Testing of Functional & Technical Textiles
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Lecture – 06
Testing of Transmission Characteristics of Textile Fabrics (contd…)

Hello everyone. We will continue with the measurement of moisture vapour transmission through fabric. In last class, we discussed the upright cup method, where a shallow cup is filled with water and the fabric is mounted on the cup and the total assembly kept in environmental chamber.

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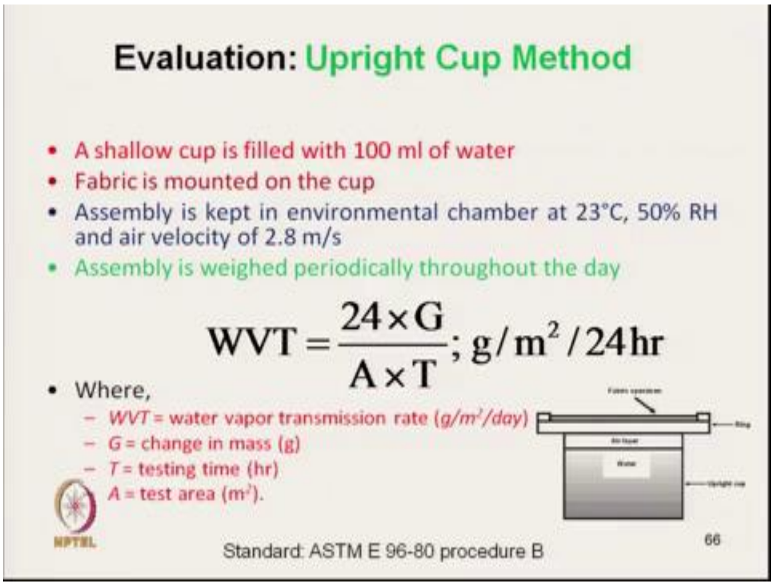

Assembly is weighed periodically throughout the day and we can calculate the water vapour transmission using this formula in terms of gram per square meter per 24 hour.

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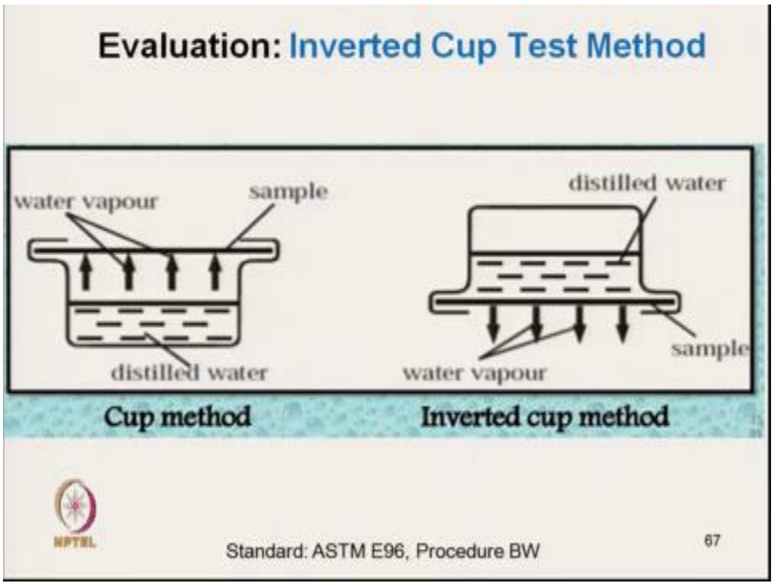

Now, after this the next method is which is Inverted Cup Test Method. So, inverted cup method; so, normal cup method is this one, where the distilled water its partially filled in a cup and fabric specimen is actually covering the cup and water vapour is transmitted so through the fabric. So, this is the normal method, but inverted cup method is a just after placing the fabrics specimen, the cup is inverted. But here the system is not that simple. Here, we have to use some other technique; otherwise the fabric will get wet and the water will drip through the fabric specimen. So, we will not be able to measure the moisture vapour transmission.

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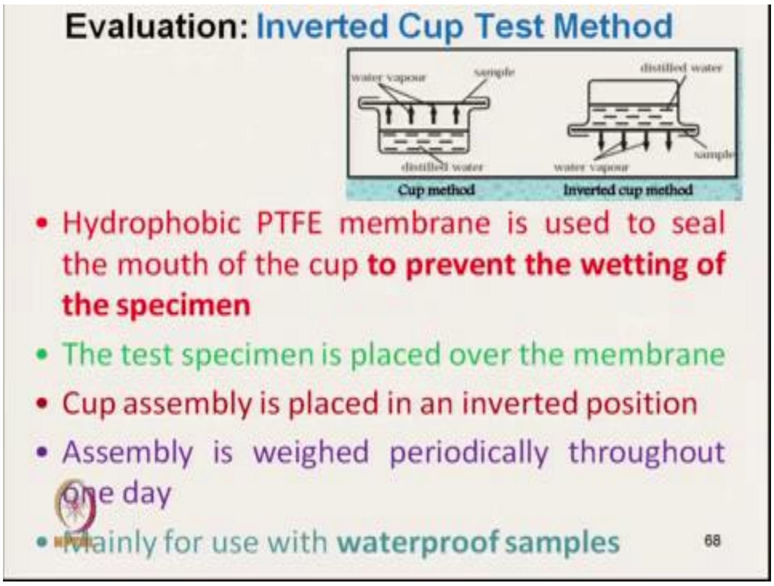

So, to do that the technique is that the hydrophobic PTFE membrane is used to seal the mouth of the cup to prevent the wetting of the specimen. So, once the fabric along with the cup is inverted. So, to prevent that wetting of the fabric specimen, the mouth of the cup is first covered with the PTFE membrane which is waterproof; but breathable. But then, the test specimen is placed over the membrane.

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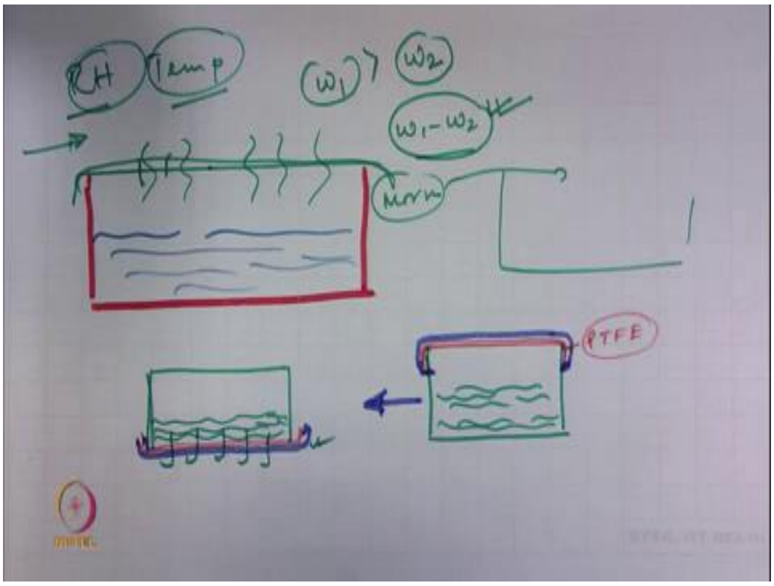

Now, if you see here this is the cup ok. In this cup is partially filled with water and first this cup mouth of the cup is covered with its PTFE membrane which is waterproof, but breathable. It allows the moisture vapour and then, the fabric specimen is placed. This arrangement is actually preventing the wetting of the fabric.

Now, after this the total system is inverted. Let me draw. This is inverted and this PTFE membrane and then you have fabrics sample and water after making it inverted, water will come in this side. Here the fabric is not getting wet because the PTFE membrane is preventing the fabric to be in touch with the water; but with this arrangement, the water vapour will pass through the fabric and this system is used mainly for waterproof type of fabric ok.

So, the cup assembly is placed in an inverted position. Assembly is weighed periodically throughout one day, as we have seen in earlier case mainly used for fabric with waterproof.

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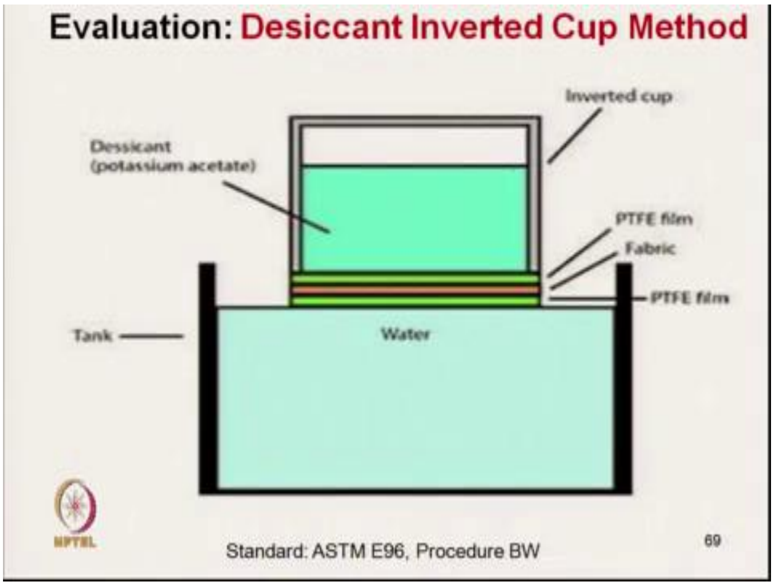

Now, after that another method is that it is called Desiccant Inverted Cup Method. Now this is almost similar to that of inverted cup method, but it has got some difference also. In inverted cup method, the cup was filled with water. But here we are not using any water; in place of water here we are using desiccant material.

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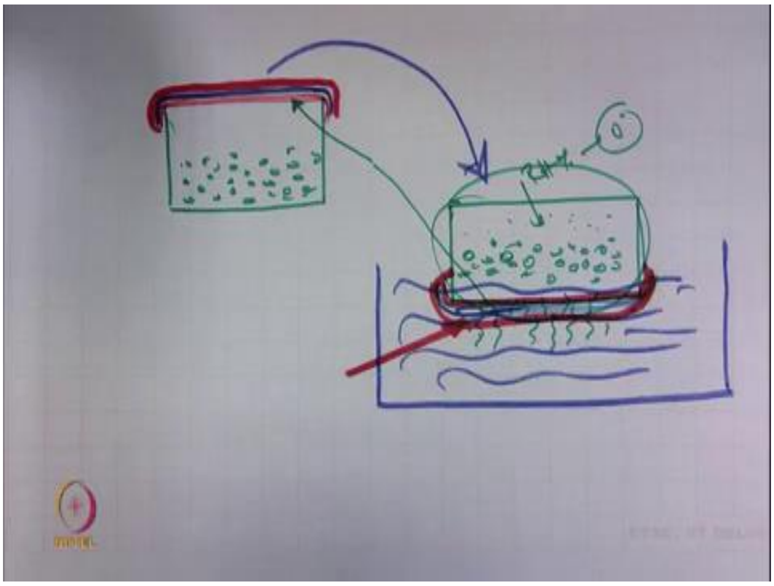

Now, the technique let me explain; first this is cup. And here some desiccant material will be there granules; will be there. Some may be a different form; may be powder form, may be granule form ok. And this cup is first the mouth is covered with the waterproof, but breathable sample may be PTFE coated sample and then, the fabric is placed here. After that we again use another layer of waterproof breathable specimen. Now, this inner one it is optional. We may or may not use this inner layer; but outer layer is must. Now, after that what we do? We take say water bath which is filled with water.

And this cup is placed in inverted condition. Now let me draw again. So, this is the cup I am trying to draw here, cup and here its inner portion is one layer. Then, we have the fabric layer, the fabric layer and we have main outer layer. This is the outer layer. Now what happens? This outer layer is preventing the fabric of being wet, it is not getting wet and we have desiccant. Now, these granules desiccant granules will ensure that the relative humidity that it will become almost 0 percent. So, it is actually the cup remains dry and whatever moisture vapour enters this desiccant, they will absorb and as it is placed inside water.

So, water vapour will get transmitted through the fabric sample and outer layer as it is a porous it will allow the moisture vapour. It will not allow the water molecule, but water vapour molecule is allowed and this will directly pass through the fabric specimen and mass of the this cup is measured and the inner layer; inner layer of this PTFE coated specimen breathable waterproof breathable, it is optional. If we want that the desiccant material to touch the fabric so that it trap it can absorb the moisture quickly so that we may eliminate the inner layer ok. So, in this picture it is showing two PTFE coated, but inner layer we can always avoid.

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So, this is similar to that of Inverted Cup Method, but the only difference is that in this method the cup used in this method is partly filled with desiccant such as Potassium acetate, Calcium chloride, Anhydrous CaSO4 like that. The drying agent, this is desiccant materials. The drying agent stays in direct contact with fabric; that means, if you do not use the inner PTFE coated layer membrane that means, this desiccant agent will be in direct contact with fabric which will minimize the path of water vapour. That means, to directly absorb, immediately absorb that is as soon as the moisture vapour crosses the fabric layer.

The inverted cup is covered by specimen and the specimen is covered by another piece of waterproof and vapour permeable membrane like PTFE that we have discussed already. The inverted cup along with the specimen is immersed into the water bath filled with distilled water with the help of specimen holder. So, a specimen holder will be there that will actually help in immersing the total setup.

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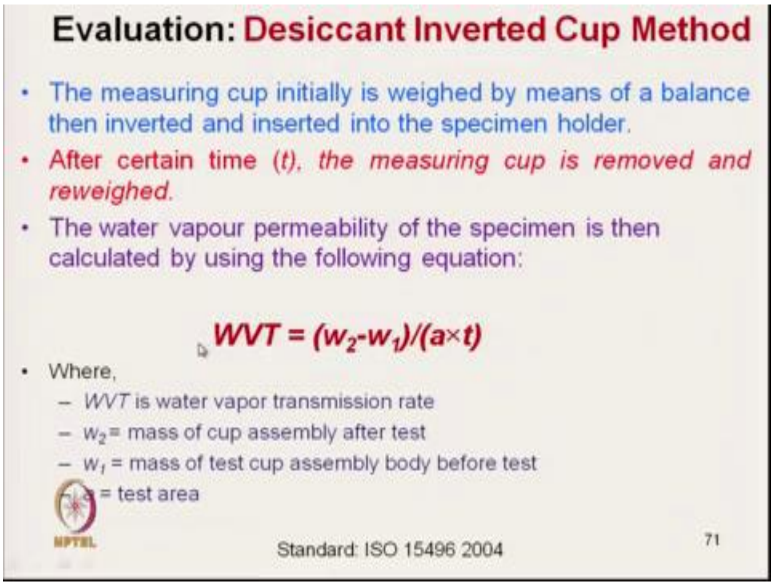

The measuring cup initially is weighed. So, before immersion we can take the weight by means of balance. Then inverted and inserted into the specimen holder. After certain time t, the measuring cup is removed and reweighed. So, as the desiccant material they absorb moisture which is transmitted through a fabric. So, the mass of the cup total assembly will change, it will be increased. So, it will be reweighed and the water vapour permeability of the specimen is then calculated by using the following equation ok.

$$WVT = (w_2 - w_1)/(a \times t)$$

- Where,
  - WVT is water vapor transmission rate
  - w_2 = mass of cup assembly after test
  - w_1 = mass of test cup assembly body before test
  - a = test area

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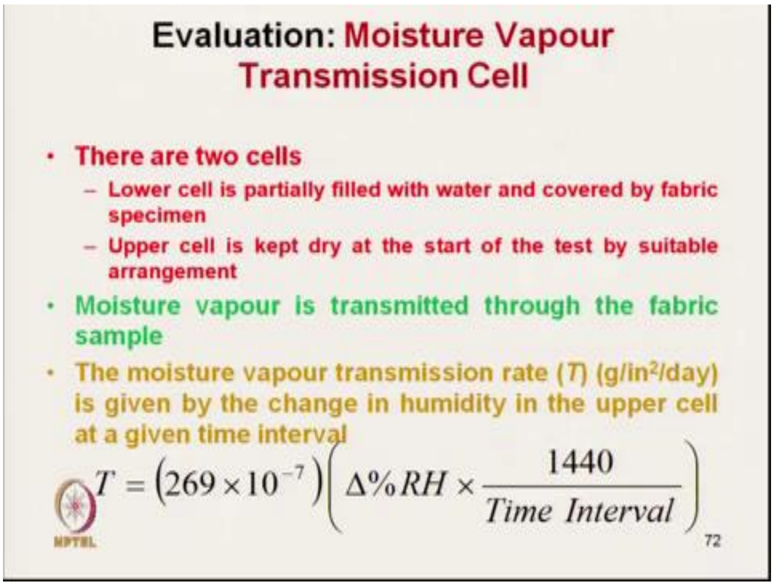

Next method is that it is a Moisture Vapour Transmission Cell. So, here we have two cells now, let me discuss this.

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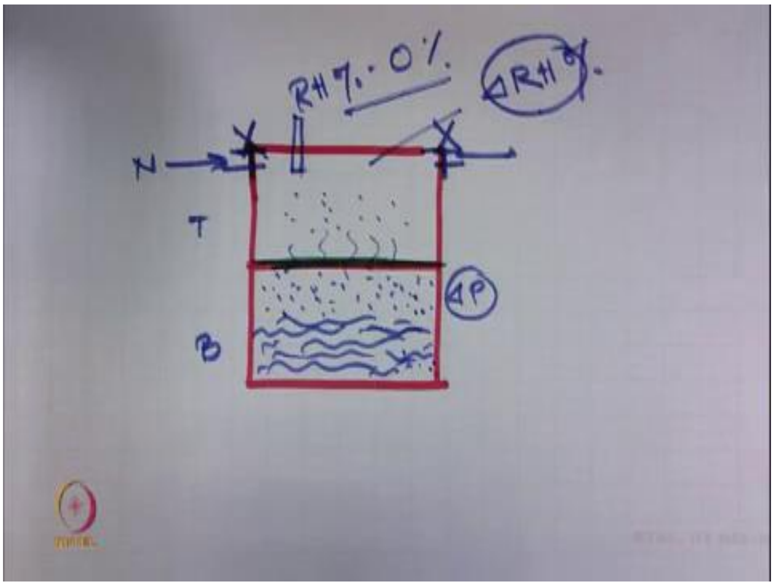

So, here we have two cells; two cells, one is bottom cell and other is top cell. This is bottom cell and this one is top cell. Bottom cell is partially filled with water and once it is actually partially filled. So, due to the moisture vapour here in this cell, the moisture is actually saturated and with have which have higher pressure. So, vapour pressure is high and the fabric specimen is placed in between. This is the fabric specimen and top cell initially it is actually get dry.

So, dry its totally its dry initially ideally it should be 0 % relative humidity by some means. We can actually flow dry nitrogen and to make it 0 %. After it is being totally dry; then this inlet and exit, we are closing it is closed and here it is the relative humidity sensor is there and moisture is getting transmitted inside the upper cell. And we can measure the change of relative humidity RH %, we can measure by the relative humidity sensor and using this RH %, change of RH % with the time with the particular time, we can measure the moisture vapour transmission.

So, there are two cells; lower cell is partially filled with water and covered by fabric specimen. The upper cell is kept dry at start of the experiment by suitable arrangement. We can use various arrangements to make it totally dry. So, its theoretically it should be 0 % relative humidity. Moisture vapour is transmitted through the fabric sample with the time. The moisture vapour transmission rate T, **g/in^2/day**.

So, that is given by the change in relative humidity in the upper cell at a given time interval. So, using this equation we can calculate the moisture vapour transmission rate. So, this is the constant of this instrument. Change in relative humidity with the time interval and 1440 is the constant of the system. So, using this formula,

$$T = \left(269 \times 10^{-7}\right)\left(\Delta\%RH \times \frac{1440}{Time\ Interval}\right)$$

if we can calculate if you can measure the relative humidity change and with the time, we can calculate the moisture vapour transmission rate. It is a simple. Here we are not measuring the mass, indirectly we are measuring the rate of change of relative humidity ok.

So, from this we can calculate the moisture vapour transmission rate. Now next method is the micro climate cum moisture vapour transmission tester.

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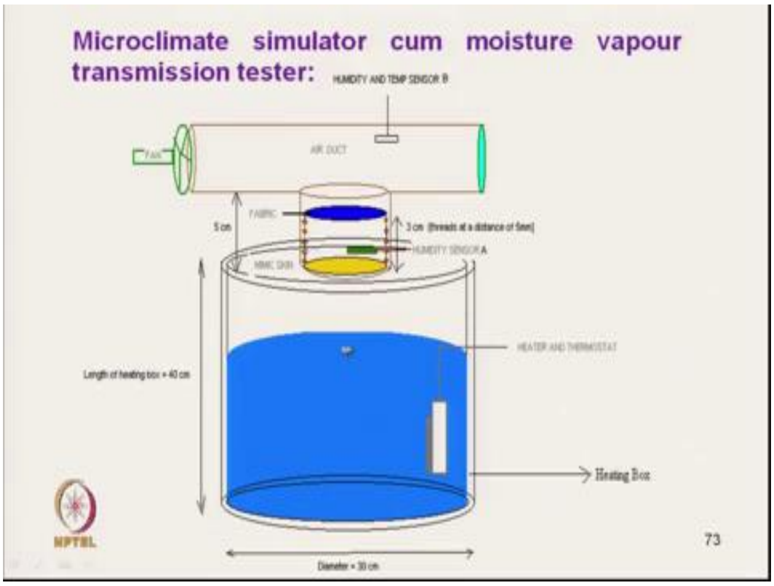

So, it simulate the micro climate and then it can measure the moisture vapour transmission. Now this is the instruments setup schematic diagram of the instruments. What is Microclimate? As we know the Microclimate is the climate between our skin and the fabric. So, we would like to know what is the micro climate condition for different fabric or different environmental condition and also we can calculate the moisture vapour transmission.

So, let us see the instrument setup. Here this is the chamber which is partially filled with water and here that it is a heating box, we can heat the water so that the moisture vapour is generated; but heating is controlled by thermostat so to maintain certain temperature. So, this temperature is important because our skin temperature, we have to maintain in the mimic skin. This is the mimic skin and this skin temperature should be around 35 degree Celsius.

So, to maintain this skin temperature 35 degree Celsius we have to maintain certain temperature and from our experience from our experimental result, we have seen if we keep around 40-41 degree Celsius of this water temperature, in that case we can maintain the skin temperature around 35 degree Celsius.

So, that is controlled temperature is controlled by the thermostat and the there is a gap created here which ensure the moisture vapour will actually transmitted through the mimics skin. This is yellow color; it is a mimic skin. We are we have used some vapour permeable membrane here and this is the micro climate chamber and the thickness of the micro climate can be changed.

It is actually 3 centimeter is maximum and we can change it to 0, where when the fabric specimen which is shown in blue color which is in when its touching with the mimic skin; that means, it is in the it shows the fabric is in touch with our skin. And in the micro climate zones what you have placed, it is a temperature sensor and humidity sensor.

Here, we can measure the temperature and humidity also and the from the skin the vapour is coming and the fabric will actually it will transmit the moisture vapour through the fabric and also here to simulate the actual condition actual windy condition, here you can use one tunnel wind tunnel and that fabric specimen through the fabric, the moisture vapour will get transmitted and it will come to the wind tunnel and where the fan is used to blow the whatever moisture vapour is accumulated there and it will simulate the forced convection.

And here will try to see as we change the flow of air, our moisture vapour that relative humidity of the micro climate and temperature also changes.

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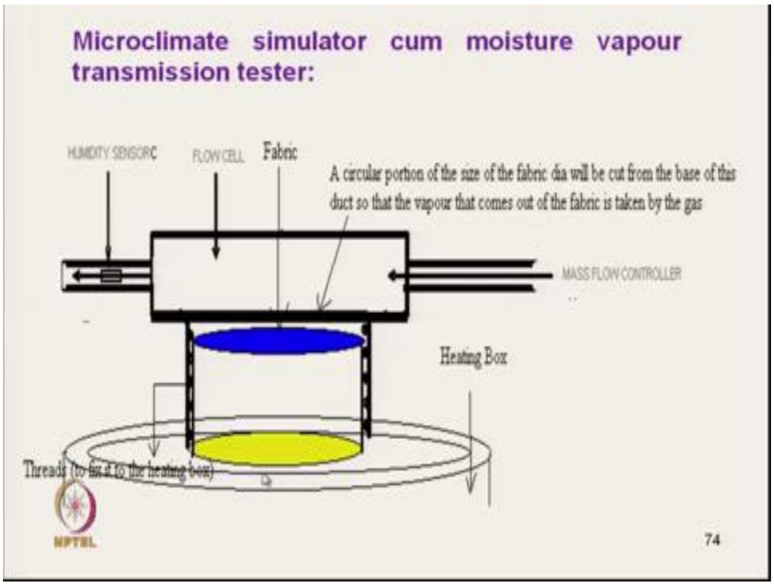

So, hear a circular portion of the fabric ok, it is placed here and this is the mimic skin; Humidity Sensor is here is placed.

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This is the actual photograph of the instrument and we can record the change of relative humidity and temperature with time.

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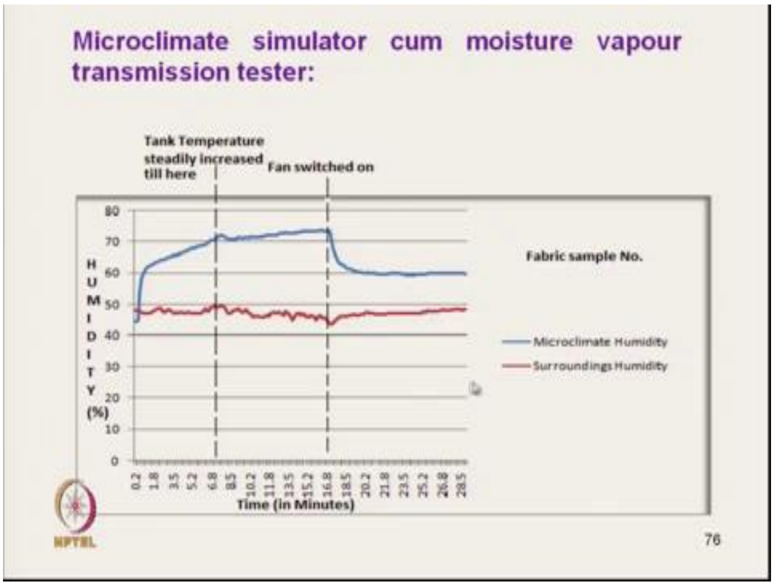

Now, this graph shows Microclimate humidity and surrounding humidity; if we see and this surrounding humidity and microclimate humidity is plotted with the time. We can see here the surrounding humidity is almost constant; it is not changing, but the microclimate humidity, it increases gradually with the time. That means, as the moisture vapour is transmitted through the mimic skin, the fabric has got its some the moisture vapour transmission rate and that will prevent the free flow of moisture vapour that is why the moisture vapour pressure is increasing and relative humidity is increasing within the fabric and the skin that is the micro climate zone and this the difference this difference has to be minimum.

So, we can if we know this difference, we can develop fabric with higher moisture vapour transmission, and at this point, this point shows which is at a 16.8 minutes, at that time when the fan switch is on; fan is switched on, the moisture in the micro climate that is relative humidity drops immediately which shows the forced convection due to the forced convection whatever relative humidity the moisture was there inside the microclimate, it has been actually forcefully drawn through the fabric.

So, which stimulates the windy condition; that means, once we feel the sweaty or humid if the wind is blowing. Then you will feel little bit dry. Due to that the forced convection and this experiment simulates that condition. Now we can test this is a typical curve typical curve of a particular fabric, we can test wide range of fabric and we can see the drop in relative humidity.

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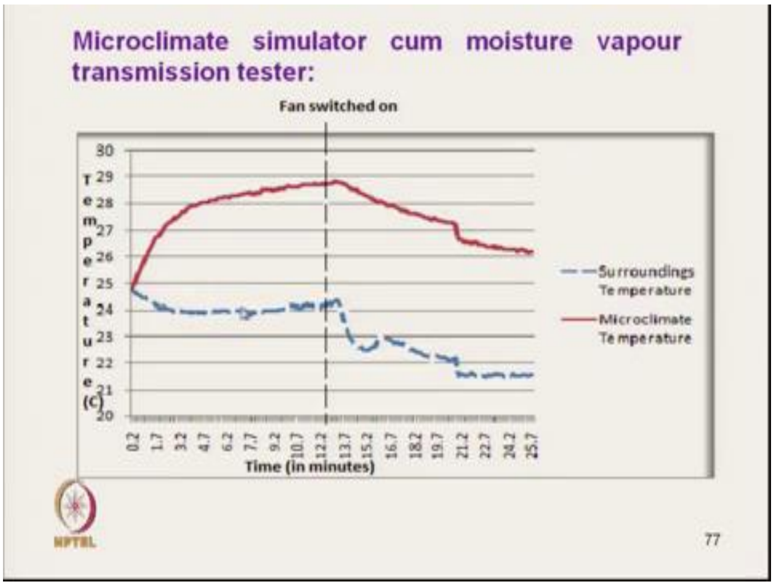

Similarly, this is the temperature of micro climate temperature that is the micro climate simulator. This is the surrounding temperature which is which remains constant before the fan is switched on. But the temperature of the microclimate increases gradually; initially at very high rate, but its increasing consistently. This is because of the increase in moisture vapour pressure and the hot relatively hot that moisture vapour comes through the mimic skin and accumulated inside the micro climate that is why it is reaching from 25 degree Celsius to gradually its reaching 29 degree Celsius and it will keep on increasing.

And it will maintain the temperature close to the skin temperature, but as soon as we switched on the fan and the moisture vapour gets removed from the microclimate and microclimate temperature starts dropping. So, that typically shows the behavior of micro climate and we can see the actual feel of coldest or hot feeling. So, we can simulate here and for different types of fabric, we can simulate, we can actually predict the performance.

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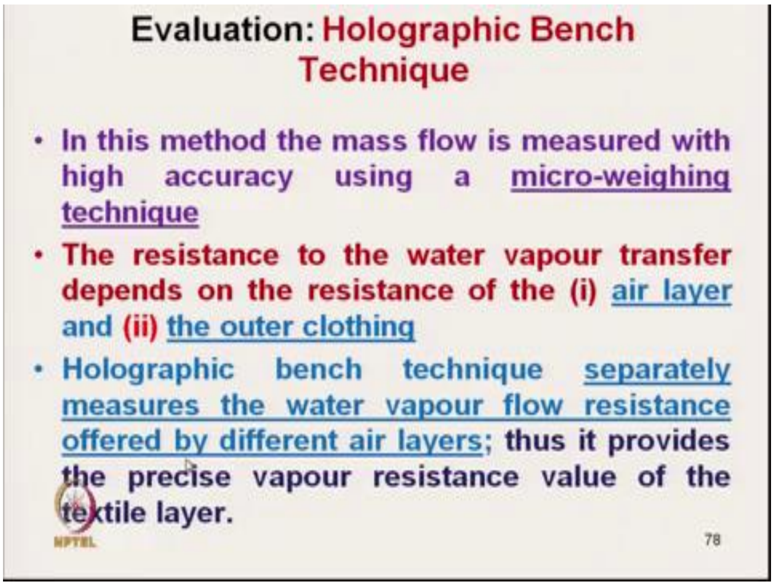

Next technique of measurement of moisture vapour transmission is Holographic Bench Technique. Here in this method, the mass flow is measured with high accuracy using a micro-weighing technique. The resistance to the water vapour transmission depends on the resistance of the air layer as well as the clothing layer and holographic bench technique separately measure the water vapour flow resistance offered by the air layer. So, it measures the water flow resistance by the air layer. Thus, it provides the precise vapour resistance value of the textile layer. So, it separates out the moisture vapour transmission; moisture vapour resistance by the clothing layer.

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Next technique is that Sweating Guarded Hot Plate. So, we will discuss later when we will discuss the dry heat transmission, the guarded hot plate the principle of guarded hot plate we will discuss later. But at this point, we will see the principle of sweating guarded plate. The working principle is similar to that guarded hot plate, but with little difference where we use the sweating plate.

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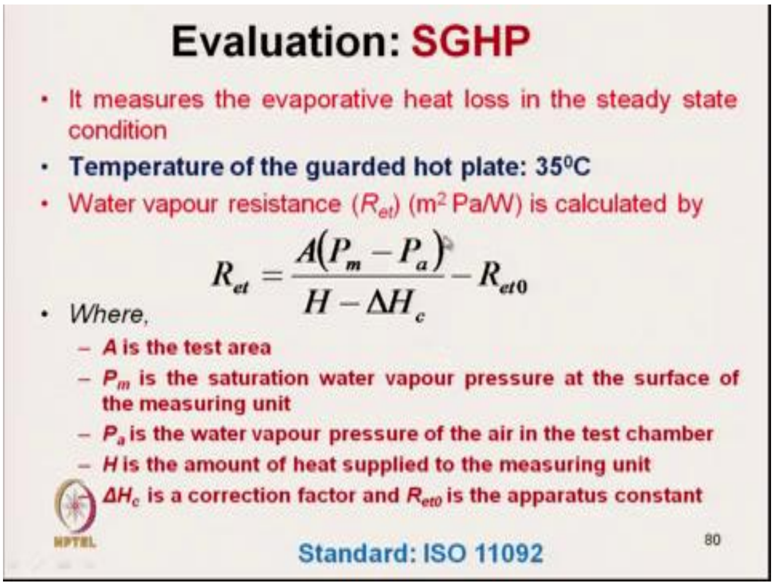

It measures the evaporative heat loss in the steady state condition. So, when the water gets evaporated and during the evaporation, it takes the heat the latent heat of evaporation that quantity of heat it measure and the heat is actually indirectly shows the moisture vapour transmission. Temperature of the guarded hot plate is kept at 35 degree Celsius because, the guarded hot plate its simulates the skin. Our skin temperature is around 35 degree Celsius. The water vapour resistance Ret which is expressed in terms of m^2 Pa/W is calculated by this equation.

So, basically its wattage required that is heat required per unit area per unit Pascal per unit vapour pressure and that is the a flux and its reciprocal of that its the water vapour resistance. So, Ret is

$$R_{et} = \frac{A(P_m - P_a)}{H - \Delta H_c} - R_{et0}$$

- **A is the test area**
- **P_m is the saturation water vapour pressure at the surface of the measuring unit**
- **P_a is the water vapour pressure of the air in the test chamber**
- **H is the amount of heat supplied to the measuring unit**
- **ΔH_c is a correction factor and R_{et0} is the apparatus constant**

So, it is the water vapour pressure of the air in the test chamber.

So, ambient vapour pressure. So, Pm - Pa is the difference in vapour pressure so which is actually the driving force. The H is the amount of heat supplied to the measuring unit to keep the guarded hot plate 35 degree Celsius. So, to keep that plate at the constant temperature, we need to supply extra heat that is H ok. And A is the area and ΔHc is the correction factor of the instrument and Ret0 is the apparatus constant. So, this is the apparatus constant which is nothing but the bare plate resistance. So, this is the resistance with the fabric specimen.

This is the resistance with the bare plate. If we actually subtract the bare plate; so, this will give us the actual vapour resistance of the fabric. So, this give in the terms of operation of wattage Pm - Pa, it is a Pascal vapour pressure and this is m^2 Pa/W. So, this is the Ret0 this its unit is again m^2 Pa/W.

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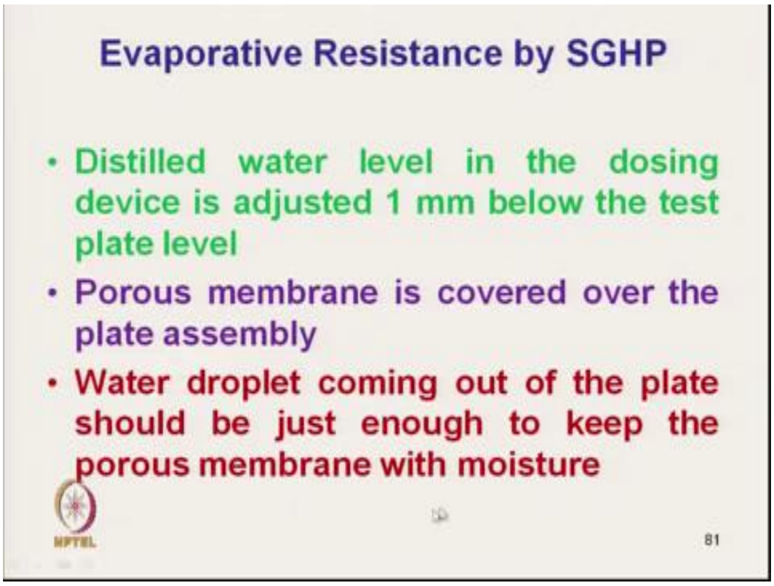

So, distilled water level in the dosing device is adjusted 1 millimeter below the test plate. So, otherwise the test plate will be flooded ok. The porous membrane is covered over the plate assembly. So, the test plate which is actually the sintered one; so, 1 millimeter below will keep the water level. And then, porous plate is covered with another porous membrane which will actually not allow the water to transmit through.

But it will allow the moisture vapour transmission. So, water droplet coming out of the plate should be just enough to keep the porous membrane with moisture. So, the porous plate, the sintered plate through that water will come and then this porous plate is covered with the porous membrane.

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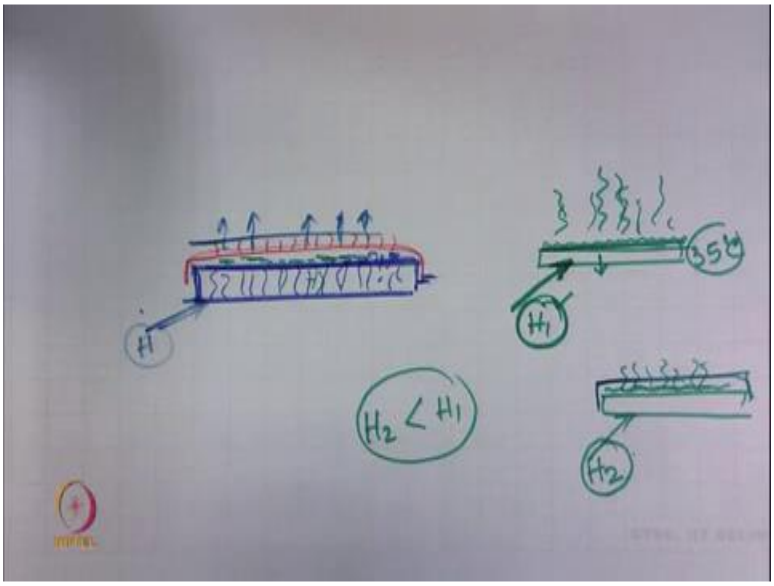

Ok. Now, let me draw this one. This is the porous plate which is test plate; water level is kept here. So, that water comes on the upper side ok. This is water. Now this is actually covered with this is the porous membrane which will not allow the water to pass through, but it allow the moisture vapour and then, we can use the fabric specimen. Here we can use the fabric specimen and through which we can measure the moisture vapour transmission and here the heat required to keep the plate temperature at 35 degree Celsius, we measured that is the H value.

So, the porous membrane is covered over the plate assembly. Water droplets coming out of the plate should be just enough to keep the porous membrane with moisture.

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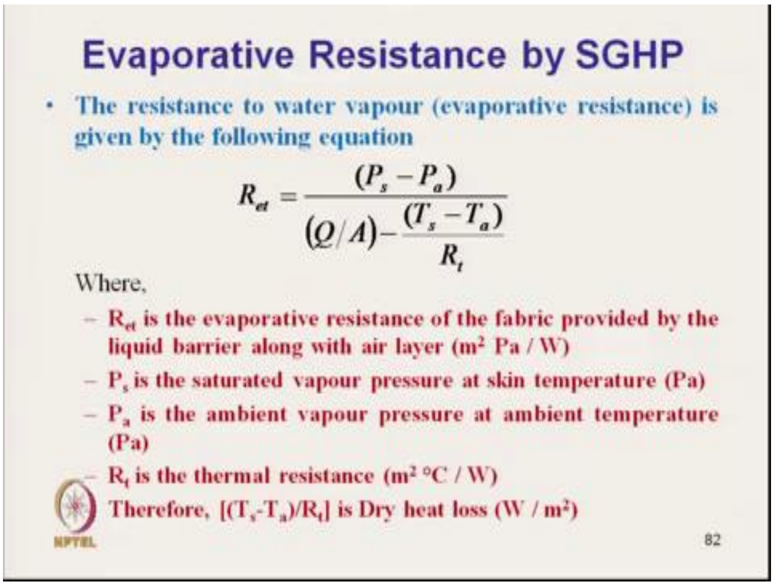

The resistance to water vapour that is evaporative resistance is given by the following equation.

$$R_{et} = \frac{(P_s - P_a)}{(Q/A) - \frac{(T_s - T_a)}{R_t}}$$

So, this is the water vapour resistance as we have seen earlier itself similar here Ps - Pa. So, where Where,

- **R_{et} is the evaporative resistance of the fabric provided by the liquid barrier along with air layer (m^2 Pa / W)**
- **P_s is the saturated vapour pressure at skin temperature (Pa)**
- **P_a is the ambient vapour pressure at ambient temperature (Pa)**
- **R_t is the thermal resistance (m^2 °C / W)**
- **Therefore, $[(T_s-T_a)/R_t]$ is Dry heat loss (W / m^2)**

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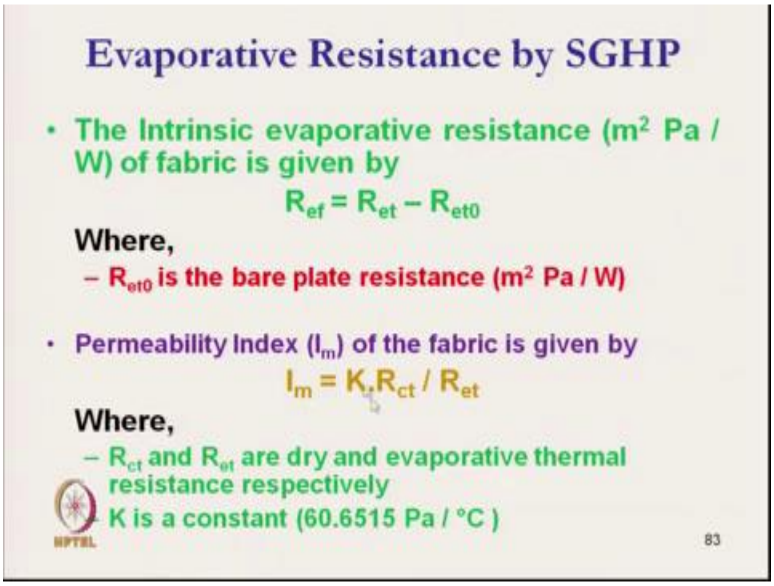

The intrinsic evaporative resistance is given by

$$R_{ef} = R_{et} - R_{et0}$$

Where,

– **R_{et0} is the bare plate resistance (m^2 Pa / W)**

So, for the total sample without fabric, there will be some resistance. So, that if we can subtract will get actual resistance required by the fabric. So, permeability index is the ratio.

- **Permeability Index (I_m) of the fabric is given by**

$$I_m = K.R_{ct} / R_{et}$$

Where,

– **R_{ct} and R_{et} are dry and evaporative thermal resistance respectively**

– **K is a constant (60.6515 Pa / °C)**

So, this permeability index it is actually it is a relationship between the dry thermal resistance and the wet thermal resistance. So, here we can measure the intrinsic evaporative resistance and also permeability index of fabric. Another method of measurement of moisture vapour transmission which is PERMETEST.

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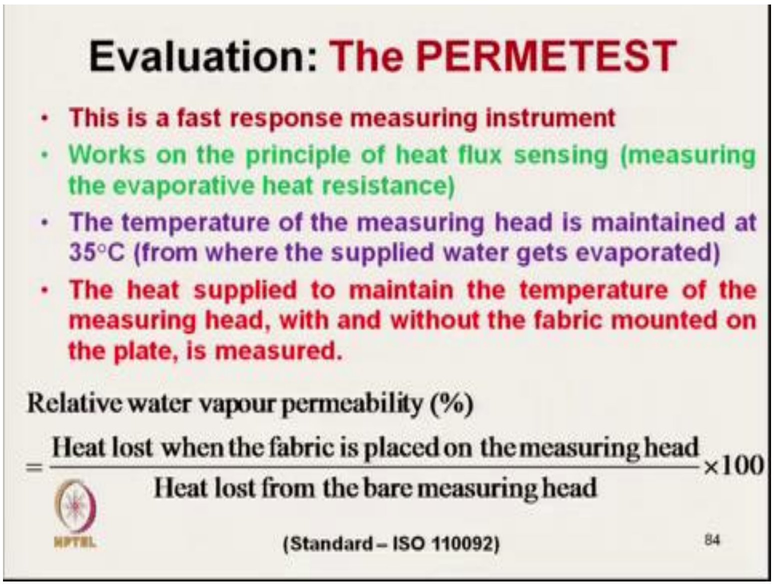

And this follow the standard ISO standard 110092 and this method its very fast response method. So, this is the fast response measuring instrument. It works on the principle of heat flux sensing that is measuring the evaporative heat resistance. The temperature of the measuring head is maintained at 35 degree Celsius. Again here we measure the measuring head temperature, 35 degree Celsius which is equal to our skin temperature from where the supplied water gets evaporated.

So, water will be supplied like our skin the water is supplied and from the skin as the water is getting evaporated, here the plate simulates the skin which is actually filled with water and that temperature is maintained 35 degree Celsius. The heat supplied to maintain the temperature of the measuring head, with and without fabric mounted on the plate is measured; that means, with and without fabric we are measuring the heat supplied.

$$\text{Relative water vapour permeability (\%)} = \frac{\text{Heat lost when the fabric is placed on the measuring head}}{\text{Heat lost from the bare measuring head}} \times 100$$

That means, if we cover the fabric cover the plate without fabric, the heat loss will be less. Now suppose this is a plate ok, plate where water is present. Now when we are heating and it is getting it is taking heat of H1 for evaporation.

So, when there is no restriction, it will evaporate more and more moisture and that is why it will take heat H1. Now in second case, when this water is there and when its covered with fabric specimen. The fabric specimen will actually restrict free movement of the water and in that case it will take the heat H2.

So, heat is taken just to maintain the temperature 35 degree Celsius during the evaporation. During evaporation, it is taking latent heat and the temperature will try to drop; to maintain that temperature, it will draw extra heat that is H1. So, when it is covered with fabric specimen; so, the heat drawn will be less. So, H2 will be less than H1.

So, this ratio will show the basically it the ratio of H2 and H1 will show the permeability characteristics; how much the fabric specimen is preventing the free flow free evaporation of liquid. So, heat loss when the fabric is placed on the measuring head, its less than the heat loss through the bare plate ok; so, because be during bare plate the more amount of the water will be evaporated.

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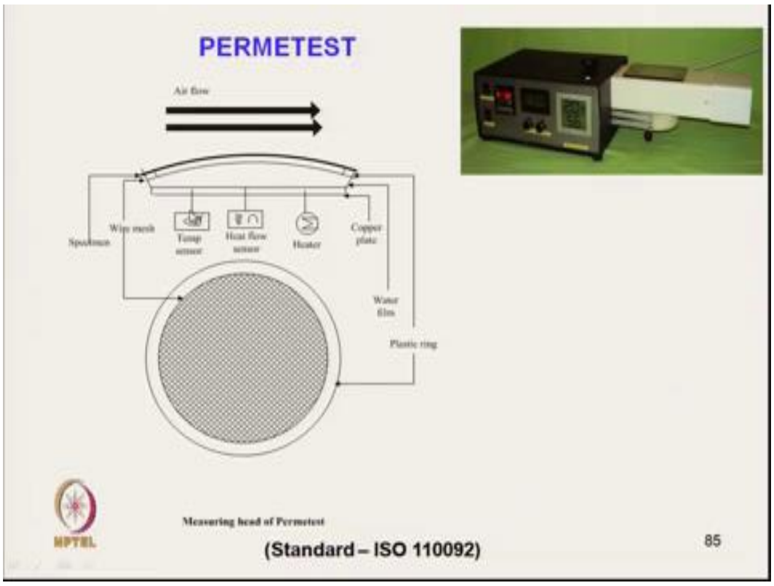

So, that is why the ratio is the relative water vapour permeability and this is the equipment. Here, we can see in this equipment. This one is the wire mesh. It is shown in the top view its wire mesh is there; on the wire mesh, we are placing the fabric. This is a fabric specimen, it is placed. Now at the bottom here it is a copper plate and then on the copper plate it is a water film is produced. So, water film is actually created on the copper plate and copper plate this plate is heated.

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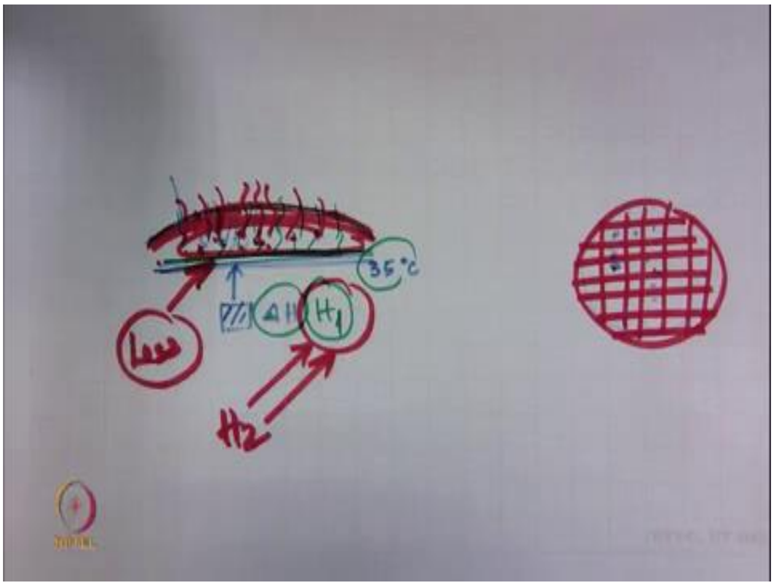

So, once the plate is heated suppose this is wire mesh and if you see, we draw the wire mesh top view of the wire mesh; this is the wire mesh. Now on the wire mesh, its total open mesh ok. Now, without any fabric suppose we are this is a copper plate; copper plate is connected with the heater. It is connected with the heater and there is a water film. Water film is created. Now once the heater is switched on, due to the heat to maintain the temperature of 35 degrees Celsius, there will be evaporation of the water and you shall freely pass through the wire mesh and it will draw this heat say H1, it will draw heat H1.

Now, after that when we place the fabric specimen here, this fabric specimen will block the free flow of the vapour depending on the vapour permeability. Initially when its wire mesh the there is no restriction, water will water vapour will pass through freely. But once you are placing the fabric over this was this mesh, it will prevent the free flow.

So, ideally if we see the fabric is totally it is blocked. There is no water vapour transmission. Its water vapour transmission is totally say 0. What will happen? It will not take the latent heat because moisture vapour transmission will not be there. So, the moisture vapour pressure will be high. So, it will draw less heat and once the fabric if the fabric is open, then it will try to take more and more heat.

So, as the fabric becomes more and more open the heat drawn by the plate will be close to say H2 will be close to H1. So, this ratio we can get and to calculate the moisture vapour transmission using the permetest and here, we can control the air flow. At different air flow rate we can measure the moisture vapour transmission.

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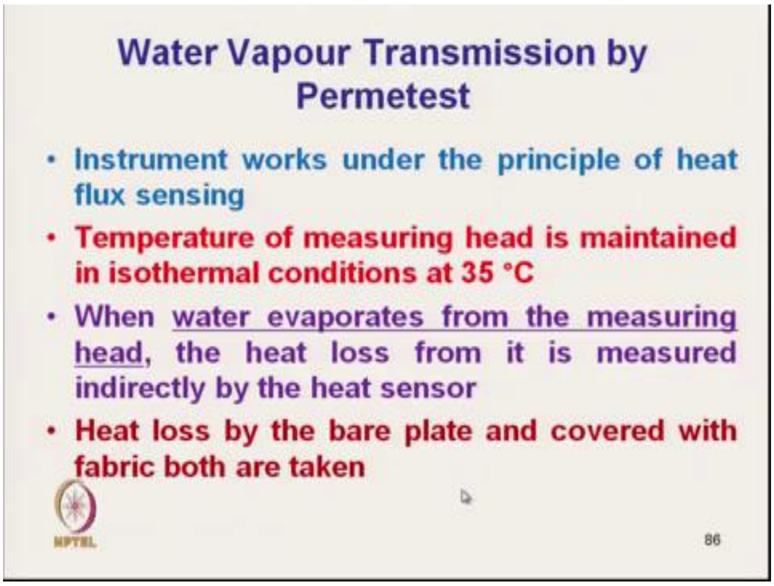

The instruments works under principle of heat flux sensing it sense the heat flux. Temperature of the measuring head is maintained in isothermal condition at 35 degree Celsius. When water evaporates from the measuring head, the heat loss from it is measured indirectly by heat sensor. Heat loss by bare plate and covered with fabric both are taken.

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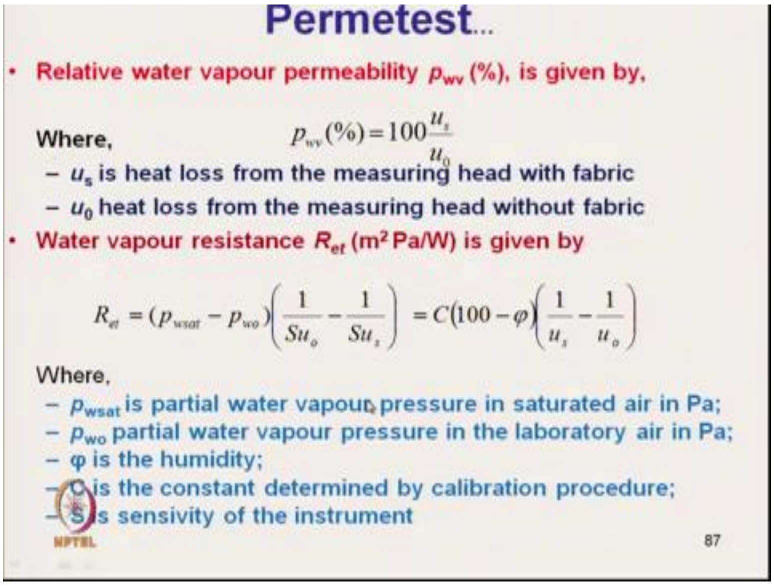

And this the ratio of this two heat is actually relative water vapour permeability; Pwv water vapour percent is given

$$p_{wv}(\%) = 100\frac{u_s}{u_0}$$

– ***u_s* is heat loss from the measuring head with fabric**

– ***u_0* heat loss from the measuring head without fabric**

What does it mean? If

u_s is equal to u_0 means u_0 will be maximum and u_s if the fabric is very open. It is to completely open fabric; then ***u_s*** will be close to u_0; that means, it will tend to 1 and water vapour permeability will be close to 100 percent.

And if it is blocking totally it is blocking; that means, there would not be any heat loss. There theoretically there would not be any heat loss because the fabric is blocking the moisture vapour to be transmitted. So, the plate temperature will not drop and it will not draw extra heat that u_0 will be 0; that means, the moisture vapour permeability will be 0. So, it is actual ranges from 0 to 100 %.

So, water vapour resistance can also be measured in this instrument.

$$R_{et} = (p_{wsat} - p_{wo})\left(\frac{1}{Su_o} - \frac{1}{Su_s}\right) = C(100-\varphi)\left(\frac{1}{u_s} - \frac{1}{u_o}\right)$$

- **p_{wsat} is partial water vapour pressure in saturated air in Pa;**
- **p_{wo} partial water vapour pressure in the laboratory air in Pa;**
- **φ is the humidity;**
- **C is the constant determined by calibration procedure;**
- **S is sensivity of the instrument**

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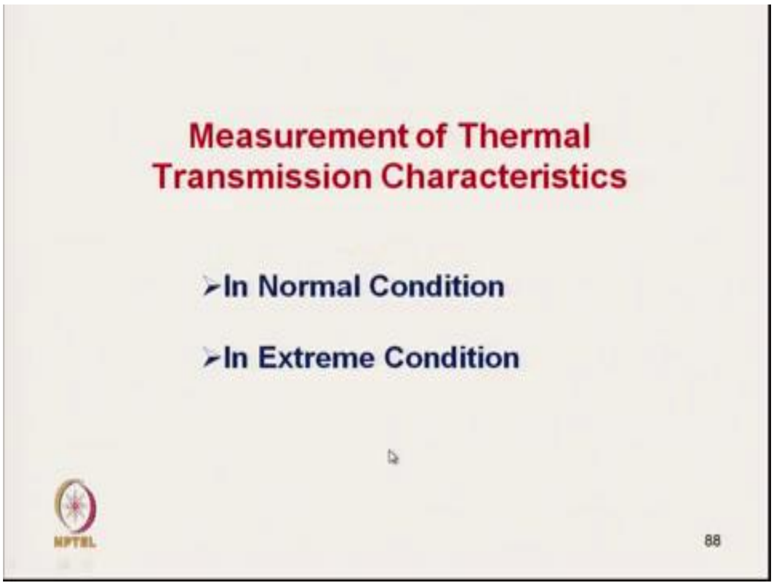

So, we have actually come at the end of the moisture vapour moisture in the form of liquid and in the form of vapour. Now will stop here will discuss in the next class the thermal characteristics. The measurement of thermal transmission through the textile material, through the functional textiles and we will measure in two aspects; one is in normal condition, another is we will see in the extreme condition. Extreme means in extreme cold and extreme heat condition may be in a flame or maybe in radiant heat condition, all this we will discuss in the next class.

Till then, thank you.