Science of Clothing Comfort
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Lecture - 27
Clothing Comfort Related to Thermal Transmission (contd...)

Hello everyone. So, we are discussing the thermal transmission related comfort of clothing. Now, in last segment we have discussed the thermal resistance under compression.

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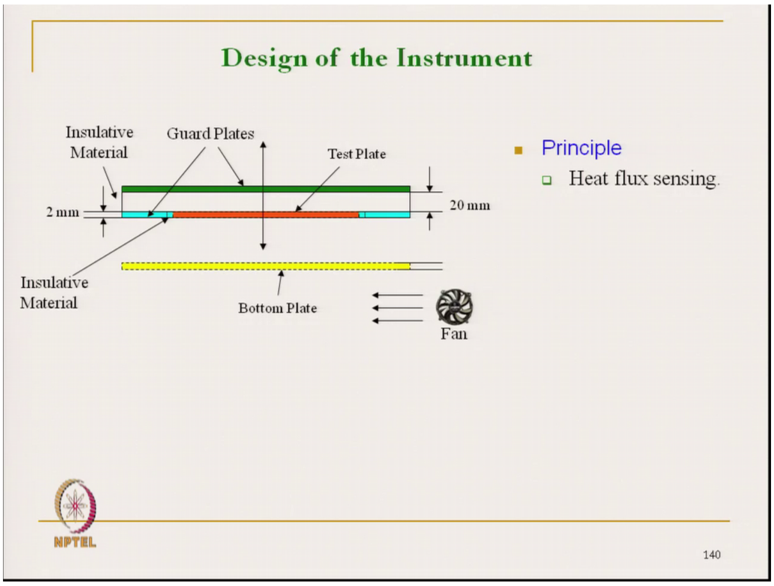

So, this instrument which is actually its modification of the guarded hot plate where at different compression level, we have seen that the thermal transmission thermal resistance changes. So, as the compression level increases, the thermal resistance of fabric reduces.

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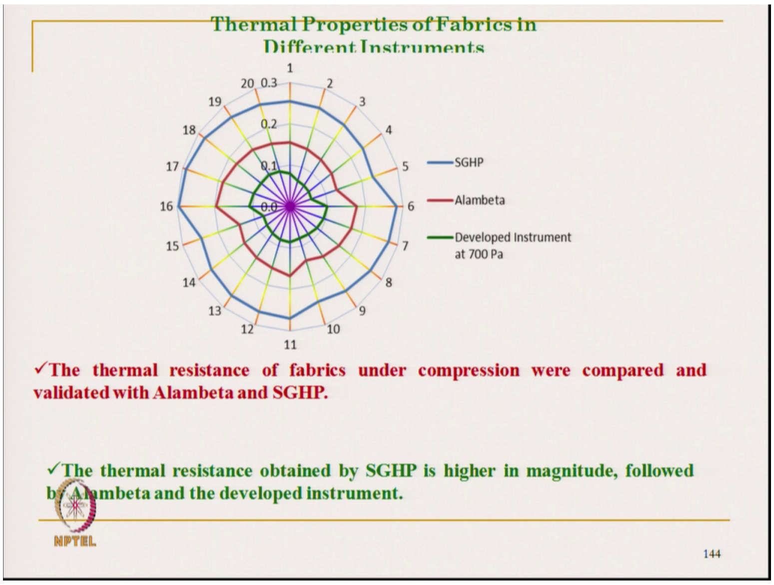

So, here the values resistance values are compared with the different other instruments like guarded hot plate and alambeta. And what we have seen the present instrument gives the lower insulation that means for same fabric which is mainly due to the higher initial pressure.

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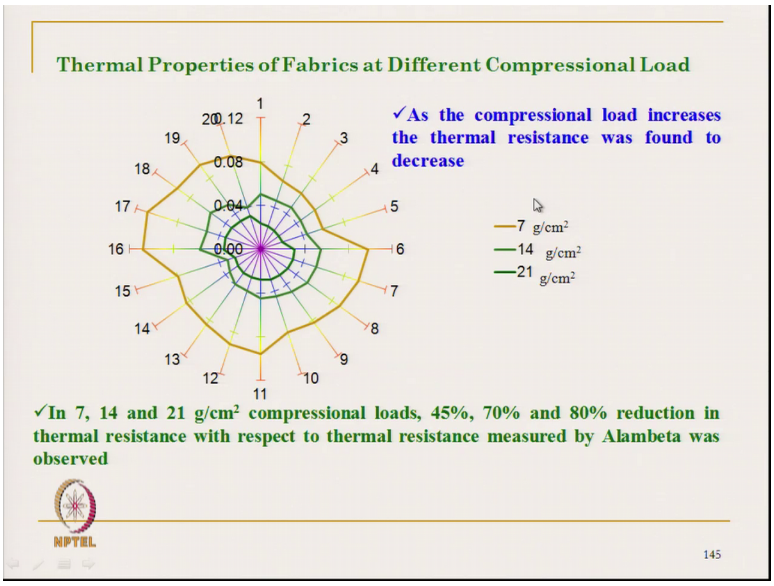

And also we have seen that for same fabric, if we increase the normal pressure, so the insulation characteristics will be low. So, fiber will lose its insulation due to compression that means when the fabric is compressed it actually releases the entrapped air. The entrapped air is lost, so it actually lost its insulation characteristics. So, from this study we know that if we can now incorporate on the other hand if we can incorporate the air pocket inside the structure somehow, so we can incorporate the insulation, we can enhance the insulation of the fabric. So, with that is idea the next study next approach was that, that how to increase the bulk.

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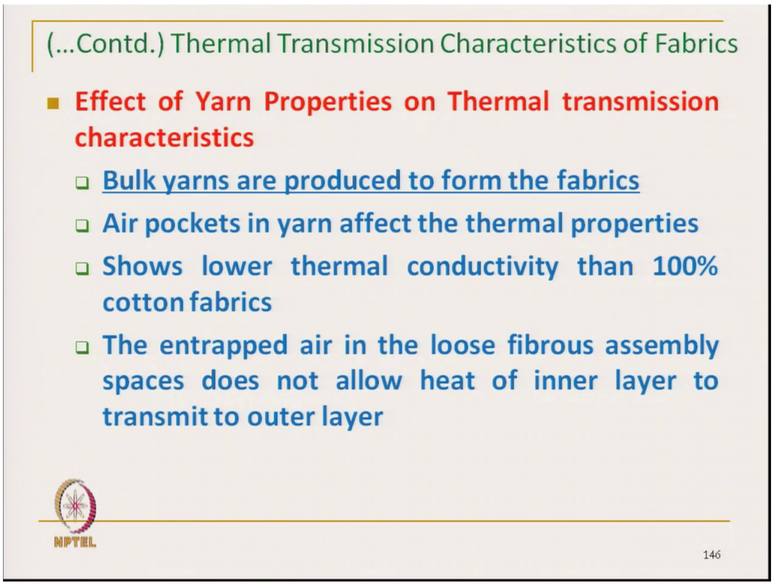

So, the increasing by increasing the bulk, we can bulk in the yarn, we can make the fabric insulated. Bulk yarns are produced by technique that we will discuss. So, when we produce the bulk yarn, we convert the normal yarn to bulk yarn, so we are introducing air pockets in yarn structure. So, still airs are entrapped and which affect the thermal transmission characteristics. So, if we entrap the air, so if we entrap the air in the cotton yarn somehow in that the thermal conductivity will be reduced as compared to 100 percent cotton yarn. So, the entrapped air in the loose fibrous assembly that space that do not allow the heat to transmit freely from the one layer to another layer.

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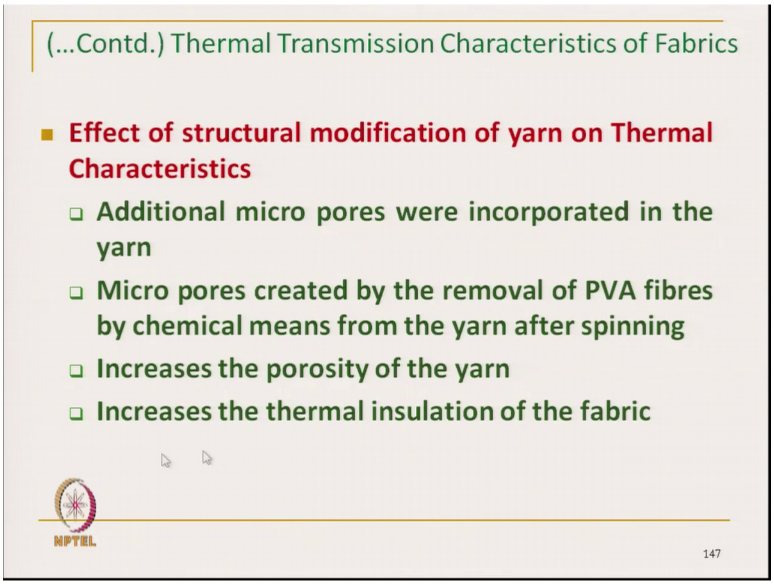

So, another approach was there to incorporate a bulk or incorporate in entrapped air that is by micro pores. We can incorporate micro pores. So, this is done by actually blending the cotton fiber with PVA. So, PVA fiber which is soluble in water in warm water it gets dissolved. So, if we blend with the certain proportion, the PVA fiber with the cotton fiber and produce a normal yarn and after washing after the fabric is made. So, if we can wash that fabric that means PVA fiber within the yarn structure will come out. So, living a micro pores within the yarn, although there are micro pores in staple yarn, but it will enhance the micro pores this micro pores will actually enhance the thermal insulation characteristics. So, it increases the porosity of the yarn, increases the thermal insulation of the fabric.

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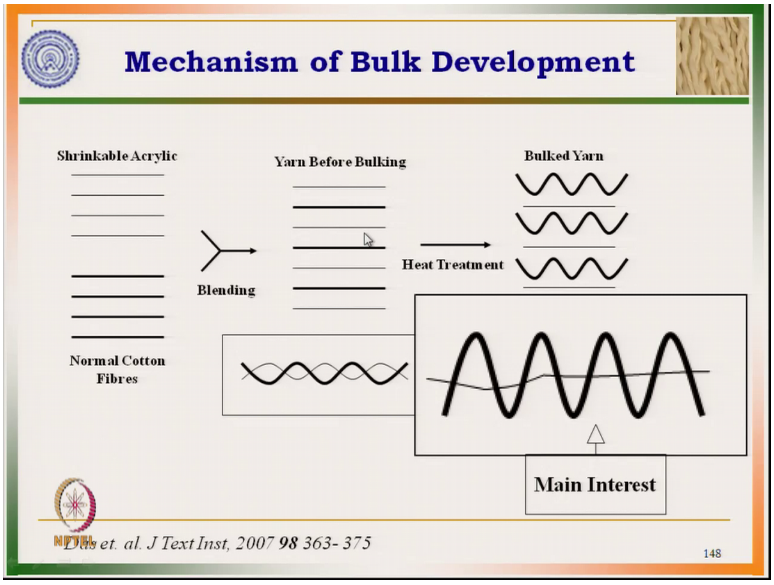

So, first we will discuss the mechanism of bulk development that is a very common development which is a bulk common principle that is we use for acrylic bulk yarn. So, in acrylic bulk yarn production, what we do we use two different types of fiber; one is a normal fiber and another is a shrinkable fiber. In the present study what we have used we have used a normal fiber which is cotton; and the shrinkable fiber which we have used the shrinkable acrylic fiber.

So, cotton and acrylic is blended. So, this is the blended yarn. So, where it is assumed that the yarn fibers are actually straight, fibers are there is no crimp is although these fibers are not actually straight, they are twisted condition, but the there is no crimp micro crimp present. But after the yarn is made the in the loose condition in hang form this yarns are treated with the steam chamber.

So, when at the heat chamber when we treat this yarn that may in that condition, the shrinkable acrylic actually shrinks. The total length of the yarn fibers say acrylic fiber gets reduced living the cotton fiber buckled. So, cotton fiber gets buckled and which forms that air pocket inside that. So, finally, we get the bulked bulk yarn. So, bulk you are incorporating the bulk air pocket inside the yarn.

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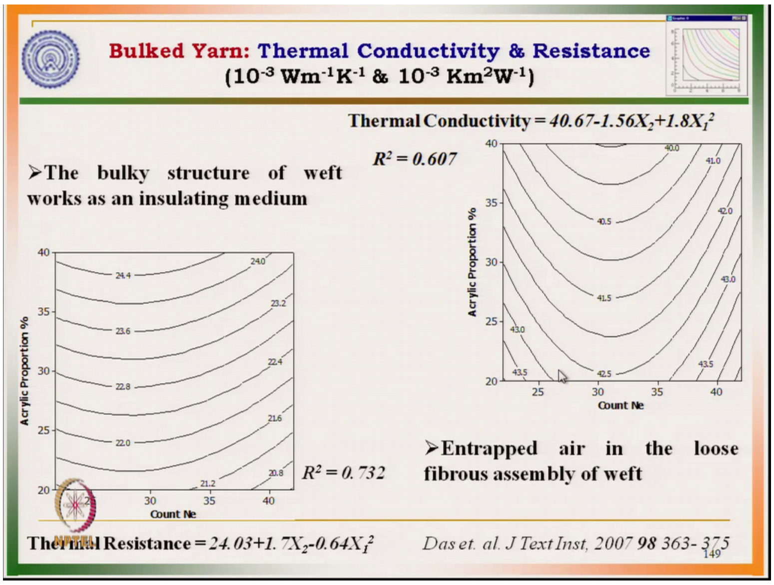

So, now let us see the what are the effect. So, this is this curve it say the bulky structure of weft yarn, because we have used this for this study what we have used we have used this cotton 100 percent cotton yarn in warm the normal yarn; and when weft yarn we have used the this bulk yarn. So, this cotton bulk yarn in weft it works as insulator.

So, the x-axis - this axis, this is the contour plot where this x-axis gives the yarn count at different count it is 25, 30, 35 and 40 different count is there. And this is the acrylic proportion; that means shrinkable fiber proportion. So, here what we have observed as we increase the acrylic fiber proportion within this limit, so 22 say 40 percent that within that limit what we have observed that bulk in the yarn increases.

So, as the bulk in the yarn within this limit it may this bulk increase, this trend may not be applicable if it is say a 60 percent or 70 percent; at a higher level bulk enhancement of bulk may not be that much high, but within this experimental level. So, 20 to 40 percent the bulk increase is there. So, this curve shows the thermal conductivity. And this is the thermal conductivity, and this curve is thermal conductivity this is the thermal resistance.

So, thermal resistance value is increasing with the increase in acrylic proportion, that means, the fabric gives the insulating characteristics of the fabric increases with the increase in bulk. So, the same fabric with the just by incorporating bulk in the yarn, we can enhance the insulation. Similarly, if we see the thermal conductivity thermal conductivity value drops just it is just opposite. The other trend we can see that effect of yarn count, it is not that significant.

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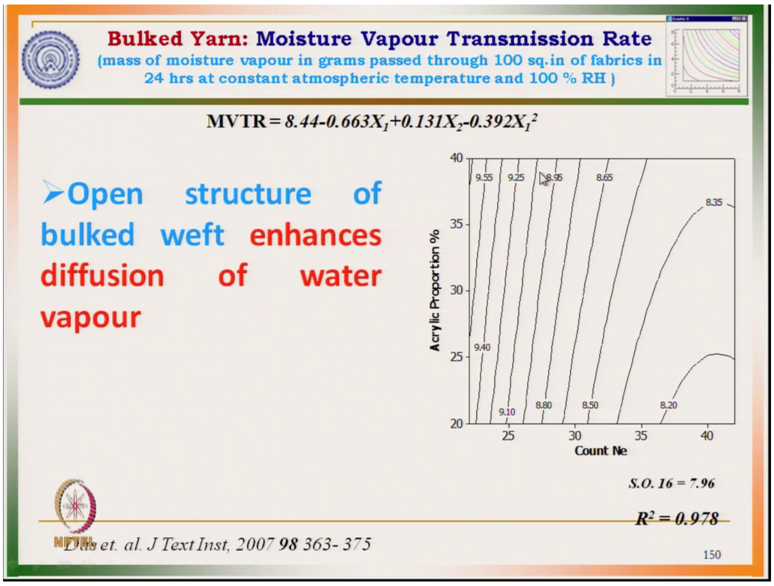

Now, if you see the moisture vapour transmission, so moisture vapour transmission if we see it is a with the increase in acrylic proportion moisture vapour transmission increases, which is due to the creation of the pores, which enhance the diffusion. So, due to higher and higher diffusion due to that a pore structure, it gives higher flow of moisture vapour.

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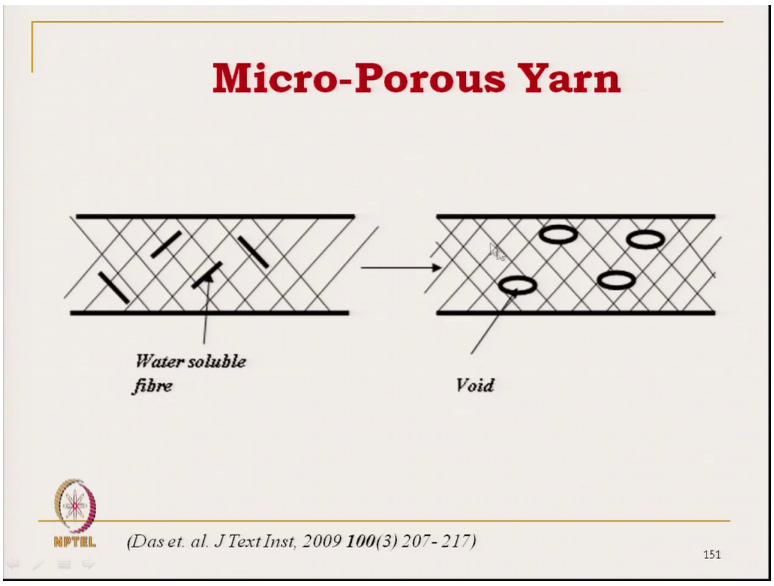

Now, try to see the micro porous, so micro porous structure we have created that we have already mentioned. The normal cotton fiber is blended with the PVA fiber which is water soluble. So, after yarn is made, then we developed fabric. And after fabric is made, then when the fabric is washed this creates the void space. And these void space are incorporating the insulation. This is still air is entrapped here and this enhance the insulation of the fabric.

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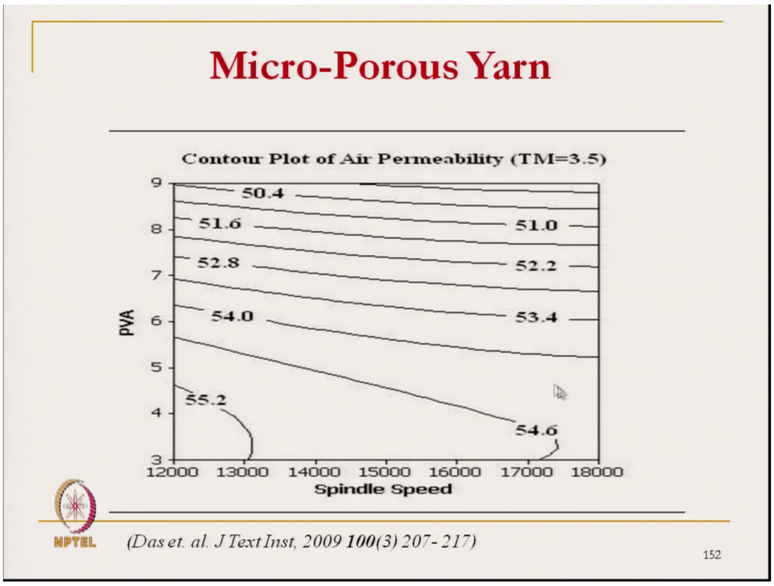

Now, if we see this is the air permeability, so as the PVA content increases the air permeability value it is actually it is as the PVA value its increasing the air permeability is reducing. So, what does it mean the yarn bulk is increasing? So, we are we have kept the total cotton content constant, so total cotton content if it is total that means total yarn diameter is more, so it is actually reduces the air permeability due to bulkiness of yarn which means that internal pore that does not affect the air permeability.

So, air moves through the interlacement between the yarn. So, if yarn diameter is more keeping the yarn count same, so we will have the lower air permeability. So, irrespective of the fact that the yarn is pores, so if that shows that air normally does not flow through the pores, it flows through the surface of the yarn the opening between the yarn. So, although this yarn is bulky, so the yarn the air permeability is reduced.

But we will see the opposite is the case of the in case of moisture vapour transmission. So, the same with the increase same trend same with the increase in PVA content, the moisture vapour transmission will be just reverse, the moisture vapour transmission will increase that is basically the phenomena of moisture vapour transmission is due to the diffusion mechanism. And here the air transmission is due to the opening through the in between the yarns.

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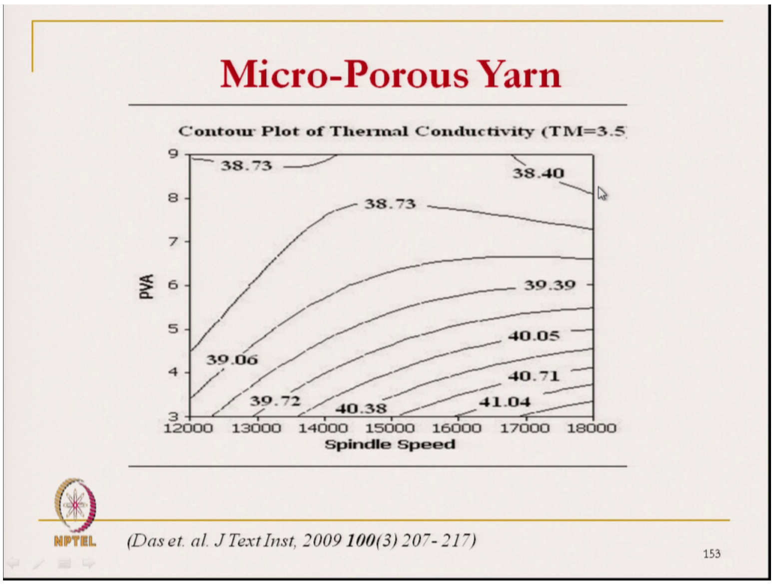

So, thermal conductivity if we see as we increase the PVA content, the yarn becomes bulky the air pockets are there and thermal conductivity is reduced. So, it is again it gives the installation characteristics. So, we can use either the bulky of approach or maybe micro porous approach or maybe any other approach by reducing the twist also we can keep make the yarn bulky. So, effectively the actual the finding is that, if we make the yarn bulky, we can get insulation. So, yarn structure plays direct role significant role in deciding the insulation characteristics of clothing.

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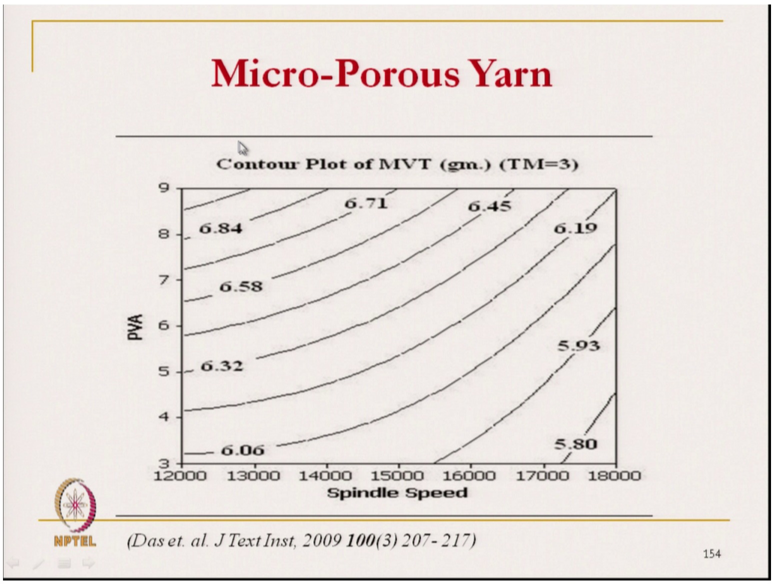

Now, see the moisture vapour transmission rate. So, in with the increase in PVA content, we have seen that the air permeability reduces; but if we see here moisture vapour transmission, it is increases significantly. So, moist that is due to as we have mentioned it is due to the diffusion characteristics. So, fiber with a yarn with the micro pores the due to the gradual transmission of moisture inside the pore, as soon as the vapour pressure increases in the pore the moisture gets transmitted to other side. So, the more smaller pores are there, the higher will be the moisture vapour transmission.

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Twist-less and hollow Yarns

Three types of DREF-3 yarns with different combinations of core and sheath fibres were used in weft

Details of Grey Fabrics

Fabric type	Details of warp	Details of weft			
		Yarn type	Core / Sheath	Core : Sheath	Count (tex)
A	2-ply cotton ring spun yarn with resultant count of 78.73 tex	DREF-III	Viscose / Viscose	50:50	59.0
B		DREF-III	Viscose / PVA	50:50	118.0
C		DREF-III	PVA / Viscose	50:50	118.0

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Our next study is in the similar line here what we have developed here the hollow yarn. Just took create here again the yarn structure exchanged two types of yarns are produced one is the twist-less yarn. So, yarn does not the fiber this is a twist-less may it is not made of the filament yarn, it is a staple yarn. It is a twist-less cotton yarn we have developed and also hollow cotton yarn. And it is compared with the normal yarn, so and three different types of fabrics have been yarns have been developed; and from there we developed fabrics.

Now, the warp which we have used, it is a two ply cotton ring spun yarn it is a normal two ply cotton yarn is used; fabric A we have used a DREF yarn DREF yarn with viscose only viscose, it is a DREF-3 yarns have been produced where core and sheath both are viscose. So, it is a 50-50 core sheath are count here, it is used 0.59 tex sorry 59 tex, 59 tex yarn is produced.

Type B yarn it is again DREF 3 yarn. But here what we have used the core is viscose ok. And sheath what we have used it is a PVA which is washable. PVA viscose it is used PVA viscose combination here, but core is viscose and PVA is at the sheath and again the ratio here it is a 50-50 core sheath ratio and its count it is a double its a cores are. It is a in tex 118 tex its a just double to that of this. Similarly, the fabric or yarn type C, where it is a just reversed combination is reversed core is PVA and sheath is viscose, 50-50 ratio and again the yarn count it is a cores are doubled to that of 100 percent viscose, it is a 118.

Now, what is the idea? Idea here is that the PVA is going to be washed away. And if we wash and that is a 50 percent and washing 50 percent PVA, it is not commercially viable. One may ask one may question about the validity of the or usability of this study it is not it is just for academic interest we wanted to study the effect of the yarn structure on thermal transmission characteristics.

So, here core viscose and sheath polyester, what does it mean, the sheath PVA sheath PVA 50 percent, if we wash finally, the after washing the linear density will be 59 tex. So, same p 59 tex we require getting, but the structure here a it is PVA as PVA is in this core that means, the fabric B the weft yarn will be the twist-less it is a there is no twist. And the washing is done in fabric state after the interlacement is done. So, the fabric stage if we cannot wash it in yarn stage because if we wash the yarn will be totally twist-less, and there would not be any strength.

On the other hand the fabric C, the type C is PVA in the core and in the surface it is a viscose. If we wash 50 percent viscose, again the count will be 59 tex. And the viscose as it is in the sheath the core will be washed away and the ultimately this yarn will be the hollow yarn. So, we have produced here the twist-less yarn and hollow yarn. And it is produced in the fabric stage.

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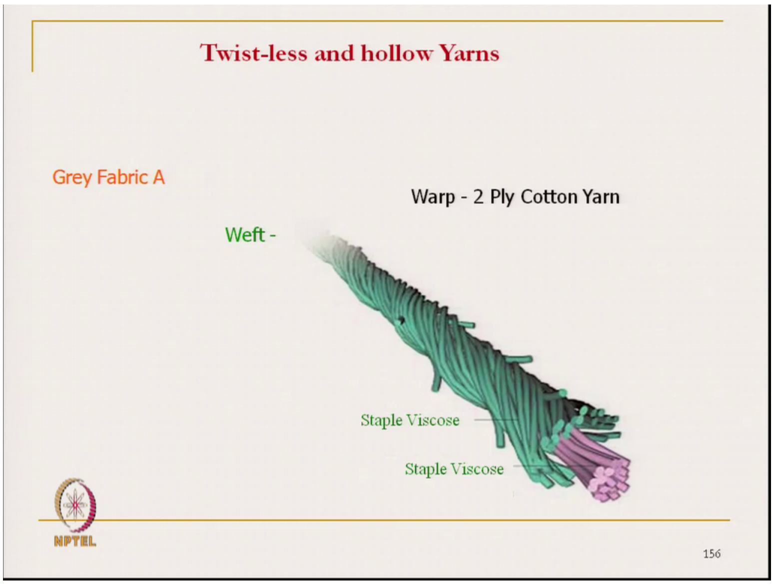

So, this is the two ply yarn here both it is a fabric a gray fabric A. In the weft warp is 2 ply cotton yarn weft-2 we are using both viscose to although it showing two different colors, but it is a viscose and viscose. So, when you wash the fabric nothing will happen see this structure will remain it is 100 percent viscose.

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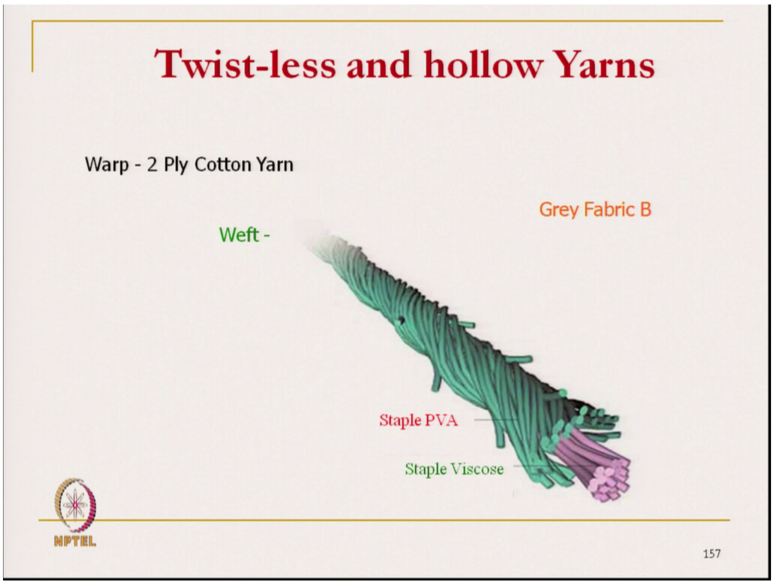

Then again this as a PVA sample B its warp is 2 ply grey yarn and PVA is at the sheath viscose is at the core purple color. This green color sheath will wash out and the ultimately this core will remain which is twist-less.

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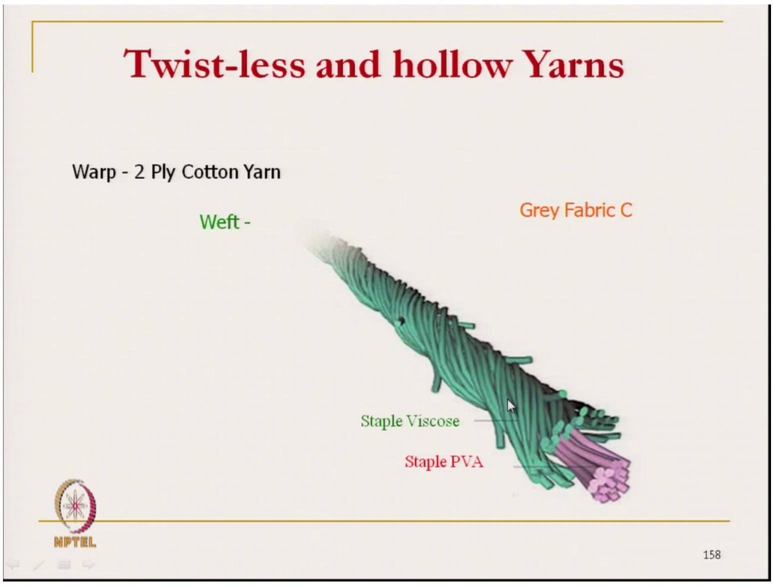

And here it is a just reverse ok. This will get this is the PVA purple color. This will be washed away and ultimately we will get a hollow yarn. Now, try to see the characteristics.

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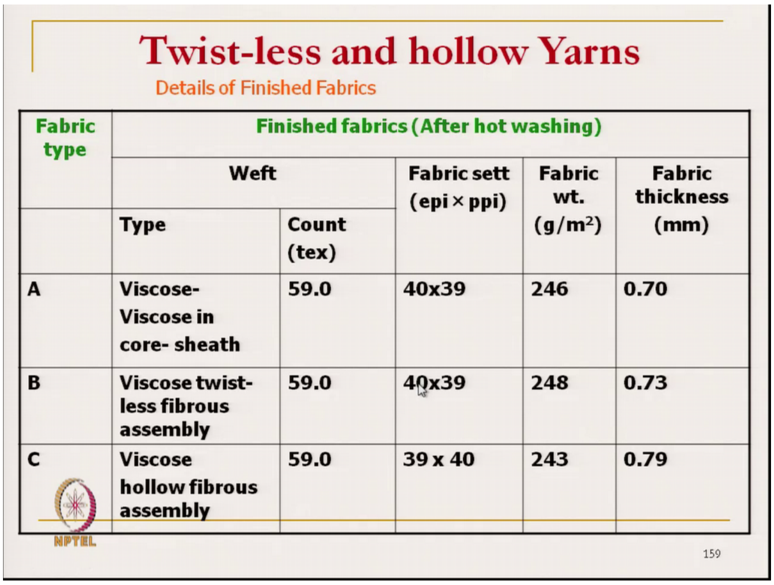

Fabric type	Finished fabrics (After hot washing)				
	Weft		Fabric sett (epi × ppi)	Fabric wt. (g/m²)	Fabric thickness (mm)
	Type	Count (tex)			
A	Viscose-Viscose in core- sheath	59.0	40x39	246	0.70
B	Viscose twist-less fibrous assembly	59.0	40x39	248	0.73
C	Viscose hollow fibrous assembly	59.0	39 x 40	243	0.79

Now, viscose, viscose in core sheath. The yarn count we are getting after washing 59 tex standard yarn count. So, this is the nominal count 59 tex. It may actually very little bit fabric ends per units peaks per units after wash we are getting almost a very close value. So, there after wash the fabric mass is almost same and thickness if we see thickness here where it is a hollow yarn is used thicknesses is little bit high, this is due to the presence of hollow yarn.

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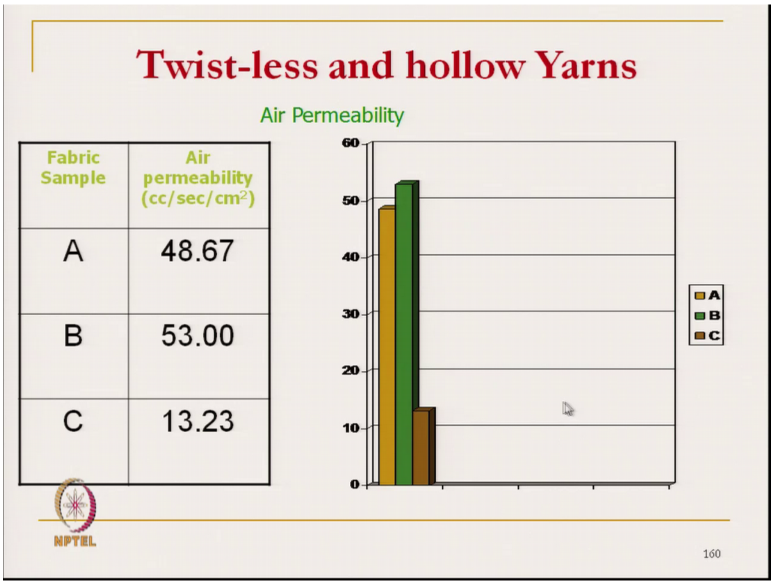

Fabric Sample	Air permeability (cc/sec/cm²)
A	48.67
B	53.00
C	13.23

And if we see the air permeability, what is happening, air permeability in fabric A and fabric B; they are on the higher side ok. So, this is the air permeability, but fabric C has got very less air probability because of the bulky nature. So, ends per units peaks per units its fabric set is same. So, due to its higher diameter again it is blocking the pores between the opening space between the yarn although this yarn has got higher pore inside the core. So, this C fabric gives lower air probability.

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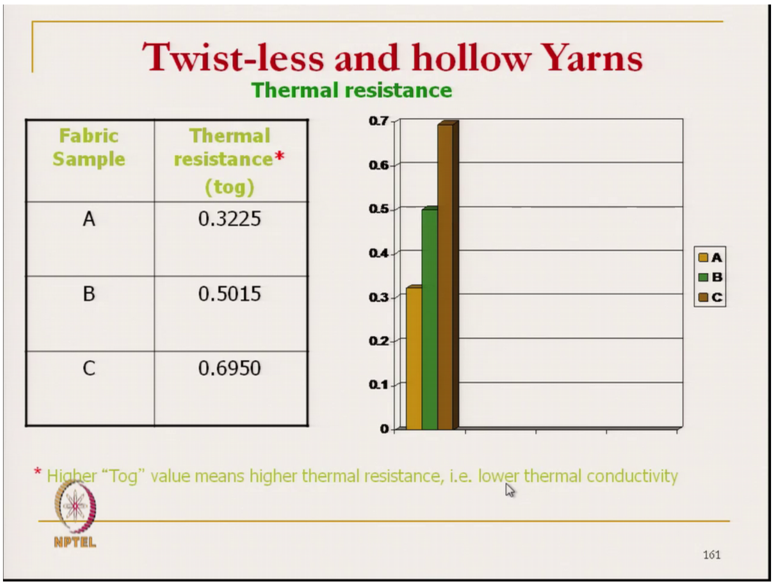

And if we see the thermal resistance value, thermal resistance in tog it is measured of the fabric. So, fabric A gives least thermal resistance, followed by fabric B and fabric C is giving highest thermal resistance, so that means, the fabric A is due to its compact structure it gives least thermal resistance the highest thermal resistance is given by the hollow yarn. So, due to the openings that is the hollow yarn entrapment.

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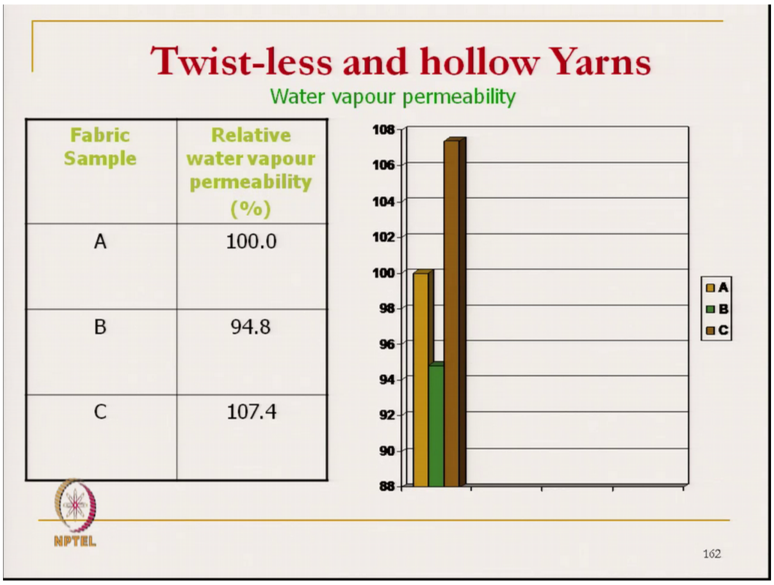

Fabric Sample	Relative water vapour permeability (%)
A	100.0
B	94.8
C	107.4

Water vapour permeability it is interesting that water vapour permeability is highest in case of the hollow yarn, so that hollow yarn gives least air permeability, but it gives highest water vapour permeability. That means, this can be used to those condition where it is a because it requires a higher air permeability water vapour permeability with least air permeability.

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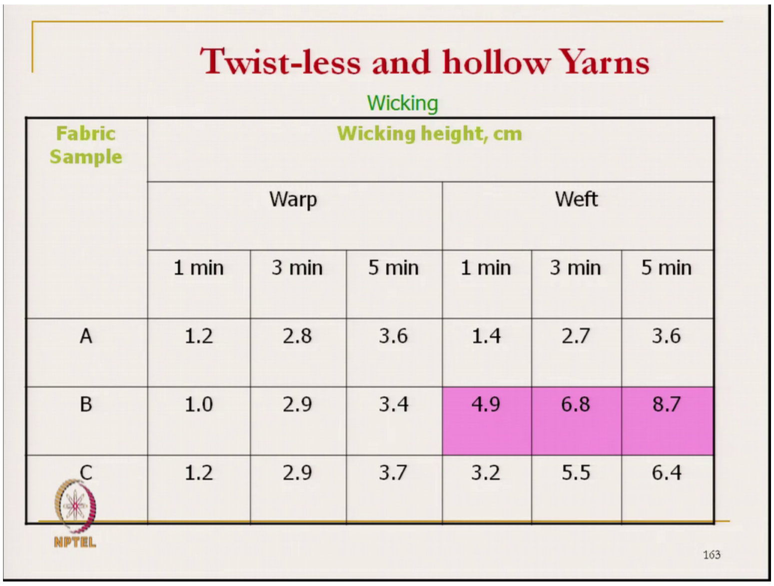

Fabric Sample	Wicking height, cm					
	Warp			Weft		
	1 min	3 min	5 min	1 min	3 min	5 min
A	1.2	2.8	3.6	1.4	2.7	3.6
B	1.0	2.9	3.4	4.9	6.8	8.7
C	1.2	2.9	3.7	3.2	5.5	6.4

If you see the wicking characteristics the liquid transmission characteristics, this where the twist-less yarn the B gives maximum wicking characteristics particularly in weft direction because this is due to the arrangement of fiber the alignment of fiber towards the weft direction, which creates the clear pore a clear capillary and which helps the increase in wicking characteristics. But the fabric with normal DREF yarn random structure which gives least wicking characteristics.

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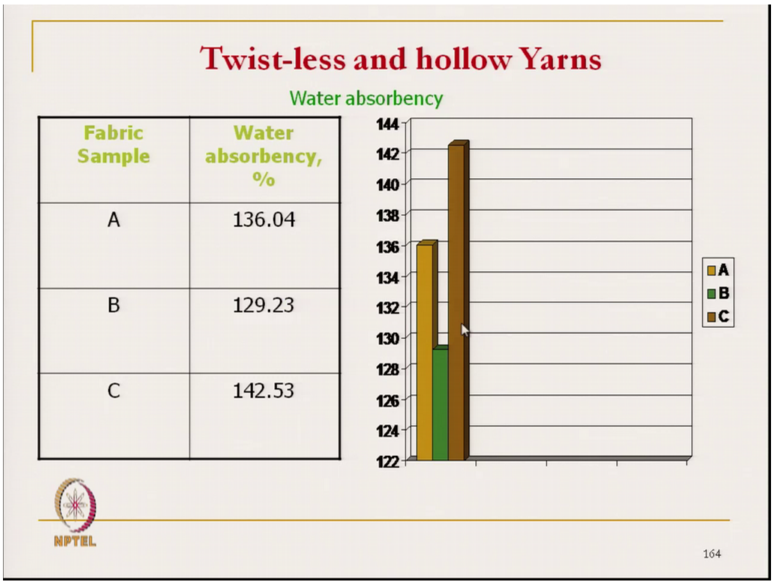

And water absorbency its a very high water absorbency of our in case of hollow yarn which is due to the fact that it contains a large pore inside the structure and gives the higher water absorbency. It can hold the more and more water inside the structure.

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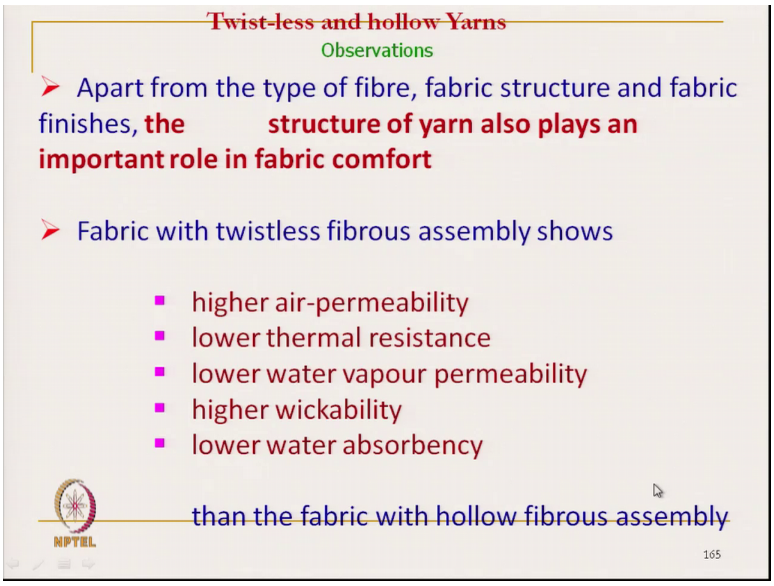

So, the observations are apart from the type of fiber, fabric structure and fabric finishes the structure of yarn also plays an important role. So, we can control the thermal comfort by type of fiber by fabric structure, by fabric finishes also, but thermal component can be controlled to a large extent by controlling the yarn structure by incorporating incorporating the bulk in the yarn structure.

So, fabric with twist-less fibrous assembly shows higher air-permeability, lower thermal resistance, lower water vapour permeability, higher wickability, lower water absorbency then the fabric with hollow fiber assembly. So, depending on the requirement we can select the yarn structure; whether should we go for the hollow yarn or should we go for the twist-less yarn or normal yarn that depends on the our requirement what type of air permeability we require, what type of thermal resistance we require, what type of moisture vapour permeability we required wickability we required. So, absorbency so these are our requirement and accordingly we can select our yarn structure.

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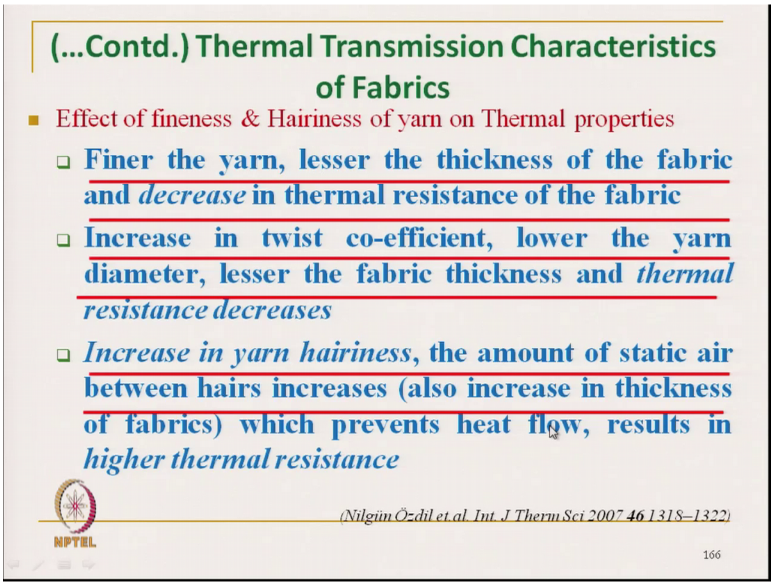

Now, if next observation is that effect of fiber fine yarn fineness and hairiness on thermal characteristics of fabric. So, if we use the finer yarn, so that will give us the lesser thickness of fabric; and lesser thickness will give the less thermal resistance. And also if we increase the yarn twist, so that means, if we increase the yarn twist it will end the entrapped air within the structure will reduce that ultimately will give less thermal resistance. And also the fabric thickness will reduce.

So, less higher twist always give less thermal resistance that is due to the different factors, one is it removes the entrapped air. So, entrapped air content is reduced. So, the conductive thermal transmission is reduced. And also with the increasing twist the diameter of yarn reduces that means, for same set fabric set same ends per inch peaks per inch for same mass per unit area, the openness in the a that is power factor of the fabric will reduce, so that will enhance the radiative and convective heat loss.

So, both all convective radiative and conductive heat is lost due to increase in twist. So, increasing twist has got the measure impact on thermal transmission characteristics. So, another parameter another factor which effect the thermal resistance of fabric its a hairiness.

If we can increase the hairiness of yarn or yarn fabric surface hairiness, we can enhance the entrapment of air still air in the surface of the fabric, so that is how that if we normally try to increase the thermal insulation by brushing at the surface, so that it prevents the heat flow that entrapped air at the surface prevents the free heat flow and which results higher thermal resistance.

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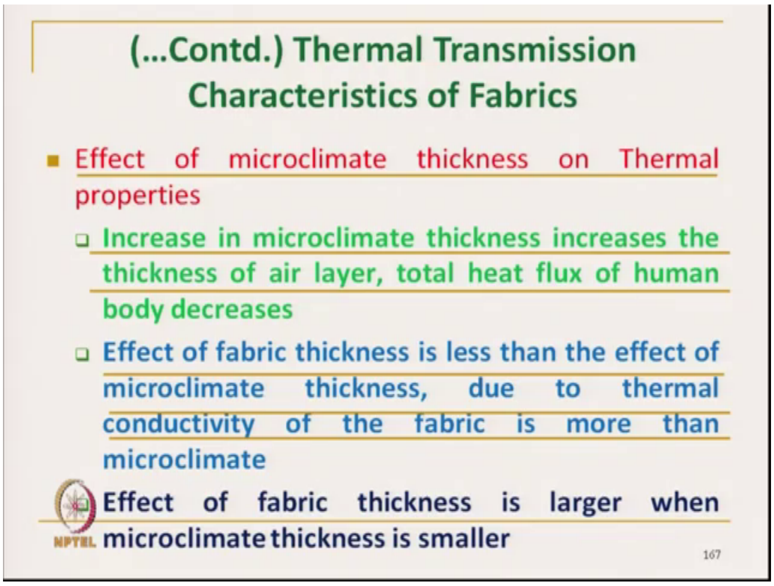

Now, another factor it is a, the effect of microclimate thickness. So, what is that the microclimate as we know that, it is a between our body, our skin and the cloth. So, depending on the microclimate thickness or insulation the thermal insulation changes of clothing changes. So, what is microclimate it is a basically still air entrapped air the increasing microclimate thickness in increases the thickness of the air layer between the skin and fabric. So, total heat flux of human body decreases. So, from our skin to the environment that total heat flux will reduce due to the entrapped air.

But this effect of thickness is less than the effect of microclimate. So, we can increase the fabric thickness to reduce the heat flow or we can increase the microclimate thickness to reduce the heat flow. So, if we compare these two, the effect is more in case of micro climate thickness. So, we have we if we have two options, if we can increase the microclimate thickness, if we can increase the entrapped air between skin or fabric or within two layers between two layers of fabric that option you should take other than that increasing the fabric thickness.

We should not make the fabric thicker unnecessarily if we can incorporate in if we can develop of a structure with higher microclimate thickness, so that effect of microclimate thickness is more prominent then effect of fabric thickness.

So, because the fabric consists of fiber, fiber has got some thermal conductivity; and the thermal conductivity of fiber is more than air. So, if we can incorporate pure air inside the structure that will be that will be preferable. And fabric thickness the effect of fabric thickness is larger when microclimate thickness is less. So, if there is no microclimate or very thin microclimate, then we can have the clear effect of fabric thickness. But if the microclimate thickness is large, then changing the fabric thickness will not affect the thermal insulation characteristics of clothing.

So, here we are talking about the clothing and sample where we can incorporate the microclimate between the skin and clothing or between different clothing layer. So, we will see in our one of the studies, next we will see the how incorporation of air layer between two fabrics layer in effect the thermal transmission characteristics, thermal insulation characteristics.

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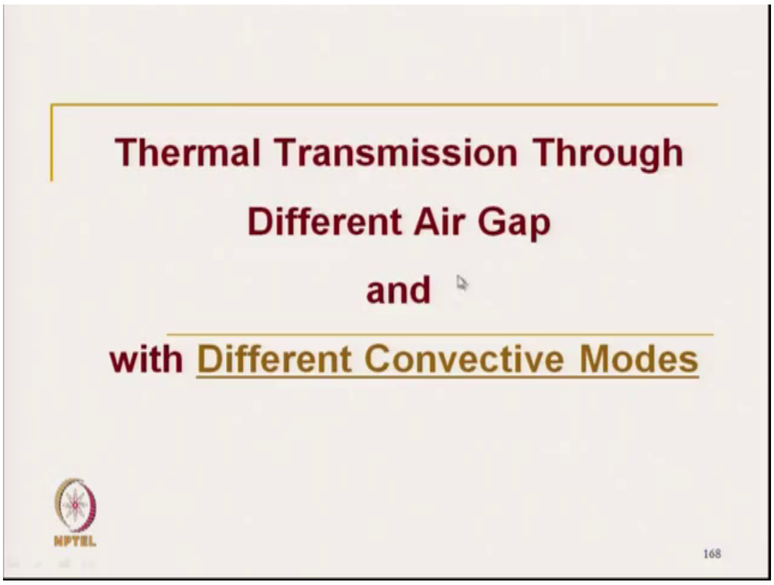

So, that thermal transmission through different air gap with different convective mode, so that study here three layers of fabrics have been taken outer layer, middle layer and inner layer. Between these three layers we have actually that we have incorporated the air layer. And thickness of air layers have been changed to just to see the effect of the microclimate thickness keeping the fabric layers same.

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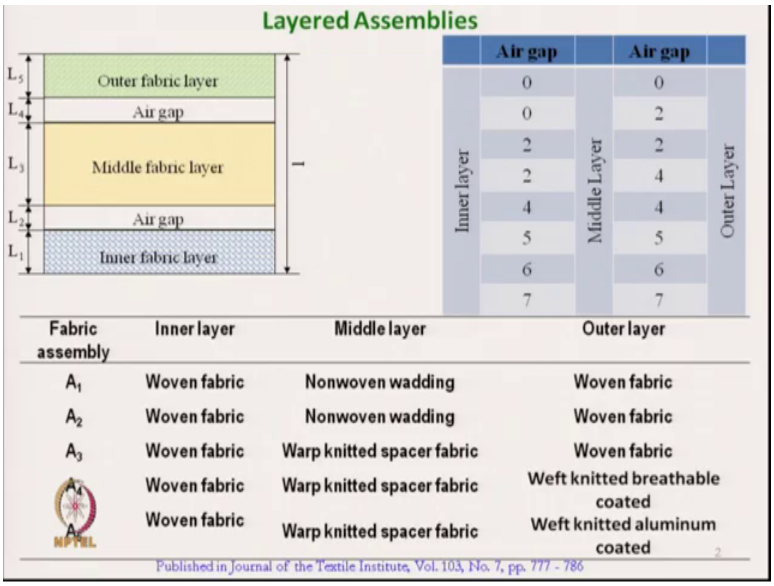

So, this is the arrangement what has been done it is outer layer fabric middle layer fabric and inner layer. Between this layers outer layer and inner layer middle layer, we have incorporated air gaps. And between middle and inner layer, another air gap two sets of air gaps are there. So, the experimental design was such that that between inner layer and middle layer, inner and middle layer, the air gap distance have been changed from 0 millimeter that is there is no air gap to maximum 7 millimeter. So, these are the combination. So, air gap the fabric combination one means there is no air gap between inner to middle and middle to this is the air gap 2 air gap 1 ok.

So and next fabric two sample when the inner and middle layer there is no air gap, but middle and top layer there is air gap of 2. So, in this way it is changed. So, if we see the this fabric final, this fabric is that first, second, third, fourth, fifth, sixth, seventh, eight, fabric if you see the total thickness of the assembly will be 14 millimeter, 14 millimeter plus the thickness of inner layer, thickness of middle layer and thickness of outer layer. So, this is the experimental design as we made. So, with to have different types of fabric layers with different air gaps.

Now, this fabric layers are of different type like A fabric assembly. So, this fabric assembly we have developed 5 fabric assemblies A 1, A 2, A 3, A 4, A 5 the assembly one where its inner layer is woven fabric, so for all inner layer we have use the same woven fabric. So, same woven fabric is used for all the fabric layers, layer 2 middle layer we have used actually we have used two different types of fabrics. One is a nonwoven wadding, nonwoven fabric and another is the wrap knitted spacer fabric.

So, the idea of middle layer is to provide the insulation. So, it was thought that that nonwoven fabric is used to give the porous in structure, so that is why nonwoven fabric is used it entrapped large amount of air also. And wrap knitted spacer fabric which also entrapped large quantity of air.

So, this with this combination it is thought, but finally, we what we found that nonwoven fabric gives better insulation than wrap knitted fabric spacer fabric, because the orientation of the spacer yarn spacer which are vertical. So, spacer yarns orientation which helps in flow transmission of heat, so that it gives lower thermal insulation.

And outer layer we have got two types of outer layer, one is the normal woven fabric. So, for fabric A 1, A 2, A 3 we are used normal woven fabric; and A 4 and A 5, this gives the coated fabric. So, coated fabrics with different known pore size it is a basically it is with very less pore size, which only allows the moisture vapour to transmit its water impermeable moisture vapour permeable fabric. So, these five combinations you have been made. Then we have measured the thermal and moisture vapour transmission.

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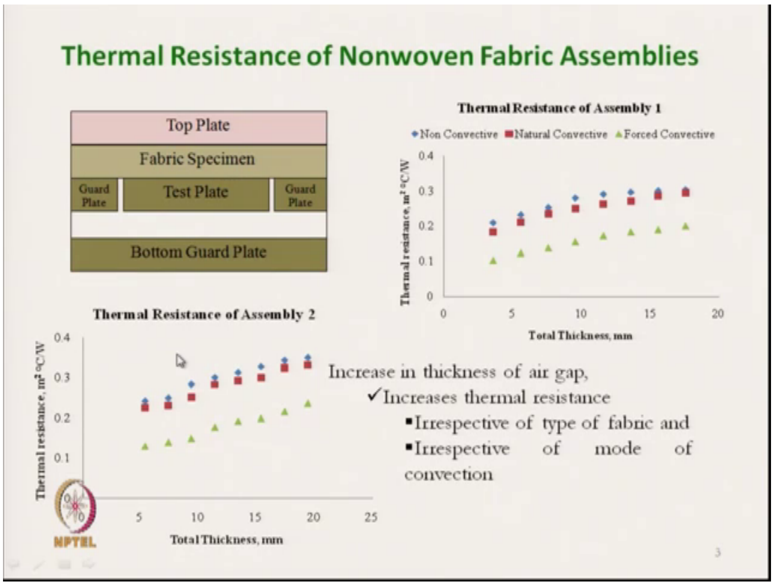

So, this is actually measured in sweating guarded hot plate. So, guarded hot plate where this is a test plate, bottom plate, fabric specimen is there, and its top plate is placed. Now, here the fabrics it is a from different types of fabrics are there. So, what we have done, the total thickness of fabric, so total thickness is changed. So, this is the minimum thickness and this is the maximum thickness, but the combination is the same fabric combinations are there.

These are the same for assembly 1, what is the assembly 1, this is the assembly 1. Assembly A 1 it is a woven fabric then nonwoven wadding and woven fabric, so which is assembly 1. And the thickness is changed thickness of total assembly is changed from one 0 to 7, so fabric that is the air gap is changed. So, this is the total thickness its goes up to say 20 or like that 20 around say 17, 18 millimeter thickness and thermal resistances given.

So, what we have observed with the increase in thickness of the air gap thermal resistance for all conditions air, air condition of mode of transmission it is a increasing. So, what are the modes, here there are three different modes have been used one is non convective mode, next is that the blue one is non convective mode, two red one is that natural convection, and third one this is a forced convection. Now, what is non convictive mode non conductive mode is where we place top plate. So, we do not allow any conviction. So, without any convection what how much heat is transmitted, so that is that that is the non convective mode.

And when we want to measure the convective natural convective mode then top plate is removed. So, the actually the heat is allowed to flow it in convictive mode also. This is the natural convection with the natural convection also. And forced convection that system is that where we have to remove the top plate, and allow the air to flow at certain speed, so that it actually simulates the windshield condition when air is blowing. So, air is then and in y-axis it shows that thermal resistance there. So, thermal resistance at different convective mode is actually it showing.

So, what does it show this picture this graph this is for assembly 1 and this one is for assembly 2. Assembly 1 and assembly 2 are almost same only that and here the top layer you have to see. What is the top layer, top layer here we have used it is a woven fabric we can see here it is a woven fabric. Both assembly 1 and assembly 2, their combinations are same only, the nonwoven wadding this fabric their thickness their mass per their mass per unit area is changed

So, here if we see the non convective mode, the thermal resistance is highest. So, there is no convection that is why it gives the highest thermal resistance. And if we see the natural convection through natural convection little bit heat is x transmitted extra heat is transmitted that is the although the difference is less, but still this difference shows the how much air how much heat is transmitted through actually convective mode. So, natural convection, so that the difference is showing the amount of heat transmitted in natural by natural convection.

Now, when air is started blowing, what is happening, total actually total phenomena has changed total principal has changed here. It takes away the air from that portion and total forced convection we started. So, when forced convection started that means, a air started growing the thermal resistance of the total system drops drastically, it is a significant drop sometimes it becomes half thermal resistance.

The total system is actually the thermal resistance of the total system; total clothing system is dropped to almost half most of the cases huge drop in thermal resistance, so that means, the thermal forced convection for assembly 1 and assembly 2 are significant.

So, that is how it is showing that the with the increase in air entrapment the thermal resistance is increasing and the it shows the non convective thermal resistance is highest, followed by the natural convective thermal resistance; and in a forced convective mode, the thermal resistance is lowest.

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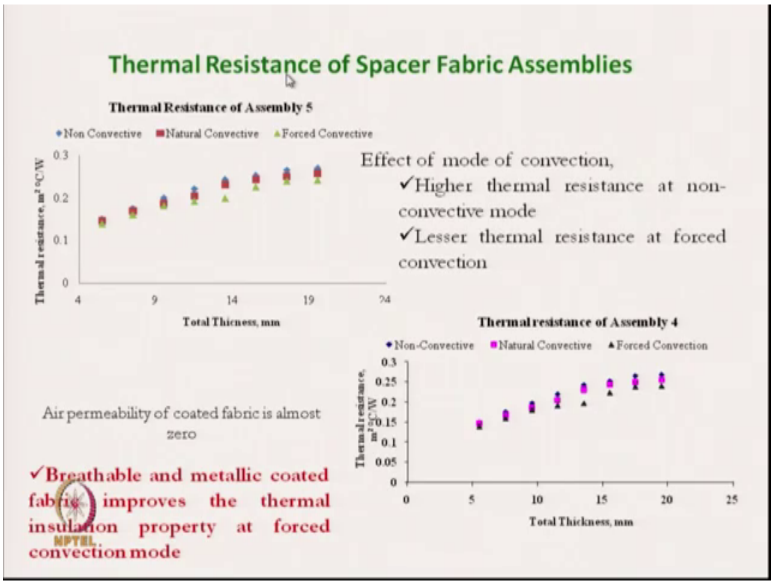

Now, if we see the fabric assembly 5, what is fabric assembly 5, fabric assembly 5 shows that its the top layer is changed with the coated fabric. So, this is the coated fabric. So, in coated fabric, the pores are almost blocked. So, whatever air is moving that does not affect the heat transmission convective heat transmission characteristics. It is almost it is close to non convective mode or natural convection. So, there is no difference, it is the fabric when if we are using a breathable layer the breathable layer outside, so that in that case the thermal resistance it can retain the thermal resistance.

So, that for the in case of wind chilled condition. So, when we cold air is blowing. So, in those application which we must use a clothing outer layer with a coated outer layer. So, here the outer coated layer its use its not only for the waterproofing and other it also prevents the heat loss due to the forced convection, so that is this curve shows here. So, higher thermal resistance at non convective mode less thermal resistance at forced convection breathable and metallic coated fabric improves the thermal insulation property at forced convection. So, we must use some breathable and layer to prevent any heat loss.

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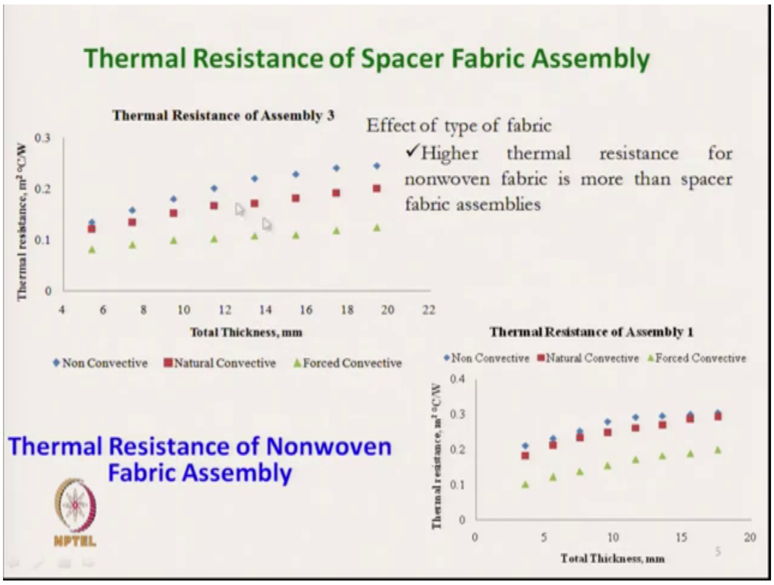

So, higher thermal resistance for nonwoven fabric is that is more than it is a spacer fabric, so thermal resistance in nonwoven fabric it os a more than the spacer fabric. If we see the quantity of thermal resistance at any level, so it is a lower the this is the fabric we with spacer fabric. So, simply three if we see it is with a wrap knitted spacer fabric.

And if we see the value here this is the spacer fabric here typically it is a 0.1 less than 0.1 a typical 0.2 here, 0.2 to 0.3. So, that overall it has been observed that the spacer fabric instead what we thought that it will give provide the insulation it is not able to in and provide insulation the reason behind is that it is a due to the arrangement of spacer yarn.

So, for extreme cold climate clothing to make ours body warm, so to enhance the thermal resistance. It is not recommended that spacer fabric is not recommended. So, in place of spacer fabric one can use the nonwoven wadding. So, this also it is a assembly one which is thermal resistance of nonwoven fabric we can see the effectively it is a total value is more than the spacer fabric.

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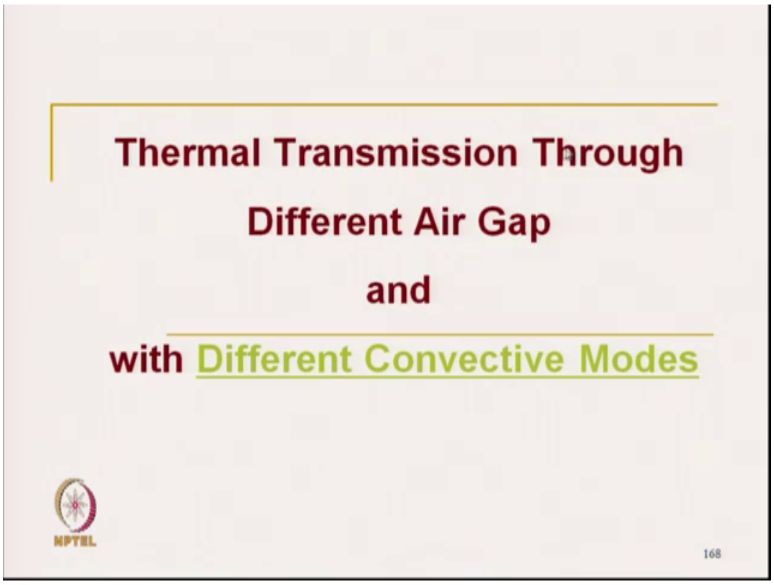

So, here we have discussed that, thermal transmission characteristics through different air gap and different convective mode.

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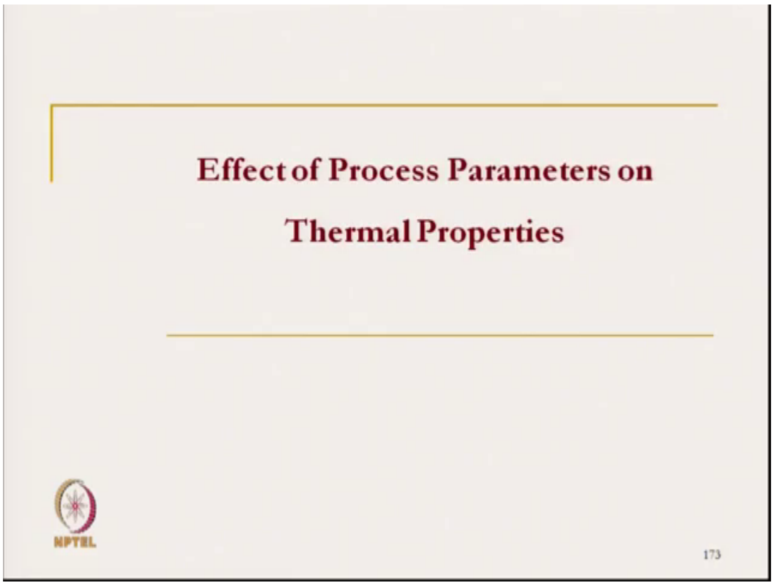

So, in the next segment we will study different process parameters which effect the thermal properties of clothing. So, here we have developed different fabrics nonwoven fabrics. And different combinations of nonwoven fabrics and effect of our needle punch density, effect of mass per unit area, effect of depth of penetration on thermal transmission and moisture vapour transmission of clothing which actually effect the thermal comfort characteristics. So, this thing we will effect we will discuss in our next segment.

Till then thank you.