Science of Clothing Comfort
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Lecture – 34
Moisture Transmission & Clothing Comfort (contd.)

Hello everyone. We will continue with the Moisture Vapour Transmission.

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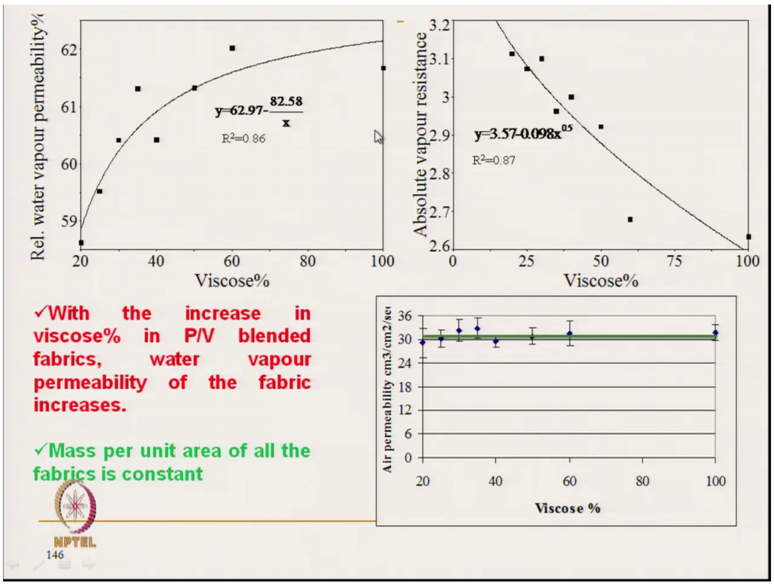

So, we are discussing the moisture vapour transmission through fabrics made of fibres at different proportion of hydrophilic fibre. So, as we have discussed that with the increase in hydrophilic content the moisture vapour transmission increases. This increase is mainly due to the absorption, desorption and also the diffusion coefficient of the material is actually reduced that this we have discussed now. Now, we will discuss that effect of the shape factor.

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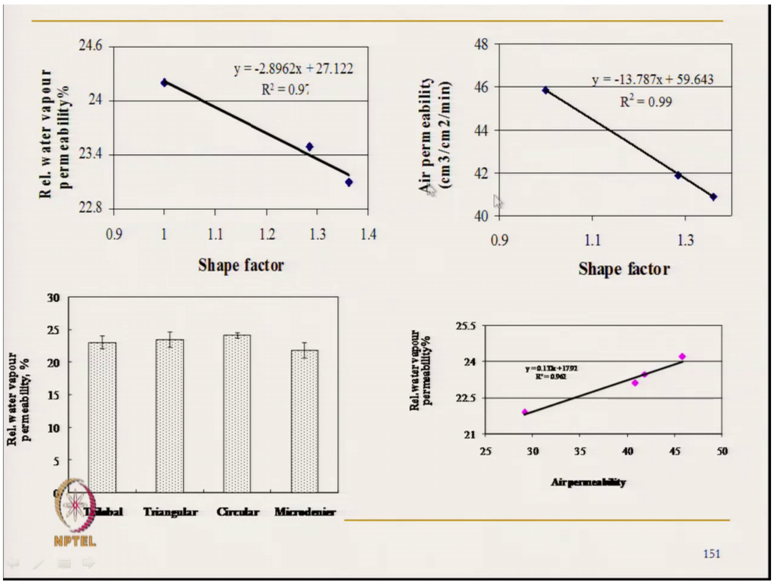

So, effect of shape factor on the relative moisture vapour permeability in earlier segment when we discussed the same for same fabrics, when you discuss the wicking characteristics, liquid to moisture transmission characteristics the increase in shape factor increases the wickability. But, in case of moisture vapour transmission the trend is just reverse. Here its moisture vapour transmission rate reduces with the increase in shape factor. Same as that of the air permeability, air permeability reduces with the increase in shape factor.

So, the higher shape factor means the trial oval in that case the triangular and the circular fibre. So, that is that circular fabric so, this is the trial oval. The circular fabric has got fabric made of circular fibre is circular polyester fibre has got highest water vapour permeability. And, if we see the air permeability and moisture vapour permeability the there is a straight line relationship. This is actually that is a highly correlated and this is the moisture transmission, here the moisture transmission is mainly through the diffusion here ok.

Mainly through diffusion because, the fibre which we are using it is a polyester, it is a shaped polyester because polyester filament. Here though non (Refer Time: 02:52) and diffusion is not there only the (Refer Time: 02:55) and diffusion takes place that is why it is directly related with the air permeability, which is air permeability the moisture transmission take place through the air pocket.

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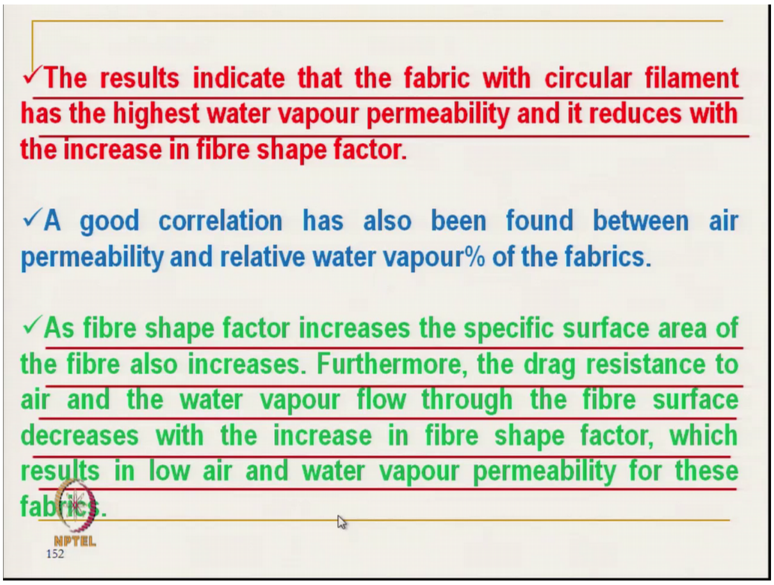

The result indicates that the fabric with the circular filament has highest water vapour permeability and it reduces with the increase in shape factor. So, this is basically due to there is a good correlation. This is basically due to the air drag, that vapour pressure drag due to higher specific surface area of the fibre with higher shape factor. So, good correlation has also been found between air permeability and relative water vapour permeability. So, that in this for a polyester fibre fabric made of polyester fibre so, if you want to know the trend of moisture vapour probability we can test simply air permeability then we can get the idea.

But for hydrophobic fibre we have other phenomena. So, that we have to understand this phenomena. As the shape factor increases the specific surface area of fibre also increases. Furthermore, the drag resistance to air and water vapour flows through the fibre surface decreases with the increase in the shape factor ok. So, the flow will decrease. So, the drag as the drag increases which results lower air flow and water vapour permeability. So, that drag increases due to the increase in the surface presented by the fibre.

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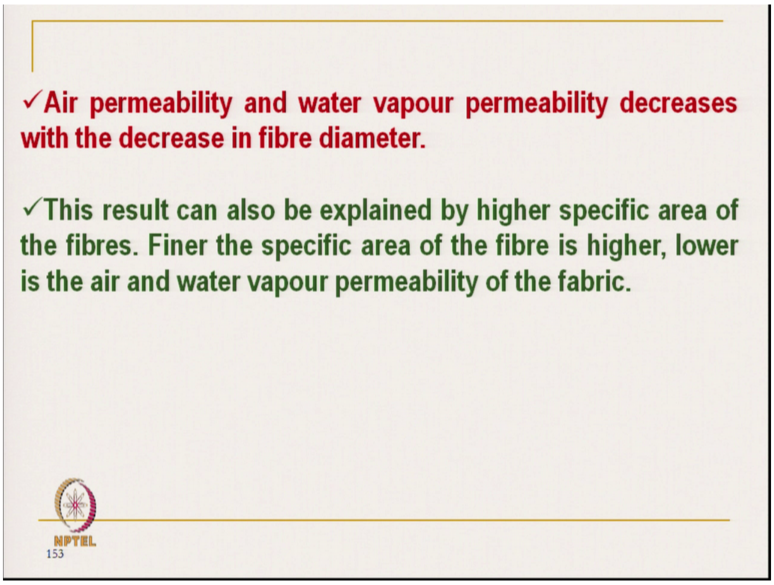

Air permeability and water vapour permeability decreases with the decrease in fibre diameter because of the increase in specific surface area. At lower fibre diameter the surface specific surface area increases that is why water vapour permeability decreases. The same trend is observed in case of air permeability also. This result can also be explained by higher specific surface area that we have seen, but this trend will be different; would be different if we use the hydrophobic fibre. Now, we will discuss another aspect important aspect of moisture transmission through textile material is moisture evaporation and moisture condensation.

These two phenomena are extremely important in clothing comfort understanding the clothing comfort. So, moisture vapour transmission if we moisture vapour gets transmitted, moisture gets evaporated, there will be associated evaporative heat transmission. And, when moisture gets condensed within the structure, within the fabric that means, it will change the thermal conductivity of the fabric. So, moisture evaporation and moisture condensation it actually directly affect the thermal conductivity of the textile material. So, understanding these two phenomena evaporation and condensation is extremely important. So, first we will discuss the moisture evaporation.

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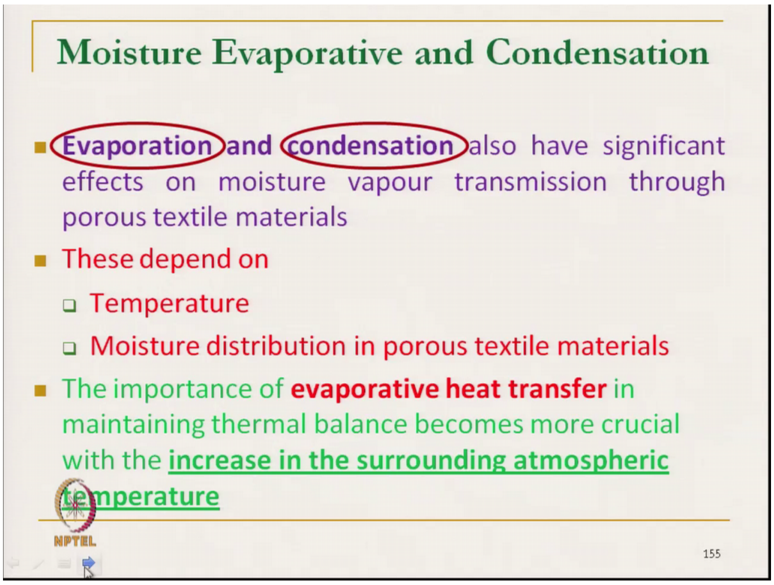

So, moisture evaporation and condensation also have significant effect on moisture vapour transmission through porous material. So, evaporation and condensation they are important and they depend on temperature of atmosphere and moisture distribution in porous material. So, that the depending on the moisture the temperature and moisture distribution the evaporation and condensation takes place.

The importance of evaporative heat in maintaining the thermal balance become more crucial with the increase in surrounding temperature that is very important. So, evaporative heat; that means, a latent heat when the moisture gets transmitted, latent heat from our body it is important when the surrounding atmospheric temperature increases. Because, the normal process of heat transmission that is conduction, convection and radiation reduces; because the temperature gradient is difference in temperature is reduced that we have already discussed.

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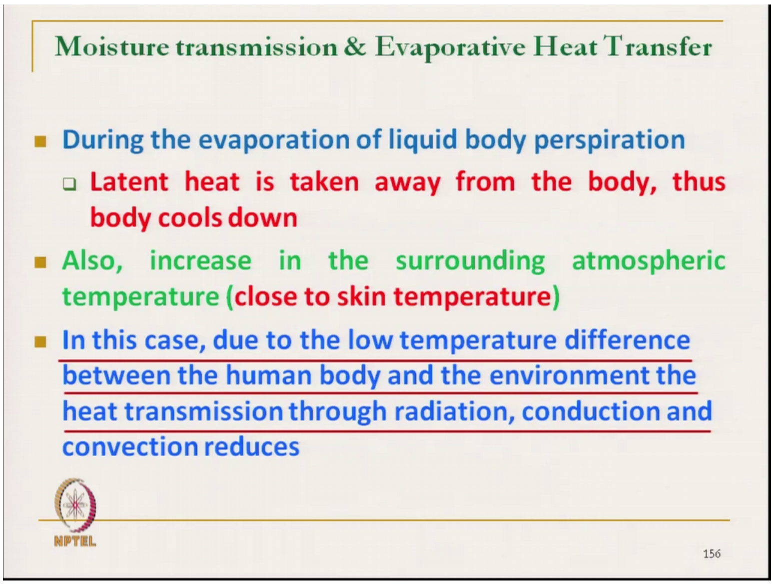

During the evaporation of liquid body perspiration that is our sweat the latent heat is taken away from the body, thus body cools down. Also, increase in surrounding atmospheric temperature close to skin. So, that as the body temperature cools down it increases because, it takes latent heat. So, surrounding temperature increases ok. In this case, due to the low temperature difference between the human body and environment the heat transmission through radiation, conduction and convection reduces. So, this is important. So, the initial initially there was temperature gradient. Our body temperature was higher than the atmospheric temperature. But, as the evaporation is taking place liquid evaporation is taking place evaporative heat is taken away from our body.

So, our body the skin temperature is reduced, but as the heat is coming out from our body to the surrounding atmosphere so, lower surrounding atmosphere has become increase, the temperature is increased. So, effectively there is the temperature gradient has reduced. So, initially supposed our body temperature was skin temperature was a 36 degree Celsius and after the latent heat is taken. So, it has become say 34 degree Celsius and surrounding temperature if it was a 28 degree Celsius, it has become say 32-33. So, the temperature gradient has reduced. So, the proper heat transmission through radiation, conduction, convection has reduced. So, in that case the evaporative heat transmission is extremely important.

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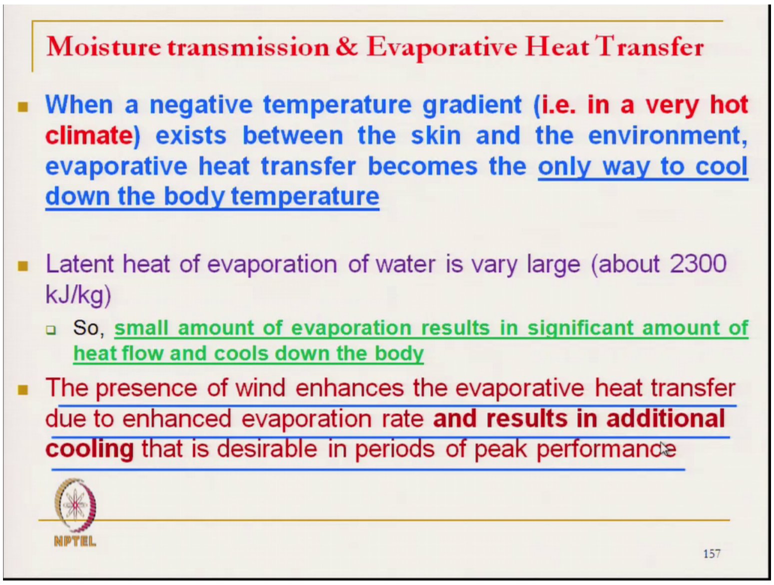

So, when the negative temperature gradient is there; that means, the at higher climatic temperature higher than our body temperature in that case as we have already discussed only phenomena is that of cooling of our body is by evaporative heat exchanger. So, latent heat of evaporation of water is very large that is 2 2300 kilo Joule per kg, it is very high. That means small quantity of evaporation which actually transmits the significant quantity of heat. The percent present of air also enhance this heat transmission because, the evaporative evaporation evaporative moisture will get removed and additional cooling will take place. So, at wind condition its cooling will take place.

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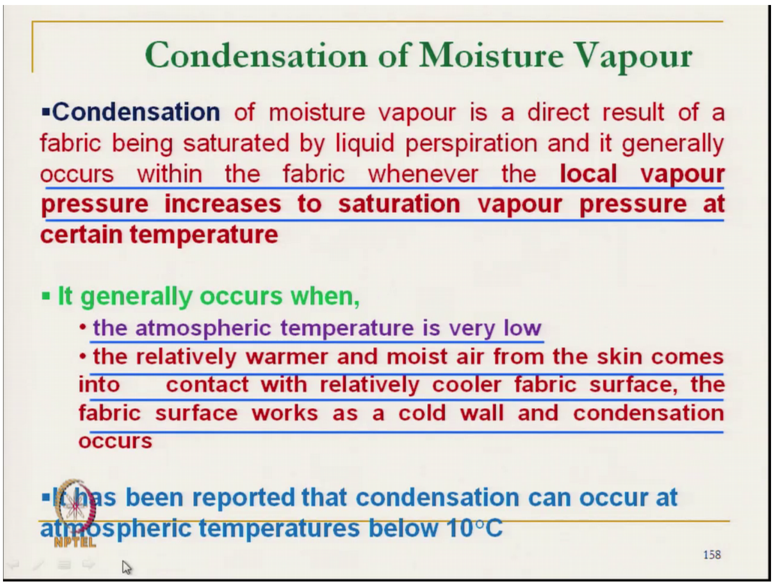

Now, coming to the next phenomena it is a condensation. So, condensation of moisture vapour is a direct result of fabric being saturated by liquid perspiration; that means, in the vapour from when it is getting transmitted it may get condensed ok. And, with the with some specific condition and it is generally occur within the fabric when the local vapour pressure increases to saturation vapour pressure at certain temperature. So, at certain temperature if the local vapour pressure is increased; that means, during transmission of moisture vapour it gets condensed.

So, one parameter is that at certain temperature at particular temperature, if the vapour pressure is high then condensation will take place and also at low atmospheric pressure. So, condensation generally occurs when the atmospheric pressure is low, the relatively warmer. So, when the atmospheric pressure is low; that means, the fabric will also be low, the temperature of the fabric will also low that relatively warmer moisture vapour when is it comes from the skin, when it comes under in contact with the cooler fabric surface in that case fabric will act as the cold one ok.

So, the condenser will take place. So, the cooler fabric; that means, at lower atmospheric temperature when moisture gets transmitted during transmission it will strike a cold wall which is effectively fabric and the moisture will get condensed. It has been reported that below so, it is the below 10 degree Celsius temperature. So, the condensation can occur at atmospheric temperature below 10 degrees. So, if the atmosphere temperature is say below 10 degree so, condenser will start.

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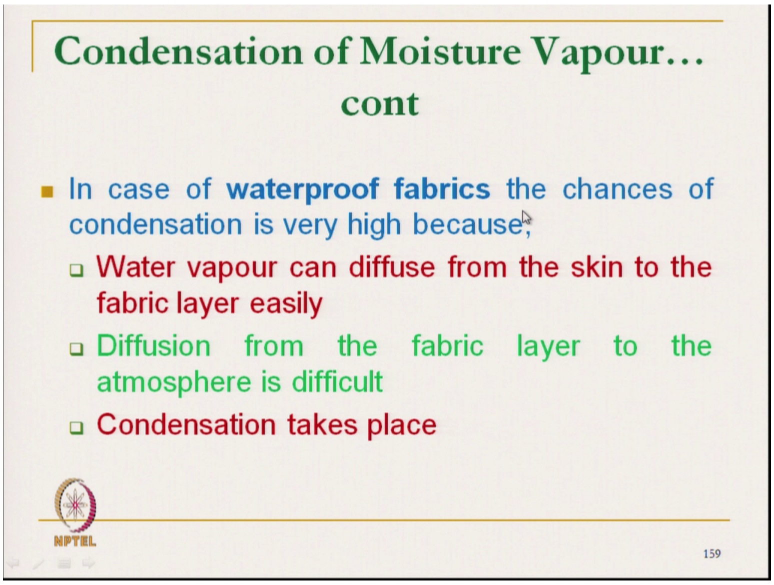

In the case of waterproof fabric this condensation phenomena is severe because, water the moisture cannot get transmitted. And, water if it forms the water droplet the moisture if it condense then it will not be escaped. So, that within the structure fabric structure moisture will start condensing ok. Water vapour can diffuse from the skin to the fabric layer easily. But, diffusion from fabric layer to the atmosphere is difficult because, it is a waterproof condensation takes place ok.

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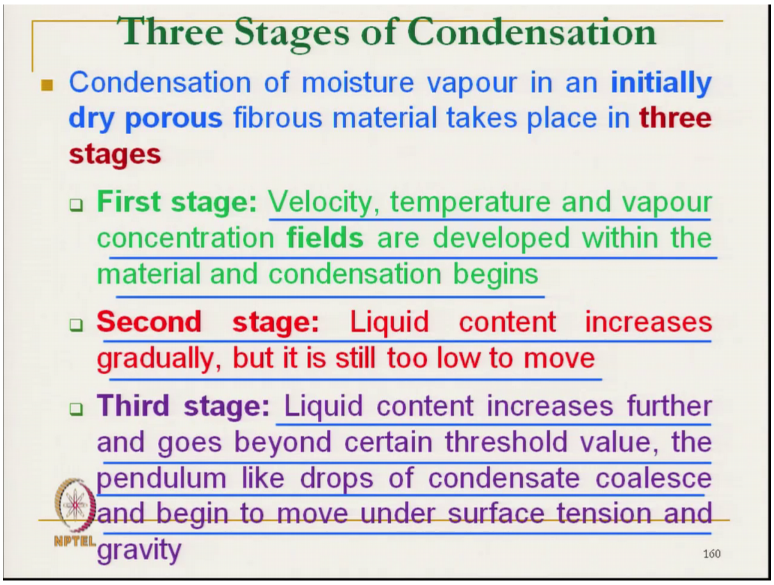

So, the condensation basically takes place in three stages initially dry porous fibrous media material takes place in three stages. First stage what is that? The certain conditions are generated that is velocity, temperature, vapour concentration field are developed. This actually proper condensation, the stages for condensation situations for condensation take place first. So, these are the field that is temperature field, vapour concentration field, velocity field are generated.

In second stage the liquid content increases gradually, but still too low to move. So, gradually the liquid content will increase from vapour to liquid formation will get initiated because, of the first stage. Because, temperature has its low it has become low, vapour pressure concentration is high velocity is also low. So, at high velocity it will take away; at higher moisture temperature moisture concentration of condenser will not place. Lower atmospheric pressure lower or lower vapour concentration, it condensation will not take place.

But, for particular situation the condition has been developed and then the liquid content gradually increase. And, in third stage liquid content increases further this is. And third stage the liquid content increases further and goes beyond certain threshold level. And, then the pendulum like droplet will start ok. Like drops of condensed ok, it start and begin to move from under the surface tension and gravity. So, gradually the condensed air will start moving from one place to another gradually to moves through along the fibre surface.

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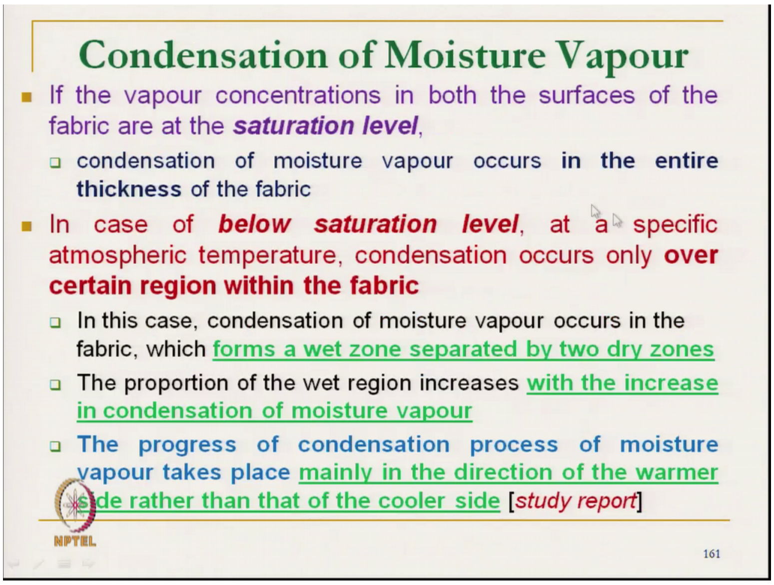

Now, the condensation of moisture that is at the saturation level. So, if the vapour concentration in both surfaces of the fabric is at saturation level; that means, the fabric is placed in saturated air. In that case what will happen the throughout the thickness the moisture concentration will be there, same concentration will be there ok. There will be condensation inside the structure. But, if in case of the condition where the atmospheric moisture is below saturation level at a specific atmospheric temperature, if it is below the saturation level the condensation occurs only over certain region within the fabric.

So, that total thickness will not get condensed. So, that will be within a particular place that is a particular zone of condensation. It is not evenly distributed; that means, that particular wet zone that is called wet zone that condensed zone is actually separated by two dry zone; both the sides. So, if we talk about the fabric thickness. So, if it is a thickness in a particular zone they are wet zone, but other zones will not be wet, it will be dry zone.

So, in this case the condensation of moisture vapour occur in the fabric which forms a wet zone separated by two dry zones and that wet zone travels. So, it is not that whole structure, whole thickness is getting condensed, but that particular wet zone it travels. And proportion of the wet zone increases with the increase in the condensation of moisture. So, gradually this thickness of the wet zone increases if the we our condensation keep on increasing.

But, if the condense that wet zone is if the increase the moisture vapour pressure is increasing ok, but if the moisture vapour pressure is not increases what happened it travels. The progress of condensation so, if gradually if it is increasing. Now, it is increasing whether it will increase in left side or right side that depends on the temperature of which particular side. So, it has been observed the study report says the progress of condensation process of moisture vapour takes place mainly in the direction of the warmer side rather than the cooler side, which is a very interesting. Typically, ideally we think that the cooler side the condensation will take place, but condensation at the wet zone the thickness of wet zone increases gradually, but that it travels towards the warmer zone. So, that is the study report.

Now, we will start the evaluation methods of moisture vapour transmission. So, there are different methods of moisture vapour transmission measurement. So, we will discuss one by one.

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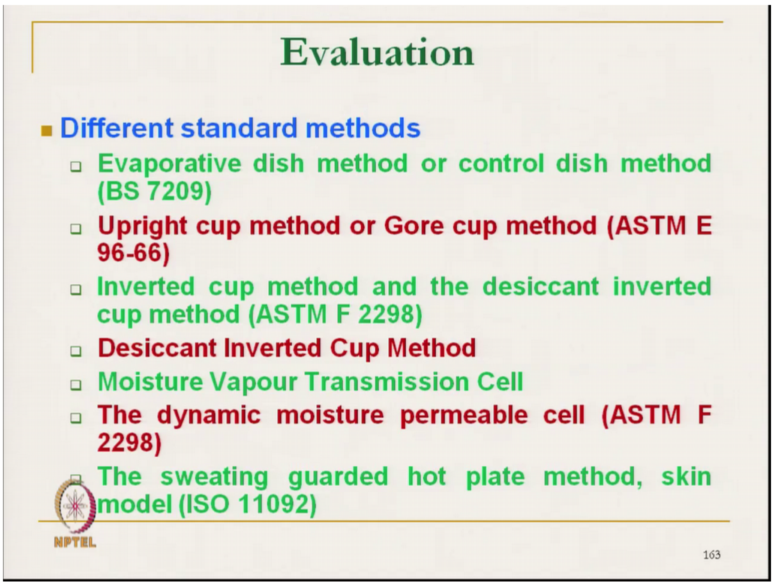

So, different standard methods are available. So, first method is Evaporative dish method or control dish method, which follows the British standards BS 7209 which is evaporative dish method. Similar to that another method is developed by ASTM: ASTM E 96-66; so upright cup method or Gore cup method, Gore cup method or Upright cup method. This is actually it is a evaporative dish method and this upright cup method these are approximately these are same methods. So, we will discuss similar.

Next is Inverted cup method and desiccant inverted cup method. So, these are the two methods inverted cup method and desiccant inverted cup method ASTM F 2298 method. Desiccant inverted cup method ok, moisture vapour transmission cell where we can measure the moisture vapour transmission rate, we will discuss and dynamic moisture permeability cell ASTM F 2298 again. Sweating guarded hot plate and also the permi test. That we will discuss Permi test is another method and we will also discuss one method development developed by our lab that is microclimate simulator.

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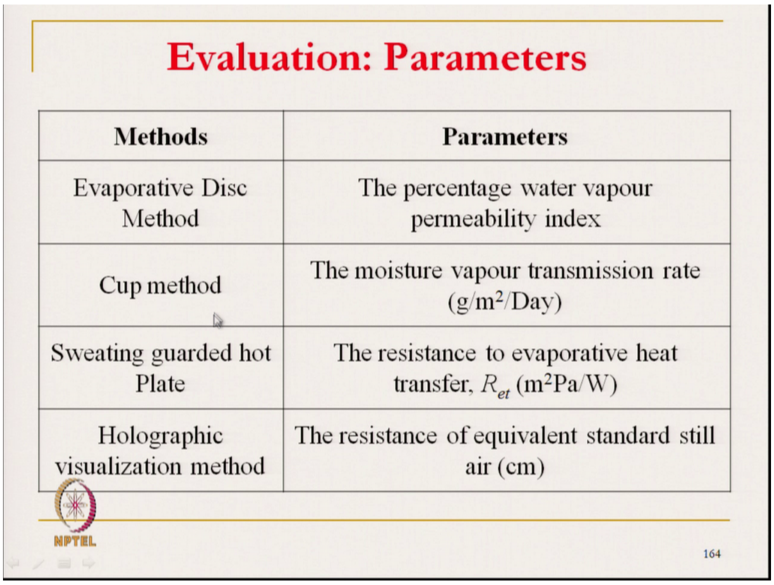

Methods	Parameters
Evaporative Disc Method	The percentage water vapour permeability index
Cup method	The moisture vapour transmission rate ($g/m^2/Day$)
Sweating guarded hot Plate	The resistance to evaporative heat transfer, R_{et} (m^2Pa/W)
Holographic visualization method	The resistance of equivalent standard still air (cm)

So, evaporative dish method it is basically percentage water vapour permeability index, permeability index in terms of percentage it measures. Cup method its measures the quantity of moisture vapour transmitted per unit area per day. Sweating guarded hot plate, evaporative heat transmission it measures. Holographic visualization method this we will discuss.

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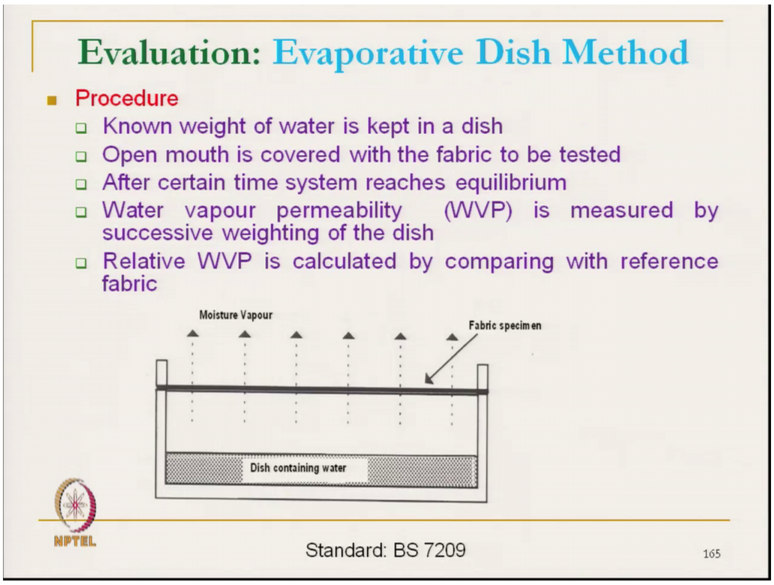

First is that evaporative dish method. In this method known weight of water is kept in the dish. So, known weight of water is kept here and it is kept in a standard atmospheric temperature. Open mouth is covered by fabric ok. After certain time the system reached the equilibrium [FL]; that means, the water flow rate is actually at it at constant rate its water is flowing. So, when it reaches equilibrium the water vapour permeability is measured by successive weighing of the dish.

So, this dish along with the sample we weigh at different time interval and relative water vapour permeability is calculated by comparing the reference fabric sample. So, this method actually measures the relative water vapour permeability with the known sample. So, first we measure the known sample then our test sample and compare with that ok.

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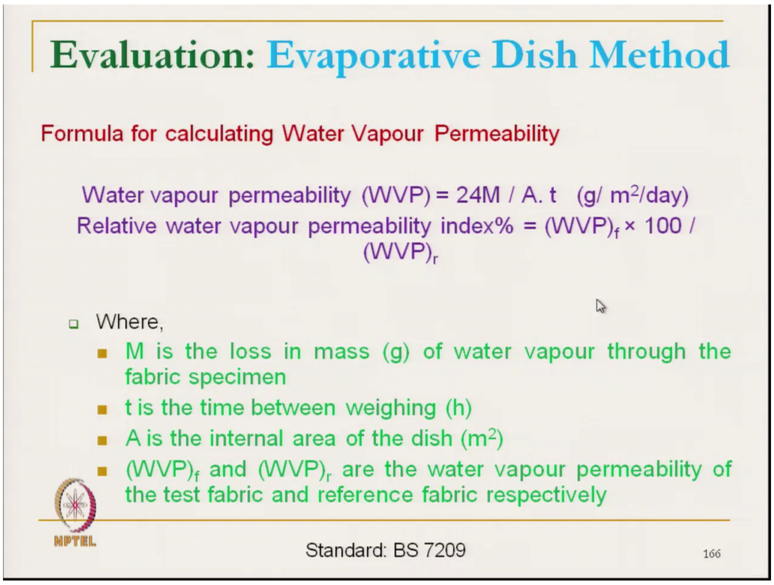

So, water vapour permeability is measured by the 24 to M where, M is the mass of the moisture vapour lost. So, at initial and at certain after time t, after time t we measure the mass. So, what is the difference? We can measure the mass of the water vapour lost ok, t is the time between the two weight, A is the area of the dish the that is the area of the fabric and water vapour permeability of fabric and reference fabric are the that is the reference fabric. And, with this ratio we can get the relative water vapour permeability ok.

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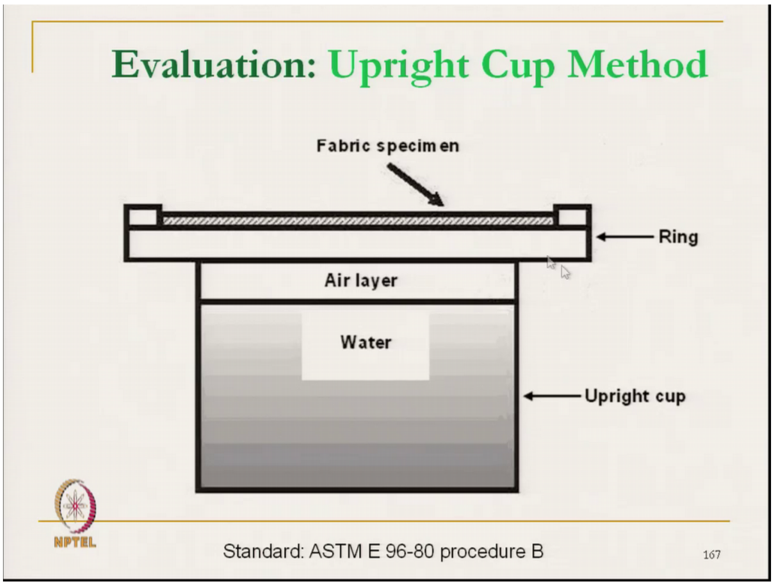

Next is the upright cup method, the system is exactly same only it follows the ASTM principle. Earlier one it follows the BS standard, the same principle air the water is there air layer and the fabric specimen is there.

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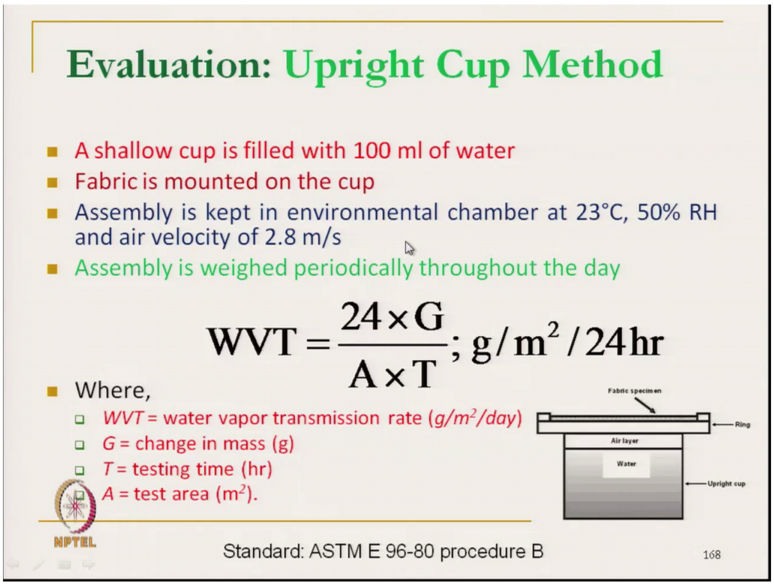

And, calculation is exactly same way we calculate. Here actually we keep the constant water. Earlier we can keep any quantity of water, here the constant quantity of 100 ml water is kept. Fabric is mounted on the cup and it is the temperature and humidity and air velocity is specified and its going and the same way it measures. G is the mass of moisture vapor transmitted, A is the area. So, this way we can measure the moisture vapor permeability by upright cup method.

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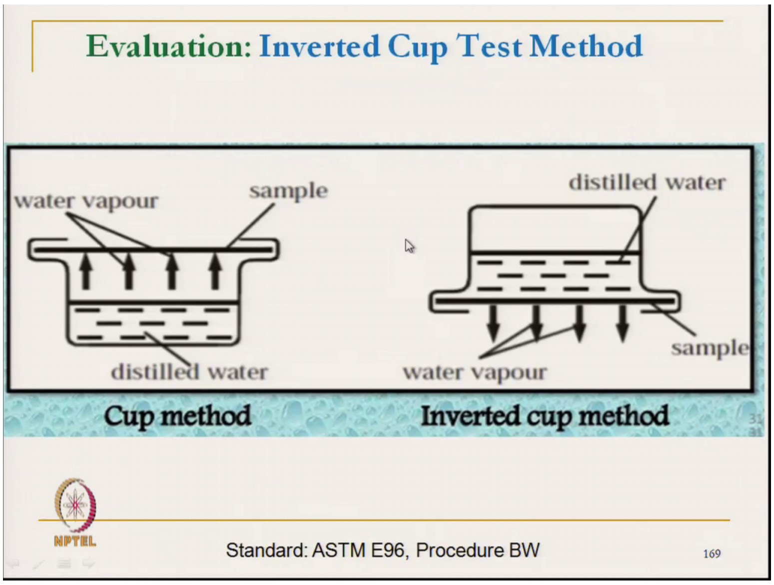

This is the cup method. And if you see it is a inverted cup method. It is just actually reversed, where the hydrophobic PTFE membrane is used to seal the mouth of the cup to prevent the wetting of the specimen. So, here it is not simple the fabric.

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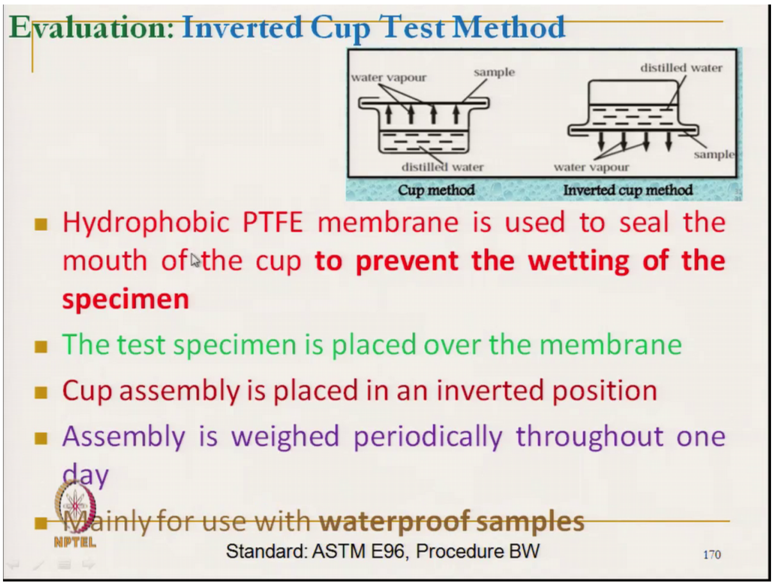

The first the fabric the cup is there and then the mouth is sealed by the hydrophobic PTFE membrane. So, the idea of PTFE membrane it is a porous microporous is there it is a waterproof, but breathable. It does not allow the water in liquid form, but it allows the moisture in vapor form. So, then the specimen is placed over the PTFE membrane and cup assembly is placed in invert condition.

So, then it is inverted condition and assembly is weighed periodically throughout the day. So, it is a simple and this is mainly used for waterproof sample. This actually the technique is used for waterproof material. And here if we can directly use measure the for PTFE membrane also. PTFE membrane can be our sample or any other waterproof sample.

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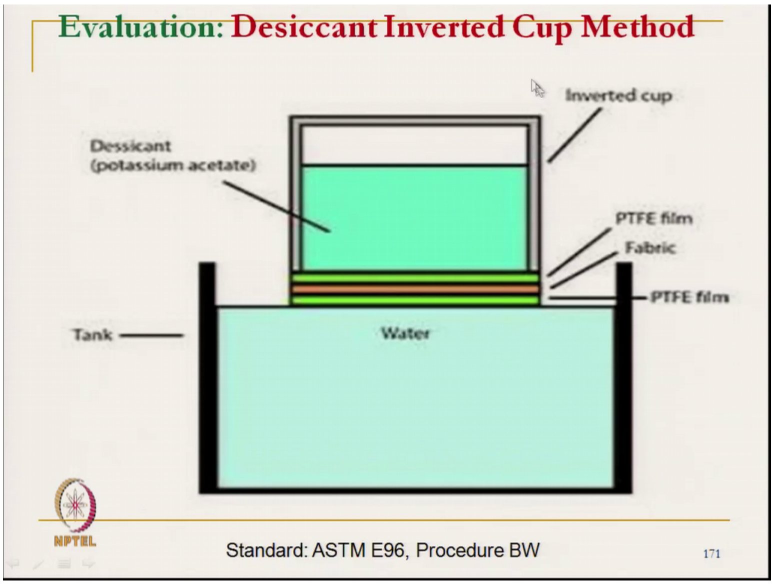

Desiccant inverted cup method, it is typically it is a similar to that inverted cup method, but here it is not that simple, but here its inverted cup but principal is totally different. Here, this is the fabric samples that yellow one is the fabric samples and it is a sandwiched in between two membrane. One is that PTFE membrane in the upper side and in bottom side another PTFE membrane. But, we can eliminate we may not may or may not use this PTFE membrane in the upper surface. Now, what is what is happening here and here it is a desiccant potassium acetate ok, in any desiccant material which actually absorbs the moisture immediately.

Now, with this set up this is the water tank, with this setup when we actually this system total system is immersed inside the water tank. The water in vapor form will get transmitted through the fabric, through this total element. But, liquid will not get transmitted as soon as the water is transmitted this desiccant its actually it absorbs,

absorbs the moisture vapor. So, that this total system remains dry and but mass is increasing. So, we can take the weight and we can calculate the moisture vapour transmission.

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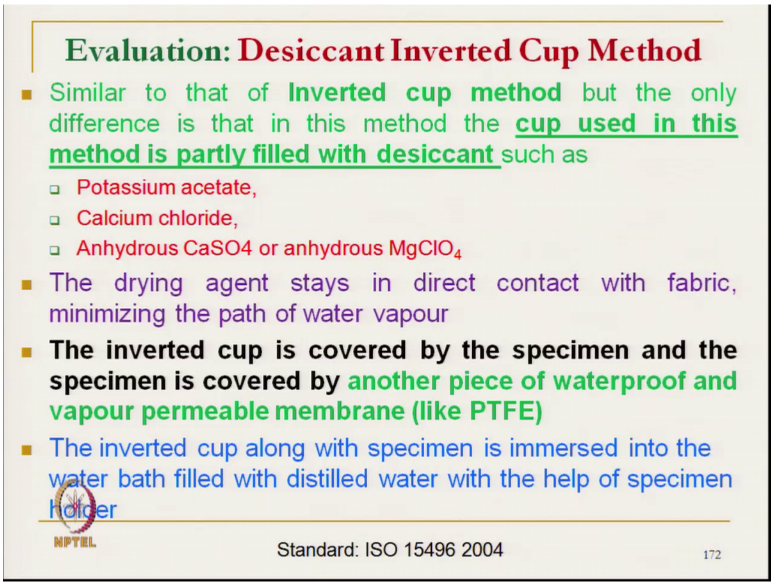

So, the similar to that of inverted cup method, but only difference is that in this method the cup used in this method is partially filled with desiccant, such as potassium acetate, calcium chloride or anhydrous calcium sulphate or anhydrous magnesium chloro sulphate. So, these are the MgClO 2 O 4. So, these are the chemicals which are actually used as the desiccant material ok. The drying agent these are the basically drying agent, the drying agent stays in direct contact with the fabric. So, we may use this upper PTFE or may not use.

So, normally we do not use this upper PTFE. So, this drying agents are these are directly contact with the fabric, minimizing the path of the water vapour flow. So, as soon as the water vapour goes in other side so, it immediately takes away. So, that proper water vapour transmission takes place. The inverted cup is covered by the specimen and then the specimen is covered by another piece of waterproof and moisture vapour permeable membrane that is PTFE membrane. The inverted cup along with the specimen is immersed into the water bath filled with the distilled water with the help of the specimen holder so that way.

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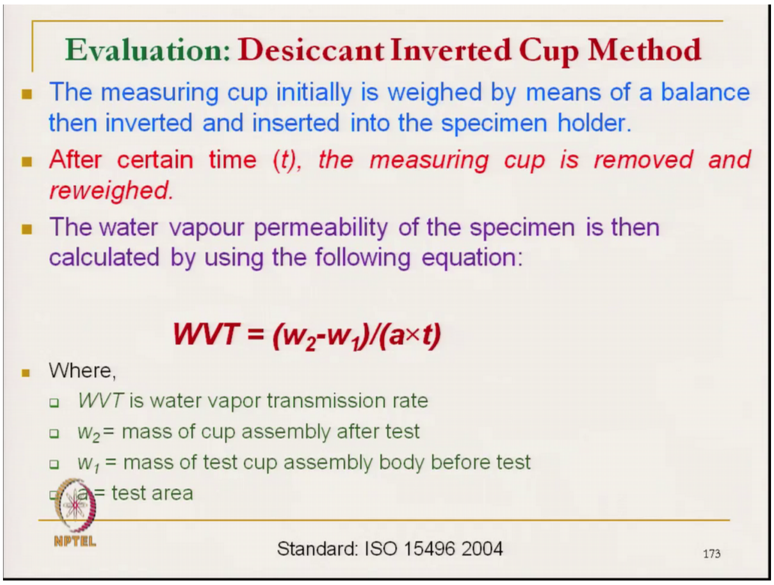

And the measuring cup initially is weighed by the by means of balance and then inverted and inserted into the specimen holder. After certain time the measuring cup is removed and reweighed again. So, the difference is in this way difference is calculated: w 2 is the weight after test w 1 weight before test. So, this is the method. So, this way we can calculate the water vapour permeability.

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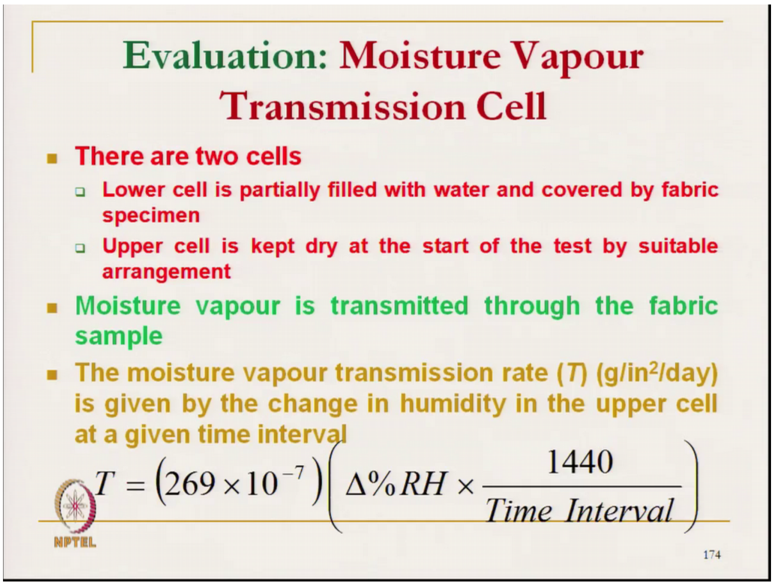

Another method is that moisture vapour transmission cell. This in this method it is a there is a two cells are used. So, one is the upper cell another is the lower cell, lower cell is actually filled partially filled with water. So, at there is a lower cell it is partially filled with water and then fabric specimen it is covered with the fabric specimen. And, upper cell is kept dry initially at the start by the drying agent, dry nitrogen we one can flow through that and it is kept dry. It is almost 0 humidity at upper cell. So, the lower cell is partially filled with water. Then the fabric specimen is kept.

And, then upper cell which is dry, then it is kept at that point. Only thing is that the moisture vapour that is relative humidity is calculated. The relative humidity is measured with the time, relative humidity of the upper cell ok. That upper cell the moisture vapour transmission T is given by the change in relative humidity of upper cell. So, that if we know the change in relative humidity in the upper cell by using this formula we can calculate the moisture vapour transmission ok. And, this all this data we can get from the standard table.

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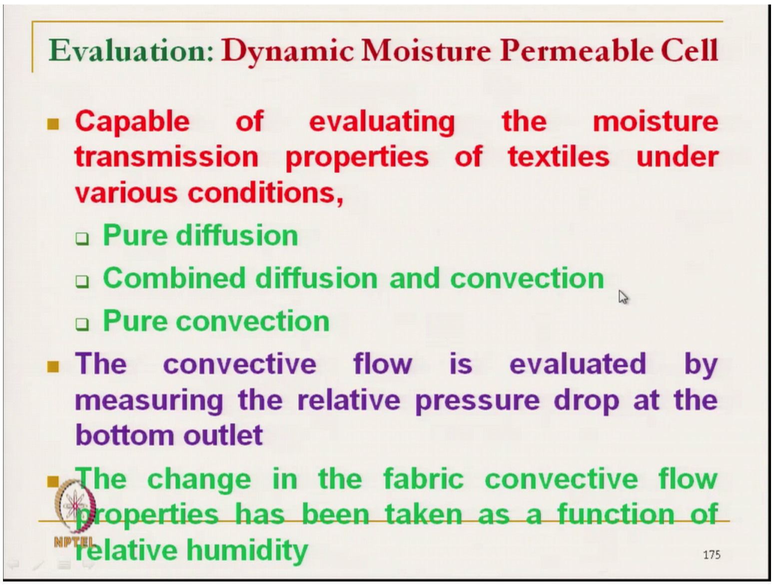

And, another method is the dynamic moisture permeable cell, which is capable of evaluating the moisture transmission properties of textile under various condition: pure diffusion, combined diffusion and convection and pure convection. So, if we want to know the moisture diffusion at different moisture transmission at different mode that in that case we can use a dynamic moisture permeable cell ok. Next is that the as we have discussed, we have developed one instrument which is microclimate simulator cum moisture transmission tester.

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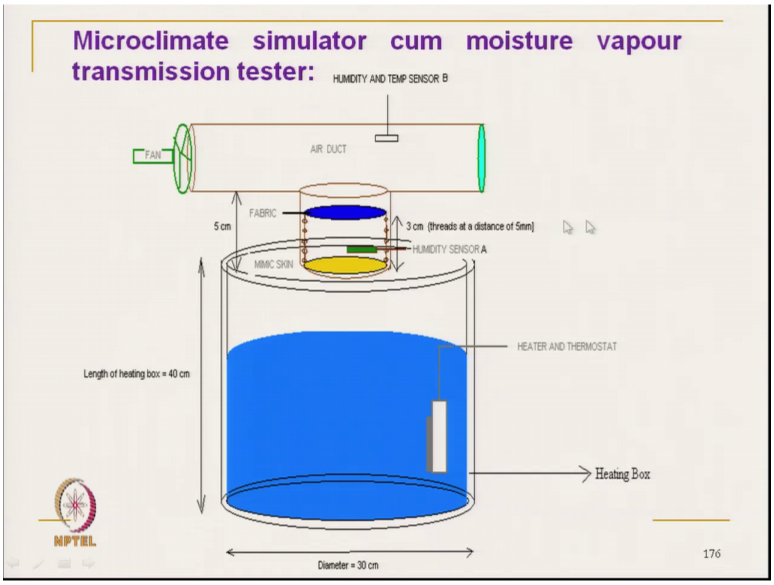

So, microclimate simulator means that we want to create the microclimate ok. This is the instrument, the schematic diagram of the instrument. Here the water tank is there which is there is thermostat control. We can control the temperature it is connected with the heater. We can control the temperature of the water in such a way so, that the skin temperature, the when it is coming out of the skin; this one the yellow one it is a mimic skin, we have used some material which actually represent the skin.

So, the temperature of water is maintained in such a fashion the so, that the moisture vapour that temperature of the skin is at 37 degree Celsius that is how we can maintain this temperature. So, as the moisture it is water is getting heated the moisture will get transmitted through this skin mimic skin. And, what we have created here the gap the dark blue one, this one is the fabric specimen. So, here we can change at distance. This is actually a skin and the fabric this actually shows the microclimate

So, what we are interested in here at this point what is the temperature and the what is the humidity of this microclimate because, the temperature and humidity of the microclimate which actually affect the comfort sensation. And, this is the fabric and depending on the fabric type, depending on the transmission characteristics of the fabric, the microclimate temperature and humidity changes. And, also here the air blow system is there, if we want to measure the at different air flow rate; what is the microclimate condition at say wind at blowing wind condition that also we can measure. So, this instrument gives idea about the comfort sensation.

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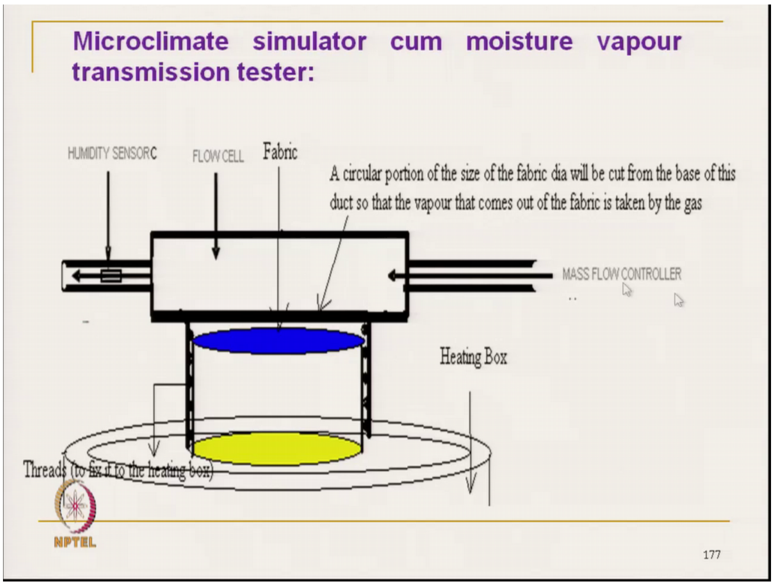

This is the condition here fabric sample and humidity sensor is kept here, mass controller is there.

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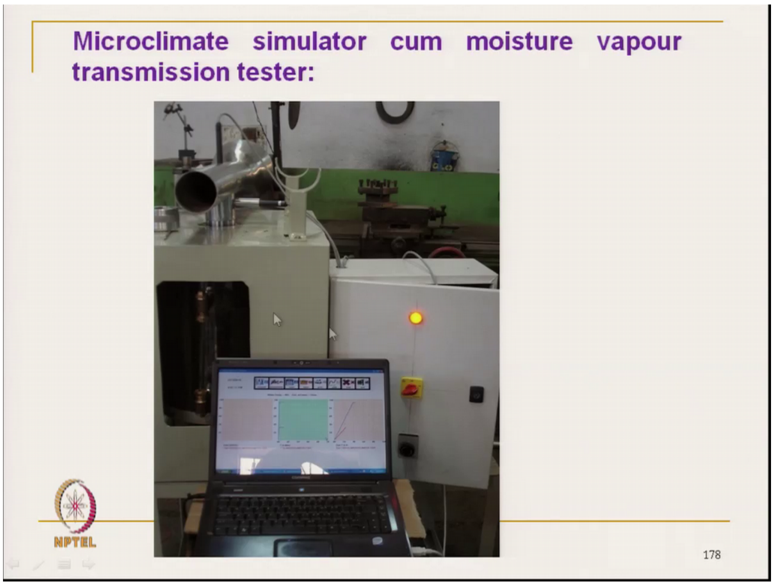

This is the actual instrument ok, this is the air channel and inside the water tank can microclimate portion is there. And, here also we can change the thickness of microclimate depending on our requirement, depending on the; we can change the thickness of this; this can be shifted.

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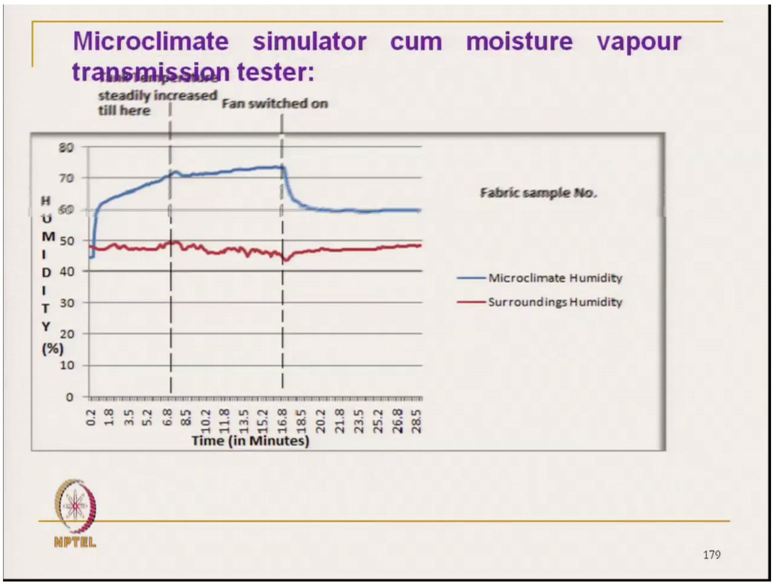

Now, if you see here this picture shows that humidity versus the time, at different time how the humidity changes. And, the blue line shows the microclimate and the red line shows the atmosphere surrounding air ok. So, humidity of the surrounding air if you see so, here in this instrument we have kept the sensor here also at the humidity sensor and temperature sensor, at the this is this is showing the atmospheric air. This is adjacent air and microclimate also we can we are measuring. So, if we see the humidity so, humidity of the adjacent air. So, atmospheric air surrounding air it is almost constant, but gradually the humidity in the microclimate increases.

So, that is due to the presence of fabric and type of moisture vapour transmission, the humidity of the microclimate increases gradually. So, it is increasing the skin temperature steadily increase till here and gradually it is also increase. So, at initially the humidity is increasing at the faster rate, but after that rate is becoming slower because, it is getting saturated ok. So, it is close to 80-85 80 percent, 75 percent. After that after certain time the fan is switched on just to simulate that air started blowing, which actually enhance the convective moisture transmission. Convective moist transmission is there and as the air blowing so, it takes away the humidity from the microclimate that is forced convection is taking place.

So, our humidity in the microclimate drops. So, that is it shows and what we have observed this is a typical curve. But, our experiment shows the at different fabric that nature of drop humidity is different. So, from there we can select the type of fabric and also it depends on the thickness of microclimate, at different thickness the drop in humidity of microclimate will be different. So, this all this detailed study has been already reported, but this instrument gives idea about the increase in humidity in the microclimate and drop in humidity when the fan is changed; so we can track the total humidity and also the temperature.

So, temperature of microclimate we have seen it increases gradually because, it is a vapour pressure increases. So, temperature of microclimate increases gradually the hot humidity is increased. So, it is from 25 degree Celsius initially at the microclimate it is going gradually it is increasing. So, it can go further up, but as we have switched on the fan it drops. So, it is dropping because of the forced convection of heat forced convection is taking place. So, this instrument measures both heat and mass transmission characteristics. Another technique is holographic bench technique which is by micro weighing of the moisture level.

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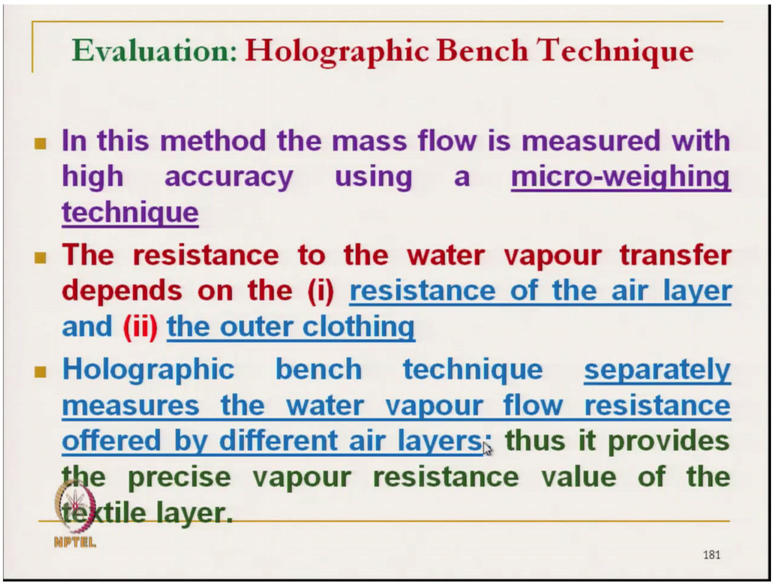

In this method the mass flow is measured with the high accuracy using a micro weighing technique, holographic bench technique. The resistance to the water vapour transmission depends on the resistance of air layer and outer air layer and the outer clothing. So, that the outer clothing the resistance and resistance to air layer. So, in this technique we measure the resistance to air layer. So, holographic bench technique separately measures the water vapour flow resistance offered by the air layer.

So, if we measure the resistance offered by the air layer then we can actually know the what is the resistance offered by the fabric layer. So, it separates out the moisture vapour resistance by the air layer. So, that is how we can measure the, we can use this holographic bench technique ok, that is provides the precise vapour resistance value of the textile layer.

So, we will stop here. We will continue with the measurement technique and the next talk we will start with the sweating guarded hot plate.

Thank you.