Science of Clothing Comfort
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Lecture – 29
Moisture Transmission & Clothing Comfort

Hello everyone. We are discussing the subject Science of Clothing Comfort. Now before we proceed further, let us first try to see what we have already discussed. Then it will be easy for us to continue further ok. So, we have already discussed on first we have tried to understand the concept of clothing comfort, what is there.

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So, first need and selection of clothing we have discussed. There are the various factors on which selection of clothing depends. Then we have discussed basic elements of clothing comfort. There are different elements different. Like a 4 different factors, 4 f's of clothing comfort, those we have discussed. Then clothing comfort and whereas, attitude we have discussed. So, even if fabric is comfortable in all sense, but whereas, attitude is also important, those aspects we have discussed. Then human and clothing interaction after that understanding clothing comfort, overall understanding clothing comfort we have discussed.

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In next segment in psychology and comfort. So, psycho physiological factors of clothing comfort we have discussed, then psychophysics laws of psychophysics wear trial technique has been discussed, then psychological aspects of aesthetic comfort which is very important, even if the fabric is totally comfortable in thermo physiologically like tactile comfort, but if it is aesthetically not pleasant. So, we may not be actually comfortable.

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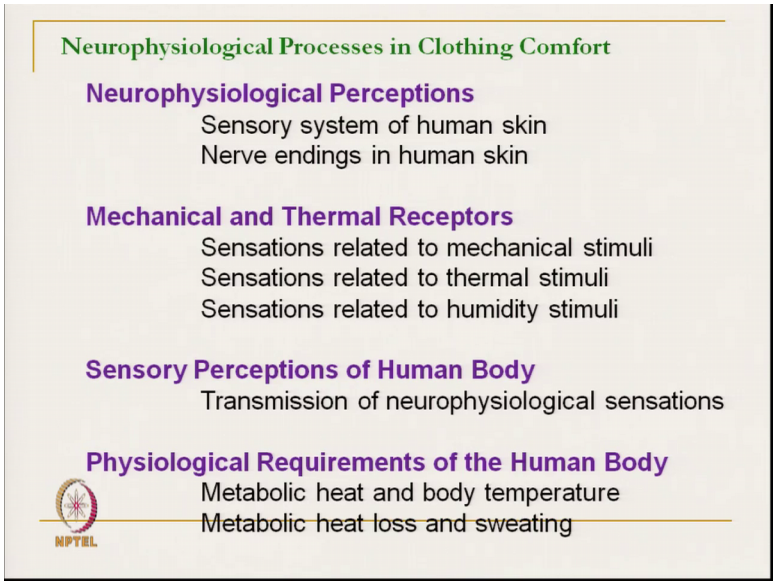

Next discussed that neuro physiological aspects of clothing comfort; where in we we have discussed in detail the different nerve endings different sensors available in our skin; with different sessions of mechanical sensation and thermal sensation. So, many types of sensors and there; one is mechanical sensor and thermal sensor another that effectively for humidity stimulation humidity sensor.

There is no specific sensors available, those aspects we have discussed. Then sensory perception of human body, how the sense transmitted to our brain, how brain reacts those parts have discussed and physiological the requirement of human body. So, there and metabolic heat body temperature so, how metabolic heat is lost, and what are the phenomena of how the sweating takes place through, all this we discuss, which are directly related to the comfort of human.

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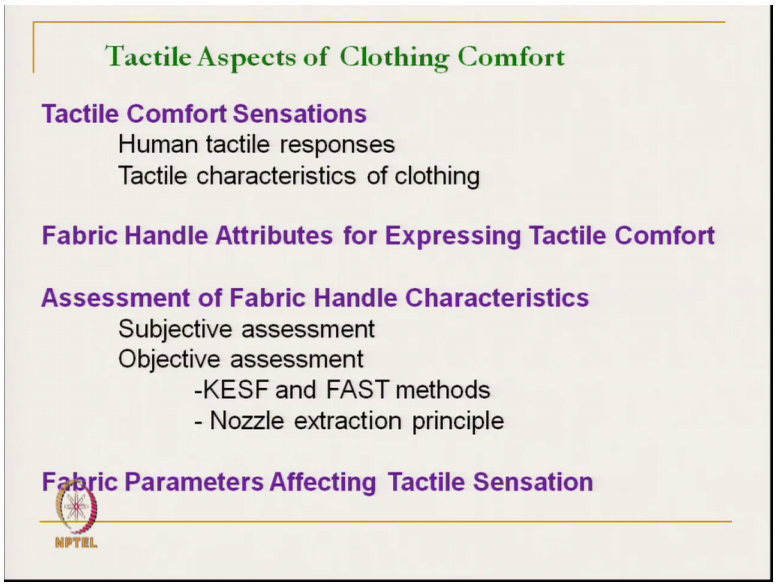

After that tactile aspects of clothing concert was discussed in detail; where human tactile response like touch, pressure, how these are related with the clothing, how clothing selection of clothing or type of clothing effect all the tactile sensation. To fabric handle attributes which is actually in directly they are related with the tactile sensation.

And measurement of human fabric handle characteristics mainly Kawabata evaluation, system for fabric and fast methods, those we have all discussed in detail and nozzle extraction principle, and how using how nozzle extraction that nozzle extraction force is related to the subjective assessment of clothing, that we have discussed in detail. Then

fabric parameters, affecting tactile sensation, that what are the different fabric parameters fabric bending rigidity fabric frictional characteristics compression, how are all these characteristics related with tactile sensation of clothing.

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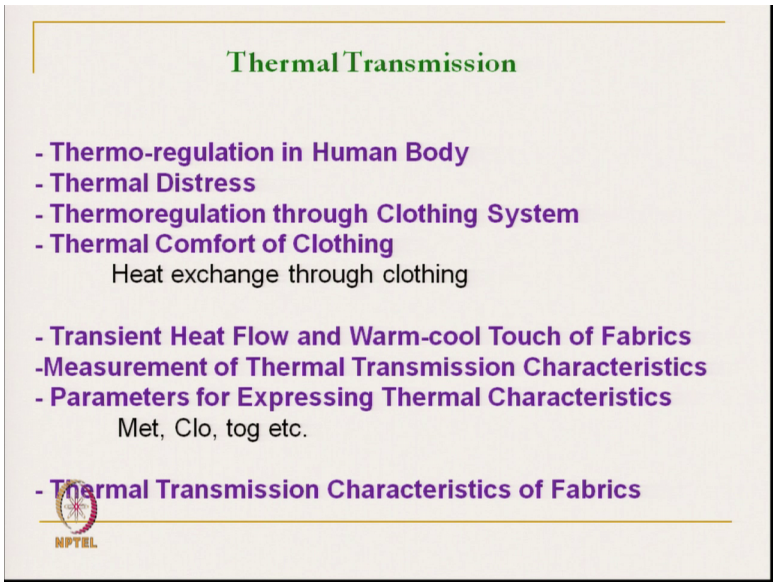

Then thermal transmission behavior of clothing we have discussed. Thermoregulation in human body, thermal distress condition if it is thermo dilution normal thermoregulation take place in normal temperature but in extreme, temperature extreme cold or extreme heat condition that it comes under thermal distress condition, and thermoregulation through clothing system, thermal comfort of clothing heat exchange through clothing that we have discussed; then transient heat which actually gives warm cool touch; that is the heat which is transmitted from our skin to the cloth immediately within second normally.

So, how then we have discussed the house of thermal transmission characteristics are measured. And what are the different practical parameters; like, Met, Clo and tog, how we can how are they related with each other, this we have discussed. And how these values this clo this actually practically used in application, thermal transmission characteristics of fabrics in detail, we have discuss the various factors which affect the thermal transmission characteristics, those have been discussed.

So, till now we have discussed all this aspects. Now we are going to start the moisture transmission characteristics and how are they related with the clothing comfort.

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Apparently it seems that moisture transmission is not that important. Only heat transmission is important. Now we will try to understand how the how important the moisture transmission characteristics for clothing comfort, to have a clothing comfortable clothing. So, to for designing comfortable clothing, the moisture management is extremely important; because the thermal transmission you we can only control by imparting the air pocket within the clothing.

But moisture transmission is extremely important, you can totally design clothing. It depends on the type of fiber used, type yarns used, yarn structure, fabric structure everything is relate even type of polymer, what type of polymer we use. So, we will discuss all these aspects of moisture transmission. Moisture normally transmitted in 2 forms. One is in vapour form; which is we called insensible perspiration, another is the sensible participation, which is in liquid or sweat form. So, this total moisture management is extremely important.

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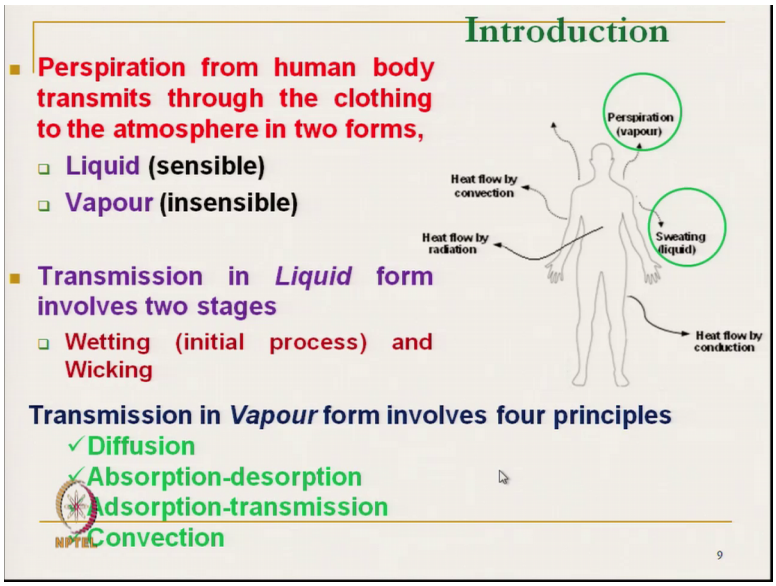

So, first let us try to see the perspiration from human body as I have mentioned, transmit through the clothing to the atmosphere from human body in 2 forms. One is liquid form which is insensible or sweat form, and second is insensible it is a in vapour form. So, in our discussion, we will discuss in detail the liquid transmission form, and then we will discuss the vapour.

So, if we see the liquid transmission; liquid transmission takes place in 2 stages. First stage, when liquid comes in to contact with the cloth with the fabric surface the fabric has to first get wet; that means, liquid should wet the fabric or here liquid we talk about here in clothing comfort liquid is the sweat. Sweat has to wet the cloth. What does wet mean? Wetting here means that the liquid has to penetrate inside the structure; that is, fast requirement for liquid transmission. And if it penetrates it is not the end that means, it has to travel. Travel through the structure and that is called vick. So, it has got 2 stages wetting and vicking.

So, we will try to understand if a fabric or if a textile structure has got wetting nature, very good it is wets. But it cannot vick, those type of fabrics are not suitable for clothing. Those fabrics we can used for wife or absorbent type cloth, but definitely we cannot use for closing, because in clothing after the water penetrate inside the structure, the total water should get transmitted, then only that will be transmitted to other side of the fabric and ultimately it will get evaporated. If the fabric only wets it is wetting is there, it does

not transmit; that means, it will start holding the moisture or holding that liquid inside the structure. Rhe that it will not be able to transmit; that means, the the total pores will get saturated will we filled. So, fabric clothing will be useless after second time.

So, all these aspects we will discuss. So, the liquid transmission if wetting or Vicky if one of them is not perfect, it is not balanced, it is not actually these are synchronized, then the fabric will fail particularly for clothing. So, if it supposed of a fabric is very good in wetting vicking, it does not wet, that it will also not help. Because the water the liquid will not penetrate inside the structure and no liquid will be available for Vicky. So, this 2 has to be there, this 2 have to be there because this 2 wetting and vicking both will go simultaneously.

Similarly, the transmission of vapour from the skin from our body, it takes place through different mechanisms. Mainly, there are 4 mechanisms. First is diffusion, it transmits through diffusion, then absorption and desorption. So, diffusion is in the vapour form, it actually it is driven by the vapour pressure. And absorption desorption means fiber material will absorbs the moisture in vapour form and it will get transmitted and then this desorption will take place it will get evaporated in other side. So, from inside the moisture in vapour form will get absorbed, then it will be transmitted through the fiber it is not through the pores thorough pores when it gets transmitted it is diffusion. And if it gets transmitted through the fiber structure which is very slow, it is absorption and desorption.

Third one is adsorption and transmission. What is that? Adsorption means moisture will get adsorbed on the surface of the fiber, typically in the little bit in the quid form micro droplets form, and then it will get transmitted through the surface; surface and it will ultimately go outside other and from there it will be evaporated. So, that phenomena is known as adsorption and transmission, and last one is that forced convection. In case of wind blowing through the fabric surface, clothing surface it will take away all the moisture vapour, and then in that forced convection the moisture will get transmitted.

So, we will discuss all these aspects ok. First we will start with the moisture transmission in liquid forms. So, in clothing if we see liquid, what is that liquid? Liquid we talk about it is a basically sweat. So, before we discuss about the wetting and vicking we must know the, what is sweat, how do we measure the sweating rate.

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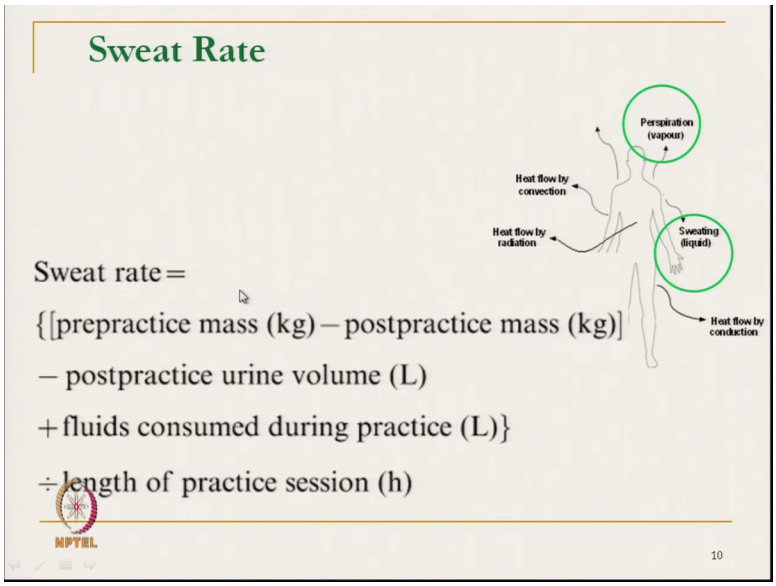

So, to understand the sweating rate so, it is actually perspiration in vapour form and perspiration in liquid form. So, heat transmission through the vapour and liquid form we actually effectively transmit our heat. So, here we are not discussing the heat flow dry heat flow through convection, conduction and radiation, because we have already discussed. So, these 2 aspect we will discuss here.

What is sweating rate? How do we measure? Basically sweating rate for any activity, it is a to amount of actual sweat, we actually we actually remove release the set per unit time, that is actually sweating rate. So, typical example is that, the sweating rate for a particular activity so, in activity particular activity prepractice mass. So, before the activity before the practice mass of the person is taken in kg. And postpractice mass; so, post practice mass it is we take. So, if we do not take extra water fluid or if we do not urinate, if you do not release any other form of liquid, then if you do not release any form of liquid, then this difference the prepractice and postpractice the mass is difference is mainly due to the release of sweat.

And suppose if we take water, if we drink water, and if we actually release urine. So, that has to be to readjust the mass. So, minus postpractice urine volume, plus fluid consumed during practice. So, this if we take that is the total effective sweat released and this total effective sweat released divided by time. So, that is the total sweating rate. So, sweating

rate is we so we have we know, that different activity level the sweating rate will be different, if our activities high then our sweating rate will be different ok.

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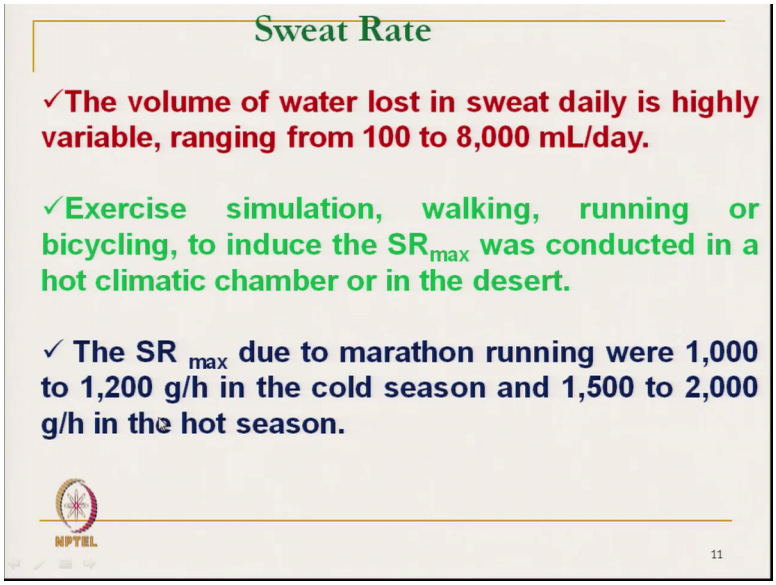

So, let us see the actual value. So, it can go from 100 milliliter to 8000 milliliter per day. So, that depending on activity, if we are actually sitting idle if we are totally taking rest, our sweating rate will be very low. And if we are active then the sweating rate will be very high that we have already mentioned somewhere.

So, maximum sweating rate SR max is actually, it is due to during running or bicycling at different activity so, we measure the sweating rate. Normally this exercises that cycling and walking running this all bicycling so, all these activities for results we conduct in hot climate chamber or in desert. So, these are the 2 standard places one can do study. Why hot climatic chamber? Because that condition the sweating rate will be high.

So, sweating rate due to marathon it is a standard sweating rate due to marathon is 1000 to 1200 gram per hour. That amount of sweat in it is in the cold season. And in hot season, it is a 1.5 kg to 2 kg 1.5 liter to 2 liter the sweat per hour we release. So, for high activity, for even for soccer and all these we have seen that it is a very high activity. This is the amount of sweat we release.

Now, try to see what are the factors, which affect the moisture transmission through clothing.

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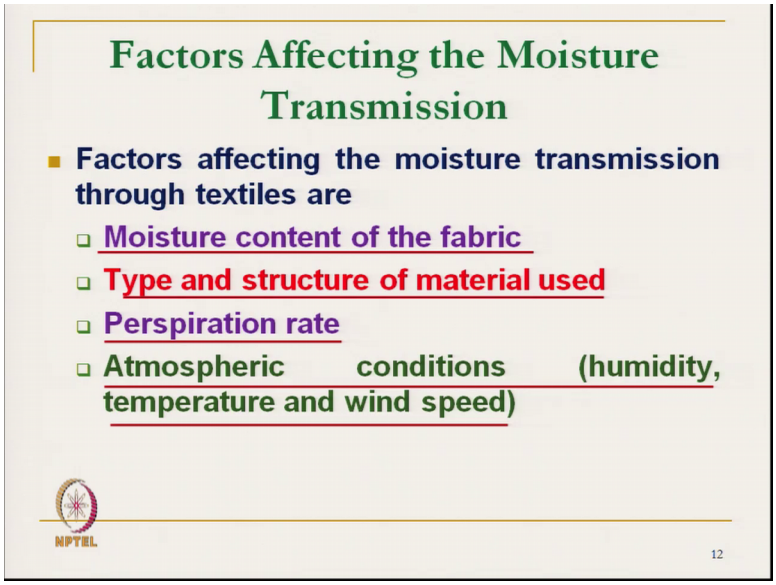

So, we know that amount of sweat we generate, and that amount of sweat we have to manage through the clothing in a liquid form. So, if we want to manage those clothing those sweat so, we must know what are the factors. So, first factor is that moisture content of the clothing. So, if the moisture content already it is very high in the clothing; that means, the it will affect the moisture transmission of the clothing.

Type and structure of the material, this part we will discuss in detail. Like, if a fabric is very compact or if it is highly porous. So, both this factors will affect. Also, a yarn made of parallel filament, and another yarn made of say staple fiber twisted, highly twisted staple fiber. So, this 2 structure will affect the moisture transmission.

Similarly, particularly in liquid form similarly a fiber with diameter radiation like cotton any natural fiber will have diameter variation. So, this fiber if we manufacture yarn out of that, ultimately the pores the capillary pore structure will not be uniform. It will be non-uniform structure. So, effectively it will transmit liquid in slow in fashion, slow transmission will be there.

Then perspiration rate. If we prepare normal ok in that case, the particular fabric will be able to transmit that moisture that liquid at a certain rate and moisture will get

evaporated. But if the perspiration level is very high, if you start releasing the sweat at very high level, and if the absorption of transmission vicking rate wetting rate is not balanced, then our moisture transmission will get affected.

If the fabric structure is saturated, then it will affect the moisture transmission and atmospheric condition; depending on the humidity, wind speed, temperature. Suppose at high humidity level, the fabric will not be able to release the moisture at that rate. Because the air is already saturated, evaporation will not take place.

So, the transmission will be affected. Similarly, if the wind blowing is there that we have mentioned that it is forced convection will take place, that in that case the moisture transmission will be high, even the temperature also effectively. So, this aspects we will discuss. So, moisture content of the fabric type, and structure of the material perspiration rate of the person and atmospheric condition ok.

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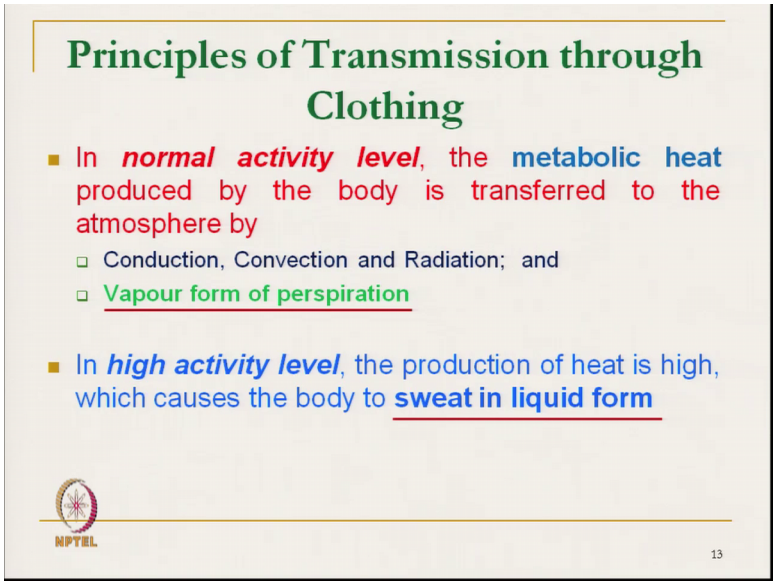

Now, principles of transmission through clothing. So, how the moisture, how the liquid gets transmitted through the clothing? So, in normal activity level so, when metabolic heat produced by the body is transmitted to the atmosphere by conduction convection and radiation. So, normal activity level. So, and also in a vapour form it moisture will get transmitted through the vapour form. So, in normal activity level we do not perspire in the sweat form, ok.

So, normally we release the whatever metabolic heat we produce, we release in terms of drive heat that is conduction convection and radiation, and also in the form of vapour. But in high activity level what happened? Will we will start sweating, and sweat comes in the liquid form, and in high activity level totals characteristics of transmission total phenomena of moisture transmission changes it changes from vapour form to the liquid form.

So, the same fabric has to act in sweat form. So, that accordingly depending on our activity level, we must know the type of sweat. So, if we know the type of sweating and rate of sweating, then we can design our clothing. So, for high activity clothing for activity level will be entirely different from clothing for normal activity level. For normal activity level, if we want to manage the moisture so, we have to take care of the vapour transmission, and in high level activity level we have to take care of the liquid form.

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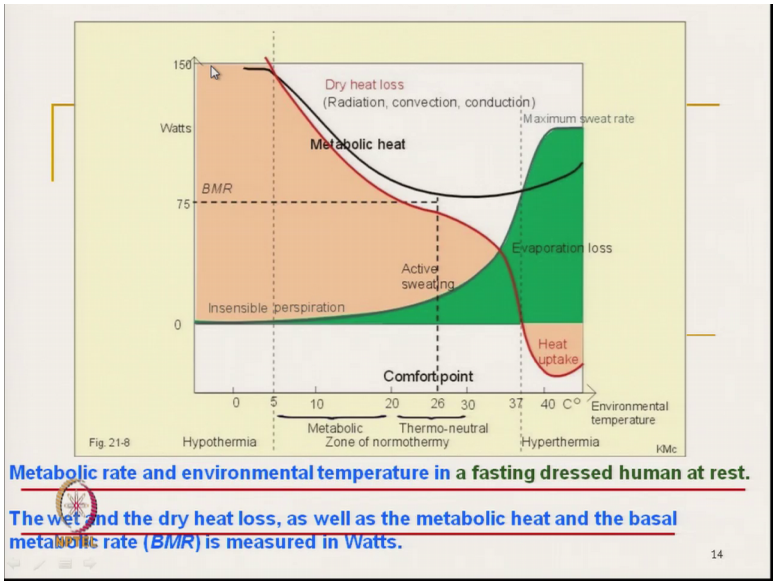

So, let us see this is an interesting picture. So, this shows the metabolic rate and environmental temperature. So, in y axis the whatever heat in terms of heat or different forms of heats are there and in x axis it is a temperature. And it shows for any standard fasting dressed human. So, this is the curve, now let us see the wet and dry heat loss as well as heat and basal metabolic rate is measured in watt.

So, in watt here, it measures wet dry heat and basal BMR Basal Metabolic Rate BMR and metabolic heat first. And it the curve here it starts from 0 degree Celsius to it is goes

up to 45 degree, 40 45 degree Celsius ok, this is 40. And here 37 degree Celsius means it is our human core body core temperature, and this is the 26 degree Celsius; when the person is dressed normal. So, typical comfortable temperature is we can say it is around say 20 to 30 degree Celsius.

So, 26 degree Celsius we can call it as comfort point. So, at that comfort point whatever the metabolic rate, that is known as basal metabolic rate the BMR. So, and this black curve shows the metabolic heat metabolic rate, and dry heat loss is the rate. Now try to see here at lower temperature say 5 degree Celsius, what happened? Dry heat loss means; it is a conduction convection radiation.

So, in totally so, if we take all this things conduction convection radiation, this rate the rate graph at lower temperature what happens? As we have seen at lower temperature as the temperature difference; that is the temperature difference is very high, the heat loss will be through the conduction convection radiation will be very high.

So, that is why this is the heat loss is very high, and it goes on reducing. It reduces as the temperature increases. So, as temperature is increasing it is going it is reducing, and it becomes 0 at 37 degree Celsius. What does it mean? 37 degree Celsius that is atmospheric temperature it is same as our body temperature typically. So, there is no difference in heat. So, heat is not getting transmitted. But if we say if we increase the atmospheric temperature further. What will take place? This is the actually uptake. Instead of heat release, it will start receiving heat, that we have seen in the form of conduction, convection and radiation.

So, this is the dry heat curve and if we see the wet; that means, the in terms of perspiration; which is important that the it shows in the green curve. And here it is a total heat loss. Now in at lower temperature, whatever heat loss takes place, its a insensible perspiration.

So, that is the insensible very low amount of moisture gets transmitted. But as we increase as we have mentioned earlier, as the temperatures increases beyond 10 degree Celsius, then the sweating starts. Sweating and it increases it is very high at say 37 degree Celsius, and as we go on increasing say 40, 45 degree Celsius the sweating rate increase. It reaches peak around say 45, 40 degree Celsius, then it goes on increasing.

So, we start sweating profusely. So, here that means, at the green portion above say 26 degree Celsius or above 37 degree Celsius, if the temperature is there, is a we start sweating and then we have to manage the sweat. So, from this curve so, if we know this graph, if we understand this graph clearly so, we can design the clothing depending on the climatic condition. And the black graph is known it is shows the metabolic heat.

So, at lower temperature as we have discussed, at we have to have high metabolic heat because at lower temperature we generate extra metabolic heat due to our body physiology sp it aj it is very high. So, as the temperature increases, temperature increases the metabolic heat also metabolic heat generation reduces gradually, and at extreme comfort condition. At comfort sweat it is a lowest metabolic heat. So, this is the almost a lowest one then it again increases.

So, this is the total basic graph which shows the heat at different different types of heat transmission at different climatic condition. And knowing the things we can designer clothing. So, this at high temperature if we talk about if we are designing our clothing at for high temperature, we have to take care of the clothing which will deal with the liquid transmission. And if we design a clothing for lower temperature so, we do not have to bother about the liquid transmission, we have to take care of the moisture vapour transmission ok.

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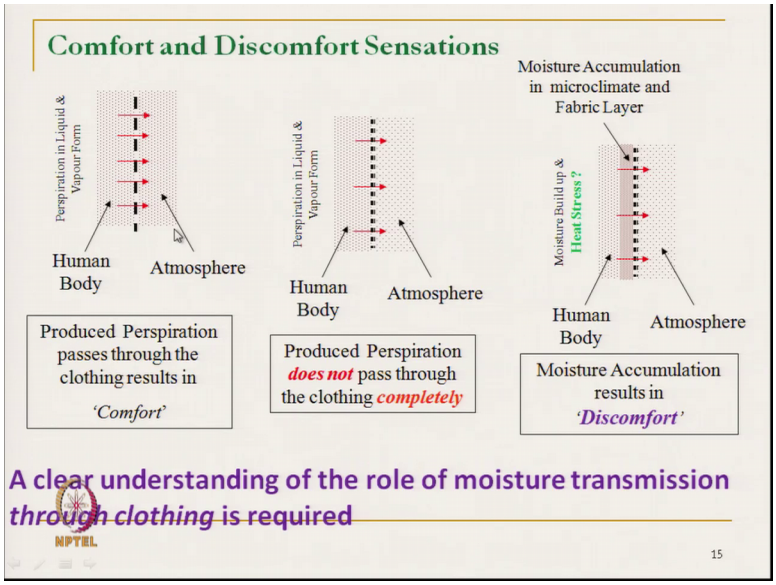

So, now let us see so, what are the comfort and discomfort sensation due to moisture? So, this picture shows here the, whatever moisture vapour and liquid or body generates, it gets transmitted through the clothing to the atmosphere. So, there is no vapour pressure generated in our microclimate between skin and the fabric. No vapour pressure is generated here this.

So, this creates comfortable climat. So, we must understand the level of moisture vapour form moisture, in vapour form level of moisture in liquid form, then we have to design our clothing so that it the total vapour form and liquid form moisture gets transmitted at certain rate. The rate at which our body is generating so that that will give us totally comfortable sensation.

But in this picture which shows that the produced perspiration does not pass through the clothing completely it gets transmitted, but this is actually it is not balanced. That means, whatever perspiration we generate in liquid form or vapour form, it is not transmitting. So, it is not giving comfort, but if it is more like it does not transmit, or if it at all transmit it is at very lower rate.

So, that will give us uncomfortable. So, that that is why and ultimately it may give our heat stress, because the vapour pressure which is generated in the inside our microclimate, it is not getting transmitted so; that means, our body our due to our physiology, will not be able to secret that much sweat, and then our internal body core temperature will increase. So, it will ultimately give heat stress.

So, so, we have seen that water management and clear understanding of the role of moisture transmission through clothing is required. So, if we know the our body, if we know our metabolic rate, if we know the our atmospheric condition, if we know our activity level, accordingly we have to design our clothing to manage the moisture.

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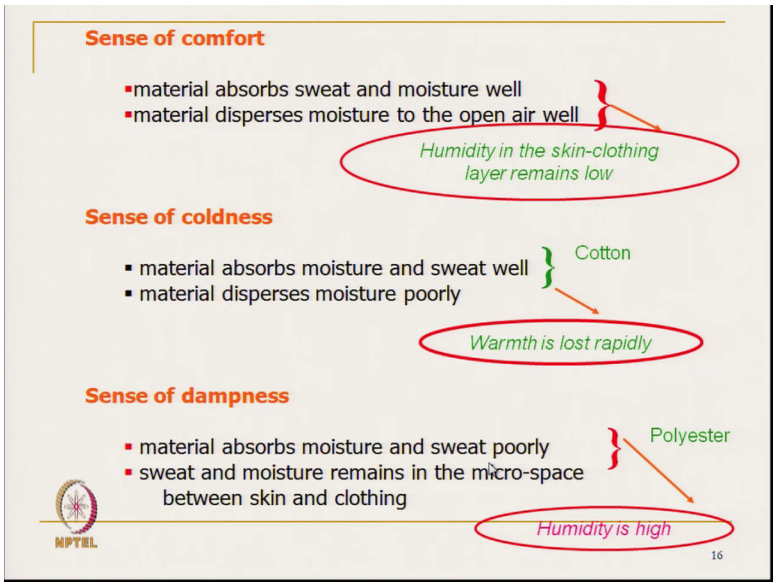

This picture shows the a material absorb sweat and moisture very well, it absorbs. And then the material disperse moisture in the open air. So, it absorbs moisture very well, whatever moisture in the liquid form, moisture in the vapour form it absorbs and it transmits and disperse to the atmosphere at the same rate.

This type of fabric will give a sense of comfort because humidity in the skin clothing layer remains low. So, humidity has to be low in the skin layer, skin and clothing layers microclimate, if we can maintain the humidity and humidity in the skin and clothing layer that is microclimate then we will feel comfortable; which is very important.

Temperature maintaining temperature in the micro climate is not that important, because at cold temperature we have to maintain high at cold humidity, cold atmosphere we have to maintain high temperature, at high atmospheric temperature we have to maintain low temperature within the microclimate. But humidity has to be always low; humidity in the sweat form or in the vapour form has to be always low irrespective of whether it is a hot climate. Or even cold climate even in the cold climate in the sub 0 temperature, if the humidity is high in microclimate, we will feel uncomfortable.

Next is that is that a material absorbs moisture and sweat well. A particular material it is absorbs moisture in liquid form or sweat in the liquid form it is a very well. But it cannot disperse at that rate. It is poor disperse, the example is cotton. So, example is cotton for

cotton so, a at very high activity level, if you wear cotton clothing what will happen it will absorb. Initially it will absorb, but it will not be able to release the moisture.

So, ultimate we will feel coolness, because the fabric the total structure total clothing will get wet and as it is wet. So, heat transmission through water is at very high rate. So, transmissivity through water is high than much higher than. So, it will lose it is insulation, and will start releasing heat at very high rate. So, then we will feel coolness ok.

And another fabric with the material absorbs moisture and sweat poorly, which is which actually that is not hydrophobic fiber; which does not absorb moisture. Normal I am talking about the normal say normal polyester it does not absorb moisture due to it is a hydrophobic fiber. And sweat and moisture remains in the micropores. So, it does not absorb and micro space between skin and clothing that is the microclimate.

At microclimate it remains because the fabric is not taking of that moisture. So, the then you will feel sense of dampness. And as it is damp, the humidity is high, irrespective of the fact whether it is cold climate or hot climate, we will feel dampness and we will feel uncomfortable. So, typical example is the normal polyester. Why I am telling normal polyester? Because if we can design a polyester fiber with the different shape, then the things will be totally different, we will discuss.

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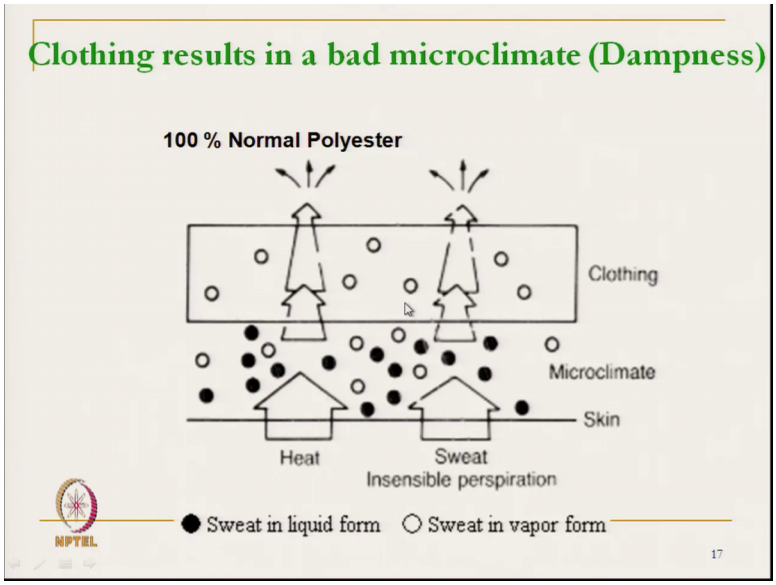

Now, in this picture we can show you can see that here that is the dark dots are sweat form, liquid form and this dots are this small circles are in vapour form. Solid circle and the hollow circles are in this is an vapour form. Now if we see this is the 100 percent polyester; say, it does not absorb ok, it gives as we have seens a dampness, bad microclimate due to high humidity.

Because this is the clothing it does not absorb moisture ok. So, the heat flow heat transmission through the clothing due to the moisture it is not high. So, it is transmits moisture in the heat at the lower rate, and transmits the moisture the voice sweat form or insensible form in lower rate; that means, this microclimate zone become humid and hot. So, it say it gives dampness it gives uncomfortable nature.

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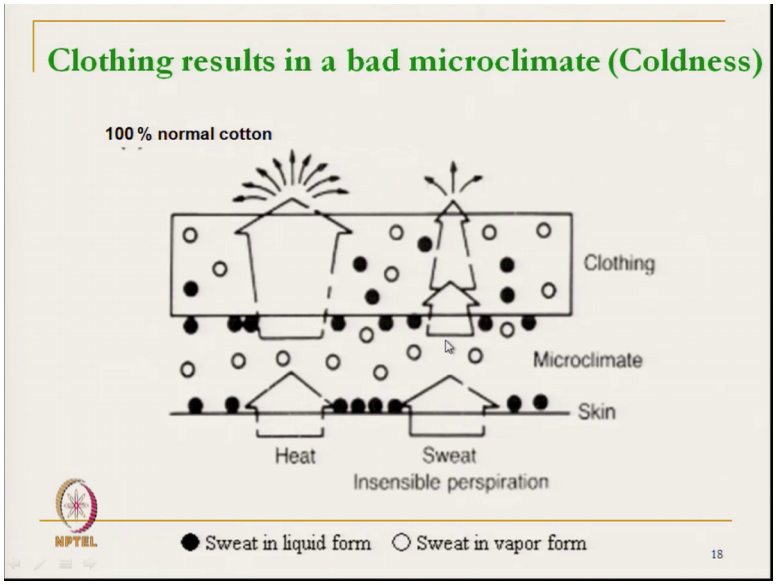

Another fabric if we can design that is a, say cotton as we have discussed, it absorbs moisture in liquid form. So, it is and liquid form it is absorbing, it is coming ok. And also vapour form it is coming, but the release of moisture is very slow ok. 3 arrows shows it is release of moisture; that means, the moisture remains in the structure, the fabric become remains wet.

So, what does it mean if fabric remains wet so, it is thermal conductivity becomes high, thermal resistance is low. So, it will release heat at very high rate. So, it becomes cool so, coldness will feel cold, if it is so and the fabric becomes remains wet fabric is wait we are feeling cold. So, it this happens in case of 100 percent cotton.

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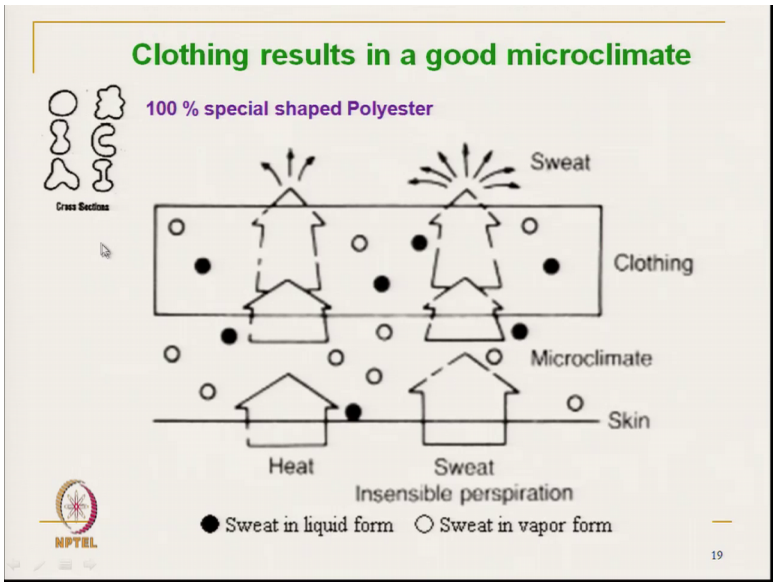

Now, if we can design say polyester with special safe shape polyester, at different types of specially shape polyester are there like trial oval dumbbell shape different flat or say 4 digitized polyester; in those fabrics, if we can design from this always polyester it is hydrophobic, but due to this special shape the contact angle is reduced ok. And it becomes it wets very nicely. And was the polyester wet, and then it will transmit moisture through vicking so, in the liquid form.

So, it immediately it absorbs moisture due to the wetting and due to vicking it goes out, and from there the sweat gets evaporated. So, the fabric remains dry the clothing microclimate remains almost dry and proper heat transmission is there. So, this will give us very comfortable whether it fabric will be very comfortable; particularly at hi sweating rate; that means, at high activities. So, we will see for high activity we normally used try to use the polyester fiber with different shaped cross section.

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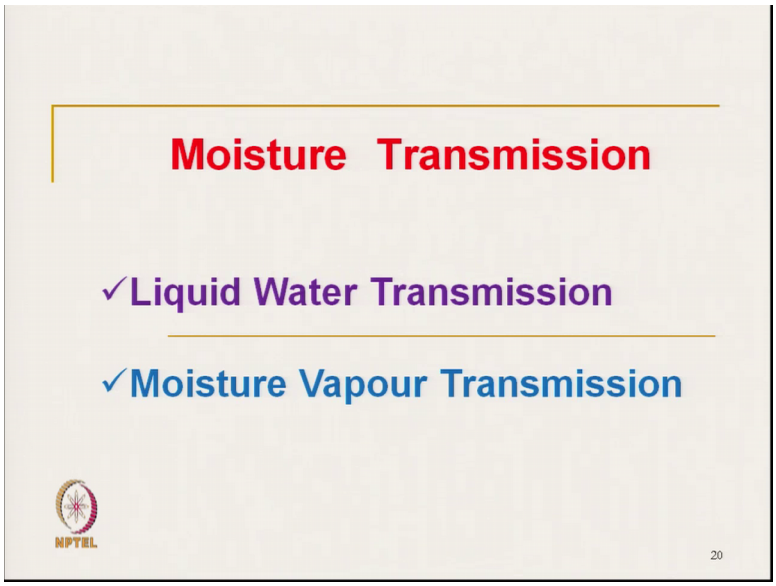

Now, we will see the moisture transmission. Moisture transmission takes place in 2 forms as we have mentioned, one is in liquid form and another is in vapour form. So, we will start with the liquid form ok.

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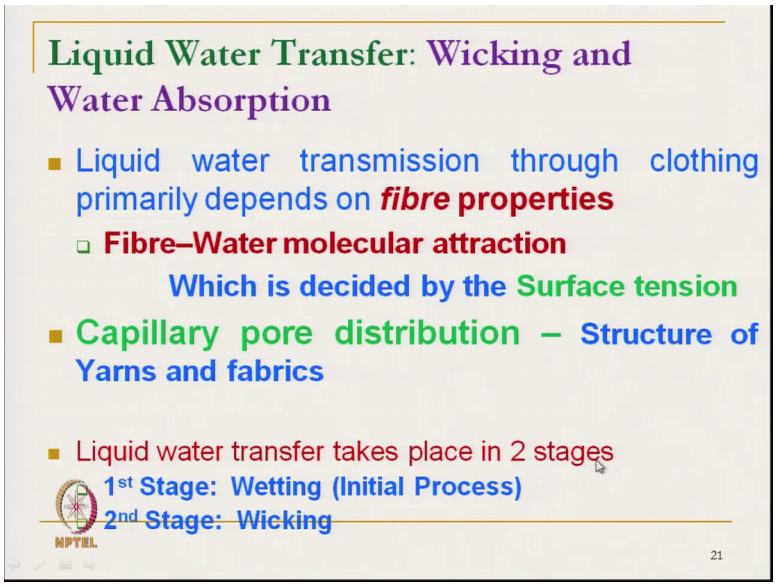

So, the liquid transmission through the clothing takes place with 2 stages. One is vicking stage, wetting stage and then is vicking stage ok. So, vicking and water absorption so, liquid water transmission through clothing primarily depend on the fiber properties. First is the, what type of fiber we are using fiber water molecular attraction that is the surface

tension of the fiber and water which is important. If a fiber has a very high surface tension with water; that means, it will not vick, it will not get wet. So, first we have to select a fiber which is having lower surface tension. And this surface tension we can actually manage, we can control by even a for a same fiber, same polymer we can control the surface tension by redesigning the cross sectional shape.

Next is that we think, it depends on the capillary pore distribution, and structure of yarn and fabric. So, what type of capillary pores are there? If whether the pore is uniform or nonuniform; whether the, what is this diameter of pore. So, all this aspects control the vicking characteristics. So, the liquid water transmission as we are discussing now liquid water transmission, it takes place in 2 stages. Stage one it is wetting, that is initial process and stage 2 is Vicky, the next process. So, we will start with the wetting point.

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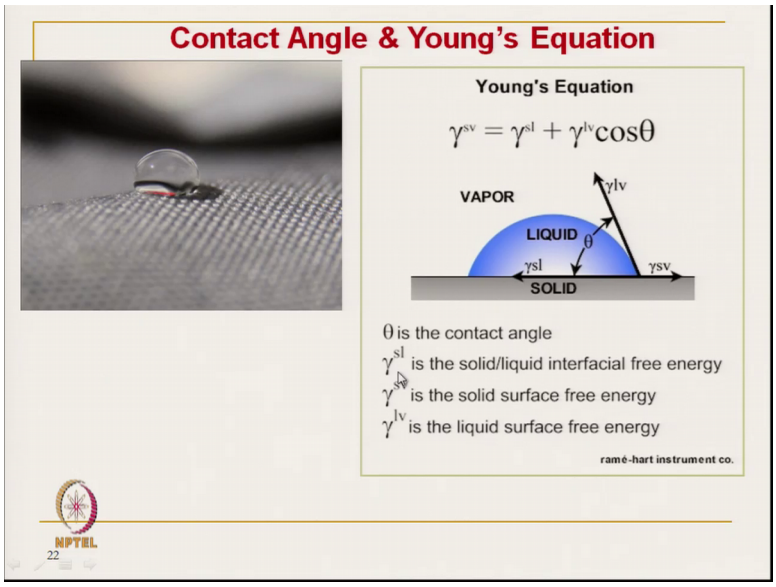

So, it is a classical Young's equation is there; where this picture shows it is a dropped which is actually on a fabric surface. And from this drop we can make out the contact angle ok, if it is a drop. So, this is the drop, liquid, and this picture shows this is the contact angle, contact angle theta which is the and gamma sl; gamma sl is the this is the gamma sl. It a solid and liquid, it is surface tension between the solid liquid interface; that is, interfacial free energy gamma sv, this is the gamma sv; which is actually tangent to this droplet ok. Gamma sv is a solid surface energy surface free energy that is between

solid and sorry, this is lv, lv that is liquid and vapour; surface tension between liquid and vapour.

Another component is, this is a sv solid and vapour, surface tension between solid and vapour.

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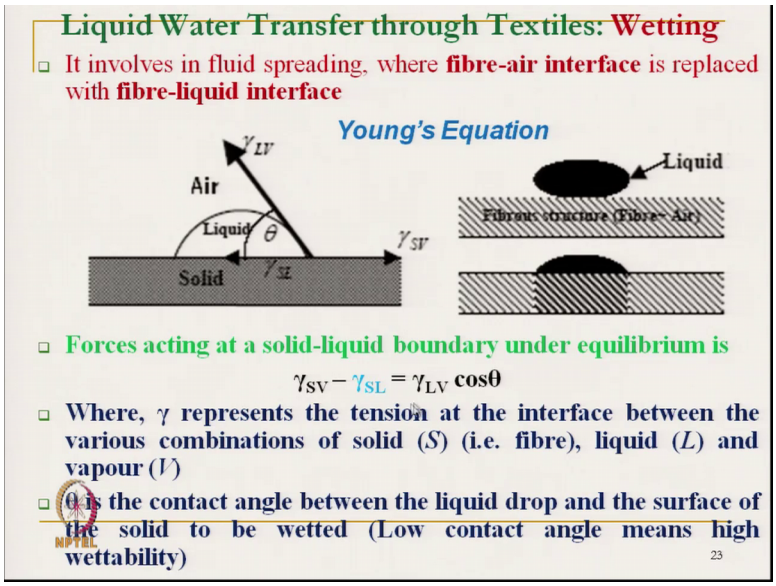

So, if we see the relationship between this it is by the equation, which shows that gamma SV minus gamma SL equal to this is the, it is balanced by gamma LV cos theta; where theta is the contact angle. So, here it is a contact angle, though involved in a fluid spreading where fiber air that is fiber air interface is replaced by fiber liquid interface. So, this is the fiber air interface, which is replaced by the fiber liquid interfere.

So, here in this picture, you see the if we here its in the top this is the liquid, and in between there are fiber and air interface. And when liquid drop pore at it is a you are dropping the liquid on the fabric surface, this fiber air interface being replaced by the fiber liquid interface; that means, it becomes wet. So, whatever fiber air interface, it will be taken away by the fiber liquid interface. So, that means the fabric becomes wet. So, the what are the conditions of wetting, those will discuss ok. And those will discuss in the next till then goodbye.

Thank you.