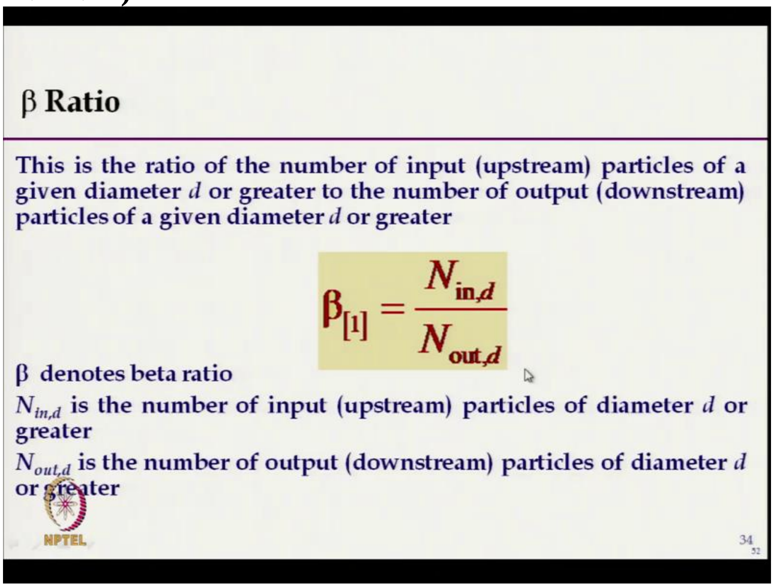

And beta ratio is another term, which is just reciprocal to the penetration. In beta ratio here, it will be N in by N out it is a reciprocal. That is number of upstream particle or by number in the downstream particle. But here, it is based on the number only, number of particles; it is not the mass of particles. And this is expressed in terms of for a particular diameter, particular size of particle. So, beta ratio is not like other term, it is not like overall average term. It is a size specific term.

So, that means for a particular size. So, for 1 micron particle, for 1 micron particle, how many particles were there in the upstream and how many particles were there in downstream, the ratio is beta ratio for that particle size. So, N in for d is the number of input that is upstream particles of diameter d, or greater. So, for that particle or more size, what is the efficiency is the ratio that is called beta ratio. Beta ratio is basically it is a reciprocal of this penetration and it is for a particular size.

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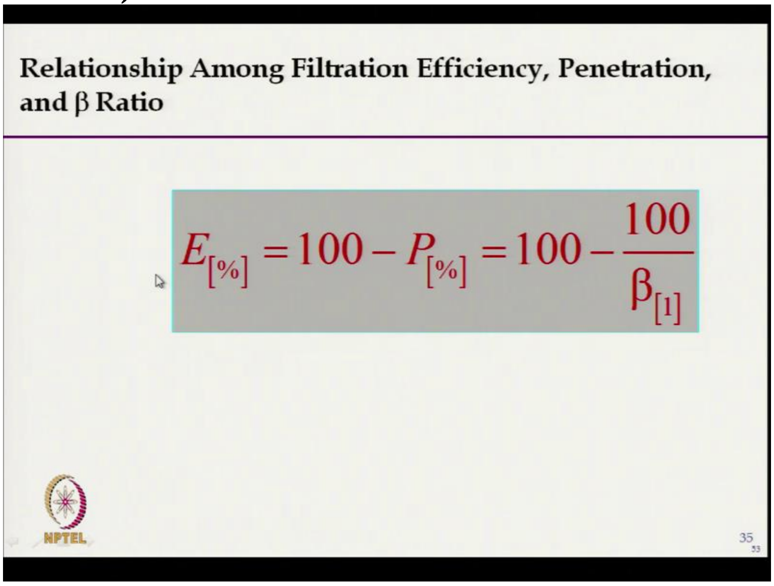

So, if we try to see a relationship, the filtration efficiency equal to 1 minus penetration efficiency, and as it is a reciprocal, so this is the type of relationship, it is a percent and beta ratio is the; it is only the ratio. It is not in the percent. That is the relationship. But here beta ratio is for a particular particle size and above.

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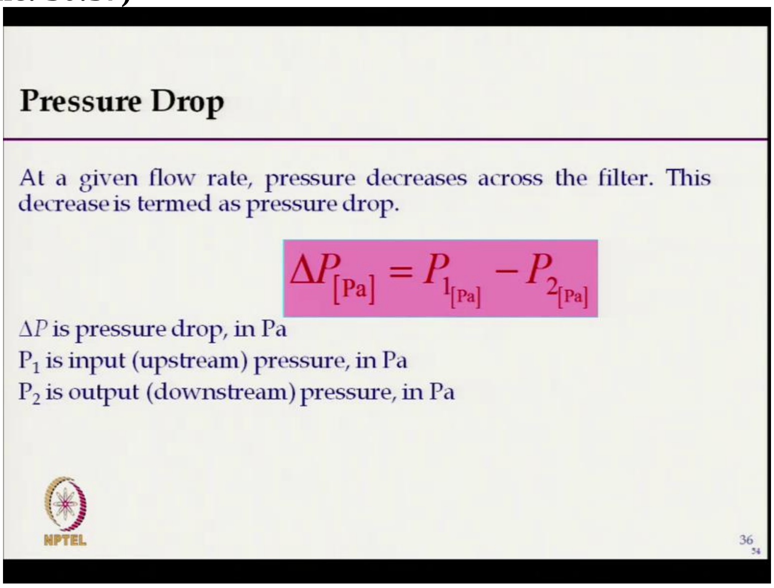

And pressure drop, as I have already mentioned, it is the difference in pressure between the upstream side and downstream side. So, upstream side pressure is always high higher than downstream side pressure. So, ideally, we should try to keep the pressure drop as low as possible. Higher pressure drop means, higher energy required. At the same time the filtration will not be proper, because during filtration it is important to allow the air to pass. Now, let us see, the importance of pressure drop here. Why pressure drop is important here.

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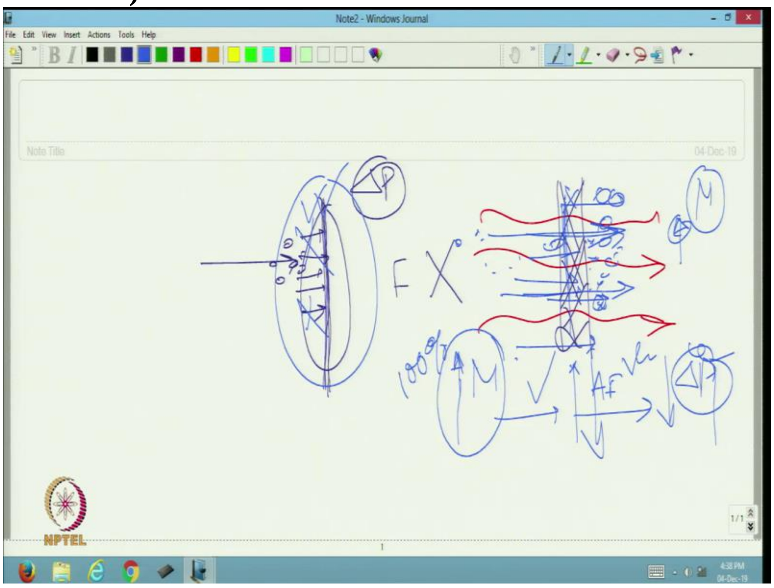

See, suppose we are if we block all the pores there is no pore, it is a polythene sheet, particles with air are moving. So, as there is no opening, so, it will not allow any particle through pass through. So, that means, it will create very high pressure drop. So, filtration as far as filtration is concerned, there is no filtration is taking place. Basically, for filtration we must allow the air to pass through this even if, during due to that some particles are going out of the other surface it is allowed.

But air must flow otherwise actually the filtration process is not initiated here in this case filtration process has not initiated, ok. So, the medium filter medium will only work when there is opening. It is better to allow particles to pass through than arresting. So, if we try to block the pores, then there will be high pressure drop, although we may get higher filtration efficiency, but that is not going to help.

I will tell. So, we have say 2 options. One is higher filtration efficiency. Miu higher filtration efficiency or higher air flow or lower pressure drop. So, higher air filtration efficiency we get with the lower air higher air flow, then it is okay, or with lower pressure drop then it is okay.

But if we want to achieve 100% filtration efficiency by very high pressure drop and very low airflow, that means the effectively the filtration is not taking place, because air if air flows then only particles will come with there.

Otherwise if air flows at a very slow rate, in that case, the filtration will not take place. So pressure drop if it is high as I mentioned, it will create higher energy requirement.

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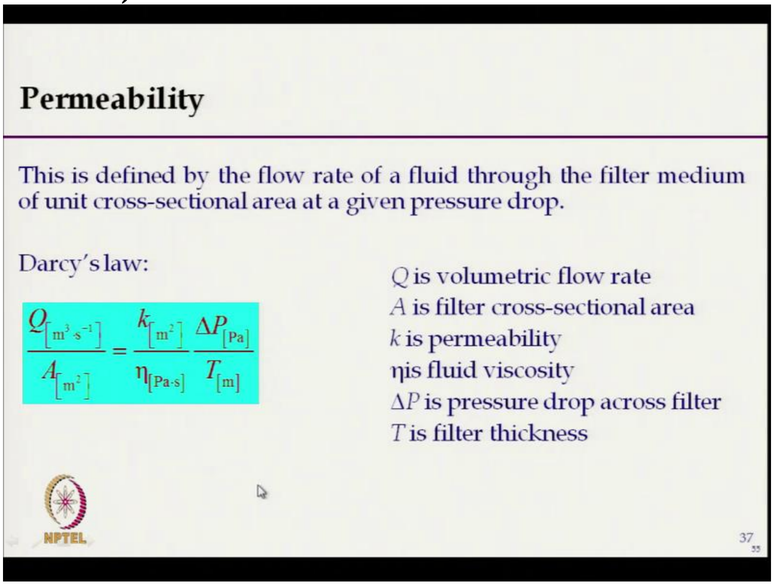

So, permeability is very important, we must know the permeability of the filter medium which is quantity of air volume of volume flow rate per unit area unit cross sectional area. So, cubic meter per square meter per second, so, this is the unit. So, after this understanding all this filtration related terms. Now we will discuss the instruments for measuring the filtration characteristics. There are different instruments available. So, these instruments which we are discussing now are for air filtration.

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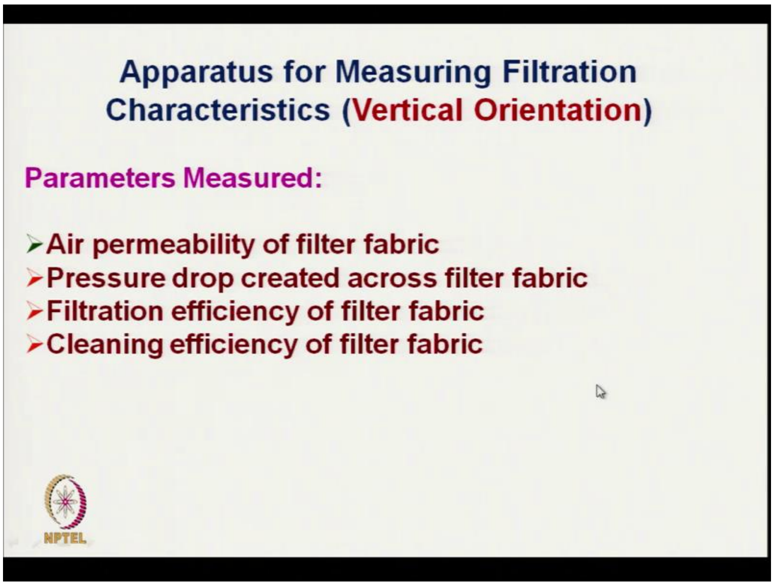

The air filters can be of vertical orientation or it can be horizontal orientation. So, this in this instrument vertical orientation, the air permeability is measured, pressure drop created across the filter fabric and how the filter that pressure drop changes with the time that can be monitored here. Filtration efficiency of filter fabric, cleaning efficiency of filter fabric.

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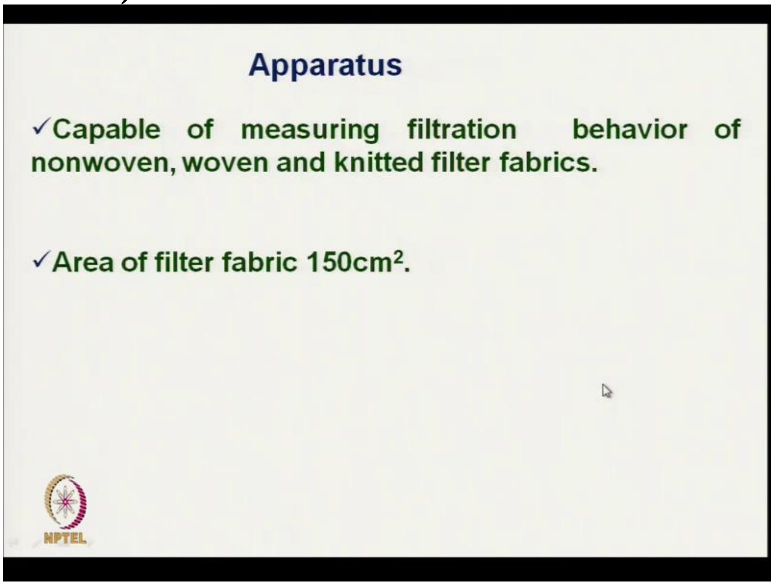

These are the different parameters we can measure. So, the instrument is capable of measuring the filtration behaviour of nonwoven, woven, knitted fabrics. So, area of filter fabrics here is 150 square centimetre.

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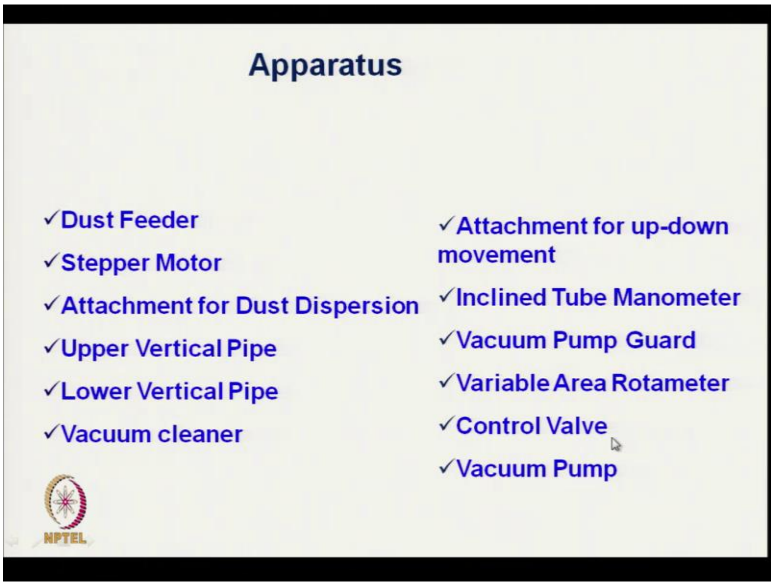

So, this filtration instrument has got different components dust feeder, stepper motor, attachment for dust dispersion. So, dust feeder is it actually feeds the dust at a certain rate where which is controlled by a stepper motor. So, we need to know the dust loading and after feeding dust has to be dispersed evenly. So, upper vertical pipe is there through which dust is being deposited and lower vertical pipe is there.

Vacuum cleaner is there to actually to clean the filter surface, attachment is there to move the lower vertical pipe up and down, inclined tube manometer to measure the pressure difference, vacuum pump, variable area rotameter to measure the air flow rate, control valves and vacuum pump.

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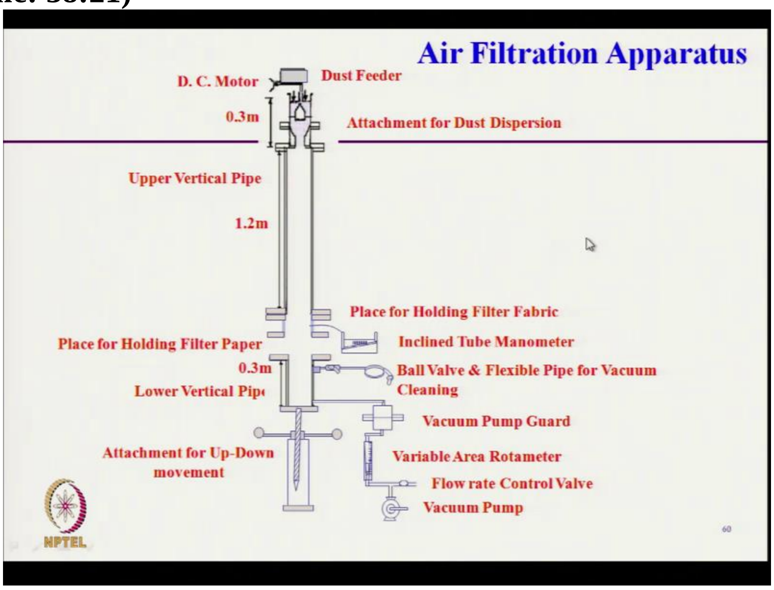

So, this is the instrument here. Here the motor actually is required to for dust feeder and dust dispersion arrangement where dust is getting dispersed and mixed with the air. Here it is the holder for filter fabric is a filter fabric holder manometer is placed just below the filter fabric to monitor the air pressure and here is the vacuum pump is there vacuum pump, which suck the air through the filter fabric.

And after certain time, if we know the dust feed rate after a certain time, we know the actual quantity of dust fed and we can take the filter out and take the mass again and the difference in mass which will give idea about the particles arrested by the filter medium and from there you can calculate the filtration efficiency. And through this rotameter, we can calculate the flow rate and flow rate and knowing the dimension of the filter fabric, we can calculate the air permeability.

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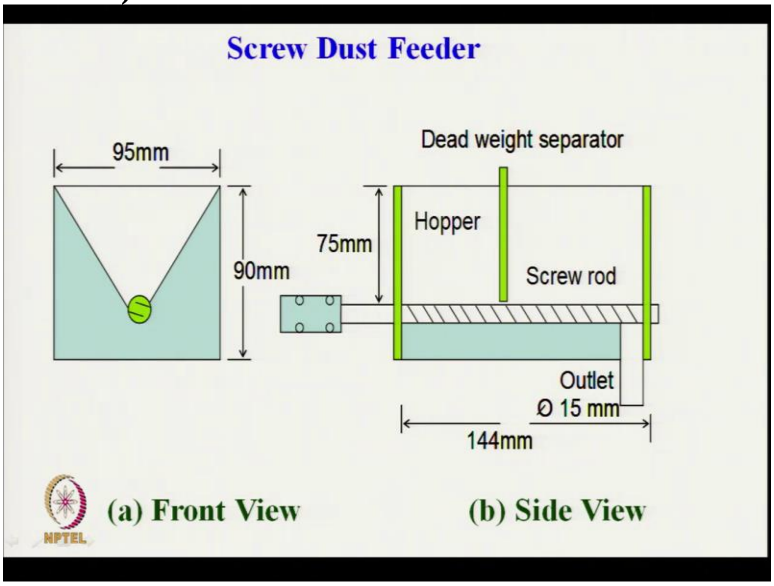

This is the screw dust feeder where the dust outlet is their front view and side view. So, hopper is here, where we actually feed the dust and through the screw rod, the dust is fed. So, by changing the speed of this screw rod, we can change the dust feed rate.

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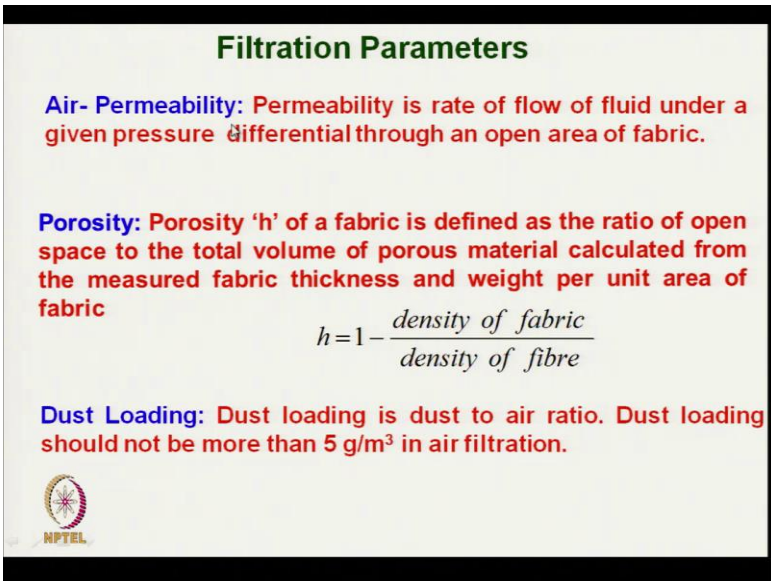

So, you can calculate the air permeability, porosity, dust loading of the by this filtration instrument dust loading. So, porosity is a parameter which shows the amount of pores available in the filter fabric.

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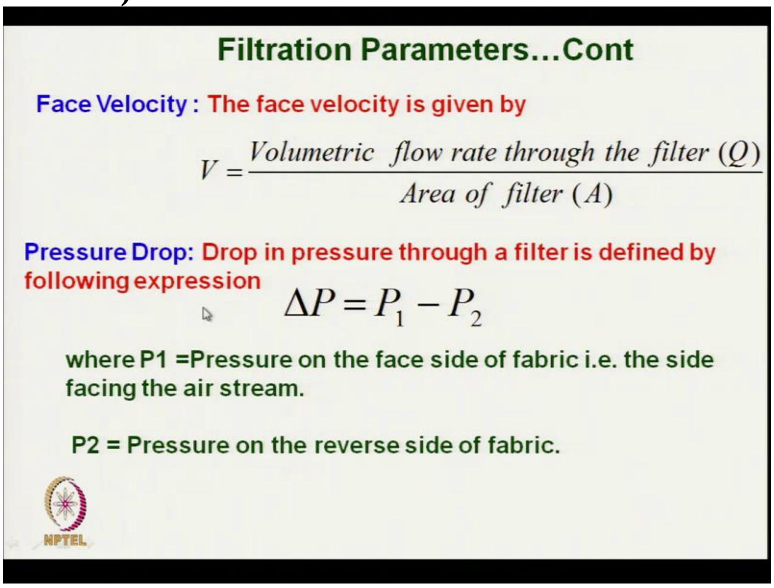

So, face velocity we can measure pressure drop can be measured here. So, we can monitor all these characteristics, all these parameters by this instrument.

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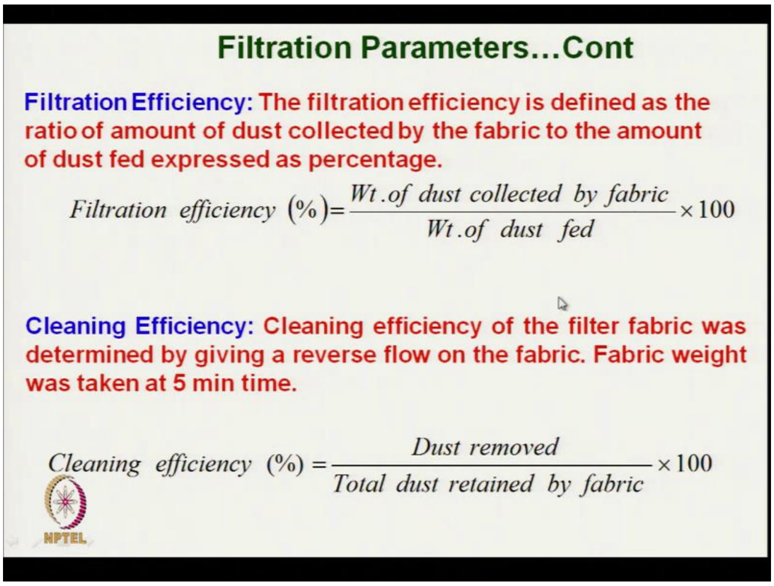

So, filtration efficiency is expressed by the weight of dust collected by fabric as I have mentioned, and total weight of dust fed and cleaning efficiency. This fabric can be cleaned by reverse airflow again. And cleaning efficiency is expressed by dust removed total dust removed from the fabric by total dust retained by the fabric. This is total dust collected. So, total dust removed by total dust returned by the fabric.

So, from there we can calculate the cleaning efficiency. It is important to know the cleaning efficiency because we have to reuse the filter fabric once again. Ideally there should be very high cleaning efficiency so that the performance will be better and it is a filter life will be longer.

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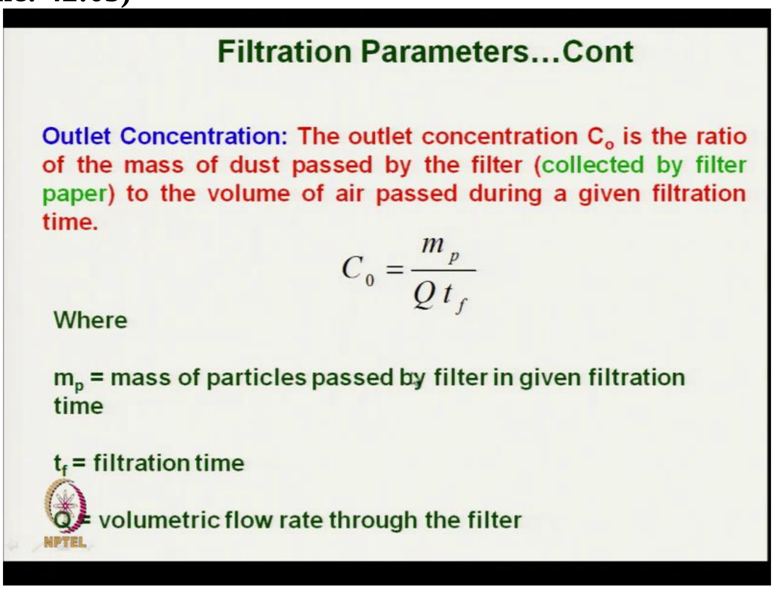

And outlet concentration of particles can be measured. So, m p is the mass of particles passed by the filter. It is giving at a given filtration time, t is the time volumetric flow. So, outlet concentration is also important, because that, after filtration, what are the how much particles are coming out from the filter medium we must know. So, that we can use another filter or micro filter that that indication we can get from this parameter.

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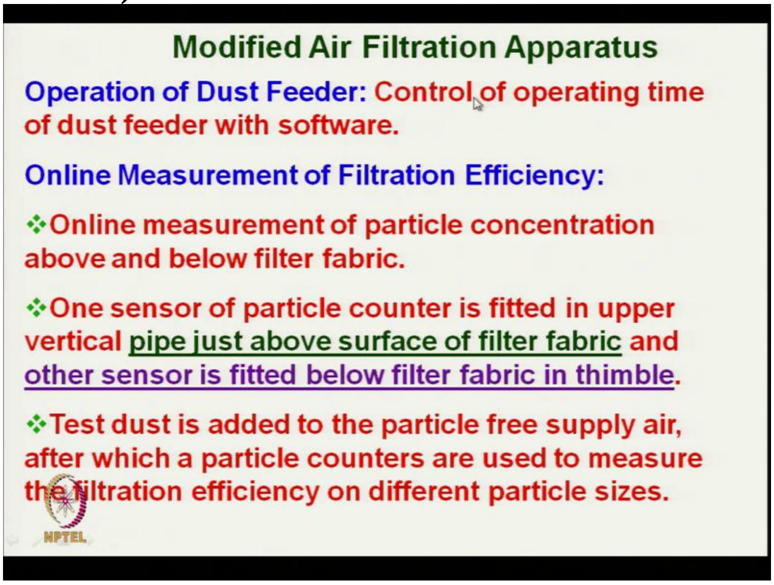

So, these are the different parameters we have discussed. So, we have again modified the earlier filtration instrument. Here the dust feeders are actually automatic control by the software. So, which controls the speed of the motor to control the dust feed rate and online measurement of filtration efficiency is there. Where, the filtration efficiency measured here on the basis of number of particles not on the basis of mass of particles.

So, here we have used 2 particle counters, electronic particle counters, one sensor of particle counter is fitted upper particle pipe just above the filter fabric and another we have placed just below the filter fabric. So, if we see here, this is one particle counter, another particle counter is here, and both the particle counters are attached with it the controller system and which is connected with the computer.

Now, during the filtration process, this particle counters they continuously count the number of particle or concentration of the particle in the upstream side as well as in the downstream side, they constantly monitor and convert into filtration efficiency continuously we get. So, here we can monitor with the time. So, initially what has been observed the filtration efficiency is low because the formation of cake or maybe larger particles, the depth filtration depth loading was taking place.

But after certain time, when the cakes were formed or depth loading completed, then we have observed the filtration efficiency has increased and at the same time gradually the pressure drop also increases. So, after certain time when pressure drop is very high. So, we have to stop the experiment.

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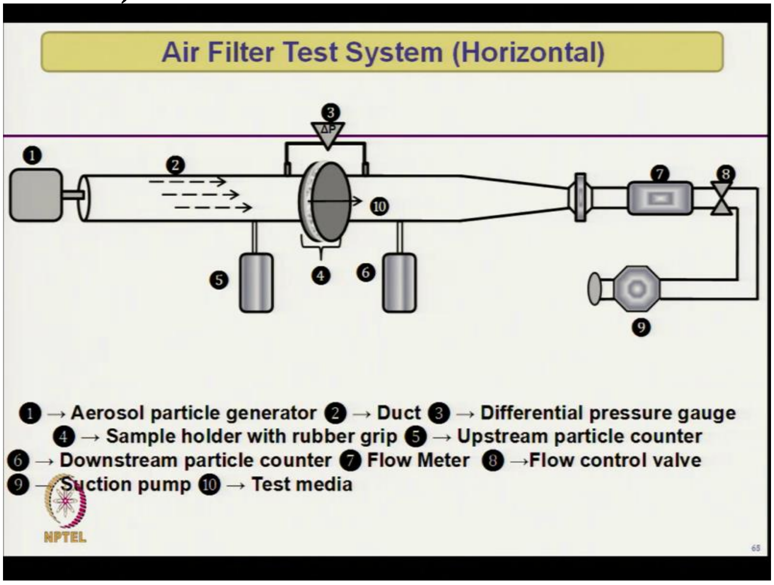

So, this instrument is it gives automatic online data of filtration efficiency. Another instrument where the orientation of the instrument is in horizontal fashion. Here again we have used particle counters. So, the one it is aerosol particle generator here we can generate the aerosol particle where particle are mixed with air, and then it is pumped through the fabric through this channel.

So, here, this is a duct through the duct the dust loaded air is passing, we can control the dust concentration depending on the standard depending on the application and this is the test medium and these are the differential pressure gauges. This is differential pressure gauge, which constantly monitored the pressure difference or pressure drop, sample holder, this is sample holder, upstream particle counter 5 and this is downstream particle counter like earlier one.

So, this 2 particle counters the data from these 2 will be used for calculating the filtration efficiency. Here it is a flow control valve we can control the flow depending on our requirement, if we require higher velocity or whether we require lower velocity. So, that depending on the standard, we can control this flow velocity here, flow meter, here it is a flow meter, which controls the, which will measure the air flow rate and suction pump. So, the overall arrangement is similar to earlier one, but here the orientation is horizontal orientation.

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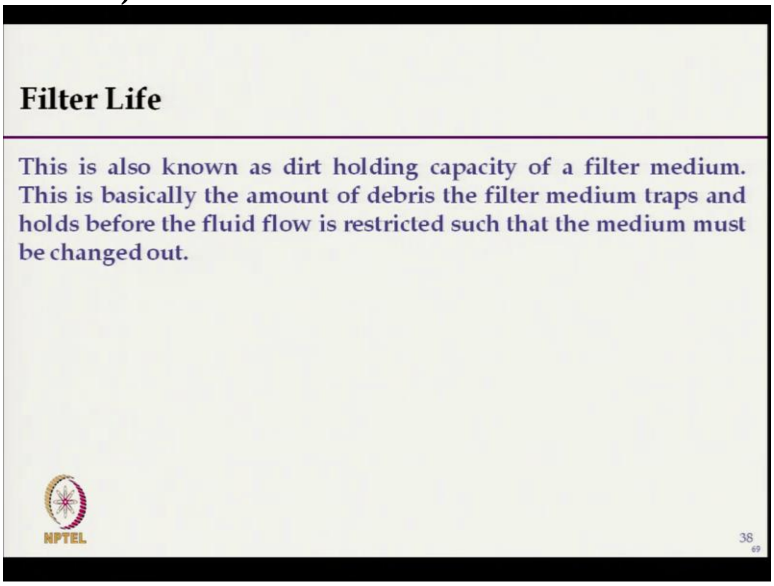

So, filter life is another important characteristic we must know, because, the dust holding capacity of filter medium we must know, if it exceeds filter life exceeds that means, there are excess pressure drop either there are excess pressure drop or there may be some damages, which will cause the improper filtration, if the particles are trapped permanently inside the structure, which we cannot actually remove or clean. So, the filter in that case needs to be changed.

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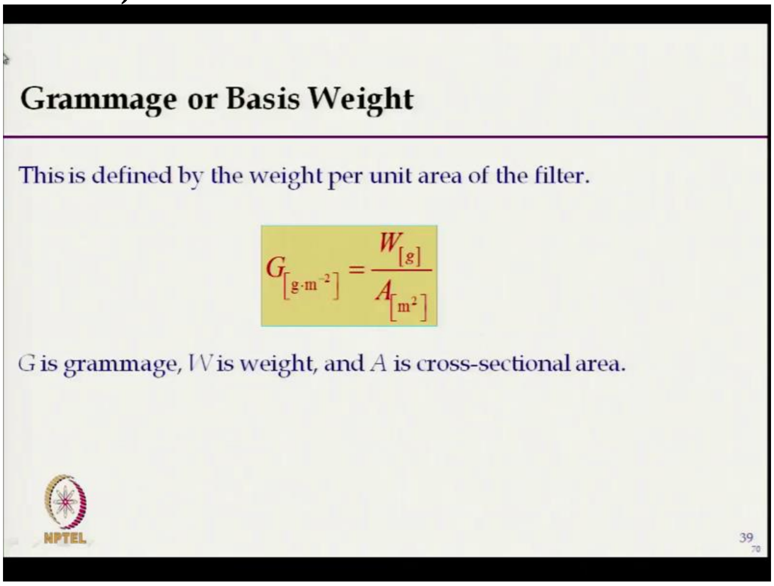

So, other parameters are here. It is a mass per unit area. It is physical parameters are their mass per unit area is important characteristic for filter fabric.

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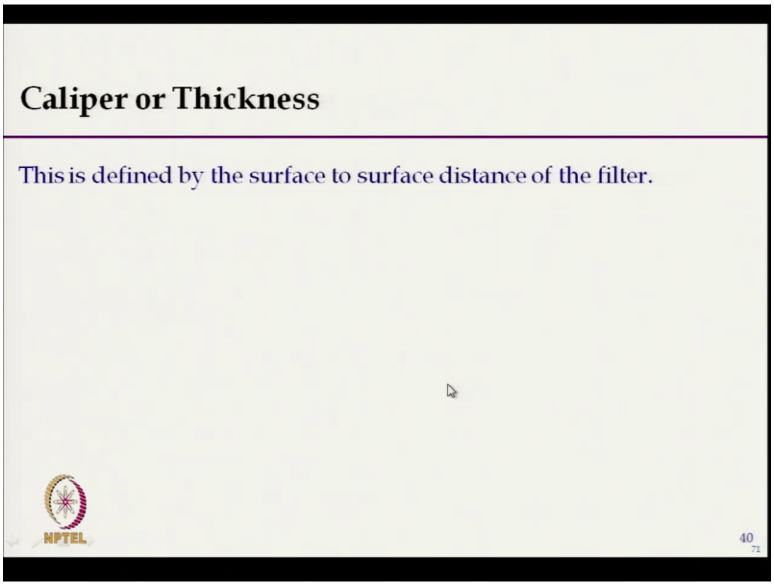

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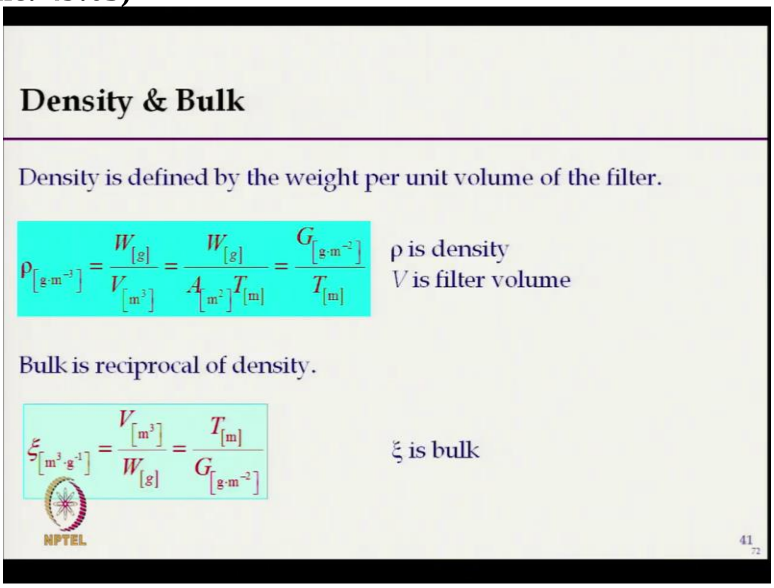

Thickness is another parameter. Bulk density o, bulk or density. So, density it is defined as the weight per unit volume of filter. So, this is density ro, which is by weight, there is a mass per unit volume. And ultimately if we know the mass per unit area and thickness, the ratio of mass per unit area and thickness is actually indirectly it gives idea about the density of fabric. Similarly, bulk is the reciprocal of density. So, this is just reciprocal thickness by the mass per unit area.

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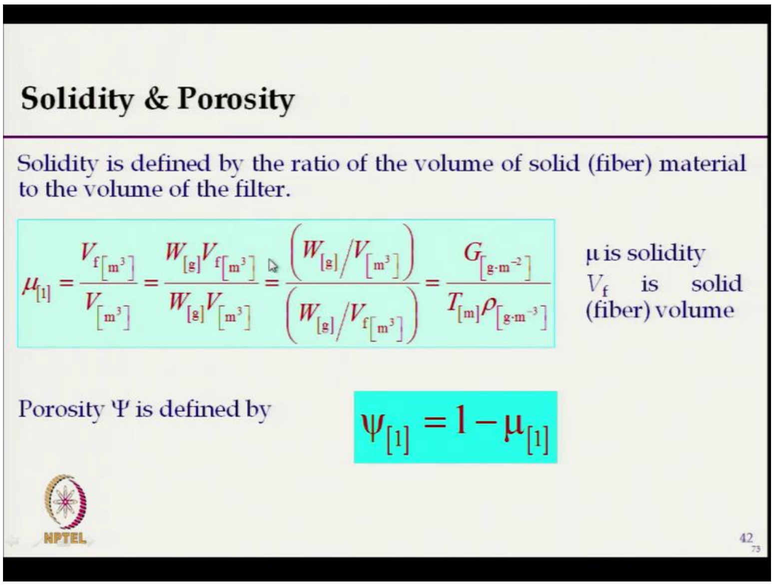

Solidity and porosity, the solidity is defined by the ratio of volume of solid fibre material to the volume of filter. So solidity is the volume of fibre by volume of filter. That is the solidity and it is the mu is the solidity and if we see the volume of fibre by volume of filter, and ultimately it is basically mass per unit area of filter, by thickness of filter and divided by density of fibre. So, from there we can calculate the solidity of filter medium and porosity is basically it is defined by 1 minus solidity. So that is the relationship that is porosity is 1 minus solidity, which is very important term which is important parameter for filter fabric.

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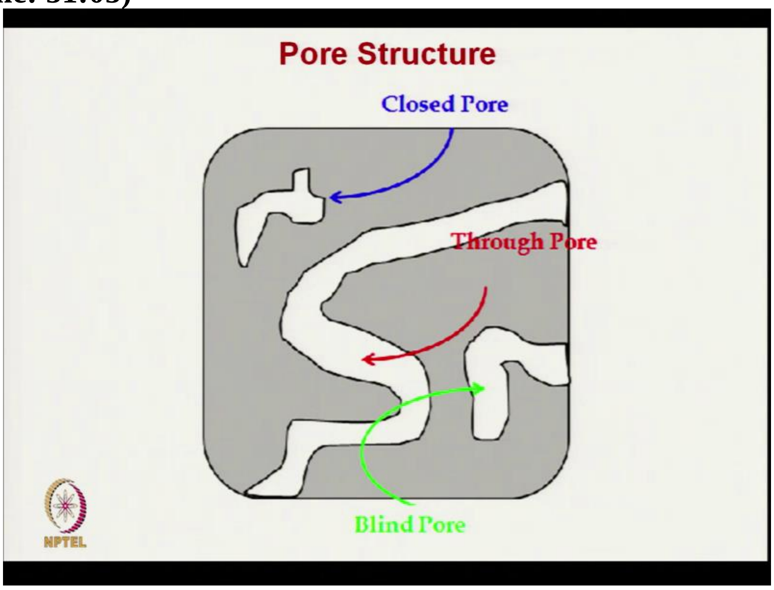

And pore structures are also very important to measure. So, there are different techniques for measurement mainly this picture shows there are 3 types of pores one is closed pore where it is covered from all the sides. Next is blind pore, the pore is started from one surface and it is actually it ends in between and another is through pores, that is, it is from one surface to other surface, it actually continuous. For filtration, this through pores are important.

So, blind pore and closed pore is not important for filtration. So, in next class, I will discuss the pore structure, how to measure the pore size pore distribution. And also, I will discuss different types of filter fabrics. Till then thank you.