Testing of Functional & Technical Textiles
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Lecture – 04
Testing of Transmission Characteristics of Textile Fabrics

Hello everyone, we are discussing the topic which is Testing of Functional and Technical Textiles. In last class what we have discussed is that testing of functional textiles.

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For that low stress mechanical characteristics have been discussed. So, in this course the two distinctly different segments will be discussed. First we are discussing the testing of functional textiles. And after that we will discuss the testing of technical textiles. So, in last class we have discussed the low stress mechanical characteristics, where we have discussed the Kawabata evaluation system, FAST system and also nozzle extraction system. Today will start the another aspect of functional textile that is testing of transmission characteristics.

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So, the transmission characteristics can be divided into different groups.

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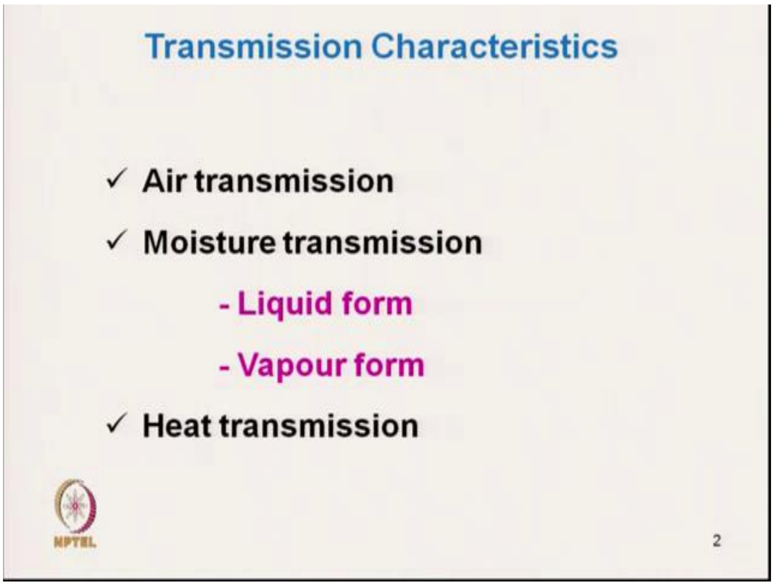

First it is air transmission where we will discuss the measurement technique of air transmission that is air permeability, next is that moisture transmission moisture transmission through fabrics we will discuss. And different methods of measurement of moisture transmission we will discuss; moisture transmission can be divided into two groups; one is moisture in the liquid form and moisture in the vapour form. The measurement techniques are totally different from liquid and for vapour transmission.

For a liquid we will see how liquid gets transmitted through fabric that is wicking characteristics we will see, we will also discuss the wetting characteristics how to measure the wetting behaviour. And then the in the vapour form we will discuss how to measure the vapour transmission behaviour through textile material. After that we will discuss the heat transmission characteristics, heat transmission, in normal heat condition. And also in extreme heat condition, how to measure the transmission characteristics. First let us start with air permeability.

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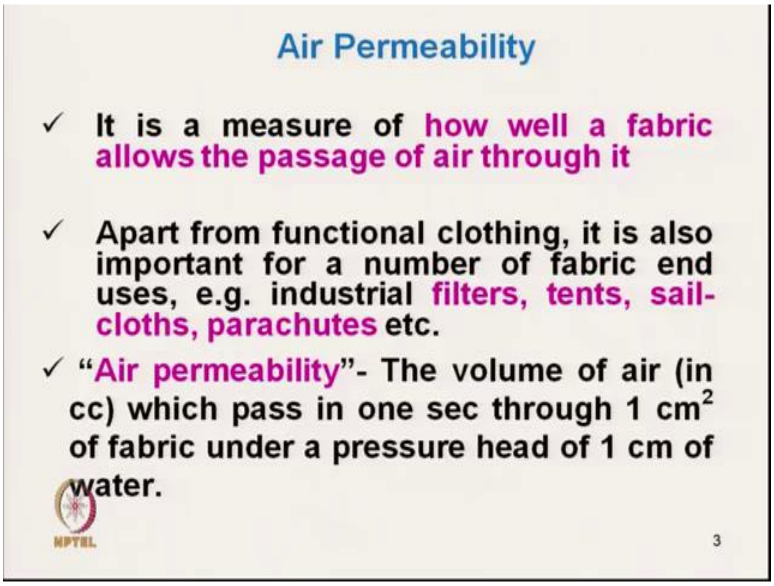

So, air permeability is very commonly used that is very common method of measurement for any textile material. So, it is a measure of how well the fabric allows the passage of air through it. That means, the air will pass through the pores available between yarn or between fiber.

Apart from functional clothing, although in functional clothing, the air permeability is important, but it is also important for a number of fabric end uses. Like particularly for industrial fabrics or for different technical textiles. For industrial filter air permeability is extremely important otherwise we will actually land up with very high pressure drop. So, less air permeability we will result very high pressure drop in that case the filtration behaviour we will get affected. Also for tents, sailcloth, parachute, air permeability measurement it is extremely important.

Like for sailcloth we cannot have a fabric, for that there is no air is passing through the fabric because to control the movement we need certain air permeability but at the same time if the air permeability is very high the performance of the sailcloth will get affected. Similarly for a parachute clothing for controlled descend of the paratrooper we need certain air permeability so we must know the air permeability characteristics of these fabrics.

So what is air permeability? Air permeability can be defined as the volume of air which passes in 1 second through unit area of fabric under unit head of water. So that means, here volume of air can be measured in terms of cm^3 or m^3 ok. And time is in second the area of fabric maybe in cm^2 or m^2 and pressure head it is in cm. So, effectively air permeability is that the rate of air, volume of air passing through the fabric.

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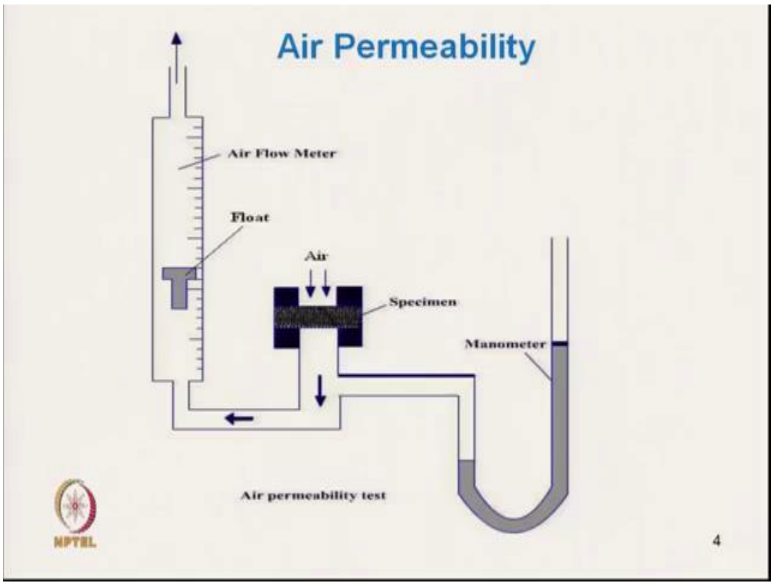

So the measurement technique here, this is the air permeability test instrument where this column which shows the air flow rate. So, this is the air flow meter which is actually gauged with different unit ok. And this one is a float and here this is the fabric sample fabric specimen. And when the motor a pump is actually switched on it will shut the air through the fabric. And the rate of air moving through the fabric is actually measured using this air flow meter ok.

Higher the airflow the height of the float will be more. So, from this height we can measure the air flow and area is known and as the air is flowing through this flow meter there will be a negative pressure, it will apply certain pressure on that and that this is basically it is a positive pressure. So, this pressure against that pressure this air will flow. So, we can measure the airflow the airflow as well as the pressure. And pressure can be measured using the manometer or we can measure using some pressure gauge. And accordingly the air permeability is measured.

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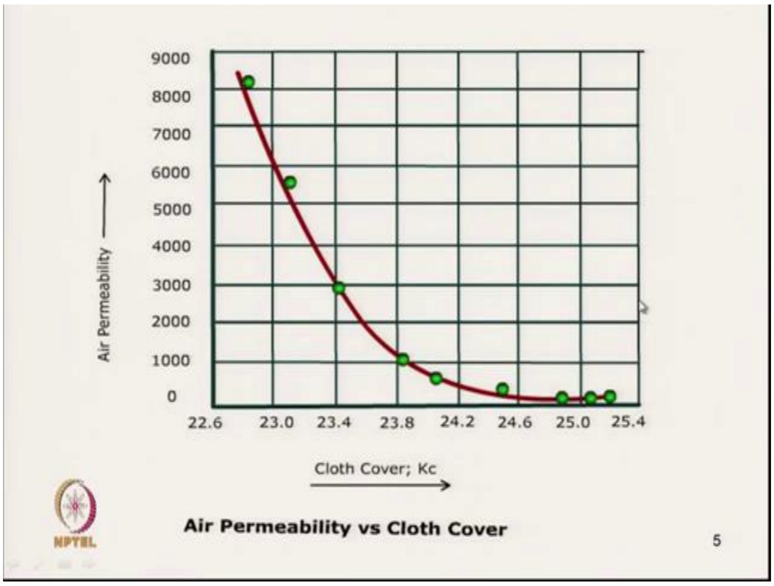

So, if you see the curve, this curve shows the cover factor of fabric against the air permeability. From this curve we can actually conclude that as the cover factor of fabric increases the air permeability reduces gradually. Now let us see what is happening here.

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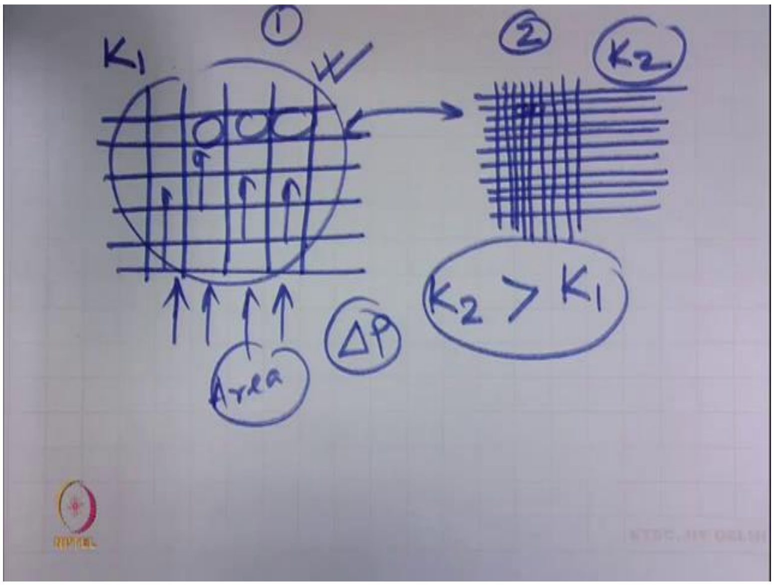

Suppose we have a fabric with certain structure, certain ends per inch and picks per inch. So, this is cover factor with K1 fabric with cover factor which is open structure. Another fabric say fabric 1 fabric 2 which is little bit compact; compact fabric. And here the cover factor will be say K2 is cover factor. So, cover factor of this fabric, fabric 2 is more than fabric 1.

So, fabric 2 is compact more compact than fabric 1. So, which means the open area is much less than this fabric 1. So, fabric 1 has got very open structure. So, it allows the air free passage ok. So, this air will freely pass through this fabric and that is why the air permeability of this fabric keeping all other conditions same the area of a fabric and pressure drop. If you keep this parameters same, so this fabric 1 will allow higher volume of air to pass through per unit time.

So, that is why if we see here the fabric suppose this one this fabric with cover factory say 23 or say 22.8 this fabric suppose it is a fabric a fabric 1. So, fabric 1 which is having very high cover factor and say fabric 2 we will say 25 cover factor, higher cover factor it has got very less air permeability. So, the air permeability is directly related with the openness of fabric ok. Now next is and this curve the earlier curve this is actually it follows the logarithmic equation.

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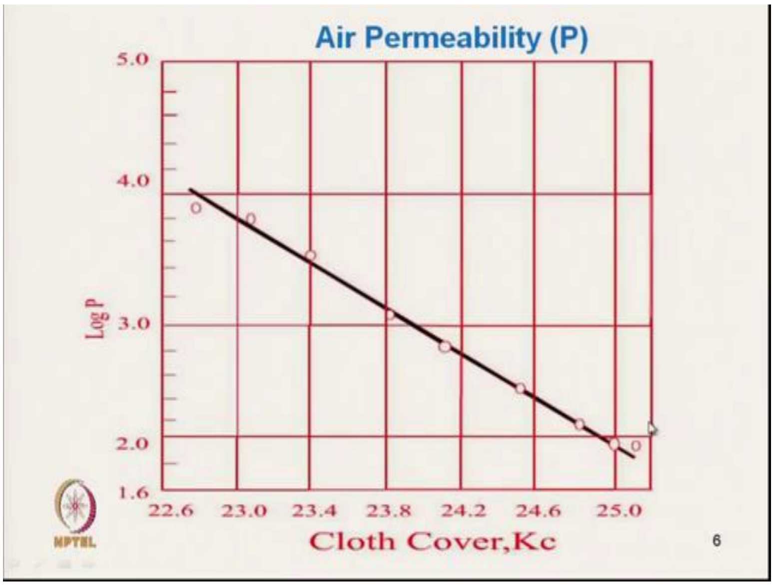

Now if we convert this curve into logarithmic form. So, in x axis it is the cover factor and in y axis logarithmic of air permeability log P. So, log P if we plot with the cover factor will get straight line curve. So that means, as the pressure remains constant at with the increasing cover factor the air permeability reduces in logarithmic form ok.

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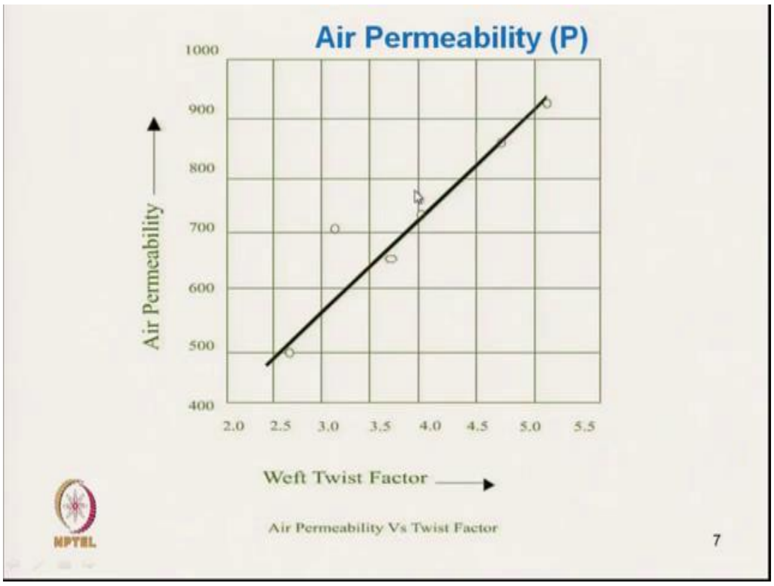

And this curve shows that weft twist factor against the air permeability. Here it is very clear that as we increased the twist factor means; the twist is increased keeping all other parameters constant the air permeability increases. So, let us see what is happening here. All other parameters means, that ends per inch, picks per inch, EPI, PPI.

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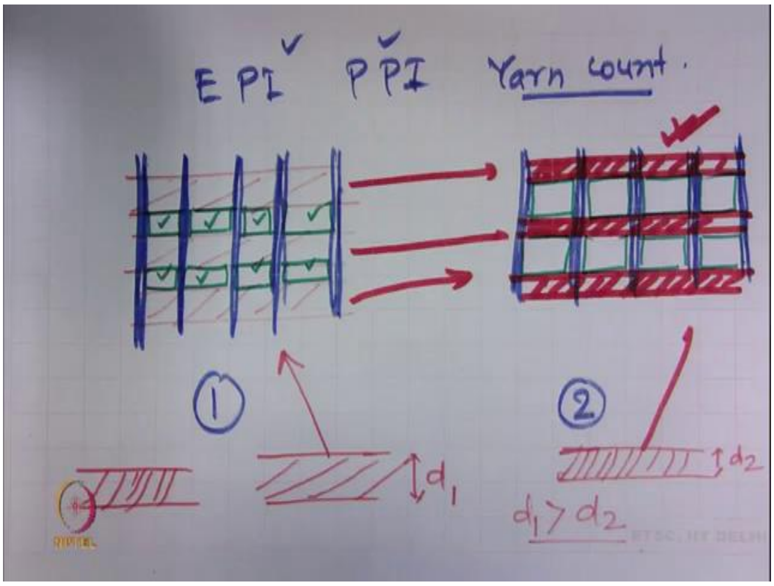

So, all this parameters are constant yarn count these are constant. So, suppose we are using the same warp yarn, this is warp yarn ok. This is these are the warp yarns. Now this is fabric 1 and fabric 2 we are keeping the same warp yarn ok. Same warp yarn we are keeping, same spacing ok. And what we are using the weft yarn. So, weft yarn if the twist factor of weft yarn is less.

So, this is the twisted weft yarn. So, with less twist factor so; that means, when the twist is very low the yarn diameter d1, yarn diameter. And if we increase the twist if we increase the twist the yarn diameter will reduced to a great extent. So, d1 is more than d2. So, this reduction in yarn diameter will actually affect the indirectly cover factor of the fabric. So, this yarn if we are using here it will show so this is one yarn, this is another yarn. So, suppose three yarns we are using here three yarns we are using here.

And same yarn only we have increase the twist factor keeping the count constant. So, this yarn we are using this is yarn 1 this is yarn 2 yarn against this, this is against this and this one is against this with higher twist factor. Only we are changing the twist factor of weft yarn. So, here in this fabric 1 if we see effective open area this is these are the effective open area. So, these are the effective open area through which the air can pass ok. The green it is showing by the green area only effective open areas.

So, rest other area covered by the either warp or weft, but in fabric 2. If we see the effective area, open area is much higher than the fabric 1. So, this fabric 2 will allow more and more air to pass through per unit time. So, that is why if we increase the weft twist factor the air permeability of fabric will increase. So, that is why this curve shows the increase in weft twist factor increases the air permeability of fabric this is mainly due to the in decrease in cover factor. So, the fabric 2 decreases the cover factor this is true for warp also. So, we can test if we change the twist factor of warp we will get exactly the same trend.

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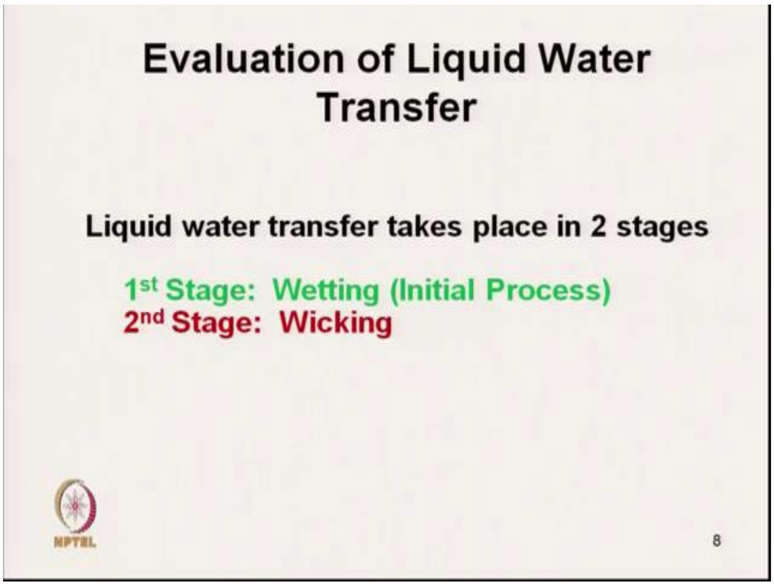

Now after the air transmission we will start discussing now the evaluation of liquid water transmission. So, moisture transmission is in two form; one is liquid form another is vapour form. First we will discuss the liquid water transmission. So, liquid water transmission it takes place in two stages. First stage is it is wetting which is initial process of liquid transmission. And second stage it is called wicking which is actually transmitting liquid from one place to another place.

First the wetting has to be there, without wetting the wicking will not take place, once the material gets wet; then only the liquid; that means, water will penetrate inside the structure. And after that due to the capillary pressure the water will get transmitted from one place to another place which is known as wicking. Here we will discuss this phenomena and how to measure all this parameters.

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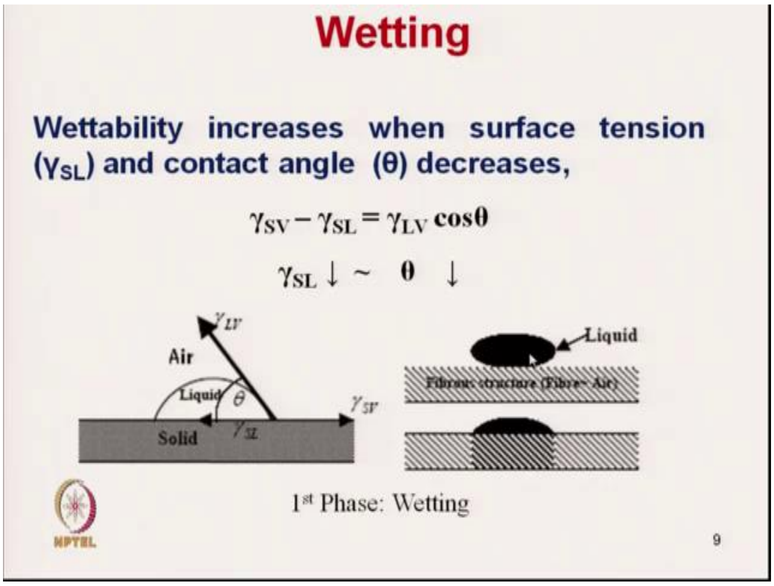

Now, first let us see what is wetting. The wettability of material increases when surface tension, that is surface tension of solid and liquid, surface tension between water and fiber surface that reduces and also the contact angle theta decreases. So, surface tension has to be lower and also contact angle has to be lower. So, this is the formula which shows that surface tension of the surface between solid and vapour.

So, if we see this is one surface a fabric surface solid surface and the liquid drop is there is a water drop is there. And if you take the tangent and this surface it is a surface tension the direction here it is a liquid and vapour. And it has got another component which is the liquid and solid and liquid ok. This is the surface tension of solid and liquid and here on the other side it is surface tension γ_{SV} which is surface tension between solid and vapour here vapour is air.

So, if we see this equation which is $\gamma_{SV} - \gamma_{SL} = \gamma_{LV} \cos\theta$. So, force is being balanced and from this equation it is clear, if we reduce the surface tension between solid and liquid the **θ** will also reduce. So that means, to have wetting to actually, for wetting of any material say textile material. We need to have lower surface tension and also the lower **θ,** lower contact angle. So, if we can achieve this then the liquid will penetrate inside the structure and that will result wetting.

So, if we see the picture in right side here we have two situations the in first situation where the there is a fiber and here is the liquid droplet. So, this liquid is actually making a contact angle which is very high. If we see the contact angle, contact angle it is a very high contact angle. So; that means, the surface tension is very high. So, that is why this liquid drop is not penetrating inside the structure; that means, the structure is not getting wet.

On the other hand the picture below that where the contact angle is very low. So, the surface tension is also low here and that is why the liquid is penetrating inside the structure and wetting is taking place. So, once the liquid penetrates, inside the pores, and the capillary then there will be capillary pressure, which will actually transmit the liquid through the plane. So, first we will see how to measure the wetting.

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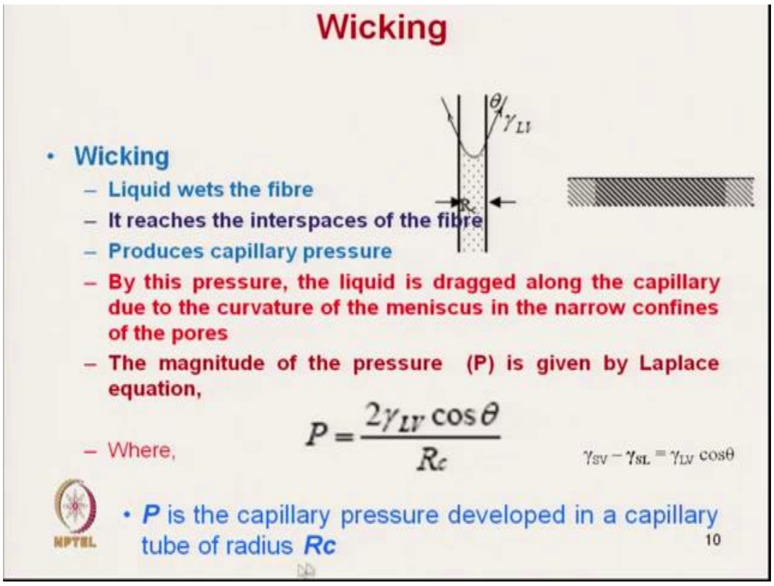

So, after this liquid penetrates, inside the structure then the wicking will take place. So, liquid first wets the fiber, it reaches the interspaces of the fibers that is the capillaries. And where capillary pressure is generated by this pressure the liquid is dragged along the capillary. So, there will be a pressure generated within this capillary and which will drag the liquid along the capillary due to the curvature of the meniscus in the narrow confine of the pores.

So, this meniscus it will have a curvature and which will try to drag the liquid upward. And if the curvature is just opposite, which is in the case of very high surface tension liquid that will not actually drag the liquid it will rather actually push the liquid downward. The magnitude of the pressure P is given by Laplace equation which is nothing, but $P = \frac{2\gamma_{LV}\cos\theta}{R_c}$

Rc is the radius of the capillary. So, from this earlier equation we can see that

$$\gamma_{SV} - \gamma_{SL} = \gamma_{LV}\cos\theta$$

And P is the capillary pressure developed in a capillary tube of radius Rc.

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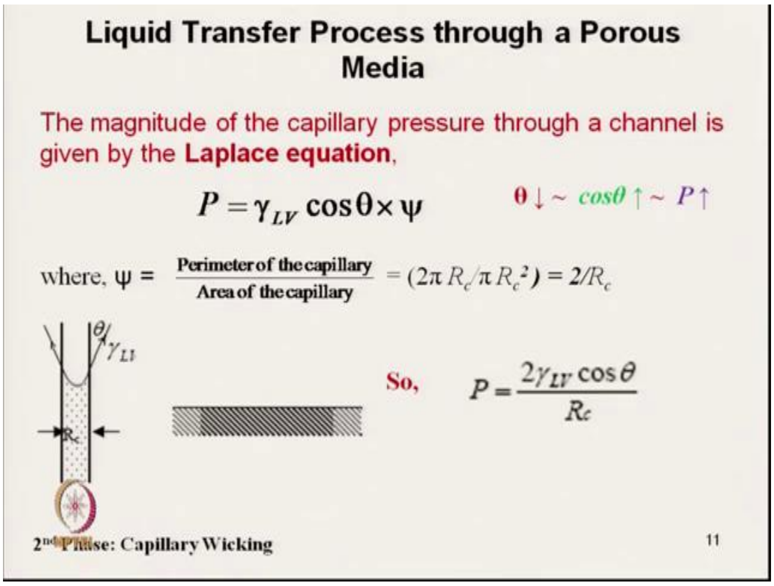

So, the magnitude of the capillary pressure through the channel is given by the Laplace equation this is the original form of Laplace equation;

$$P = \gamma_{LV}\cos\theta \times \psi$$

where

where, $\psi = \frac{\text{Perimeter of the capillary}}{\text{Area of the capillary}} = (2\pi R_c/\pi R_c^2) = 2/R_c$

So, if we see if it is a incase of a circular capillary it is a cylindrical capillary circular cross section, we can actually calculate the $\Psi = (2\pi R_c/\pi R_c^2) = 2/R_c$

Where,

$2\pi Rc$ that is the perimeter of circle. And area of capillary that is cross section is πR_c^2. And which is nothing, but $2/R_c$.

So, if we actually replace psi with 2 by Rc we will get the form which we have already explained

$$P = \frac{2\gamma_{LV}\cos\theta}{R_c}$$

So, this is the pressure which will drag the liquid upward; what does it show? This shows that if we have theta lower, theta lower theta means this cos theta will be high ok. That means, the P will be more. So, the liquid with lower contact angle will have higher capillary pressure; that means, the liquid with lower contact angle will have better wetting as well as it will actually get transmitted higher at higher rate with due to higher pressure.

And also capillary radius with lower radius the capillary pressure will be high; that means, the yarn with lower capillary the compact yarn will have better pressure higher pressure Means it will transmit the liquid at higher length or at higher rate; that means, the yarn with higher twist higher, twist means compact yarn will have better pressure due to lower Rc value. Now we will discuss the measurement techniques, first we will discuss the measurement technique of wettability.

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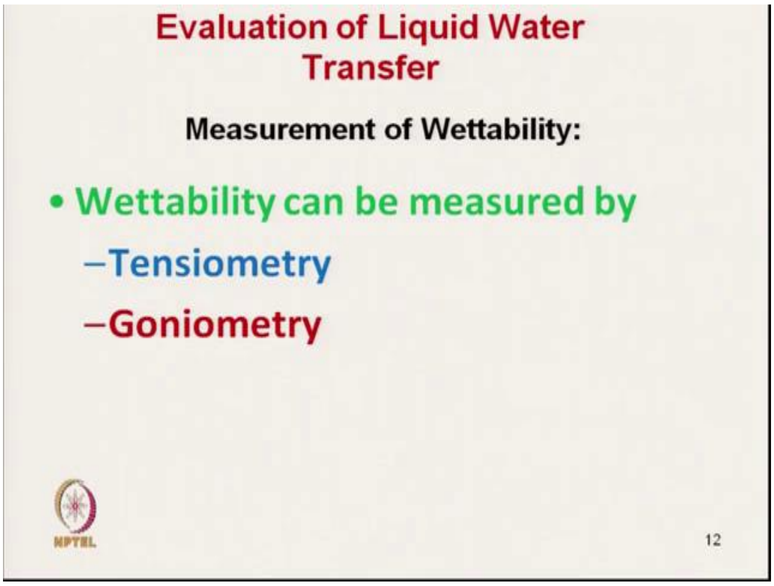

How to measure the wettability? So, it can be measured by two techniques, normally it is a one is tensiometry technique another is, it is a goniometry.

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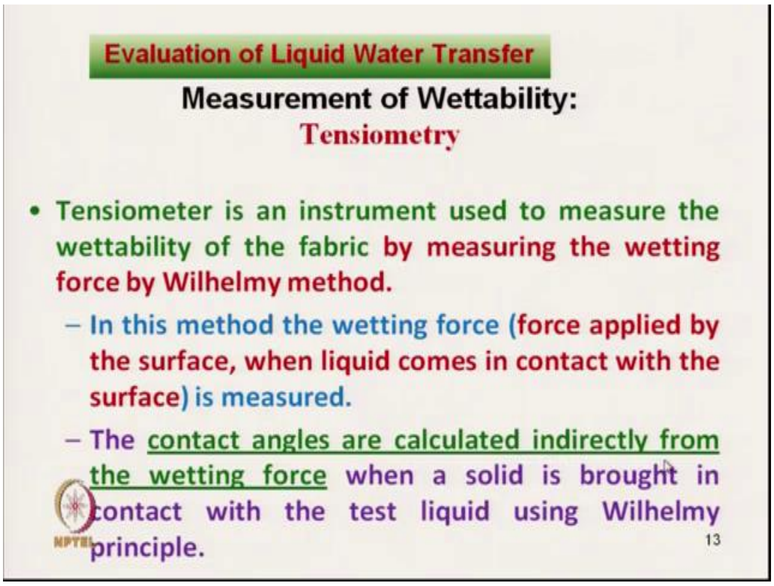

So, tensiometry is actually it is tension is measured. So, in tensiometer it is an instrument used to measure the wettability of the fabric, by measuring the wetting force using Wilhelmy method. What is that Wilhelmy method? In this method the wetting force. That means, wetting tension that is force applied by the surface when liquid comes into contact with the surface is measured. Now let us see in tensiometer what normally we measure here.

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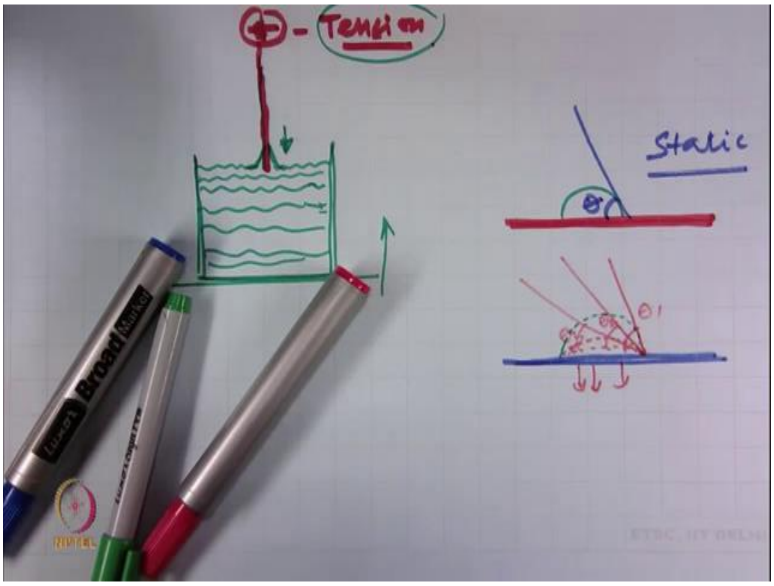

So, this is liquid and here suppose we are or fiber I will use another color red color it is a fiber ok. And which is gripped and connected with tension measuring system so any tensiometer ok. Here we measure the tension, tension measuring system and this beaker is placed on a platform which will gradually it is suppose it is we are lifting it.

So, after certain time as soon as this liquid is in contact with this fiber depending on the wettability characteristics, the liquid will try to form some contact angle and this will create some downward pull. And this pulling force will be measured by tensiometer here and from there using Wilhelmy equation we can calculate the contact angle ok. This is the technique for measuring the wettability characteristics or the contact angle of fiber.

So, this Wilhelmy method it is generally method it is not only used for the textile material fiber, it is for any engineering any material it is used. The contact angles are calculated indirectly from the wetting force. So, the force which is measured which is that is known as wetting force. When a solid is brought in contact with the test liquid, here solid is saying in our case it is fiber and test liquid we can say it is a water using Wilhelmy principle.

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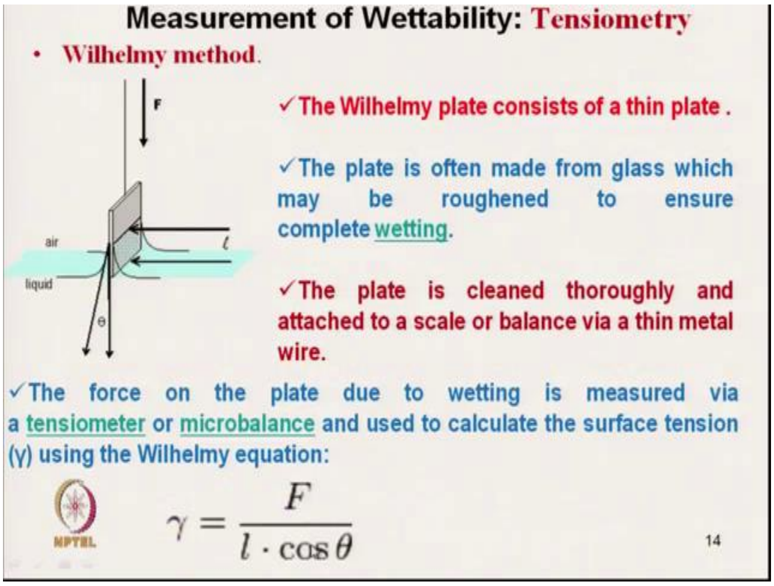

Now, in this case in this picture here the solid is say it is a glass plate. So, the Wilhelmy plate consist of thin plate thin glass plate. The plate is often made from glass which may be roughened to ensure complete wetting. So, complete wetting is required, the plate is cleaned thoroughly otherwise if it is actually contain some impurity it will affect the wetting characteristics. And attached it to a scale or balance via a thin wire.

So, this is a thin wire and with this it is attached with a some tension measurement system. The force on the plate due to wetting is measured via a tensiometer or microbalance which is actually force measurement system. And used to calculate the surface tension γ using the Wilhelmy principle. Now the equation here it is a very simple

$$\gamma = \frac{F}{l \cdot \cos\theta}$$

where gamma is the surface tension if you want to measure the surface tension.

So, gamma is actually can be calculated and F is the force which is the wetting force, l is the actually contact length and cos θ, θ is that that contact angle. So, this is the contact angle from there we can calculate the γ. Now for easily very easily wettable material like a liquid and solid which actually wets very easily; in that case we can consider θ as 0 that case the equation will be very simple.

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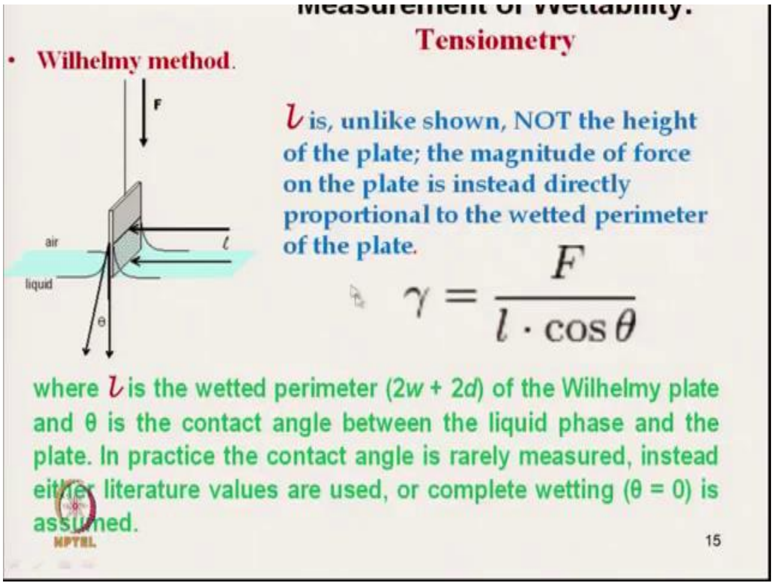

So, here as in this picture it shows the l. It is not that this l actually, l is that wetted perimeter. So, l is unlike shown not, the height of the plate the magnitude of the force on plate is instead directly proportional to the wetted perimeter of the plate. So, l is nothing, but the wetted perimeter of this plate. Now what is wetted perimeter? If the thickness is say depth is say d and w is width. So, in that case l will be equal to **(2*w* + 2*d*)** which is wetted perimeter of the Wilhelmy plate. And **θ** is contact angle between liquid phase and the plate so this is the contact angle.

In practice the contact angle is rarely measured. So, you do not normally do not measure the contact angle instead we use some literature value. So, in Wilhelmy method the contact angle they use from the literature value and measure by measuring the force we can calculate the surface tension. But in our case in textile material we would like to measure the contact angle. If contact angle is known then we can measure the surface tension. But if you want to measure the contact angle so we have to use other method, which is known as the goniometry.

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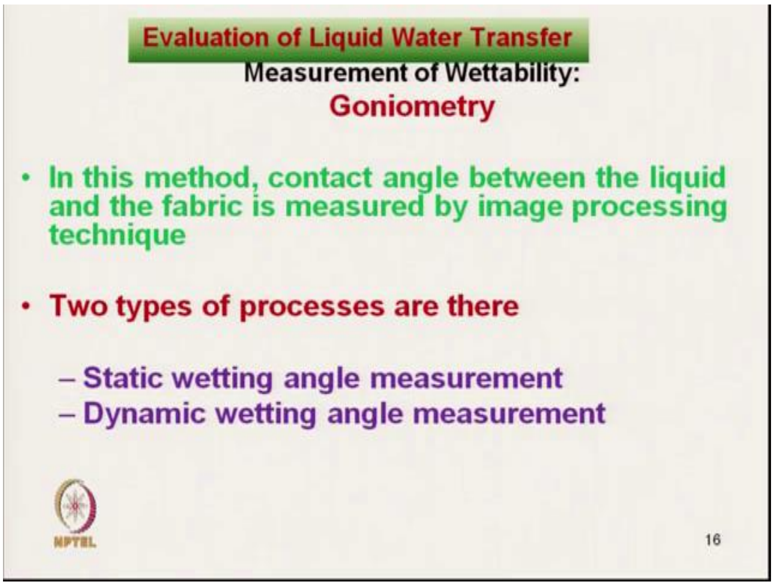

In goniometry the contact angle is measured directly. So, in this method the contact angle between the liquid and the fabric is measured by image processing technique. There are two types of processes; one is static wetting angle measurement and another is dynamic wetting angle measurement. Now, if we see suppose this is the surface of textile material say fabric surface or may be filament surface and this is the liquid.

And if we see the contact angle, this one is the contact angle θ. This we can use by using camera and it is a static. But for a material which is highly absorbent material highly absorbent material where the liquid gets absorbed. So, initially this is the profile and after certain time the profile due to absorption profile gets changed. And gradually it will become flattener.

So, as the liquid penetrates inside this gets changed. So, contact angle we will see it is continuously changing. So, θ1, θ2, θ3 like this' contact angle is continuously changing. So, this is actually dynamic process of measurement. So, one is static wetting angle measurement another is dynamic wetting angle measurement.

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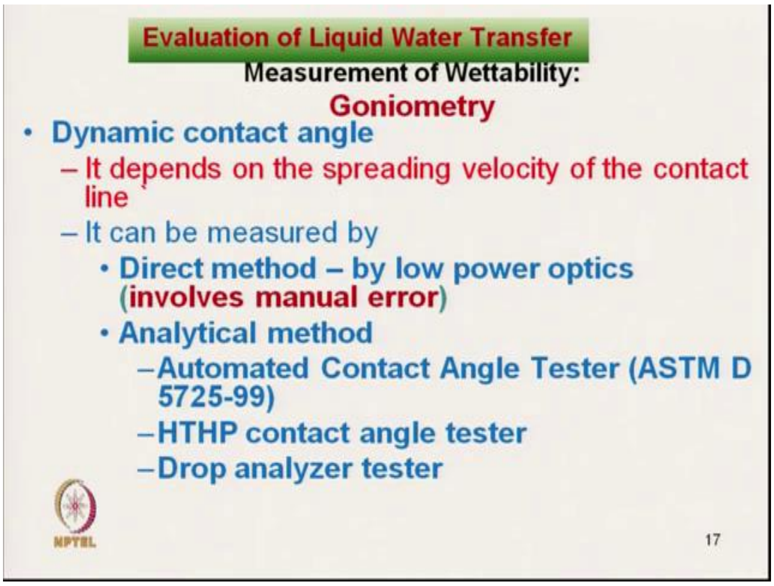

So, dynamic contact angle it depends on the spreading velocity of the contact line. It can be measured by direct method by low power optics. So, by direct method low power optics we can actually manually a measure with the time how the contact angle is changing. So, this involves manual error to some extent then analytical method which is automatic method. So automated contact angle tester ASTM D 5725-99.

So, using this method we can actually record automatically the change in contact angle HTHP contact angle tester, drop analyzer these are the techniques which is actually, which is following the continuous change in contact angle method under goniometry technique.

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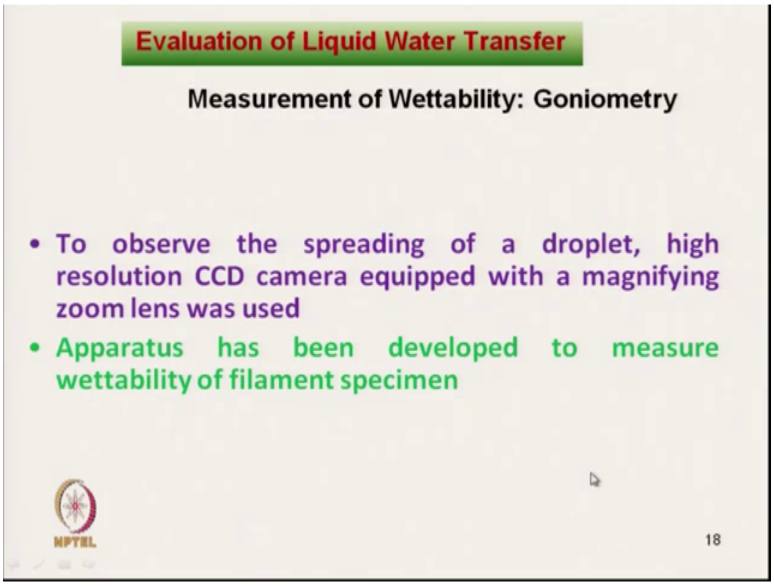

To observe the spreading of a droplet high resolution CCD camera, equipped with a magnifying zoom lens was used. So, CCD camera is used to observe the spreading of the droplet; that means, how the angle contact angle is changing. Apparatus has been developed, to measure wettability of filament specimen.

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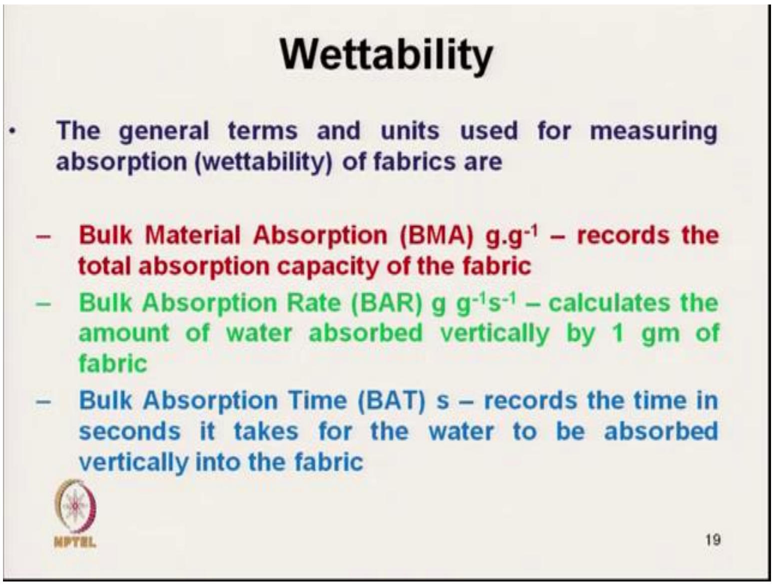

The general terms and units used to measure the absorption that is wettability of fabrics. So, there are different terms used. So, we have seen the wetting characteristics how to measure the contact angles. But we can actually express the wettability of fabric. First is the bulk material absorption BMA it is g/g. That means, the mass of liquid, mass of say water absorbed by a unit mass of fabric. So, records the total absorption capacity of fabric.

So, g/g it was we can express in terms of g/g that is a BMA bulk material absorption. Next expression is that bulk absorption rate BAR, what is that? That means, for unit mass of material what is the quantity of water absorbed per unit time that is g/g/s which calculates the amount of water absorbed vertically by one gram of fabric per unit time per second. Another is bulk absorption time which is expressed in terms of second, which records the time in second it takes for the water to be absorbed vertically into the fabric.

So, these are the techniques; these are the expression by which we can express the wettability characteristics. So, wettability measurement we have seen how to measure wettability by measuring the contact angle. And also wettability we can measure by expressing this in terms of g/g, g/g/s or bulk absorption time. So, after wetting then we will discuss the second stage.

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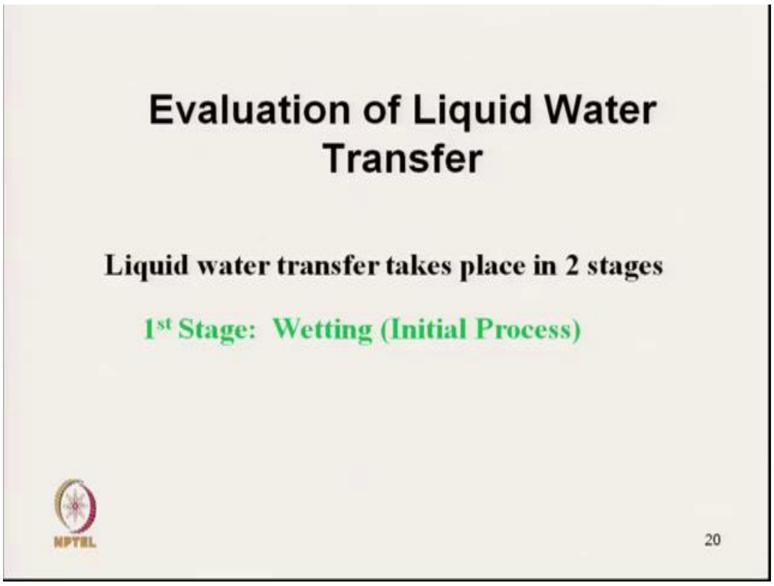

So, in first stage we have discussed wetting which is initial process.

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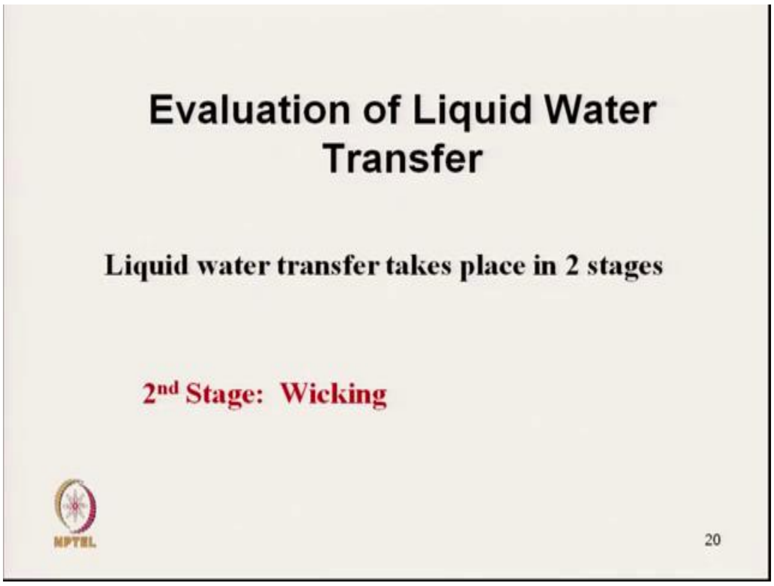

Now, we will discuss the second stage which is the wicking. What is wicking? Wicking is the transmission of liquid from one place to another place. So, that is transmission of liquid through the capillary inside the structure.

And before it reaches to the capillary we must have wetting. So, wetting helps in the transmission of liquid from outside to the capillary. And capillary when it reaches the capillary, the capillary pressure will be generated and which will drag the liquid.

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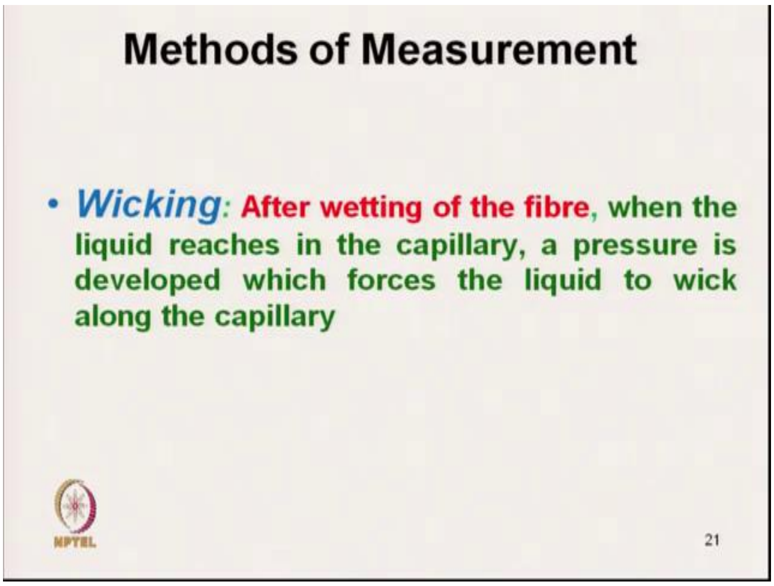

So, wicking is that after wetting of the fibers when the liquid reaches in the capillary, pressure is developed which forces the liquid to wick along the capillary, that is wicking.

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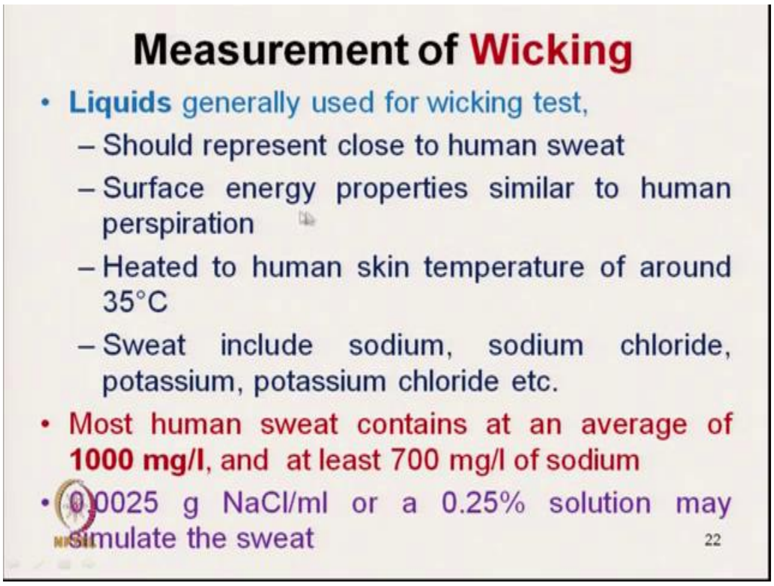

Now, before measurement of wicking, we must know that for the textile material which liquid we have to use? So, in clothing in functional clothing, the liquid transmission is basically it is a sweat. So, that means the liquid should represent close to human sweat. So, we have to simulate the human sweat, you should know what is there in the sweat. So, the we cannot use simple water or distilled water. In that case we will get some wrong result. Wrong interpretation we will actually arrive at. So, it should represent close to human sweat. The surface energy properties similar to human perspiration, heated to human skin temperature of around 35 degree Celsius.

So, for wicking test we cannot test wicking at any temperature we must test wicking at least for the clothing the functional clothing. We must test wicking for 35^0C. The sweat, human sweat include sodium, sodium chloride, potassium, potassium chloride or some other ingredients which are not that significant. So, most human sweat contains at an average of 1000 mg/l. So, 1 g/l maximum or minimum 700 mg/l sodium. So, between 700 to 1000 mg/l sodium is present in human sweat.

So, just to simulate that quantity of sodium so we can use the sodium solution. So, sodium chloride we can use which is available actually easily. So, 0.0025 g/mg or a 0.25 % solution may simulate the sweat. If we use 0.25 % sodium chloride solution that will closely simulate the human sweat. So, you should not use the normal water or distilled water, we have to use 0.25 % sodium chloride solution just to simulate the human sweat.

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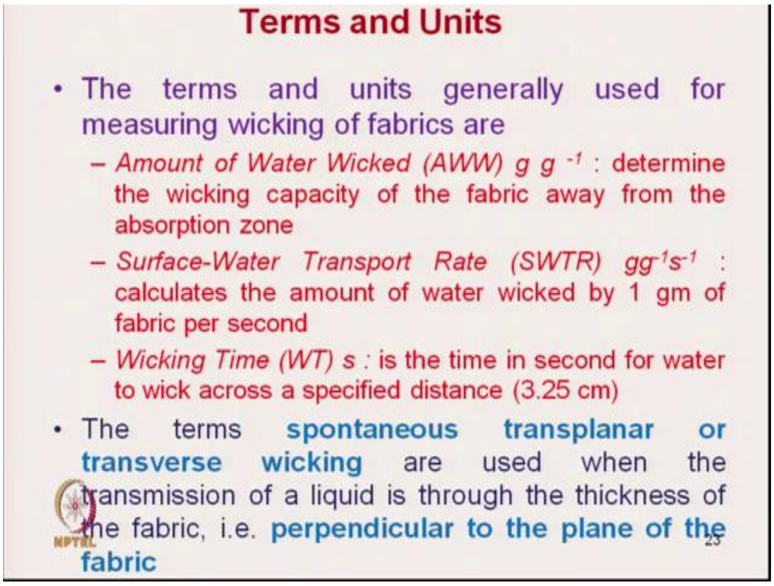

So, again like wetting, here we have to use different terms the terms and units generally used for measuring wicking of fabrics are amount of water wicked so AWW. So, which is expressed in terms of g/g of fabric. So, determines the wicking capacity of fabric away from the absorption zone. So, that means, in a particular absorption zone whatever liquid is been absorbed.

How far it is wicked, how much it is wicked in terms of in g/g of fabric. Next is that Surface Water Transport Rate, SWTR which is expressed in terms of gram/g/s ok, which calculates the amount of water wicked by 1 g of fabric per second. Third is that wicking time, what is that it is the time in second for water to wick across the specific distance. So, particular specific distance is being specified here, the distance is 3.25 cm.

That means, for a water to be transmitted through the fabric of distance 3.25 centimeter, How much time is required what is the time required to transmit water up to that distance 3.25 cm distance. The term spontaneous transplanar or tranverse wicking are used when the transmission of liquid is through the thickness of the fabric that is perpendicular to the plane of the fabric. Now, let us see here which is extremely important for functional clothing.

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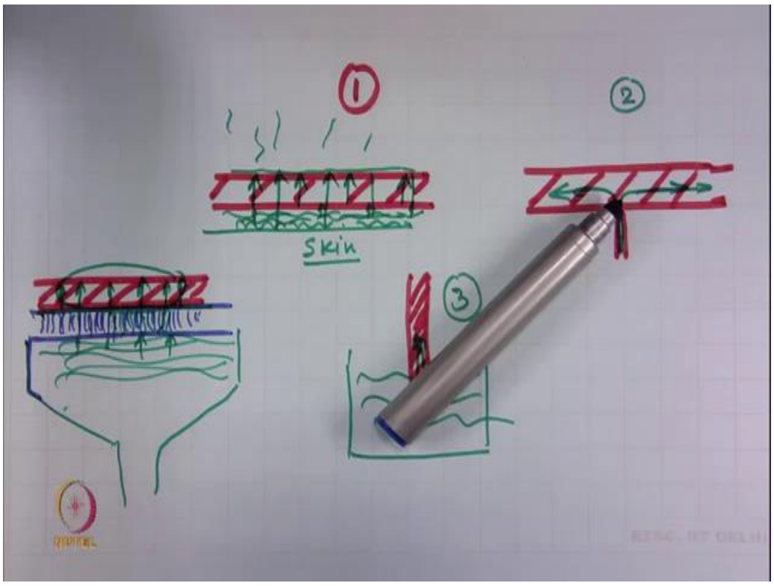

This is fabric; now transplanar is that this is water, as soon as this surface is touching the water; water will get transmitted across the plane through the thickness of the fabric and we will reach to other surface. This transplanar wicking is extremely important because this is the human skin which is actually releasing the sweat. And sweat has to transmit from inner surface to outer surface from there it gets evaporated. So, transplanar wicking is extremely important which is actually that is perpendicular to the plane of the fabric.

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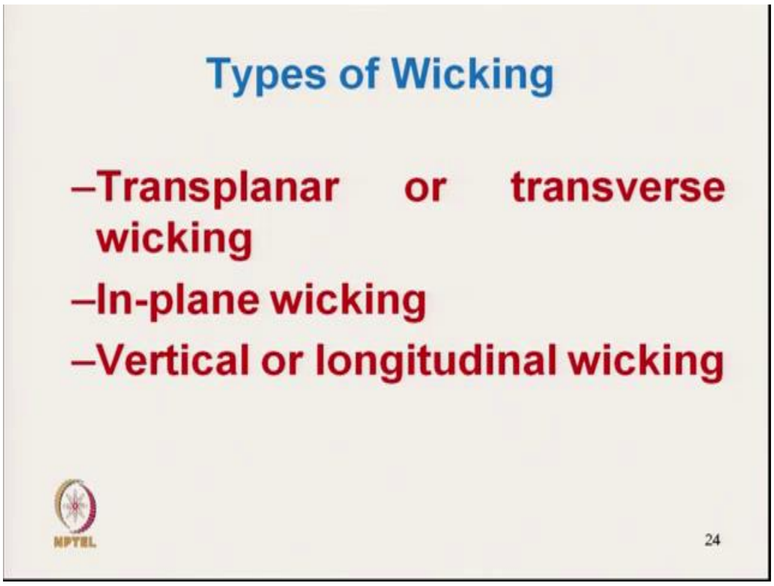

So, if you see the wicking type there are three types of wicking. One is transplanar or transverse wicking, next is in plane wicking. And then third one is that vertical or longitudinal wicking. So, as I have discussed here this is the transplanar wicking. First is the transplanar wicking, second this is the fabric where we are supplying water at the center.

So, circular fabric say it is a supplying water at the center center of the fabric and from there the liquid is getting transmitted along the plane. So, this is called the in plane wicking and vertical wicking is that suppose we have the water. And when a fabric is actually hanging and one end is in actually when it is touching the water. The water will actually be wicked through, the fabric this is called vertical wicking. So, we have effectively three different types of wicking.

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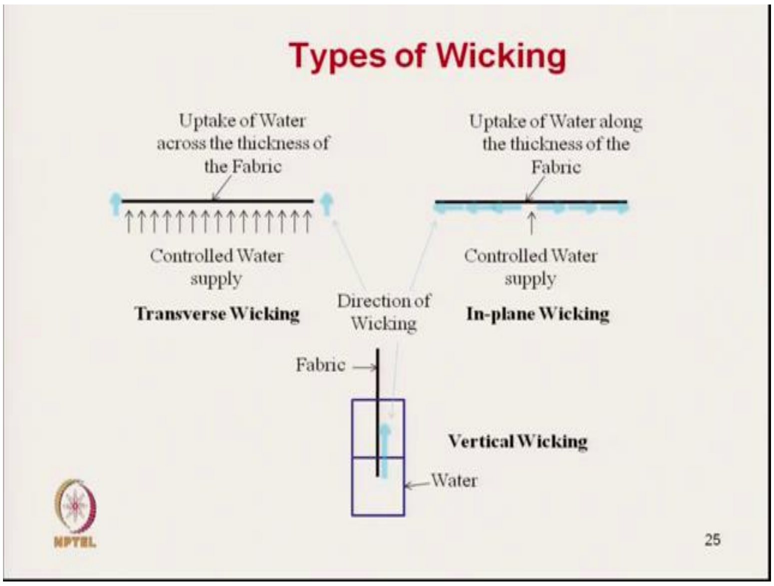

So, we can see here from this picture, the controlled water supply is there and we have the fabric. And water supply is throughout the surface of the fabric and when the water is supplied from the back side the water will get transmitted to the other side. This transplanar wicking is extremely important for our clothing. And here in this process in inplane wicking the water is actually supplied at the center.

And when the water penetrates inside the center, the water will get transmitted along the plane. So, this controlled water supply is through the center in case of transplanar the controlled water supply through the total surface of the fabric. And in vertical wicking the liquid is getting transmitted along the fabric against the gravity. So, the liquid is being pulled through the capillary pressure against the gravity. And here we can measure the height for a certain time or maybe we can measure the mass of liquid transmitted.

There are various ways of expression and now we will start the measurement techniques how to measure all these wicking characteristics. So, uptake in case of transverse wicking or transplanar wicking uptake of water across the thickness of the fabric here or in case of in plane uptake of water along the thickness of the fabric. So, along the thickness of the fabric the water is being transmitted.

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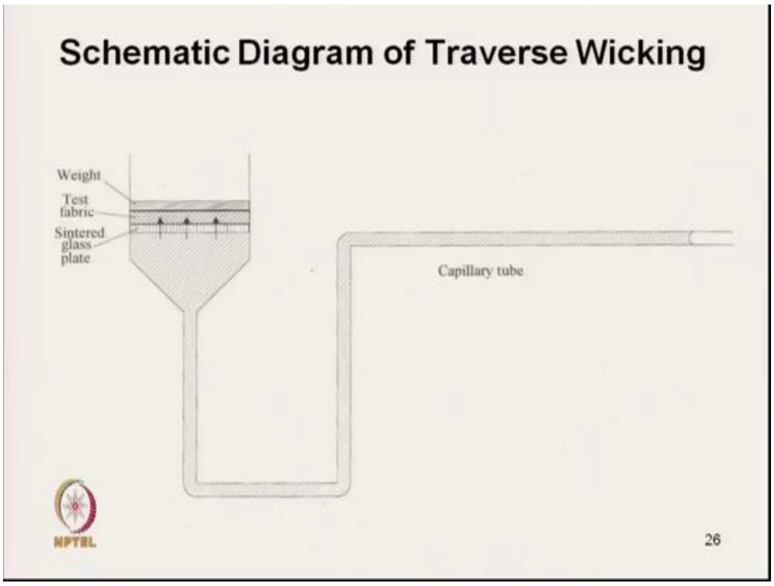

So, the transverse wicking will actually it is measured using this instrument, where the test fabric is placed on sintered plate sintered glass plate. What is sintered glass plate? In sintered glass plate what happened it has got the pores. So, let us discuss here this is test fabric.

Test fabric is placed on this is sintered glass plate which is actually porous. Porous glass plate and bottom of this plate we are supplying water. Bottom of this place in touch with the water liquid, and due to this porous structure liquid will be transmitted to other surface.

And this top surface it simulates our the sweating skin and this liquid will be actually transmitted through the fabric. And quantity of the liquid amount of liquid which is transmitted through the fabric per unit time is actually measured in this system. So, so in this instrument here it is a capillary tube is there which may be sometime flexible tube and here it is a water supply.

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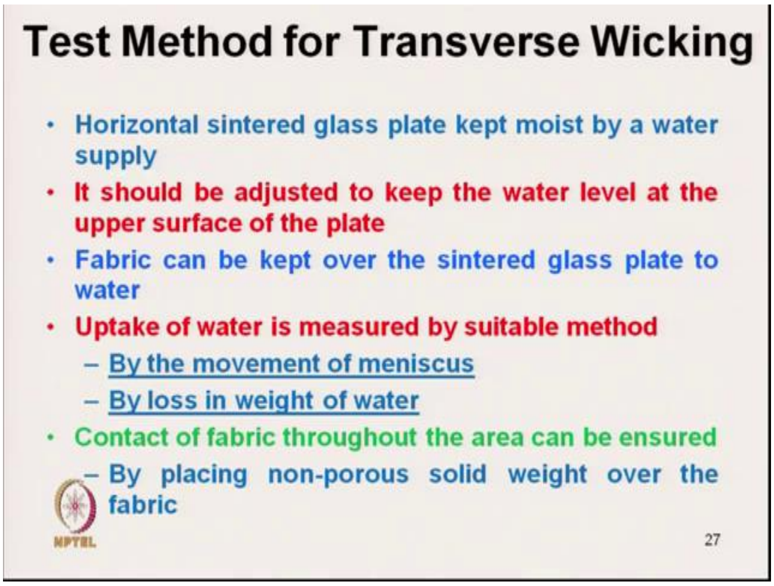

The horizontal sintered glass plate kept moist by water supply always or we have to keep supplying water from the bottom. It should be adjusted to keep the water level at the upper surface of the plate. So, this height should be adjusted in such a fashion that actually supplies the upper surface of the plate. That means, that top surface of the plate is always moist.

Fabric can be kept over the sintered plate to water uptake. So, uptake of water is measured by suitable method. One is by the movement of the meniscus and by loss of water. So, this two methods are adopted, the contact of fabric throughout the area can be ensured by placing non porous solid weight over the fabric. So, we must ensure the contact 100 percent contact should be there otherwise proper flow of water will not be there. So, we will continue with this topic in the next class till then.

Thank you.