Testing Functional & Technical Textiles
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Lecture – 16
Testing of Filter Fabrics (contd..)

Hello everyone, we will start discussing the properties of Filter Fabrics. In last class, we have discussed the mechanisms of filtration; we try to understand how the particles are being captured by filter medium.

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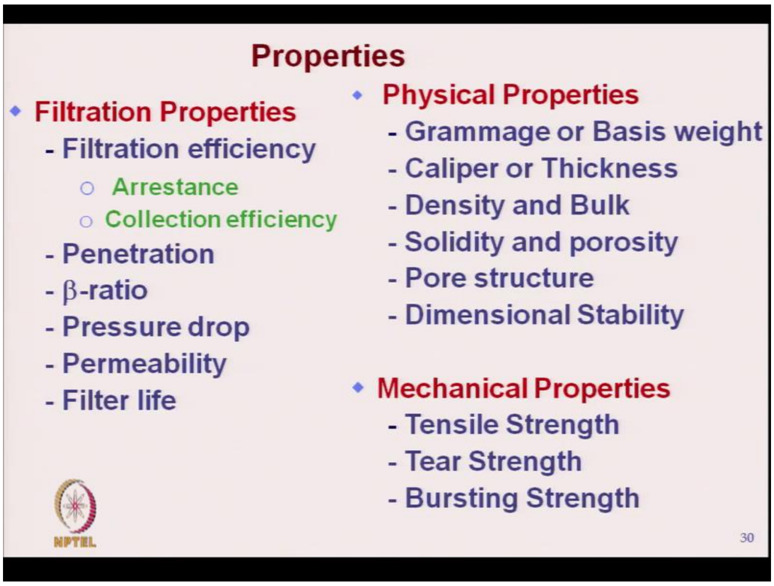

So, the properties are there three different sections of filtration properties. So, the filter fabrics are mainly meant for filtration. So, the filtration properties are extremely important and along with that there are other properties, these are physical properties. And for having proper service life, there is another property which is mechanical property. So, all three properties are important.

So, filtration properties are filtration efficiency. The filtration efficiency can be expressed in terms of arrestance and in terms of collection efficiency. Along with filtration efficiency the other properties are penetration, then beta ratio, next is pressure drop, then permeability of the fluid and then its a filter life. So, this, all these properties will be discussed one by one.

And physical properties are mass per unit area that is basis weight or grammage, thickness or sometime it is called caliper, density and bulk of filter fabric, solidity is amount of solid content or porosity, pore structure and dimensional stability. Among the mechanical characteristics that is tensile strength, tear strength and bursting strength.

So, to evaluate the characteristics of a particular filter medium, we must test all this characteristics. First we will start with filtration properties. So, filtration properties are measured using filtration tester there are different types of testers available commercially. And these filters are basically either woven filter, nonwoven filter or maybe combinations and the filtration test equipments are basically one is vertical alignment where the filters are placed horizontally. And the air or fluid movement along with the dust particle is in vertical direction. In another type, the filter fabrics alignment is vertical orientation and the air movement is in horizontal direction.

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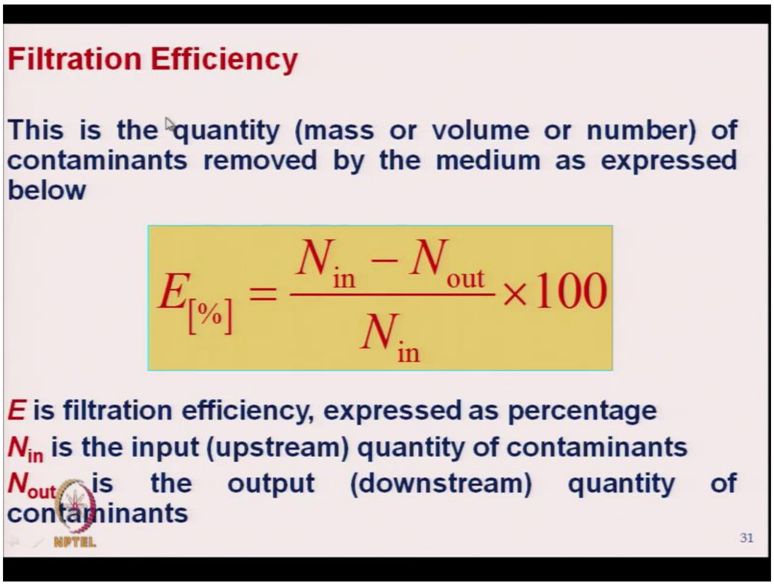

The filtration efficiency is expressed as the quantity of contaminants, the quantity is in terms of mass or volume or number of contaminants which is removed by the mass of the fibrous medium that is the filter medium. So, these particles which are present in the fluid, once it is flowing through the filter fabric, it has been removed. The filtration efficiency E is expressed in percentage, where Nin is the input that is in upstream quantity of the contaminants, this maybe in terms of mass or volume or number. Typically we used in terms of mass or in terms of number. So, quantity in terms of mass which is in input or upstream is Nin and quantity in downstream which is out of the filtration medium which Nout,

$$E_{[\%]} = \frac{N_{\text{in}} - N_{\text{out}}}{N_{\text{in}}} \times 100$$

so this is the filtration efficiency.

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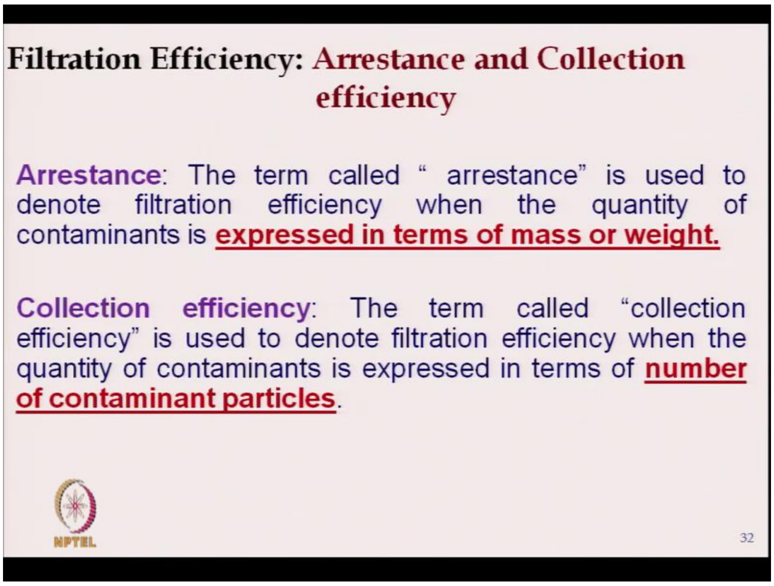

This filtration efficiency can be expressed in two ways; one is arrestance and another is collection efficiency. Typically this two terminologies are actually filtration efficiency. So, arrestance the term we used when we express the contaminant quantity in terms of mass or weight. The term called arrestance is used to denote the filtration efficiency when the quantity of contaminants is expressed in terms of mass or weight.

And collection efficiency the term called collection efficiency is used to denote filtration efficiency when the quantity of contaminants is expressed in terms of number of contaminant particles. So, for getting the collection efficiency, we must count the number of particle using particle counter. And to calculate the arrestance percent, we must know the mass of input particle and mass of output particle.

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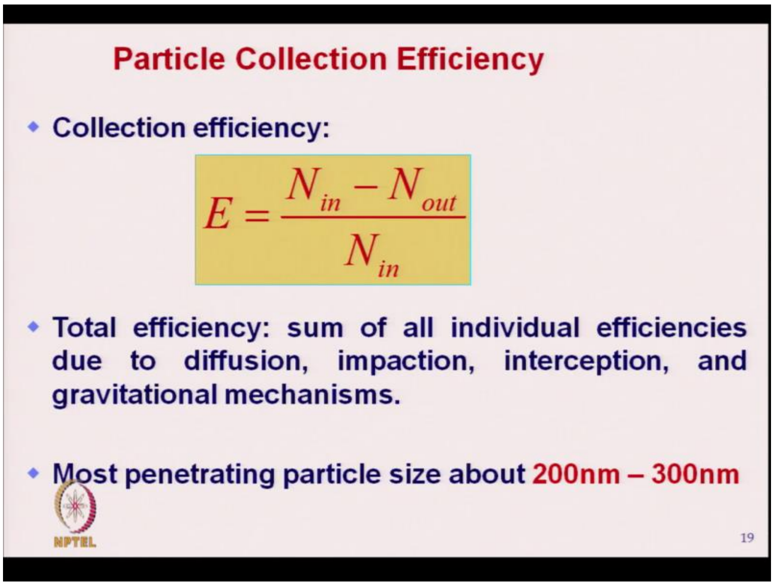

So, collection efficiency is

$$E = \frac{N_{in} - N_{out}}{N_{in}}$$

So, total efficiency is a sum of all individual efficiency is due to diffusion, impaction, interception and gravitational mechanism. So, this efficiency it includes all the mechanism. Most penetrating particle size about 200 nanometer to 300 nanometer.

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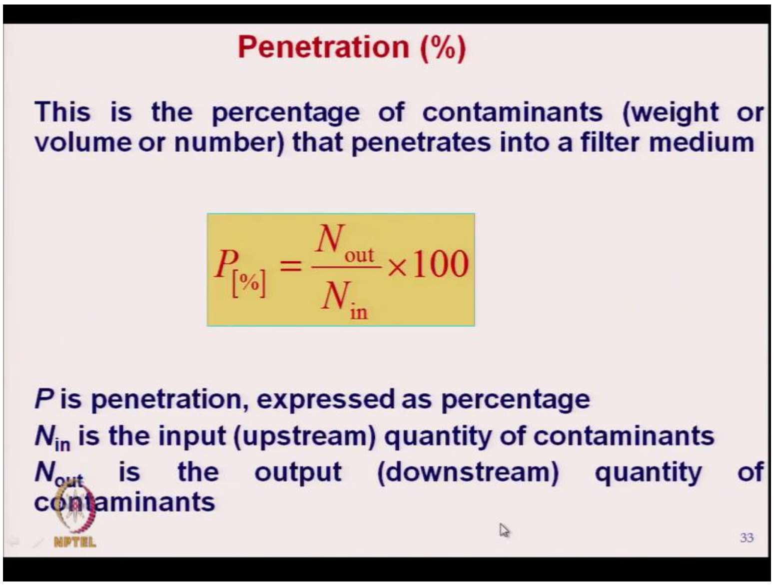

And in terms of penetration percent, so this penetration percent this is the percentage of contaminants that is weight or volume or number that penetrates into the filter medium. So, penetration percentage is

$$P_{[\%]} = \frac{N_{out}}{N_{in}} \times 100$$

This is the ratio of the contaminant which is going out through the filter medium divided by the Nin.

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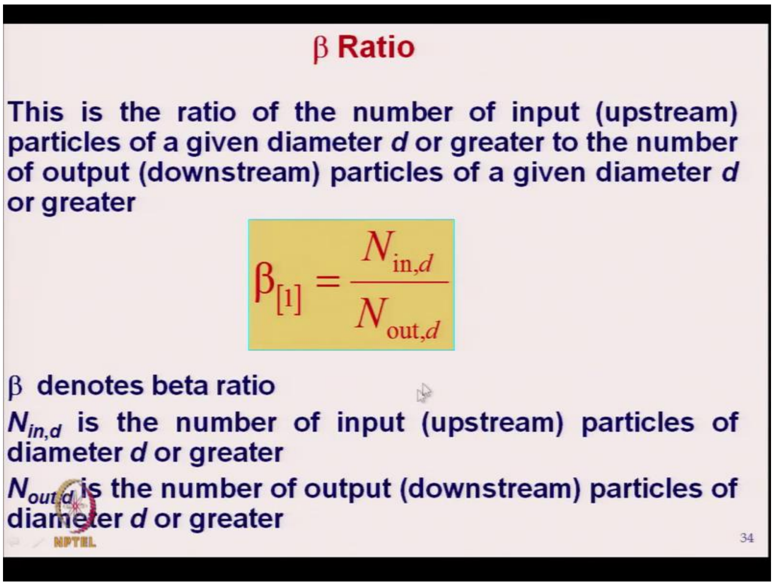

And beta ratio, this is the ratio of number of input that is upstream particle.

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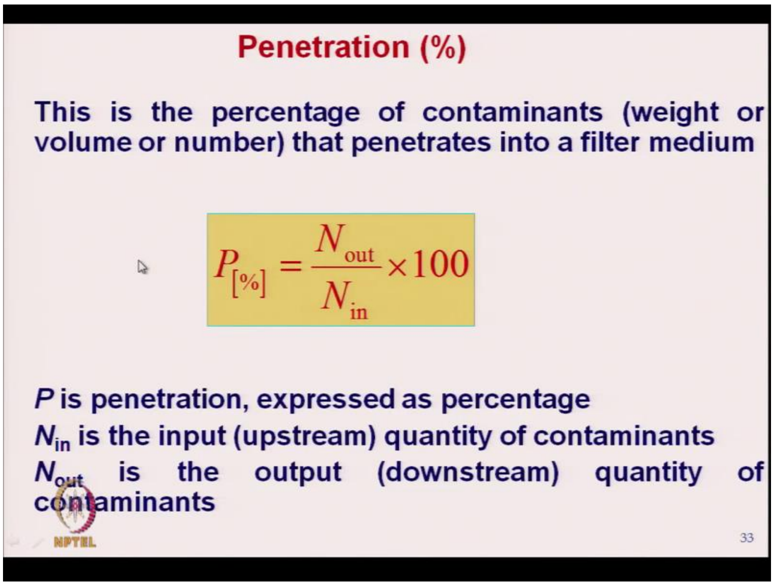

So, in earlier case, in penetration efficiency, it was Nout/Nin, it may be in terms of weight volume or number. But in beta ratio, this is the ratio

$$\beta_{[1]} = \frac{N_{\text{in},d}}{N_{\text{out},d}}$$

so that means, this is just reciprocal of penetration efficiency, but here the number of particles of specified diameter.

So, beta ratio for a particular filter medium varies when we changes the diameter of particle. So, keeping same filter medium and same input dust or dusty air, we can change the beta value beta ratio value if we change the specified diameter. So, Nin,d is the number of input particles of diameter d or greater. So, here the size of particle is also specified.

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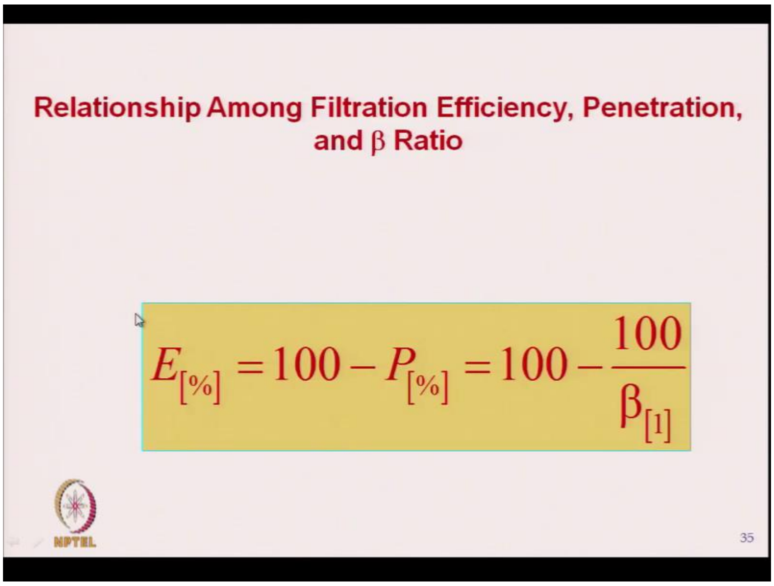

This is the relationship between filtration efficiency, penetration percent and beta ratio.

$$E_{[\%]} = 100 - P_{[\%]} = 100 - \frac{100}{\beta_{[1]}}$$

So, this is the relationship. So, if we know one parameter, we can get other parameter.

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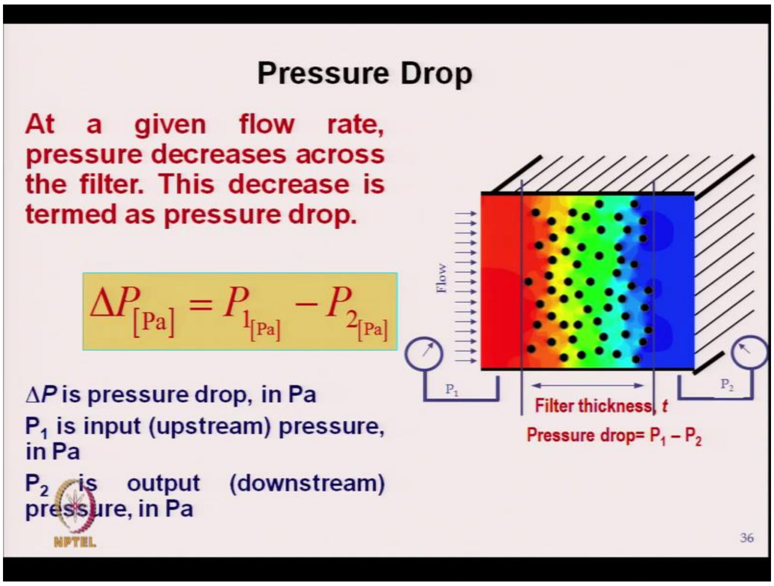

Another important parameter for filtration which is pressure drop. At a given flow rate the pressure decreases across the filter. This decrease is termed as pressure drop. So, when the particle along with the liquid medium flows across the filter media, so this is the flow direction, this is upstream, other side its downstream. So, in upstream side, we have very high pressure and as its flowing through the filter media and then other side there will be lower pressure.

So, these difference between this pressure P1, upstream side and pressure P2 downstream side, its known as the pressure drop. So, this pressure drop, its very important characteristics of any filter media. Irrespective of the fact the filtration efficiency whether its a very high or low if the filter medium results very high pressure drop, then the filtration system will actually fail. So, we need lower pressure drop, so that the fluid flows with low pressure.

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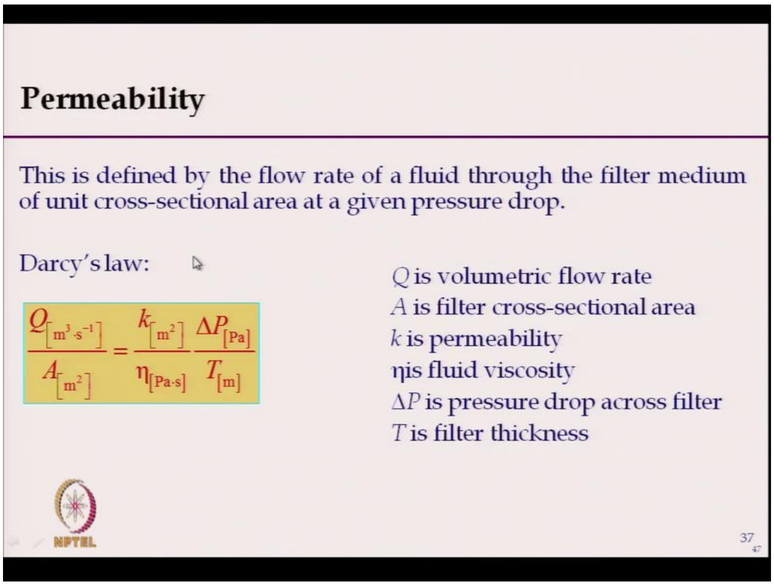

Another important characteristics is the permeability. This is defined by the flow rate of a fluid through the filter medium of unit cross-sectional area at a given pressure drop. This is simply the permeability of the filter medium like air permeability or water permeability. As per the Darcy's law this is

$$\frac{Q_{[\mathrm{m}^3 \cdot \mathrm{s}^{-1}]}}{A_{[\mathrm{m}^2]}} = \frac{k_{[\mathrm{m}^2]}}{\eta_{[\mathrm{Pa} \cdot \mathrm{s}]}} \frac{\Delta P_{[\mathrm{Pa}]}}{T_{[\mathrm{m}]}}$$

where, Q is the volumetric flow rate and A is the cross section of filter medium. So, it depends on the fluid viscosity, pressure drop and filter thickness; k is the permeability.

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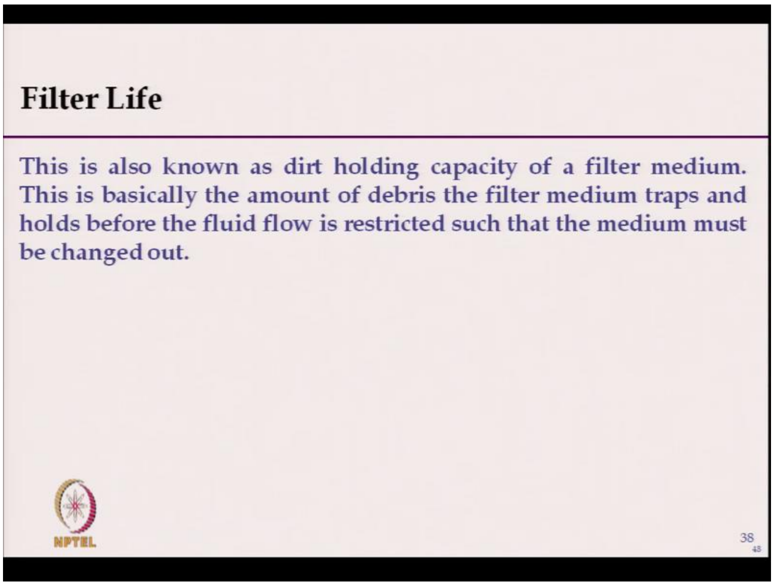

And filter life is also an important characteristics. This is also known as dirt holding capacity of a filter medium. This is basically the amount of debris the filter medium can trap and hold before the fluid flow is restricted such that the medium must be changed out. So, the filter medium is gradually loaded with the dust particle. And after certain time, the filter medium is blocked with the dust particle. So, all the pores will be blocked, in that case it will not allow any flow of fluid, so that will show that is end of the filter life. But in some filters, specifically the surface filter, we can reuse the filter by cleaning.

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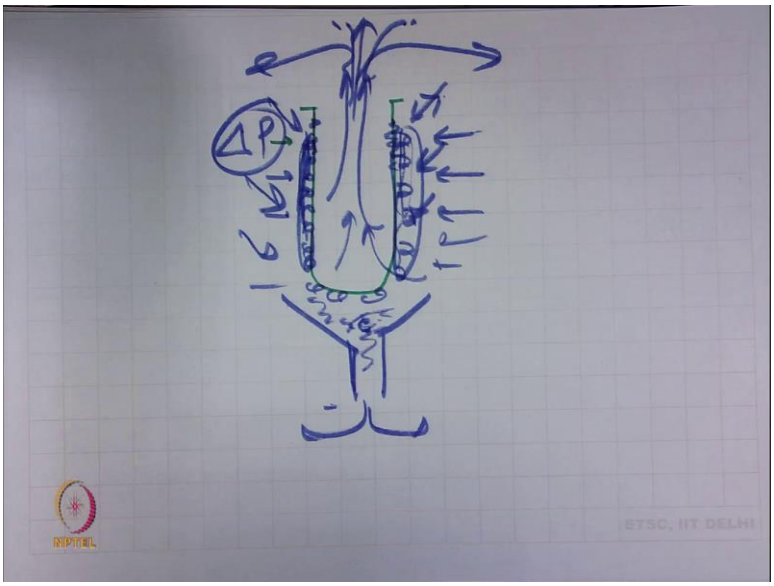

So, let us see one example is pulse jet filter; so, this is the filter bag. Typically, if we use a woven filter bag where the dust particles are deposited on the surface and these are the dusty air penetrating and the clean air is passing through this. And its used, it is reused or it is actually released in the environment. And the particles are actually arrested at the surface and as it is surface filter. So, after certain time, this surface outer surface will be loaded with the particle and the air flow will be less and pressure drop will be very high.

So, either we can replace the filter medium or we can reuse by cleaning the filters. Here we can use the pulse jet to clean the filter may there will be sudden shaking of the filter, and all the dust particles will be released and it will be collected in the hopper and then it will be thrown away. So, after cleaning we can reuse this filter.

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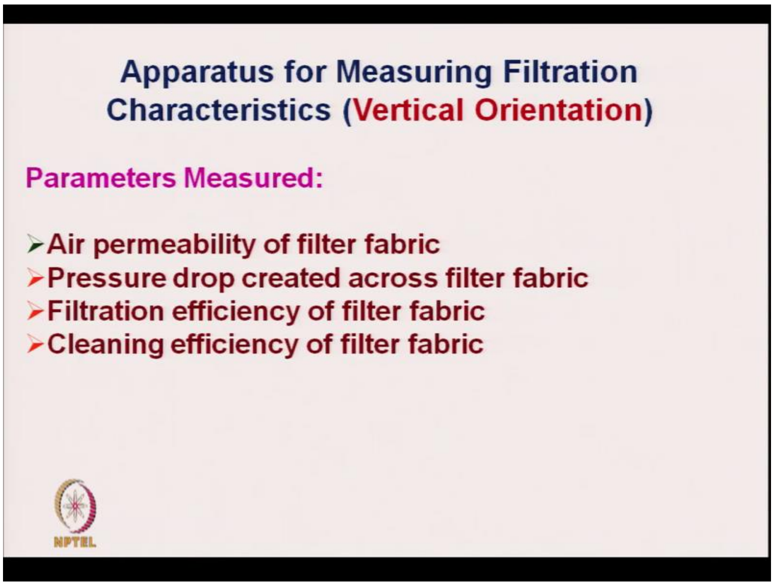

Now, we will discuss the apparatus for measuring filtration characteristics. So, there are two different types of orientation; one is vertical orientation, another is horizontal orientation. The parameters which are measured; here is that air permeability of filter fabric, pressure drop created across the filter, filtration efficiency of filter fabric, cleaning efficiency of the filter fabric.

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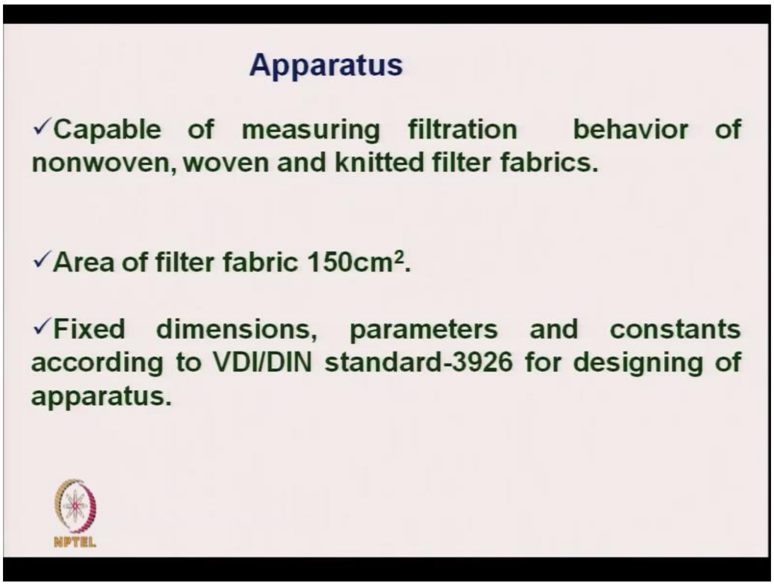

So, this apparatus is capable of measuring filtration behavior of nonwoven, woven and knitted filter fabric. Area of filter fabric is 150 square centimeter, so, we can change also, it has fixed dimension parameters and constants according to VDI, DIN standard-3926 for designing the apparatus.

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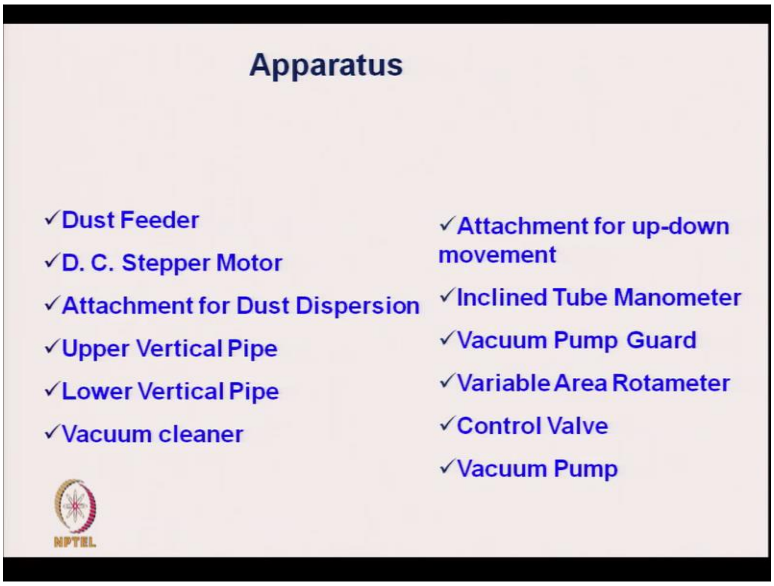

So, this instrument follows that this standard. This apparatus has got different components, dust feeder, DC stepper motor, attachment for dust dispersion. So, the dust feeder will be responsible for feeding the dust at a certain rate in the filtration equipment.

The rate is controlled by the stepper motor. And after the dust is being fed, it has to mix properly with the air that is the attachment using the dust dispersion attachment. There will be vertical pipe which is responsible for channelizing the dust loaded air through the filter medium.

There will be lower vertical pipe that is the below the filter medium, vacuum cleaner will be there. Attachment for up and down movement that is for replacing the filter fabric the specimen; inclined tube manometer to measure the pressure drop across the filter medium. Vacuum pump guard, variable area rotameter that is to measure the speed air flow rate, control valve and vacuum pump.

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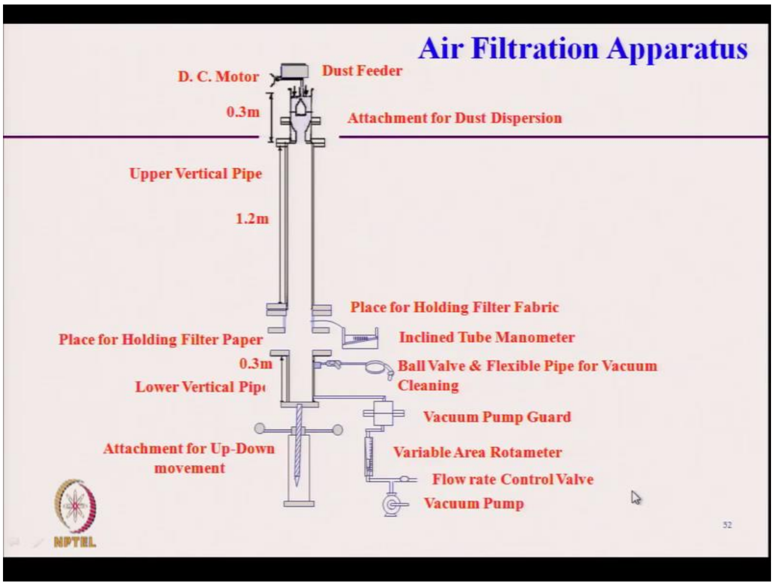

This is the equipment, schematic diagram of the equipment. Here there is a DC motor connected with the dust feeder. So, dust feeder feeds the dust at predetermined rate. There will be one dust dispersion attachment which is responsible for dispersing the dust, mixing the dust along with the air. Vertical pipe, this pipe is responsible for channelizing the dusty air and the length is 1.2 meter. And this is the holder which holds the filter fabric. And this manometer here shows the pressure of air just after the filter fabric. Air pressure at the downstream portion; and in upstream portion as the its open; so this is as per the atmospheric air pressure.

And then this is the place for holding filter paper, which is extremely important because to collect the particles which are coming out from filter fabric, we need the filter paper.

And this is arrangement for moving up and down the lower vertical pipe just for placing the or removing the filter paper and filter fabric specimen. This is vacuum pump guard and vacuum pump which actually is responsible for sucking the air through the filter fabric at known rate ok. This is variable area rotameter which measures the flow rate of air.

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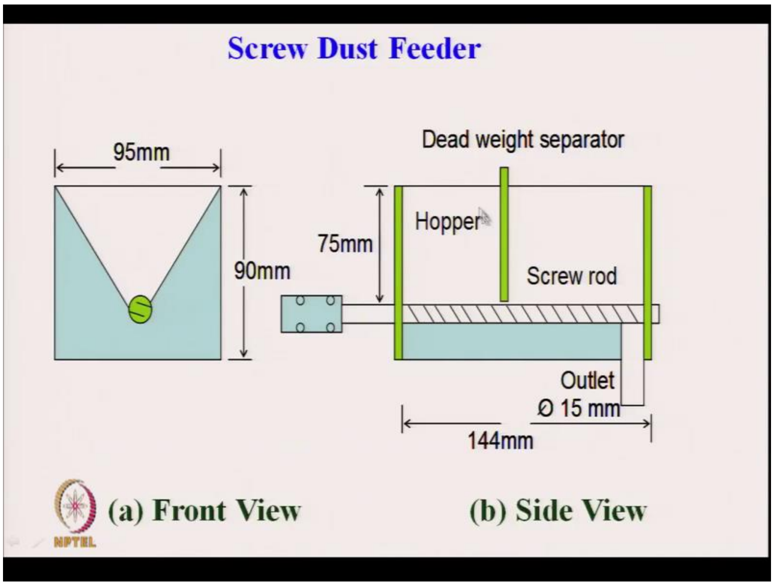

Now, the screw type dust feeders are used normally this is stepper motor connected with the screw rod ok. And here its a front view; this is a side view. Once this motor rotates at known speed, constant speed due to the screw system, the dust from the hopper is flowing through this horizontal side from left to right. And here at the exit point, this is actually feeding the dust in the vertical pipe. And the flow rate of dust or dust feed rate can be changed by changing the speed of the motor.

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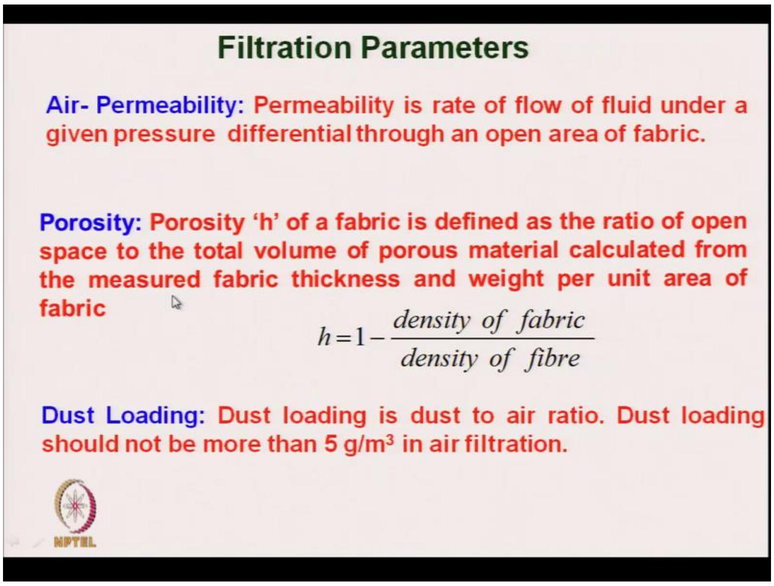

Now, this instrument can measure the air-permeability that is when we are not feeding any dust if we measure the flow rate per unit area of fabric. So, by measuring the air flow rate, so we can measure the air permeability of fabric. The porosity of fabric can be measured by measuring the density of fabric and density of fiber density of fabric can be measured by measuring the thickness and mass per unit area of fabric.

Dust loading is the, dust loading is the dust to air ratio. Dust loading should be less than 5 gram per meter cube ok. So, for this air filtration, it should be less than 5 gram per cubic meter; otherwise the heavy dust loading will immediately choke the filter pores.

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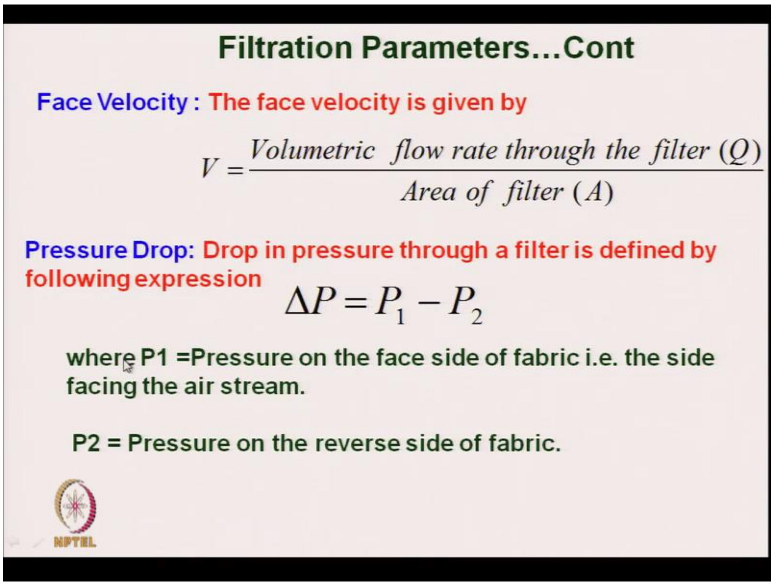

What is Face velocity? The Face velocity is given by volumetric flow rate through the filter that is Q by area of filter. So, Q/A. Pressure drop, drop in pressure through the filter fabric is defined by P1 - P2; P 1 is the pressure on face side and P 2 is pressure on reverse side.

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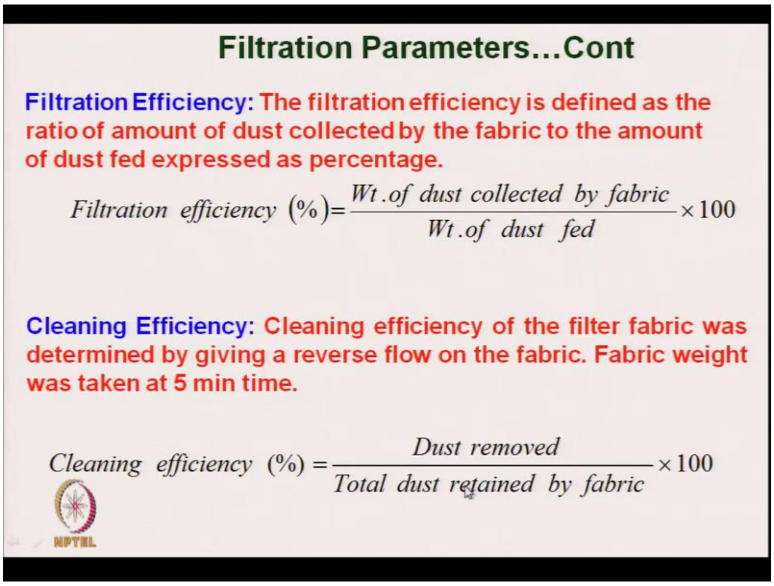

Filtration efficiency has been mentioned. It is

$$Filtration\,efficiency(\%) = \frac{Wt.of\ dust\ collected\,by\ fabric}{Wt.of\ \ dust\ \ fed} \times 100$$

So, we can measure the filtration efficiency by measuring the weight of dust collected by the fabrics. So, weight of dust collected by fabric is measured first before testing we calculate the total weight of the fabrics. So, we can take the mass of the fabric that is m1 is the mass. After filtration texting if the mass is m2, which is more than m1, so, the difference is a dust collected by the fabric dust arrested by the fabric. And total mass of dust, its calculated by the weight of dust collected by the fabric plus weight of dust collected by the filter paper, assuming the filter papers efficiency is 100 percent, so that ratio gives the filtration efficiency.

And cleaning efficiency it is the actually it shows the ability of filter fabric for being cleaned. So, cleaning efficiency of the filter fabric was determined by giving the reverse flow on the fabric. Fabric weight was taken after 5 minute time. So, dust removed by total dust retained by the fabric and its expressed in terms of percentage.

$$Cleaning\,efficiency(\%) = \frac{Dust\,removed}{Total\,dust\,retained\,by\ fabric} \times 100$$

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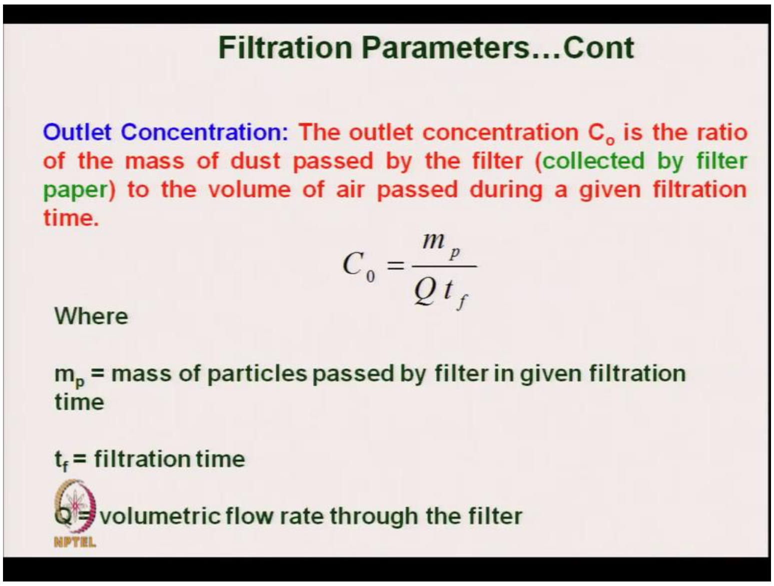

Outlet concentration, the outlet concentration is at this is expressed in terms of Co.

$$C_0 = \frac{m_p}{Q t_f}$$

Where

m_p = mass of particles passed by filter in given filtration time

t_f = filtration time

Q = volumetric flow rate through the filter

So, this if you multiply Q with t f that will give the total volume of air passed through the filter medium. So, the ratio of m p by total volume gives the outlet concentration. So, this outlet concentration is very important, it will show the effectivity of the filter fabric. So, after filtration what is the quantity of particles present in the air that will shown by the value Co outlet concentration.

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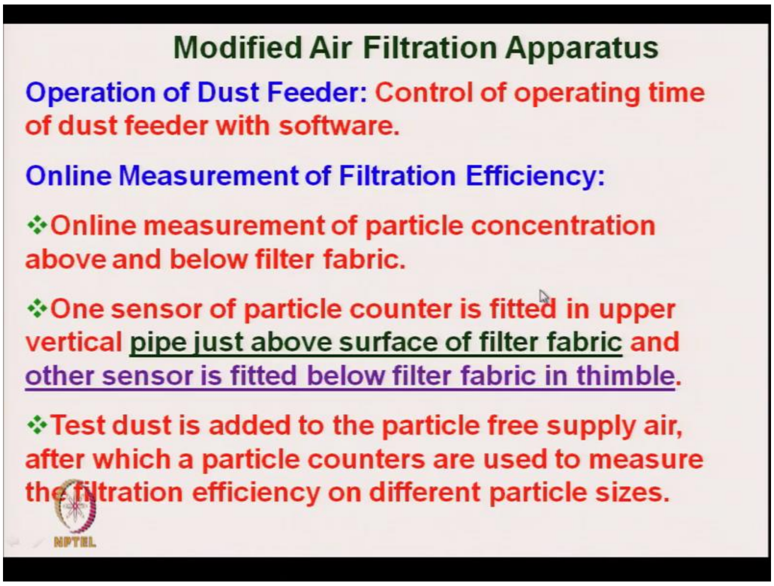

Now, this vertical orientation, filtration apparatus has been modified to make it totally automatic ok. So, operation of dust feeder, there is a one change, where dust feeder operation is controlled by computer, its computer controlled and that the dust feed rate can be controlled depending on the requirement. Another automation was that the online measurement of filtration efficiency. In earlier case the system was to take out the filter fabric and measure the mass of filtrate collected.

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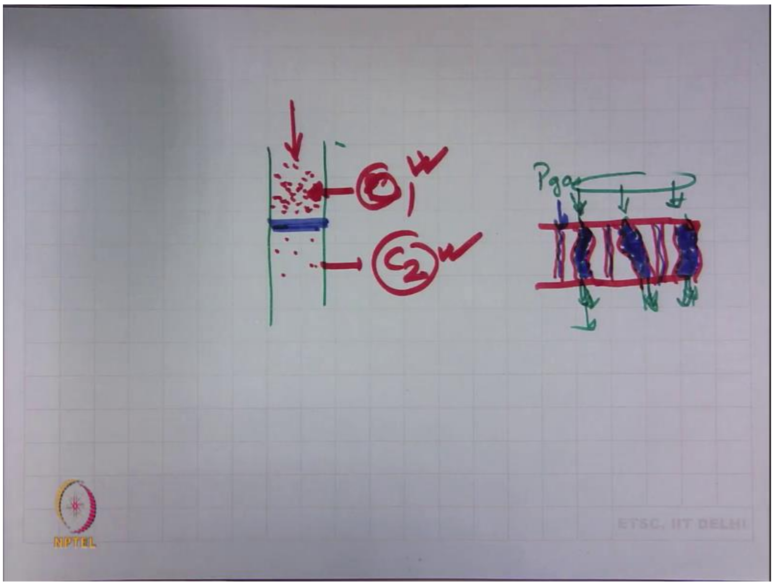

But in this system this measurement system, this is the vertical orientation of pipe, here we have the filter medium. And the dust particles are coming this is in upstream direction; and after that this is down downstream direction. And here we have put one, counter 1, here we are putting counter 2 and this particle counters will count the number of particles per unit volume of air.

So, by calculating the number of particles in upstream and downstream side, we can calculate the filtration efficiency. So, online measurement of particle concentration above and below filter fabric, one sensor of particle counter is fitted in upper vertical pipe just above the surface of filter fabric and other sensor is fitted just below the filter fabric ok. The test dust is added to the particle free supply air and its mixed thoroughly after which the particle counters are used to measure the filtration efficiency on different particle size.

So, we can measure the filtration efficiency for a particular fabric with different particle size. So, it will automatically give the filtration efficiency and with the time how the filtration efficiency changes this data also can be obtained using this instrument modified instrument.

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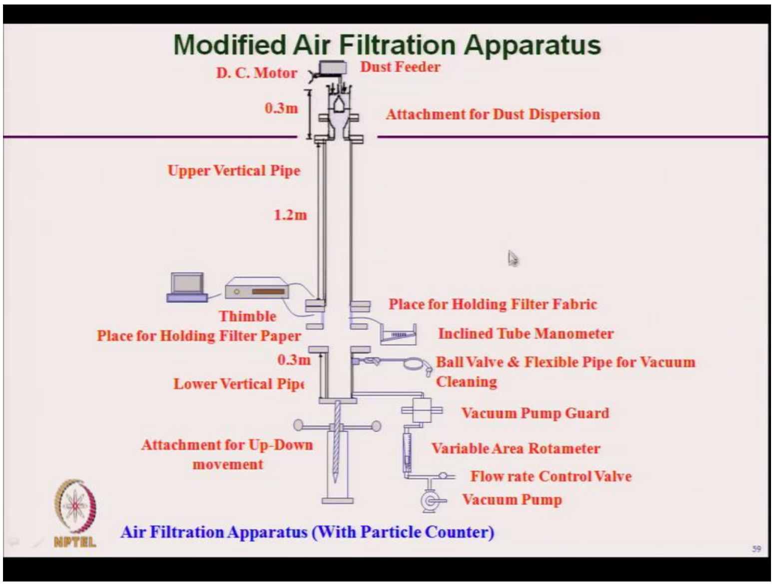

So, here this total system is connected here; its controlled by the software. And the data of the filtration efficiency and the dust free data are captured. These are the particle counters. Here you have the particle counter at the upstream side and another is the downstream side and the data is calculated filtration efficiency data is calculated. So, automatically with the time, we can calculate the filtration efficiency. So, other mechanisms are exactly same as has been discussed already.

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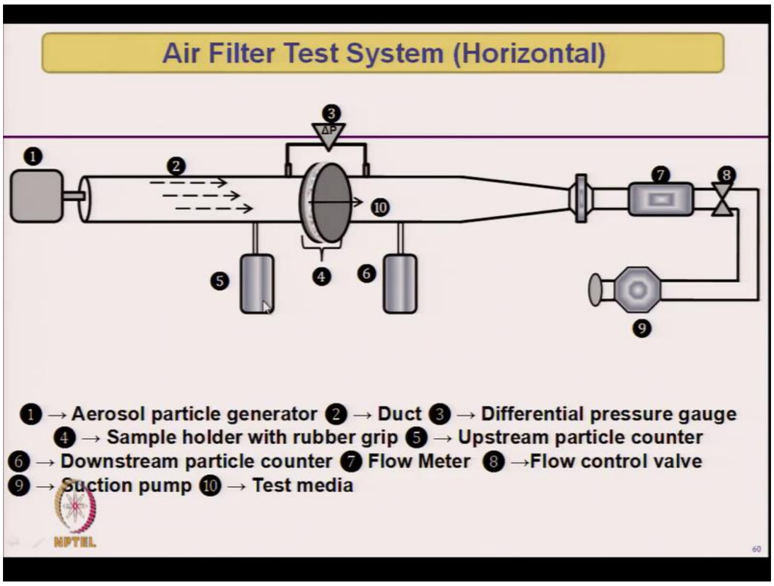

This is another equipment which is horizontal orientation. Rest other mechanisms are same. Here one is the aerosol particles generator, here the generator will generate the aerosol particle. And this particle will along with the air will flow through this duct. And here 3 is the differential pressure gauge, this will measure the pressure difference. And this one 4th is a sample holder with rubber grip. So, sample holder is required to hold the specimen and 10 is a test medium. So, this medium can be woven, nonwoven or any other test medium, 5 is the upstream particle counter here we have particle counter in the upstream side.

And another particle counter 6, which is placed in the downstream side. 7 is the flow meter which measures the flow rate of the air. 8 is flow control valve; we can control the flow rate. And 9 is the suction pump, so suction pump will suck the air, so that the total air aerosol particle will flow through the filter medium. And the filtration efficiency is calculated from the data with the particle counter 5 and 6. In the same way as has been discussed earlier, only difference here is that its a horizontal orientation.

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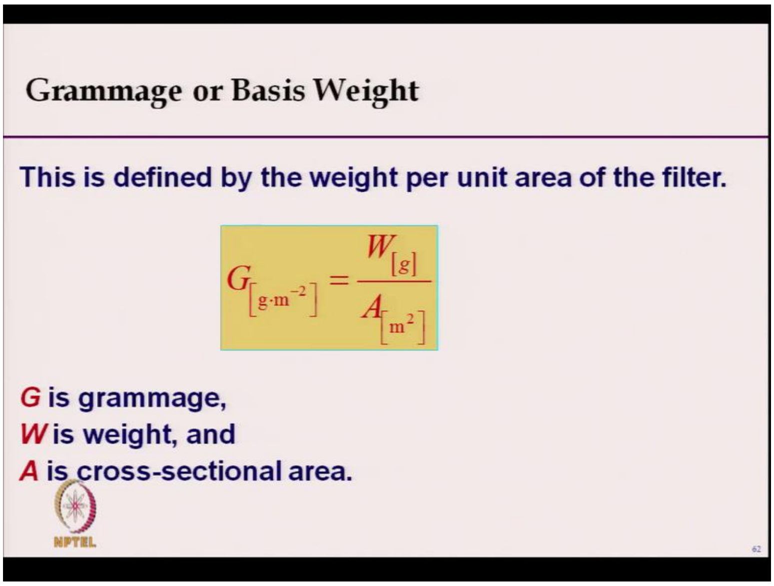

Now, we will discuss the physical properties of filter fabric. First is that grammage. This is simple mass per unit area, its nothing special in it here mass of fabric in gram and take the area. And we calculate the mass per unit area that is expressed either in terms of basis weight or grammage. In filter fabric, we use that term grammage or basis weight very commonly ok.

$$G_{[g \cdot m^{-2}]} = \frac{W_{[g]}}{A_{[m^2]}}$$

***Where, G* is grammage,**

***W* is weight, and**

***A* is cross-sectional area.**

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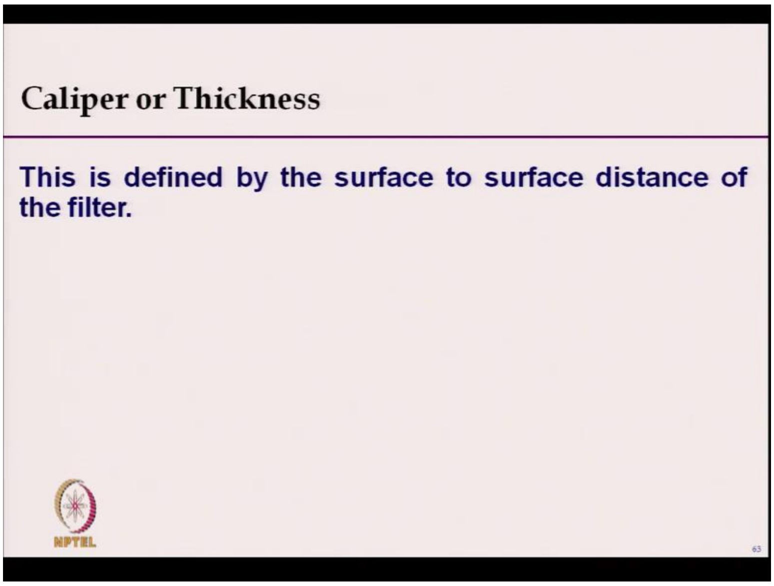

Then caliper or thickness, its nothing but the distance between the two surfaces of filter fabric.

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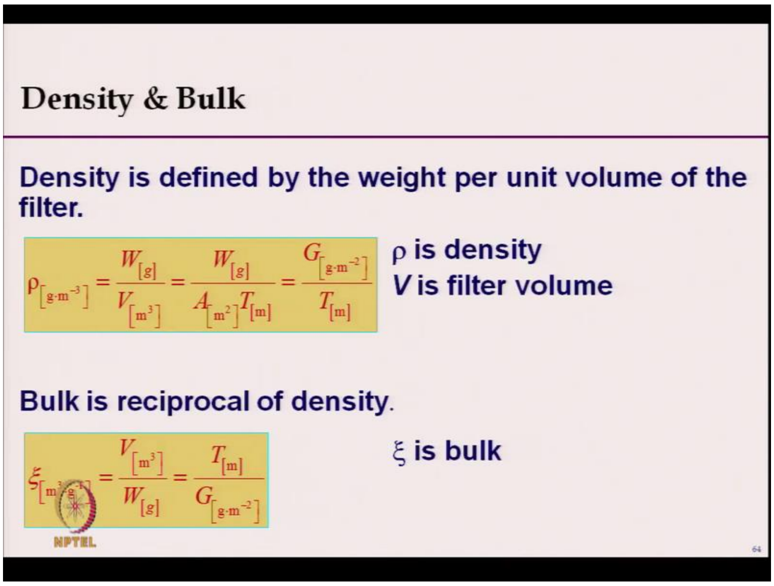

Next is density and bulk. And density is defined by the weight per unit volume of filter and density its this is W is a weight and volume V. And from there, if we actually the replace volume with cross sectional area and the thickness that will be G is the grammage; the mass per unit area W by A by thickness. So, density we can get from mass per unit area and thickness. So, we can calculate the mass per unit area and we can calculate the thickness of the fabric. So, we from there we can calculate the density of the fabric, and bulk is reciprocal of density, it is just reciprocal.

$$\rho_{\left[g\cdot m^{-3}\right]} = \frac{W_{[g]}}{V_{\left[m^{3}\right]}} = \frac{W_{[g]}}{A_{\left[m^{2}\right]} T_{[m]}} = \frac{G_{\left[g\cdot m^{-2}\right]}}{T_{[m]}}$$

Where, ρ is density

***V* is filter volume**

$$\xi_{\left[m^{3}\cdot g^{-1}\right]} = \frac{V_{\left[m^{3}\right]}}{W_{[g]}} = \frac{T_{[m]}}{G_{\left[g\cdot m^{-2}\right]}}$$

Where, ξ is bulk

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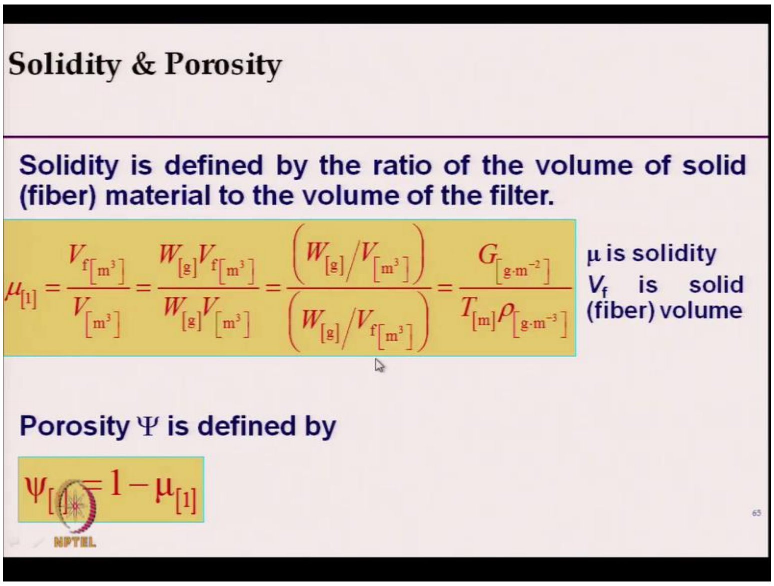

Solidity and porosity; so, what is solidity? Solidity is defined by the ratio of volume of solid that is the fiber material to the volume of filter that is total material filter. So, it is expressed in terms of **μ**, volume of fiber by volume of filter medium.

$$\mu_{[1]} = \frac{V_{f\left[m^3\right]}}{V_{\left[m^3\right]}} = \frac{W_{[g]} V_{f\left[m^3\right]}}{W_{[g]} V_{\left[m^3\right]}} = \frac{\left(W_{[g]} / V_{\left[m^3\right]}\right)}{\left(W_{[g]} / V_{f\left[m^3\right]}\right)} = \frac{G_{\left[g \cdot m^{-2}\right]}}{T_{[m]} \rho_{\left[g \cdot m^{-3}\right]}}$$

Where, μ is solidity

***V*f is solid (fiber) volume**

Finally, its coming out to be this grammage, thickness and this is the density of fiber. So, from there we can calculate the solidity and porosity is the basically 1 minus solidity,

$$\psi_{[1]} = 1 - \mu_{[1]}$$

so that way we can calculate the solidity and porosity. Solidity and porosity, these are very important term as far as filtration is concerned, because if the material is porous then it will allow the air to pass through easily with less pressure drop.

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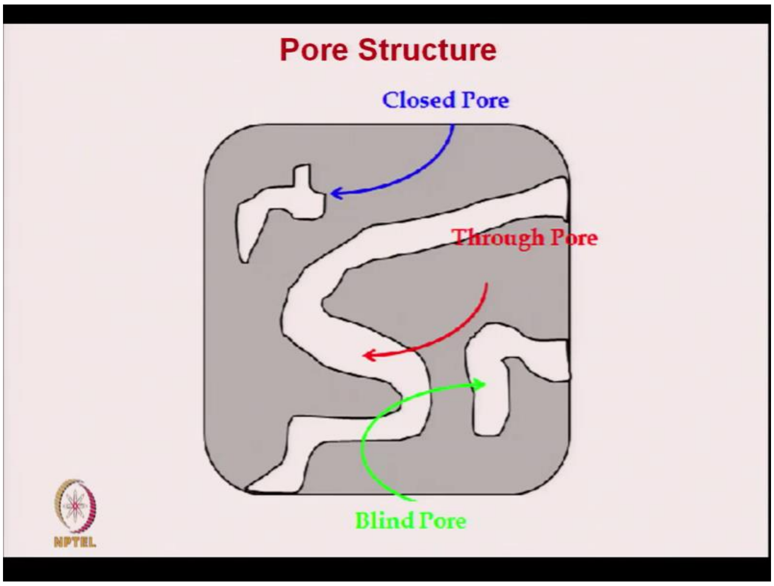

Now, one of the most important physical parameters of filter fabric is pore structure. Now, pore structures are basically three different types. One is closed pore within the structure there will be an isolated pore which is closed from all the sides ok. Next is that blind pore where pore starts at the surface, but its ended within the structure. And third one is that through pores where pores are starting from one surface and its actually ended in the other surface of the fabric. So, particles can flow through one side and can be travel can travel to the other direction or the air can pass through this through pore very easily.

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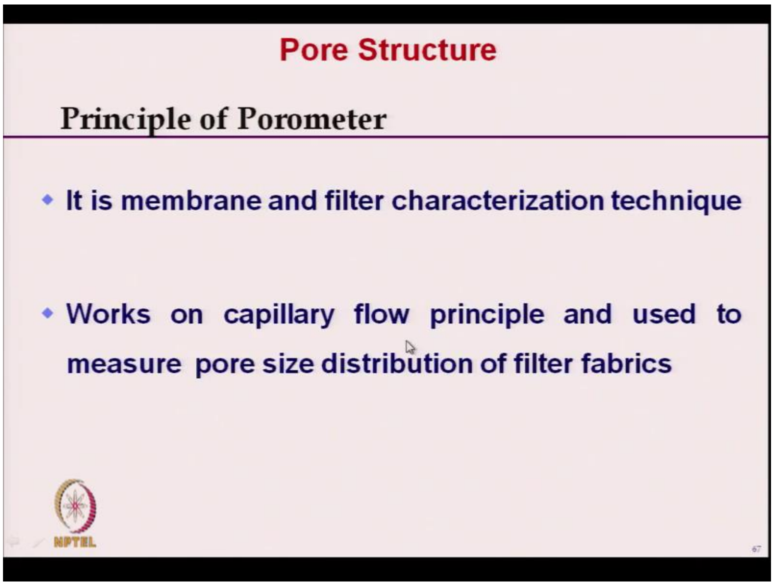

Now, the pore structures are measured using porometer. So, porometer is an instrument which measures the pore structure. It is membrane and filter characterization technique. Works on capillary flow principle and used to measure pore size distribution of filter fabric.

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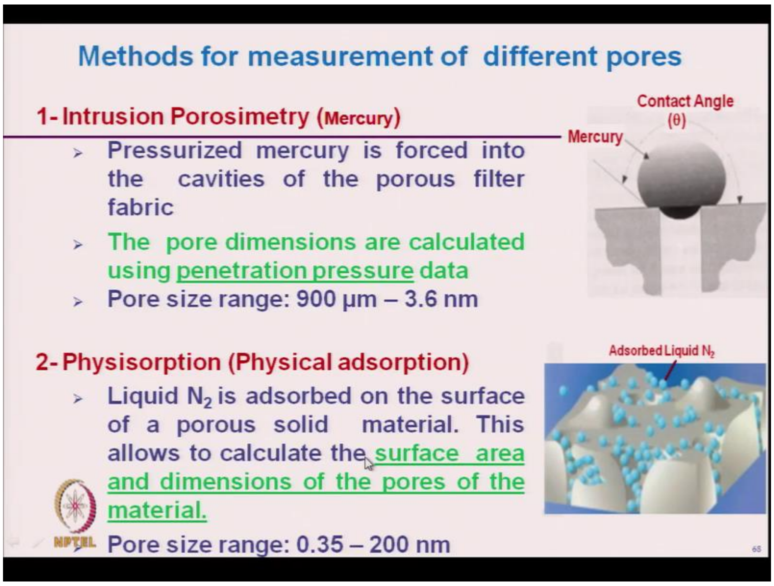

There are different types of porometer. First is that intrusion porometry that is mercury intrusion porometry. This method is where mercury is used, pressurized mercury is forced into the cavities of the porous filter fabric. So, this is the cavity. Here the mercury with very high contact angle is being forced into this cavity. The pore dimensions are calculated using penetration pressure data that means, if the penetration pressure is high the pore dimension, pore diameter will be low. So, depending on the pressure applied for penetration, we can calculate the pore dimension. So, this technique is used for pore size range between 900 micron to 3.6 nanometer.

Next is that physisorption; physisorption means physical adsorption where liquid nitrogen is adsorbed on the surface of a porous solid, this is the porous solid and liquid nitrogen these are the liquid nitrogen's are adsorbed on the surface. This allows to calculate the surface area and dimensions of the pores of the material. So, this surface is inside a porous medium and liquid nitrogen it is when the structure adsorb the liquid nitrogen.

So, depending on the quantity of nitrogen absorbed, we can calculate the total internal surface of the pores. So, surface area we can calculate accordingly dimension of pores also being calculated. So, the pores size range here 0.35 to 200 nanometer. So, within that range this physical adsorption technique is used; here these are the adsorbed nitrogen.

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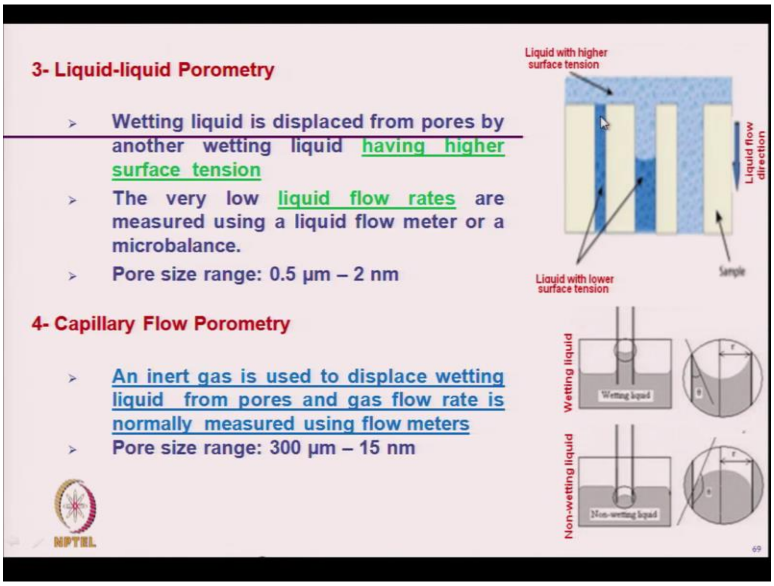

Third technique is liquid-liquid porometry. Just the name implies here we can use two different liquids. In this picture, two liquids are shown; one is in dark color; here this dark color is the liquid with lower surface tension. These are the liquid with lower surface tension another liquid is used here its with the higher surface tension. So, first this pores in a porous medium is filled with the liquid with lower surface tension. This is the liquid with lower surface tension. And after that after it is getting wet with the liquid with lower surface tension another liquid which is having higher surface tension is being forced which will force out the liquid with lower surface tension. This liquid will be forced out of the porous medium and from the flow rate or from the pressure, we can calculate the pore dimension.

So, wetting liquid is dispersed, wetting liquid means liquid with lower surface tension. Wetting liquid is dispersed from the pores by another wetting liquid having higher surface tension. The very low liquid flow rate are measured using a liquid flow meter or microbalance. So, this flow rate can be measured by using liquid flow meter or microbalance. And accordingly depending on the flow rate, we can calculate the pore dimension. The pore size range here is 0.5 micron to 2 micron within that range we can measure the pore size.

And next technique is capillary flow porometry. Here we use the capillary principle. An inert gas is used to displace the wetting liquid from pores and gas flow rate is normally measured using flow meter. So, here this is the initially filled with the liquid and an inert gas is flown through the material porous material. And that inert gas will displace the wetting liquid and gas flow rate is measured ok and this gas flow rate is actually it shows the pore dimension.

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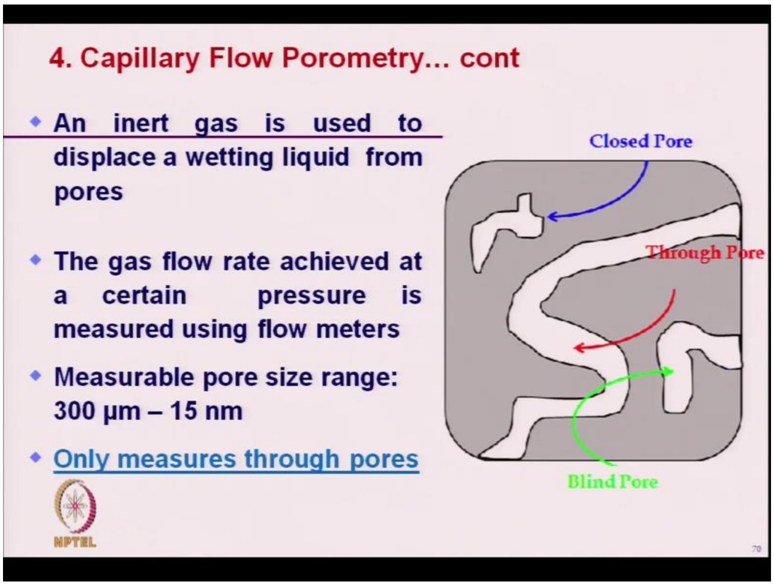

So, let us try to understand in detail the capillary flow meter, this is capillary flow porometry which is basically used for only measures the through pores, only through pores is being measured the it does not measure the closed or blind pores. So, an inert gas is used to displace the wetting liquid from the pores like this is the pore, it is initially filled with the liquid ok, the gas flow rate achieved certain pressure, it is achieved at certain pressure which is measured using the flow meter. So, this gas is inert gas is actually flown at certain pressure and accordingly we can measure the flow rate using the flow meter. Measurable pore size is ranging from 300 micron to 15 nanometer.

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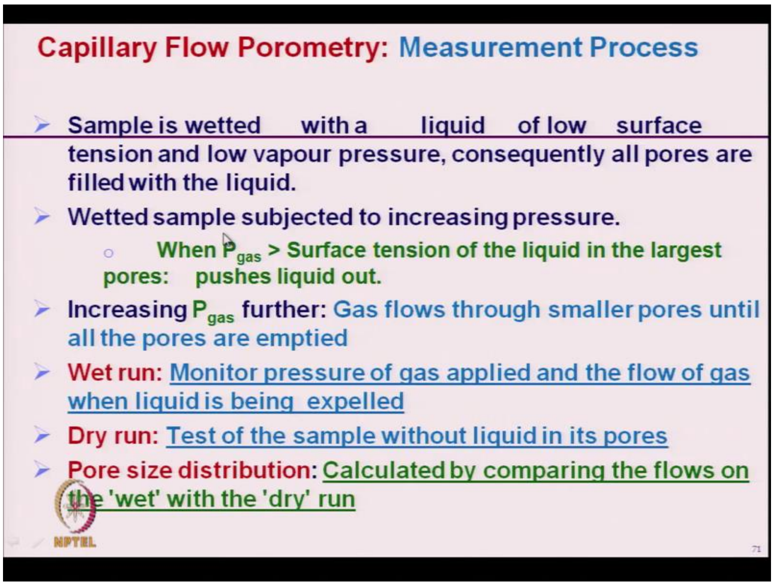

So, the process is that sample is wetted with the liquid of lower surface tension; sample is first wetted. And low vapour pressure consequently all pores are filled with the liquid. So, initially the pressure is measured and the liquid is wetting the total surface ok.

Now, let us see here this is through pores ok. And these pores are filled with liquid of low surface tension. Hence it is once the filter medium is wet, then the inert gas is forced through this filter medium which will force the liquid out of the pores. And we measure the pressure and flow rate from there from this data we can calculate the pore dimension. The wetted sample subjected to increasing pressure. So, we increase the pressure gradually till the wetted liquid is actually coming out. When P gas that pressure of gas is more than the surface tension of the liquid in the largest pore pushes liquid out ok, so that is the Pgas increasing Pgas further the gas flow through the smaller pore until all the pores are emptied.

So, here what happened initially the P gas will be there at initial stage there will be large from the larger pore the liquid will flow out. So, then liquid will start flowing out and the gas will flow. And from the smaller pores then it will from the smaller pores, the liquids will come out gradually as we increase the pressure of the gas. So, increasing P gas further gas flow through smaller pores until all the pores are emptied, so this is called wet run. So, the wet run monitoring the pressure of gas applied and the flow of gas in liquid is being expelled.

So, we monitor the pressure and flow rate with the same specimen without any liquid we run the same test which is called dry run, test of the sample without liquid is in its pore. Pore size distribution is calculated by comparing the flow on wet and dry run. So, this if we compare, we can calculate the pore size distribution.

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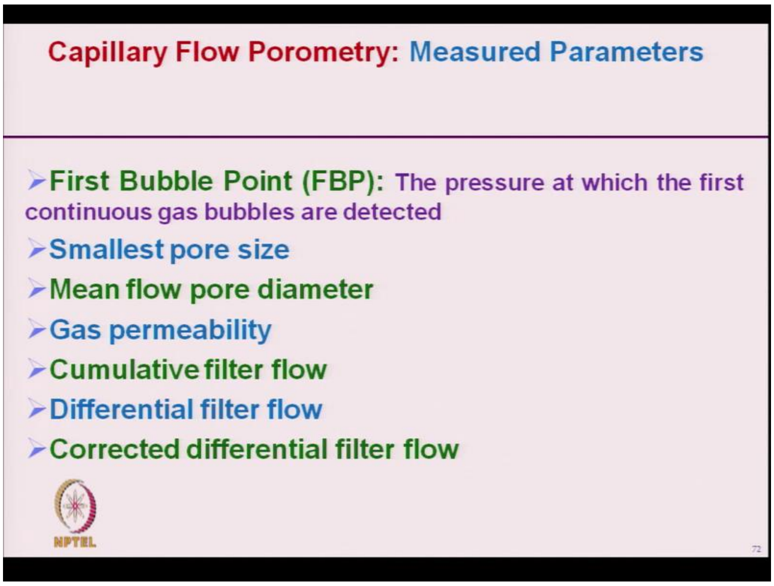

So, here the parameters are first is that it is called FBP First Bubble Point the pressure at which the first continuous bubble is formed and its detected, its called first bubble point this is the pressure. Then we can calculate the smallest pore size, mean flow pore diameter, gas permeability, cumulative filter flow, differential filter flow, corrected differential filters flow. So, all these parameters can be measured using capillary flow pormetry.

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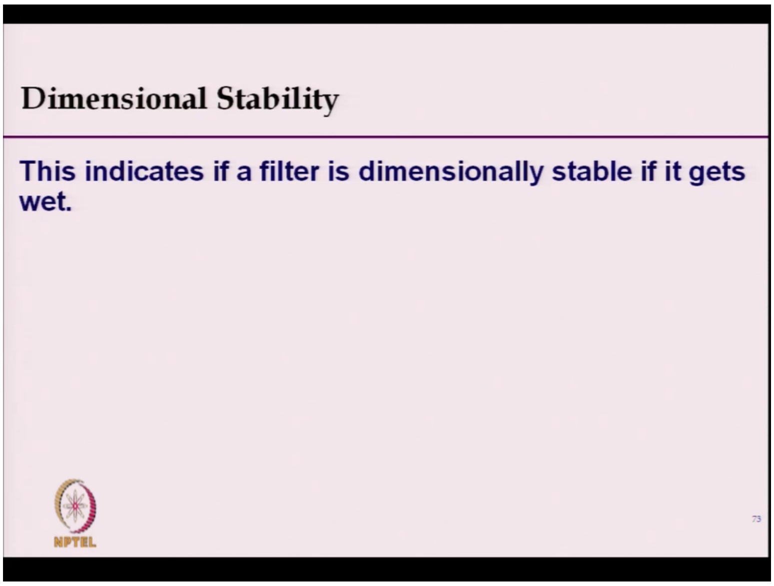

And another parameter physical parameter its a dimensional stability which is important. And when the filter gets wet, its dimension changes, so accordingly we can calculate the dimensional stability. So, we will stop here. In next class we will start mechanical properties and other aspects of filtration parameters.

Till then thank you; thank you for patient hearing.