Technical Textiles
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Lecture No- 28
Ultraviolet Protective Textiles (contd...)

Hello everyone, so we will continue with UV protective clothing. In last class, we were discussing the different parameters which affect the UV protective performance of textile material; these parameters are raw material related parameters, yarn related parameters, fabric geometry related parameters and technological parameters and all these parameters if we can manage, if we can manipulate properly we can develop the fabric with higher UV protection.

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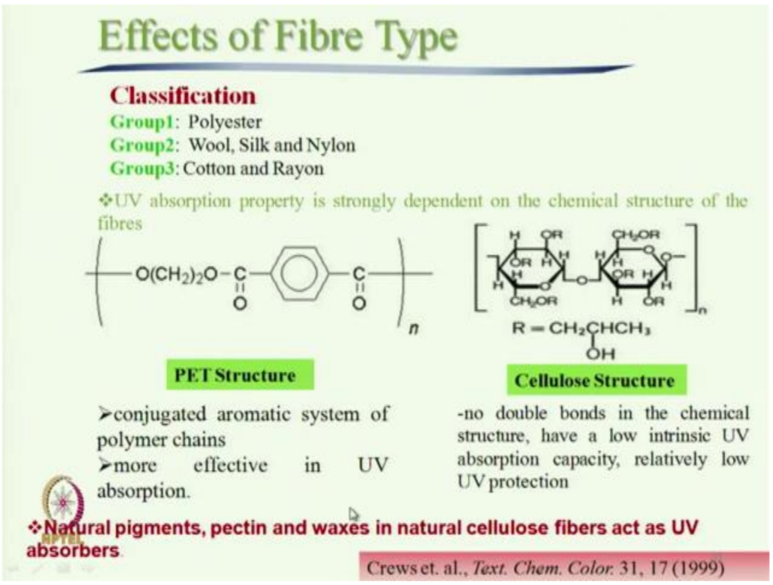

First we will start with raw material, we will try to understand the raw material. Here if we see that these are classified into three different groups, polyester is one group, group 2; wool, silk, nylon and group 3 cotton, rayon. So these are the cellulosic structures and polyester is having the structure conjugated aromatic type structure, it is polymer chain. Due to this type of structure of polyester they are UV protector.

So these are more effective in UV absorption this type of structure. So in cellulosic structure, there is no double bond in the chemical structure. So they have less, the UV protection here.

Sometime the natural pigments pectin and waxes in natural cellulose fiber, like cotton or jute act as natural UV observer. So the fibers before scouring will have more UV absorbing capacity.

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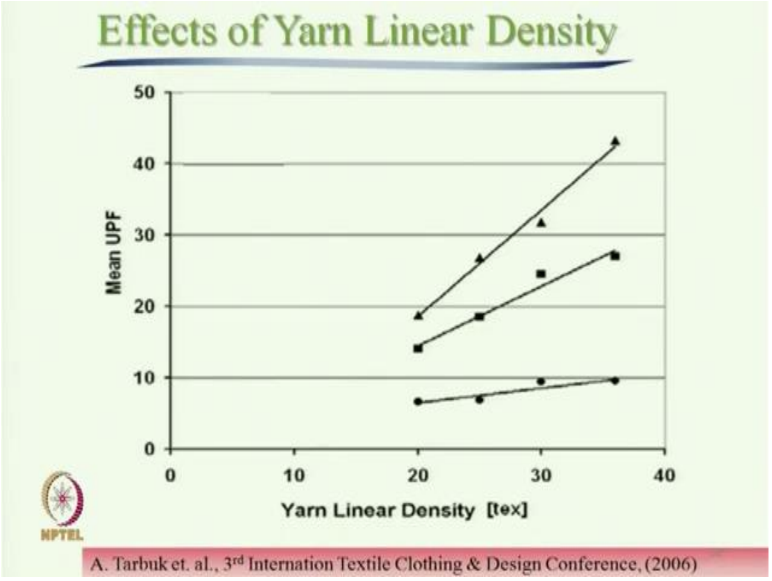

Now coming to the yarn parameters, it has been reported that as the yarn linear density increase yarn becomes thicker the UPF increases. So if we keep the fabric constructional parameter same, the higher yarn linear density higher tex of yarn means it is coarser yarn. That means the mean openness of fabric will reduce at the same time the effective thickness of the fabric will increase. So this will effectively increase the UPF value.

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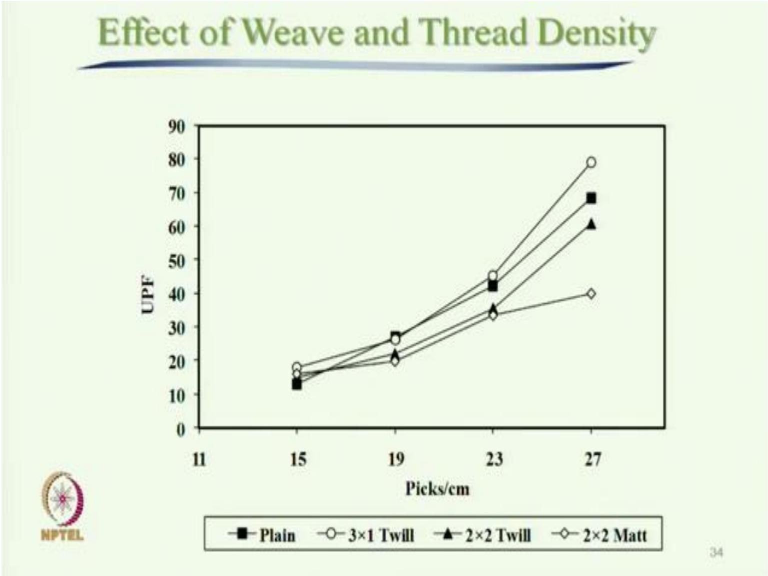

This figure also shows the similar trend. So weft count has been increased from 20 to 40, so in English count if it increases that a yarn becomes finer. So as the yarn becomes finer the UPF value reduces so to have higher UPF value we have to use the coarser yarn. The picks per centimeter, so as we increase the picks per centimeter pick density, we get compact structure keeping all other parameters constant.

So with the increase in picks per centimeter the UPF increases because effective the openness of fabric reduces.

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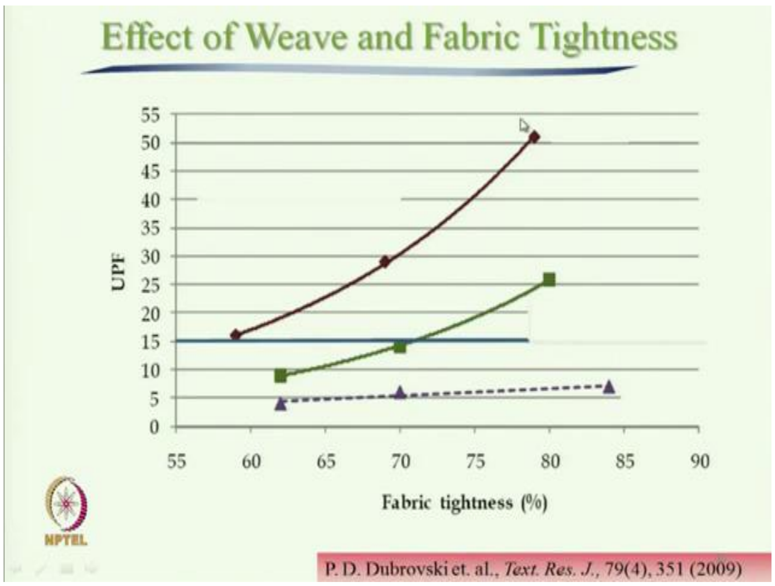

Similarly fabric tightness, so as we increase the fabric tightness, the UPF increases. So to have higher UPF, we must use coarser yarn with tighter fabric structure.

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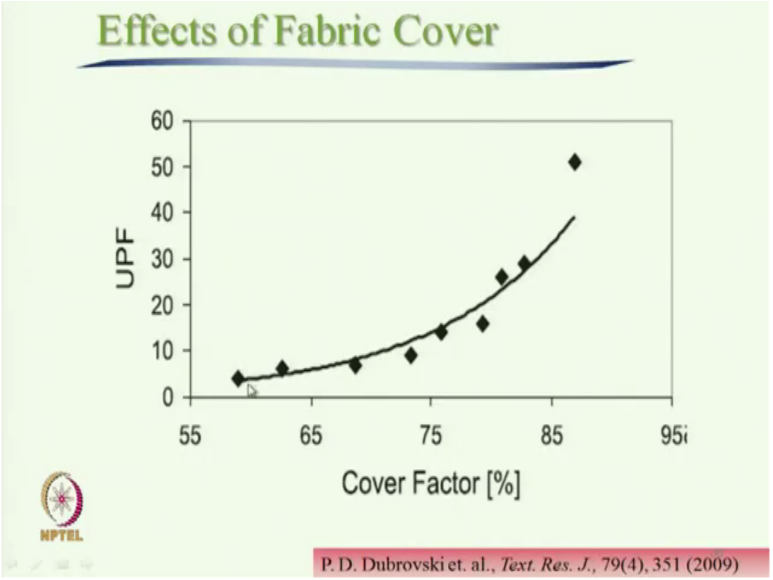

Like as cover factor increases so UPF increases. So these are the similar trends we get.

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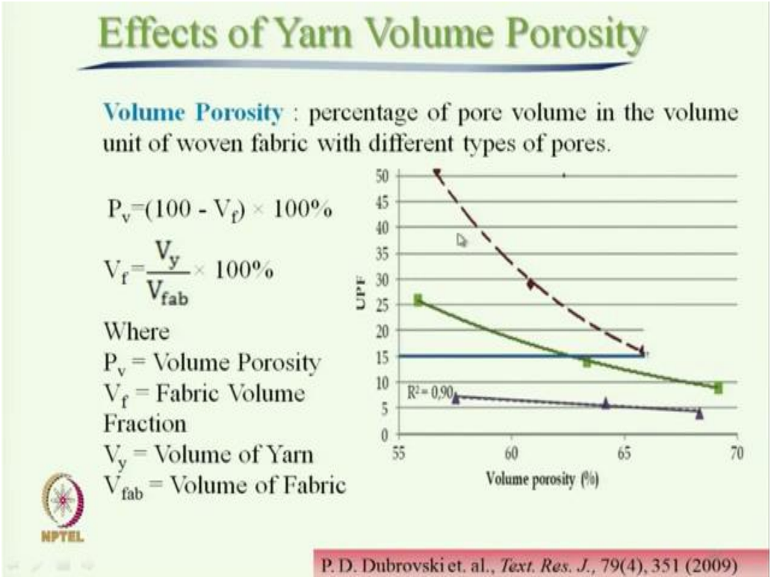

As far as volume porosity is concerned with the increase in porosity of fabric, that means the void present in fabric, the UPF value reduces. So these are for different types of fabrics, woven structure. So for all the fabrics we get similar trend.

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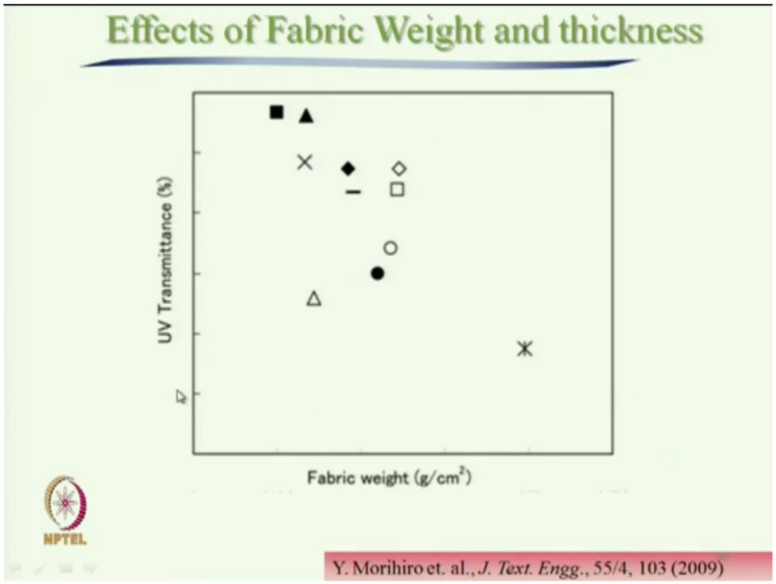

Fabric mass per unit area if we increase the mass per unit area the UV transmittance, so whatever ultraviolet ray transmission through the fabric takes place it reduces, that means UPF increases.

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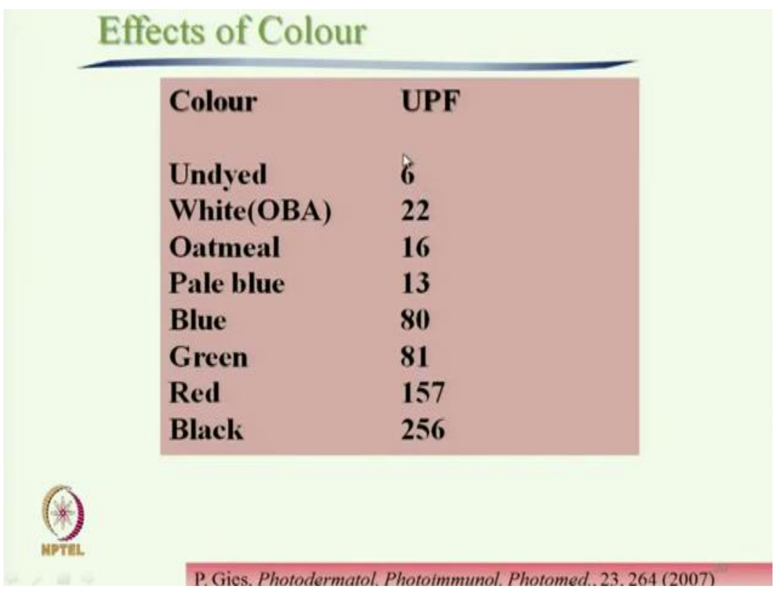

So effect of colors; we can see here the darker the color the higher is UPF. So for black color UPF is as high as 256. The same fabric undyed if we use its UPF is 6. So if we use the darker color, so for UPF higher if we have to use the darker color.

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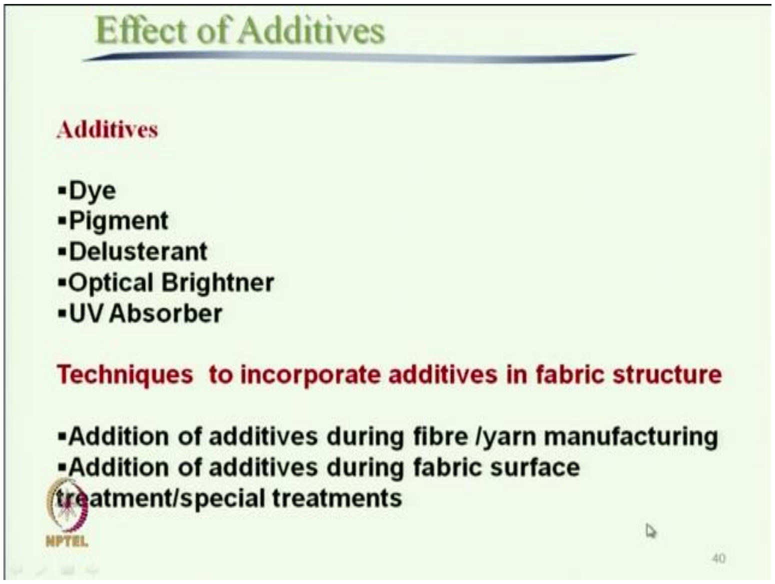

So effects of some additives these are; dye, chemicals, pigments, delusterant, optical brightener UV absorber. The application of this additives will increase the UPF of textile fabric, the techniques to incorporate additives in fabric structures are addition of additives, during fiber and yarn manufacturing. We can incorporate this pigment or delusterant during the fiber manufacturing to get the inherent UV protective fiber.

Or else we can apply during yarn manufacturing and also during the wet processing of fabrics; we can use this additives on the fabric structure.

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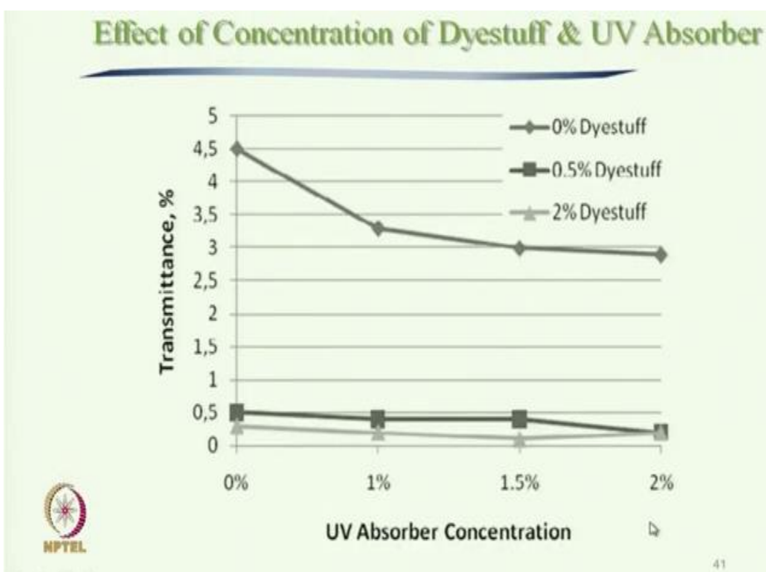

If we see here, UV absorber concentration here the UV transmittance here for undyed fabric, initially the UV transmittance was very high but with the increase in concentration of UV absorber the transmittance decreases gradually and the similar trend is true for the dyed fabrics also, although the effect is not that significant because for dyed fabric initially the transmittance percent was very low.

Now, we will discuss different research studies to engineer fabric to improve the UV protective performance.

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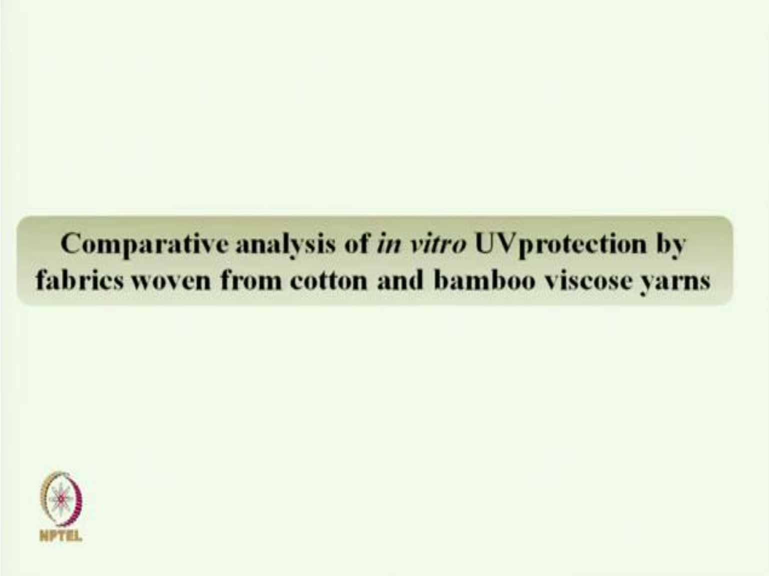

First, we will see here a comparative analysis of in vitro UV protection by fabric woven from cotton and bamboo viscose yarn. It is reported in literature that bamboo viscose they have inherent UV protection performance. To reconfirm this conception, the bamboo viscose fabrics were produced along with the cotton fabric it is reported that;

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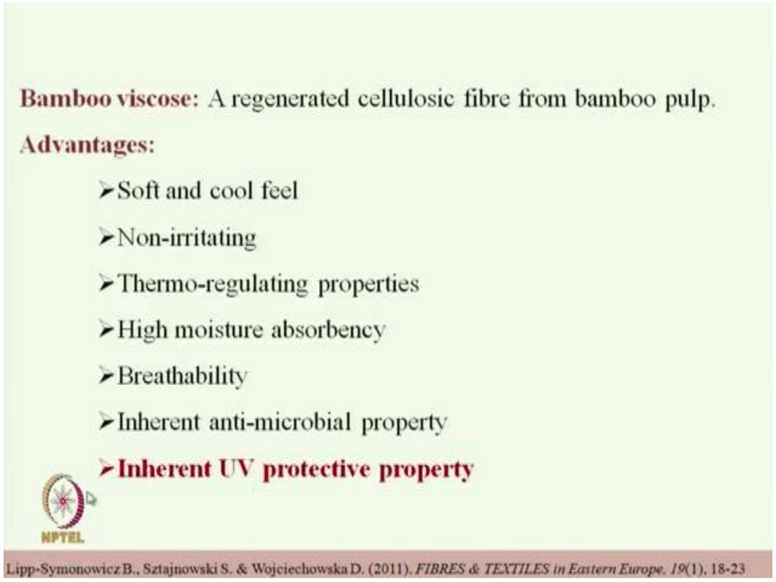

Bamboo viscose they have various positive characteristics; soft and cool feeling, non-irritating, thermo-regulating process properties, high moisture absorption, breathability and their inherent anti-microbial properties and most importantly, they are inherent UV protective properties. So in the present situation as we are dealing with UV protective properties so here the detailed study was carried out to understand the UV protective performance of bamboo viscose fabric made from bamboo viscose.

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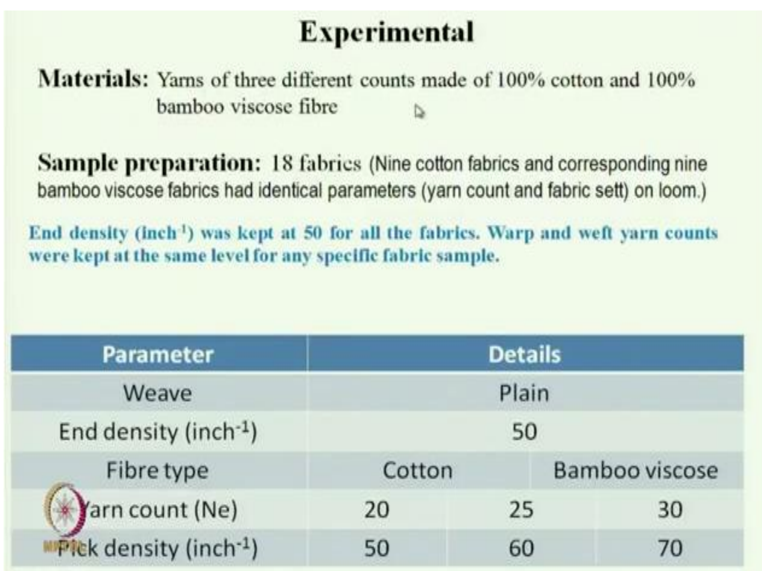

Fiber and cotton fabric, three different counts of cotton and bamboo viscose yarns were taken. So English count 20, 25, 30 fabrics were produced with ends per inch 50 and picks per inch was varied 50, 60 and 70 same parameters were kept for both for cotton and bamboo.

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Methods

1. **Thread density (inch^{-1}):** ASTM D3775-03
2. **Areal density (g/m^2):** ASTM D3776
3. **Cover (%):** determined optically using Nikon SMZ1500 microscope
4. **Shrinkage (%):** calculated from the yarn spacing before and after wet processing
5. **Ultraviolet protection factor (UPF):** AATCC 183:2004

Thread density, areal density, cover percent shrinkage percent and UV protection factor were measured.

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Results and Discussion

Ultraviolet Protection Factor

Fabric specification		UPF		
Yarn count (Ne)	Pick density (inch^{-1})	Cotton	Bamboo viscose	% Increase
20	50	7.82	11.12	42.29
20	60	10.15	13.45	32.53
20	70	12.79	16.32	27.56
25	50	5.08	7.08	39.41
25	60	6.64	9.78	47.21
25	70	8.68	11.02	26.90
30	50	3.73	5.13	37.72
30	60	4.20	5.80	37.98
30	70	4.96	7.54	52.07

Here if we see the UPF for both for cotton and viscose for different fabrics; yarn count 20, 25, 30 for pick density 50, 60, 70, so what we have seen here, overall, the UPF of viscose is higher than much higher than the cotton. So typically, the increase is around say 30, 40% even 50% increase is there as compared to cotton and this fabric specifications, yarn count and pick densities are in the loom stage, not at the final stage.

And UPF was measured after the finishing of the fabric, it is not in the loom stage fabric but as reported in earlier literatures the viscose fabric was giving higher UPF value.

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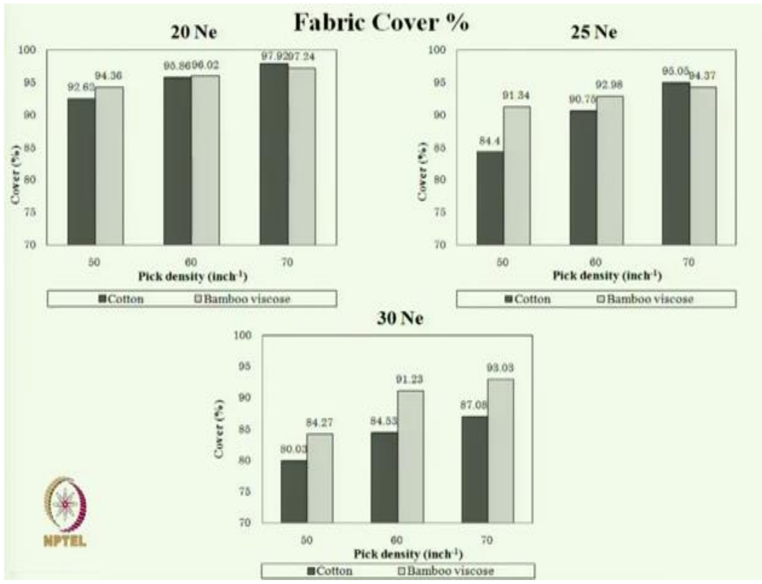

Now to understand the detail, the phenomena why the viscose is giving higher UPF, so different studies were carried out, so here if we see the pick density, this is for cotton and viscose and cover factor at 50 pick density of fabric in the loom stage. So cover factors were measured here effectively, there is no specific trend here, but at lower cover factor lower pick density. The cover factor of bamboo fiber was higher than cotton and for higher pick density they are almost same.

There is no specific trend this is for 20s count, 25 count for coarser yarn. There is no such trend but when we talk about the finer yarn finer weft yarn, this is 25 counts and 30s count so both warp and weft, so 25s count and 30s count the trend clear trend was observed in case of 30s count, 30s count it has been observed that the cover factor of bamboo viscose is higher than the cotton for all the pick densities. This has given us one clue why the cover factors are increased they have increased

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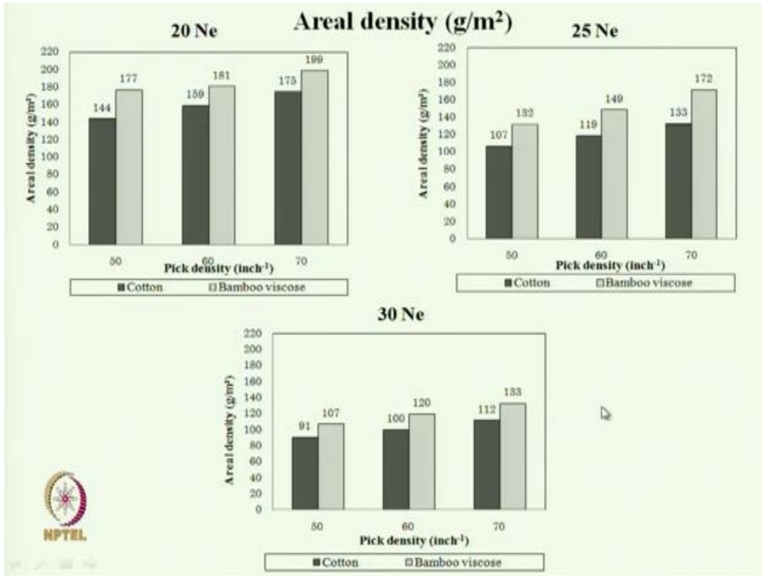

So areal density has been observed that areal density the fabric mass per unit area for all the conditions for different yarn count, different pick densities, in all the combinations it has been observed that the areal density of viscose bamboo viscose is always higher than the cotton. Keeping all the parameters same this increase in areal density is only due to the shrinkage which is taking place after weaving.

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Shrinkage

Fabric specifications		Fabric shrinkage (%)			
		Warp direction		Weft direction	
Yarn count (Ne)	Pick density (inch^{-1})	Cotton	Bamboo viscose	Cotton	Bamboo viscose
20	50	13.79	20.63	18.03	23.08
20	60	11.76	15.49	19.35	25.37
20	70	7.89	14.63	20.63	24.24
25	50	16.67	20.63	12.28	23.08
25	60	10.45	17.81	16.67	24.24
25	70	10.26	16.67	19.35	26.47
30	50	12.28	18.03	16.67	21.88
30	60	10.45	16.67	18.03	25.37
30	70	11.39	16.67	19.35	26.47

So this table shows clear indication here, this is the warp counts, fabric shrinkage percent. For warp wise direction for cotton shrinkage is around 7 to say 13%. Warp wise bamboo viscose is shrinkage is much higher, it is around 15 to 20% and weft wise shrinkage is also high it can go up to say 25% or something, whereas this cotton is around 18 to 20% in this. So it has been observed for all the combinations.

The viscose, the bamboo viscose fabric is having higher shrinkage so that increase in mass per unit area is mainly due to higher shrinkage.

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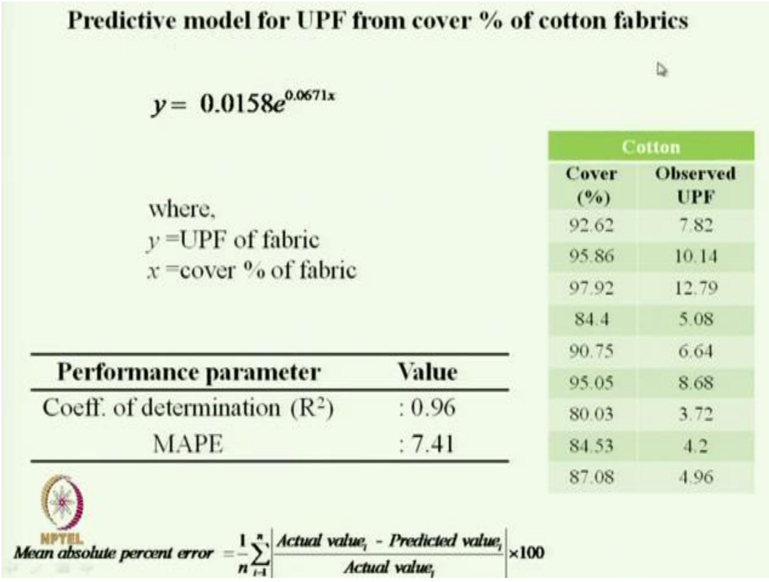

Now to predict the UPF value we can use either cover as parameter or mass per unit as parameter. So cover means that distance between threads, higher cover means higher protection that means it will actually obstruct the UV ray to pass through that we can, if we take. So UPF is taken as y parameter and cover is x as parameter, okay? So this is UPF value x is cover percent. So we will get this equation y equal to 0.0158 e to the power 0.0671x.

So this is the equation exponential equation we get and here mean absolute percent error is giving 7.41%, this is the error percent. Here, predicted model of UPF from cover percent of cotton fabric.

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Prediction of UPF For bamboo-viscose fabrics using cotton cover % model

$$y = 0.0158e^{0.0671x}$$

Cover (%)	Observed UPF	Predicted UPF	Actual error	Absolute error (%)
94.36	11.12	8.88	2.24	20.14
96.02	13.45	9.93	3.52	26.17
97.24	16.32	10.77	5.54	33.97
91.34	7.08	7.25	-0.18	2.49
92.98	9.78	8.09	1.68	17.19
94.37	11.02	8.89	2.13	19.33
84.27	5.13	4.51	0.62	12.04
91.23	5.80	7.20	-1.40	24.21
93.03	7.54	8.12	-0.59	7.79
R^2		0.84	*MAPE*	18.15

Now, predated model for bamboo using cotton cover means using the same equation, which we have observed for cotton fabric with cover percent as the x parameter, what we can observe here? Here the error percent is increased. Cotton if we use with the cotton model the error percent was 7.41%, same model if we try to use for viscose the error percent has increased which means that the cotton model we cannot use for viscose fabric bamboo viscose because, they behave entirely in different ways.

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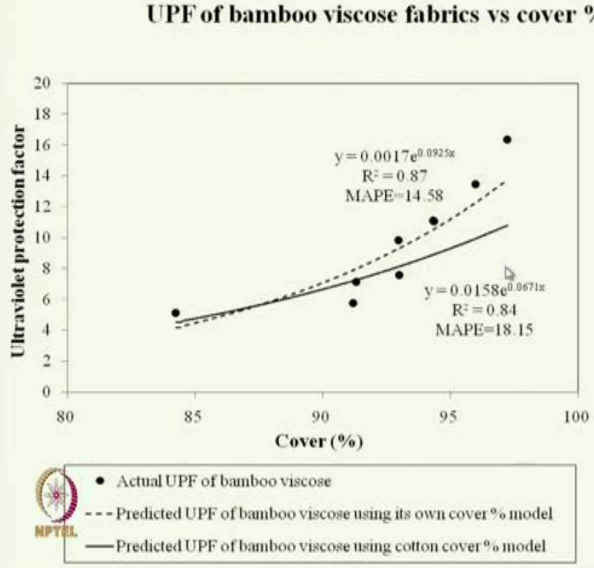

Bamboo viscose	
Cover (%)	Observed UPF
94.36	11.12
96.02	13.45
97.24	16.32
91.34	7.08
92.98	9.78
94.37	11.02
84.27	5.13
91.23	5.80
93.03	7.54

Now, if we use bamboo viscose fiber, fabric versus cover this is the, here the bamboo viscose bamboo viscose cover percent. So same fabric, if we use the relationship will be here 0.0017 e to the power 0.092x, This is the equation here if we use the viscose model, viscose cover factor model and the error percent has reduced to 14.58, if we use viscose model and in case of cotton model as we have seen the error was 18.15.

Still we see the cover factor if we take, still even with the viscose, the bamboo viscose model the error percent is high. Apart from the core factor another parameter which affect directly the UPF that is mass per unit area.

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Prediction of UPF for bamboo-viscose fabrics using cotton areal density model

$$y = 1.0476e^{0.0145x}$$

Areal density (g/m^2)	Observed UPF	Predicted UPF	Actual error	Absolute error (%)
177	11.12	13.64	-2.52	22.66
181	13.45	14.45	-1.01	7.51
199	16.32	18.77	-2.45	15.02
132	7.08	7.10	-0.03	0.39
149	9.78	9.09	0.69	7.02
172	11.02	12.69	-1.67	15.17
107	5.13	4.94	0.19	3.64
120	5.80	5.97	-0.17	2.99
133	7.54	7.21	0.33	4.36
R^2		0.97	*MAPE*	8.75

Now, let us take the areal density that is mass per unit area and for cotton model, cotton areal density model. This is coming out to be y equal to 1.0476 e to the power point 0145 x, where x is the areal density of cotton fabric and here the error percent is 7.24, that is the error and if we use this areal density of cotton with the bamboo viscose the error has increased to 8.75, but still this error is much lower than the cover factor here.

We can see here it is 4.93, when we use the viscose as a model and using cotton model, it is becoming 8.75. So one can now see that to predict the UPF of fabric we can use that areal density as independent variable.

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UPF prediction accuracy of various models

Input parameters	Performance parameters	UPF prediction		
		Cotton fabrics with own model	Bamboo viscose fabrics with cotton's model	Bamboo viscose fabrics with own model
Cover %	Coefficient of determination (R^2)	0.96	0.84	0.87
	MAPE	7.41	18.15	14.58
Areal density (g/m^2)	Coefficient of determination (R^2)	0.95	0.97	0.97
	MAPE	7.24	8.75	4.93

Now, if we see that areal density for cotton with cotton model it is 7.24 and areal density of bamboo viscose with bamboo model it is 4.93, bamboo viscose with its own model, so 4.93. So it is recommended that we should use their own model, but areal density as independent variable not the cover factor. So cover factor gives higher error percent.

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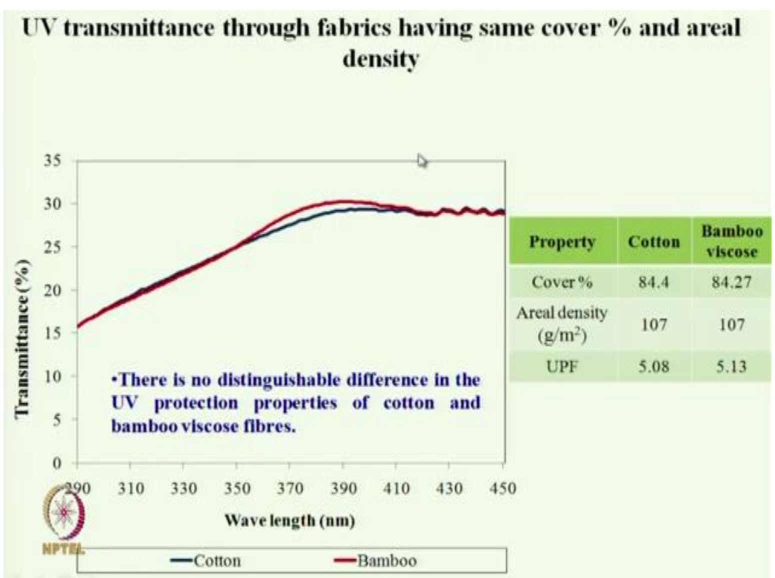

Now to extend this study what we have done here that UV ray transmission we have measured at different wavelengths and what we have developed? We have developed fabrics of cotton and the bamboo viscose is bamboo viscose cotton keeping the mass per unit area and cover percent same exactly same. So two fabrics were developed after finishing the mass per unit area were close to 107 and cover percent was around 84%.

In grey stage we have arranged the ends per inch, picks per inch in such a fashion that after shrinkage after washing the fabric's cover percent becomes 84%, this we have done based on previous experimental result. If we know the shrinkage percent that we can arrange we can manipulate the structure, so effectively cotton and viscose as far as mass per unit area and cover percent are concerned they are exactly same.

And for that this figure shows there is effectively no change no distinguishable difference in UV protection properties of cotton and bamboo viscose fiber, so earlier assumptions were that that bamboo viscose gives higher protection but the present study shows, that there is no difference, effectively there is no difference between cotton and bamboo.

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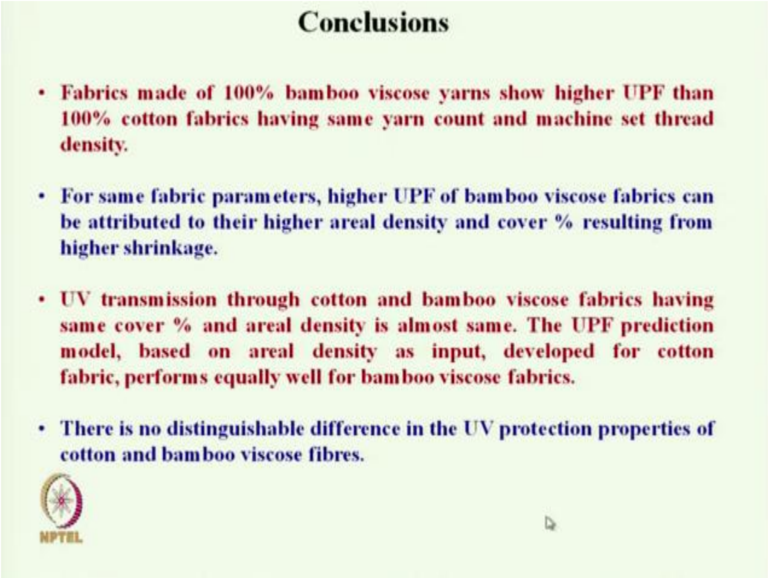

So the conclusions are fabrics made of 100% bamboo viscose yarn shows higher UPF than 100% cotton fabrics having same yarn count and machine set thread density, this is machine set thread density not the final thread density. For the same fabric parameters higher UPF of bamboo viscose fiber fabrics can be attributed to their higher areal density and cover percent resulting from higher shrinkage.

So UV transmission through cotton and bamboo viscos fabrics having same cover factor and same areal density, they are almost same. So there is no difference in UV protection properties of cotton and bamboo viscose. So if we see the protection purpose so we can use cotton as well as viscose depending on our availability, so bamboo viscose does not add to any extra protection.

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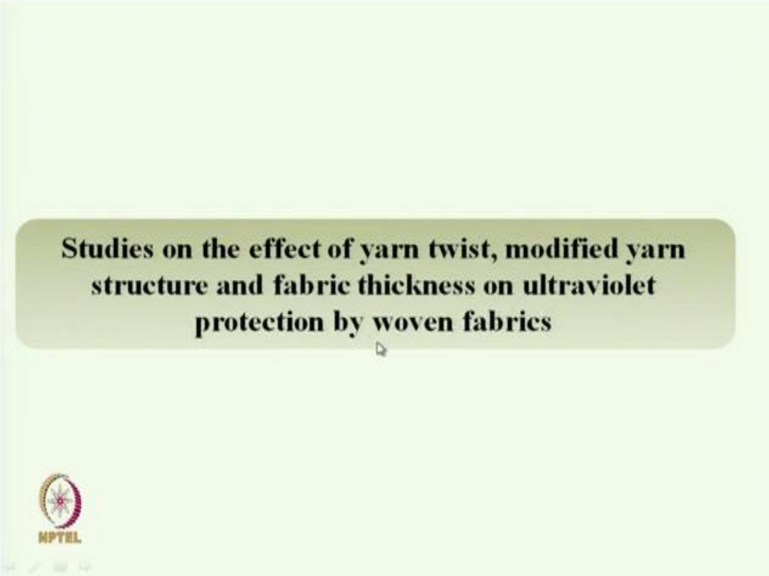

Now we will see the effects of yarn twist, modified yarn structure and fabric thickness on UV protection of woven fabrics. So these are the parameters which directly affect the UPF of woven fabrics. First we will see the yarn twist modified yarn structure means, here what we have created the hollow structure, hollow structure and it is compared with the normal yarn and fabric thickness was by changing the yarn count, yarn linear density keeping the mass per unit area same.

It has reported that higher fabric thickness will give higher protection but in the present study what we have tried to keep the mass per unit area constant and we have changed the thickness by changing the yarn linear density or yarn diameter.

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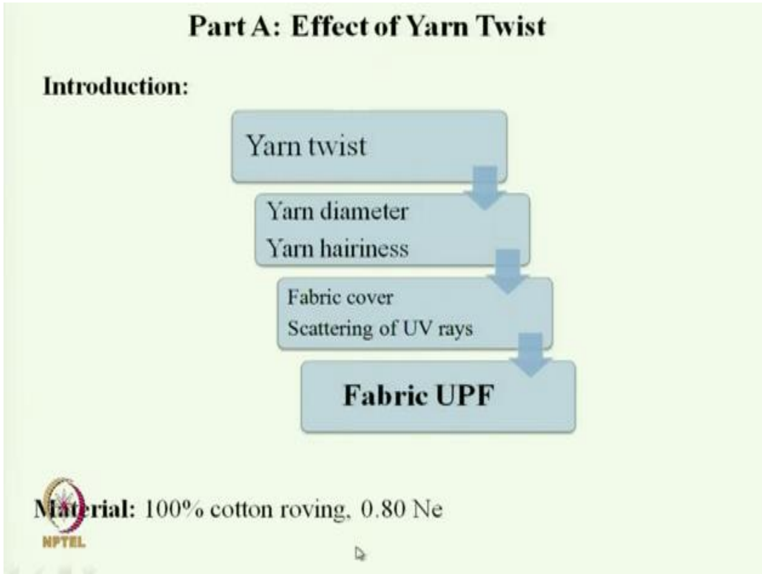

First, let us see the effect of yarn twist, so if we change the yarn twist, if we increase the yarn twist the yarn diameter will reduce and increasing and twist will affect the yarn hairiness, so higher and twist will have higher yarn hairiness. So these two factors indirectly affect the fabric cover and the yarn UV protection. Hairiness also affect the it scatter the UV ray, and ultimately the affect the UPF of fabric 100% cotton yarn was produced from roving of 0.8 Ne.

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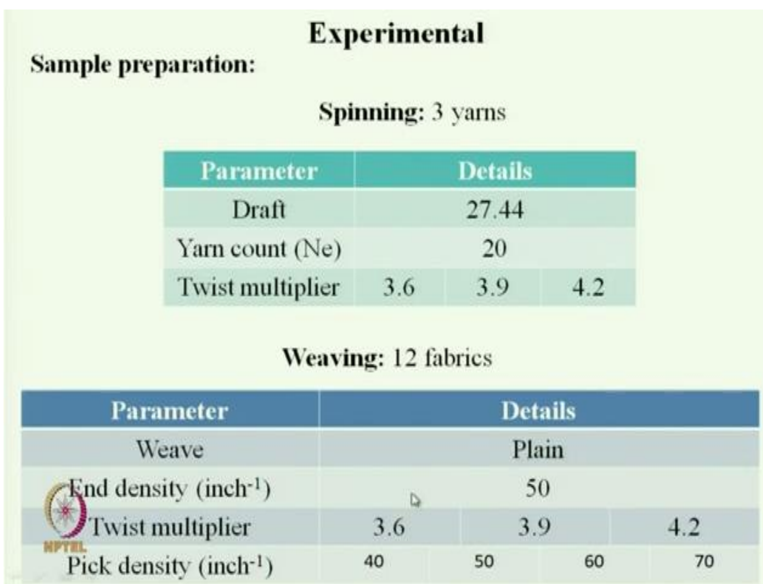

These are the spinning parameters, 3 yarns were produced with 3 different twist multiplier with yarn count of 20s Ne, 3.6, 3.9 and 4.2 twist multipliers were given, total 12 fabrics were produced with end density 50 ends per inch 3 different twist multiplier with 4 different pick density; total, 12 fabrics were produced.

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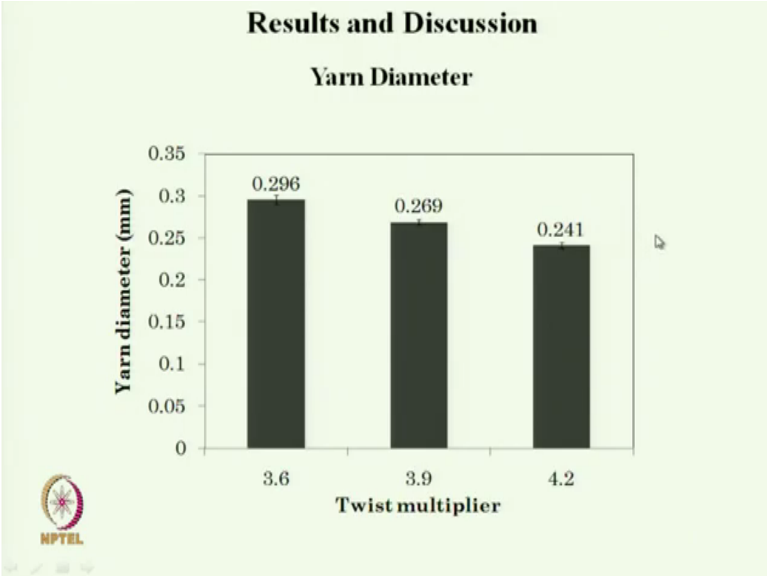

If you see the as we increase the twist multiplier the yarn diameter reduces. This is obvious because yarns are becoming more and more compact, so yarn diameter reduces.

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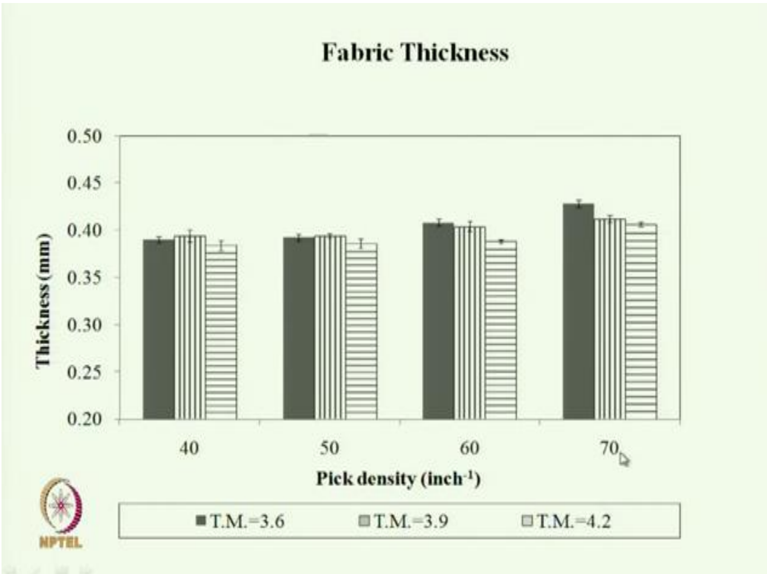

Now as we increase the pick density 40, 50, 60, 70 the effect of thickness is not that significant. So and for different twist multiplier 3.6, 3.9, 4.2, the thickness effect is although there little bit but not that significant at very high pick density, very compact fabric the effect of thickness is visible, but for low pick density, it is not that visible.

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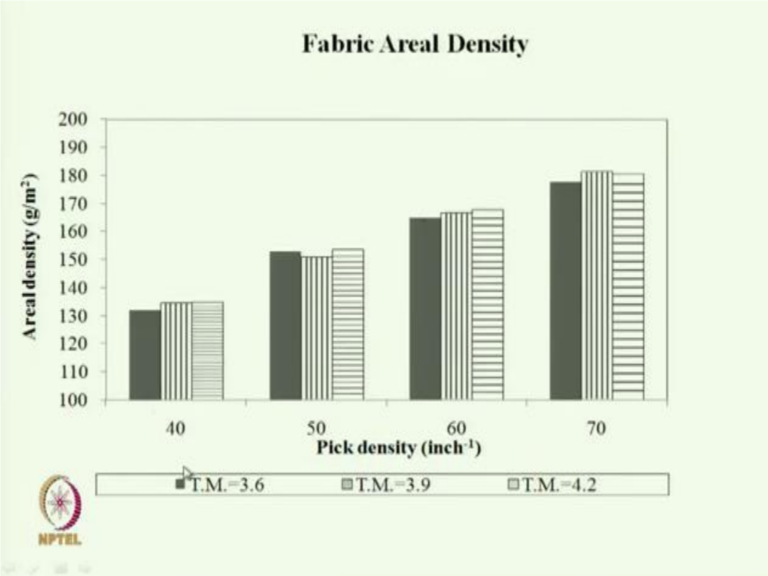

Areal density, as we go on increasing the pick density, areal density increases but the twist multiplier does not have any effect on areal density. So areal density there is no effect of twist even as per as thickness is concerned, there is no such significant effect of thickness of yarn twist on thickness.

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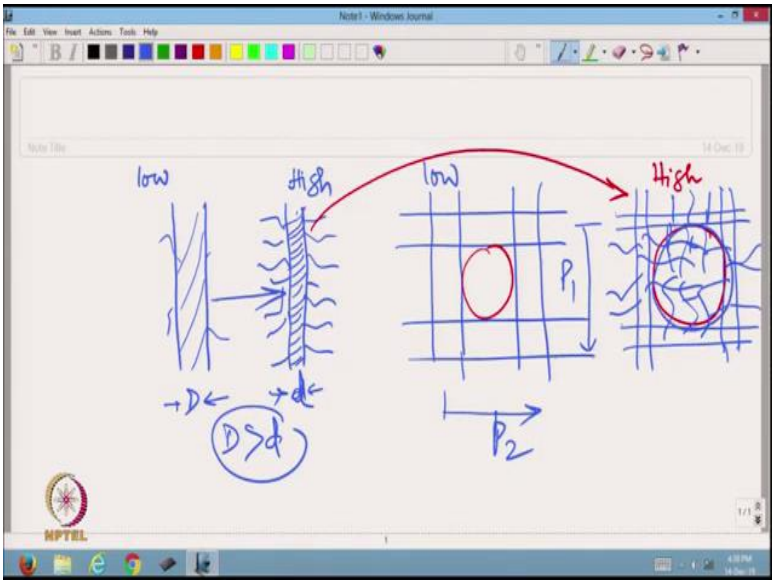

So effectively that, the twist multiplier does not have any significant effect on the UPF of fabric, so no specific trend has been observed on UPM with increase in twist level. So twist level if we try to keep the mass part unit area ends per inch, picks per inch constant this twist level it is not showing any significant trend the reason can be explained here in the two factors which I have already mentioned.

This is at low level of twist and at high level of twist this is low level of twist. Same yarn if we increase the twist at higher level twist has been increased, what happened? The diameter of yarn is D here diameter is d same yarn count, so the diameter has reduced but the at the same time the with the increasing twist the hairiness has increased here hairiness was less. So this two effect they are basically contradictory effects.

Now, if we draw the fabric structure, this fabric is made of low twisted and this is the pick density or this is the end distance or pick distance, whatever may be, so P2, take this P1. Now, we are keeping the same ends per inch picks per inch. So here effective opening is more. So ideally this is high twist, ideally this should this fabric with high twisted yarn should have transmitted more and more UV ray.

But at the same time the second factor comes into picture with hairiness increase. So this extra hairiness which is actually blocking the pores which has been created due to higher twist will prevent the UV ray to flow through transmit through and also it will try to scatter the UV ray. So that is why, this 2 contradictory factors will actually nullify the effect of yarn twist on the UV transmission. So for this reason there is no effect as observed though, no specific trends were observed.

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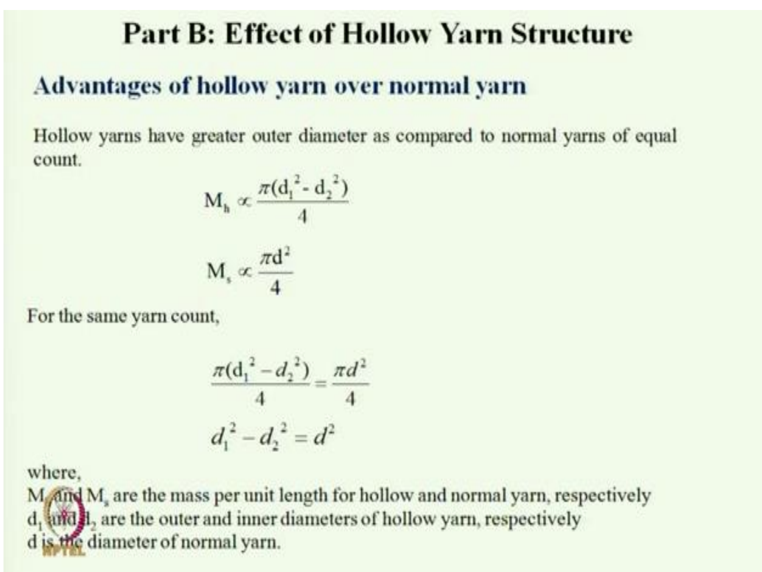

Now in the second part, it was tried to develop hollow yarn and to see the effect of presence of hollow yarn on the UV protection characteristics of the woven fabrics. This hollow yarn with greater outer diameter as compared to the yarn with normal yarn of equal count, that means mass per unit length of yarn both the yarns are same. So, hollow yarn will have higher diameter, outer diameter.

So d1 is the diameter, the outer diameter of the hollow yarn and d2 is the inner diameter. So mass per unit length is proportional to the cross sectional area and here this is the cross sectional area of the normal yarn. So effectively d1 square - d2 square equal to d square, so d1 square is always higher than d square. So to keep the same mass per unit area the two yarns were used one was hollow yarn another was normal yarn.

And end per inch and picks per inch, so end density and pick density were kept same. So in that case, it has been observed that hallow yarn with higher diameter covers more area than normal yarn.

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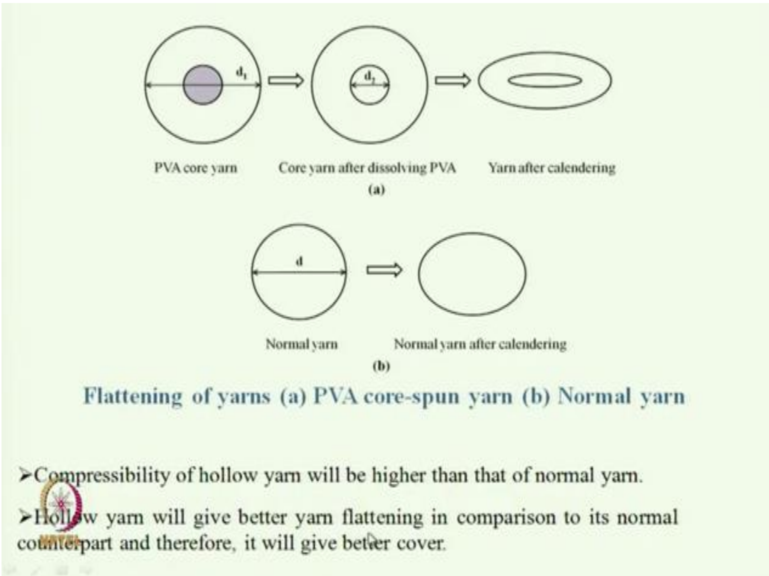

This is the hollow yarn and here is normal yarn but the fact is that hallow yarn after removal of the core when it becomes hollow, but during processing yarn gets flattened. So it further covers the yarn that inter yarn space and this core was of PVA yarn PVA fiber and after washing in warm water this PVA gets dissolved leaving the hollow portion and normally yarn when we press this does not get that much flattened.

So compressibility of volume will be higher than the normal yarn. So hollow yarn will give better yarn flattening as compared to normal yarn therefore, it will give higher fabric cover. So that was the idea to improve the UPF value by incorporating the hollow yarn.

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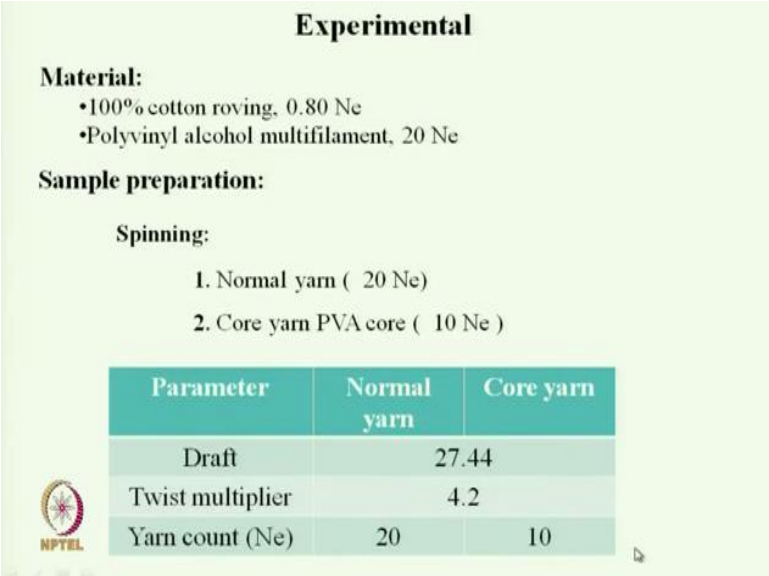

The materials were used hundred percent cotton roving and PVA multi filament yarn. So with 20 English count in the ring spinning process, the core yarns were produced with the twist multiplier point 4.2 and yarn count 2 yarn counts were produced 20s count and core yarn 10s count. So normal yarn 20s count core yarn 10s count means, here the mixing was that 50-50, 50% core and 50% sheath, sheath material was cotton.

After washing after removal of the PVA core this yarn will become 20s. So both the yarns hollow yarn and normal yarn effectively, they are 20 English count.

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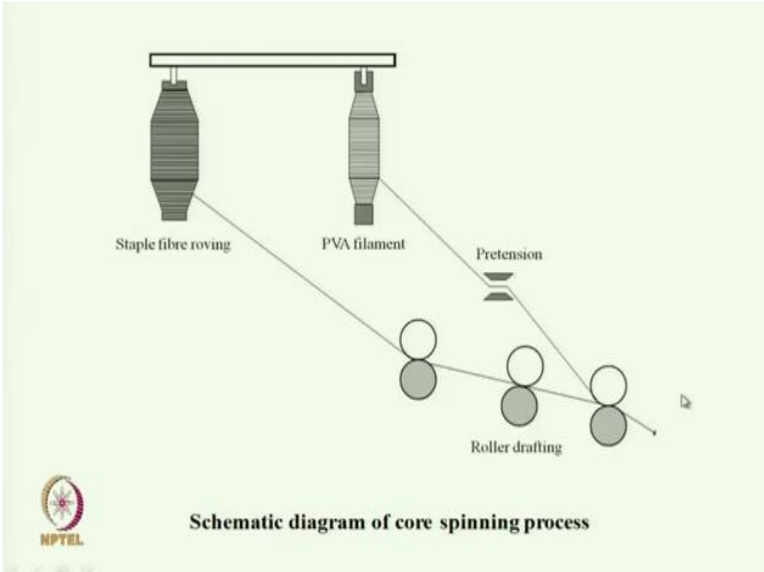

This is the manufacturing process PVA filaments where pre tensioned and they are fed at the front ruler and staple yarn, staple roving that is cotton roving was used it has been drafted and after front roller during twisting they this PVA filaments form the core structure.

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Weaving: 8 fabrics

Parameter	Details			
Weave	Plain			
End density ($inch^{-1}$)	50			
Yarn type	Normal yarn (20 Ne)		Core yarn (10 Ne)	
Pick density ($inch^{-1}$)	20	30	40	50

Post Weaving

Wet treatment (Desizing, scouring, bleaching) → **Calendering** (Ironing)

Allows hollow structure of yarn by washing off PVA from core

Allows yarn flattening

And here the fabrics were produced 8 different fabrics were produced with a plane woven fabric ends per inch was kept constant for all the fabrics 50, two types of yarn normally yarn and core yarn, here the washing was done after the fabric manufacturing. So effectively core yarn linear density was 10 Ne count pick density is where 20, 30, 40, 50, so a different pick densities the fabrics were produced, the wet treatment desizing, scouring and bleaching was done.

And during this wet treatment the PVA fibers were dissolved forming the hollow yarn and calendaring process was done after the wet treatment which allows the yarns to be flattened and hollow yarns were observed to a flattened more.

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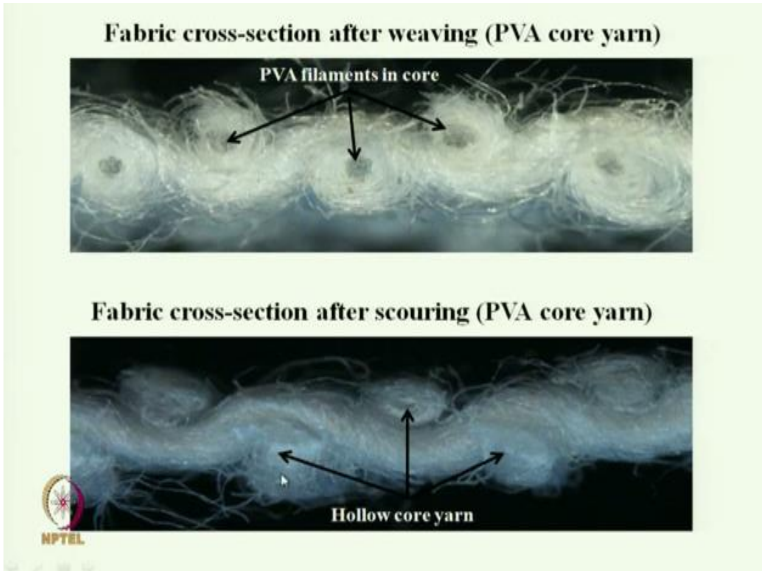

If we see the cross section here these are the core p spun yarn. Core spun yarns and this core spun yarns this portion, it is a core PVA core. PVA filament core and after the washing treatment the PVA cores were dissolved and hollow yarns are produced. These are the hollow yarns here we can see the voids are there.

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And if you see the fabric cross section here, the hollow yarns in the weft where flattening takes place, so during flattening we see this hollow yarns they were almost cover the open space between the threads due to flattening whereas, this normal yarn they did not flatten in that extent. So there are openings present in the fabric structure.

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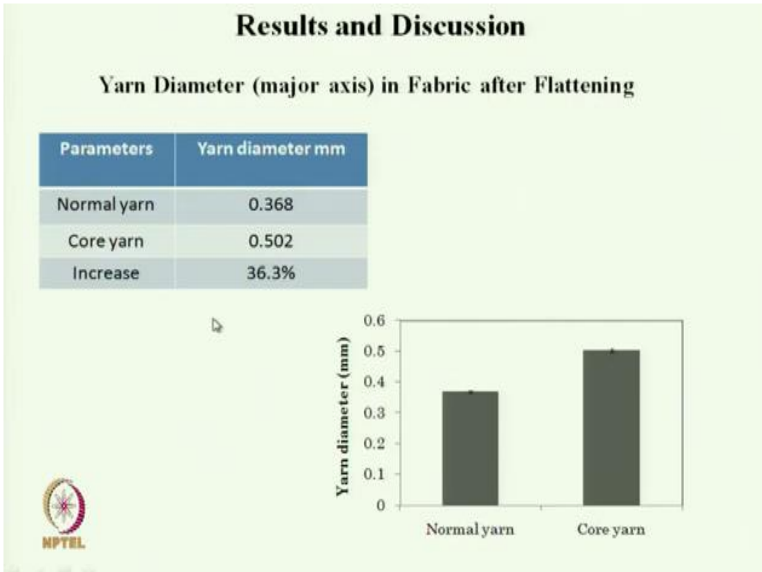

The yarn diameter that is measure axis in the fabric after flattening normal yarn it is 0.368 after flattening that the major axis the core yarn has become 0.502, although their linear densities are same 20 English count, these are taken from fabric stage so increase in yarn diameter major axis diameter it is 36% increase. So there is a 36% increase in diameter.

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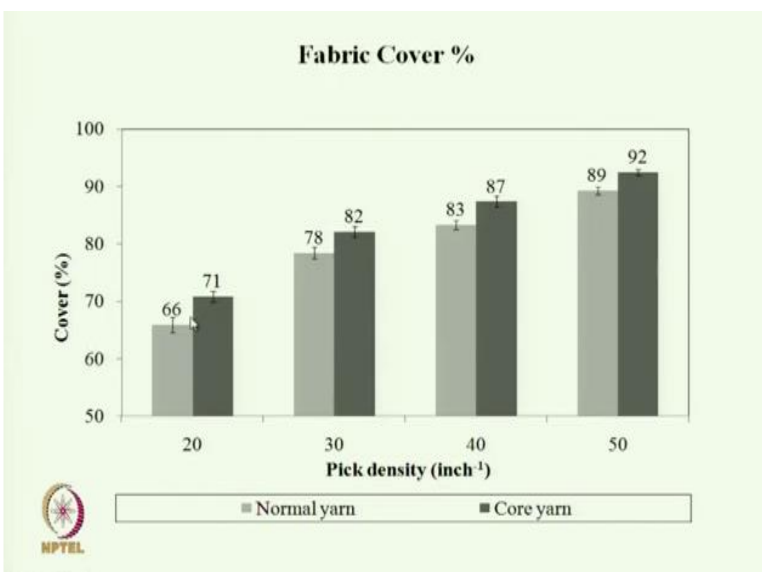

That is why cover factor is cover percent is always higher than the normal yarn and the cover percent also increases with the increase in pick density.

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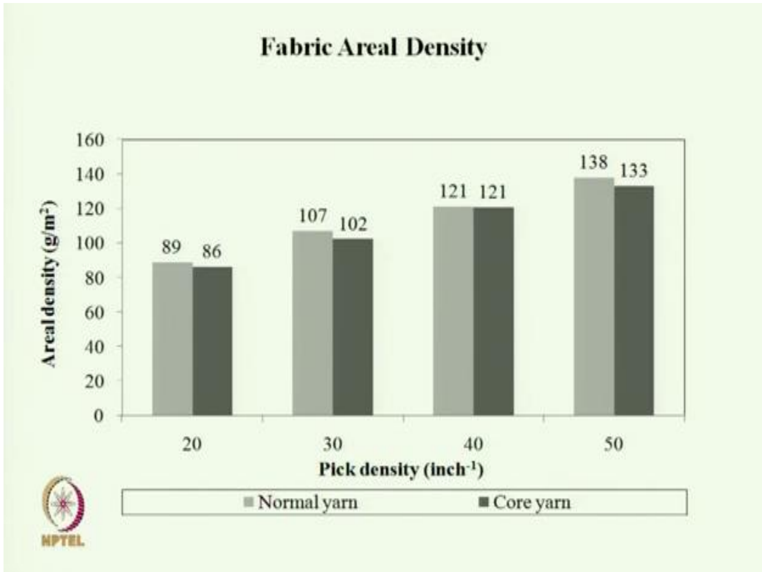

If we see the areal density, areal density is almost same for both the cases. So by yarn engineering what we have created different cover factor, but same mass per unit area that is created. So we wanted to see the effect of mass per unit area is significant or effect of cover factor a significant.

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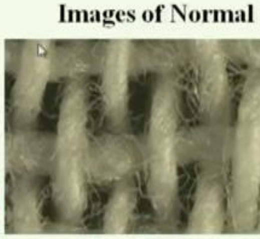
Ultraviolet Protection Factor

Pick density ($inch^{-1}$)	Yarn Type		
	Normal yarn	Core yarn	Increase (%)
20	3.55	3.64	2.5
30	4.1	4.29	4.6
40	5.08	5.38	5.9
50	6.7	8.01	19.6

Images of Normal and Core yarn fabrics



Normal yarn, 20 PPI

Core yarn, 20 PPI

Here we can see here that for different pick density the increase in cover factors, proportion of increase in curve factors are reported here for lower pick density the cover factor increases only

2.5% for 20 pick density, that increase from normal yarn to core yarn but for higher pick density this increase is around 20%, 19.6% increase. That means as we go on increasing the pick density the proportion increase in cover percent increases.

So image of normal yarn and core yarn; this is normal yarn with higher openings, these are the core yarns these are before flattening.

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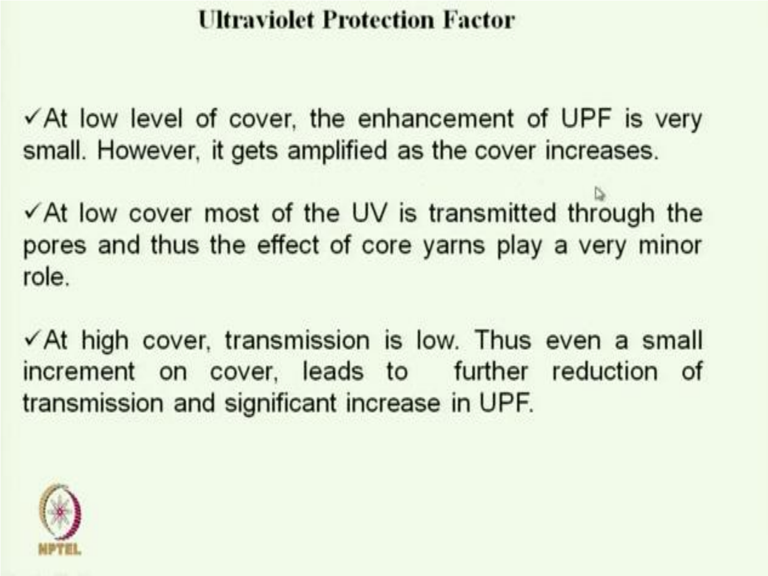

So at low level of cover the enhancement of UPF is very small. However, it gets amplified with the increase in cover percent. Now here if we see again, the effect of hairiness will come into picture.

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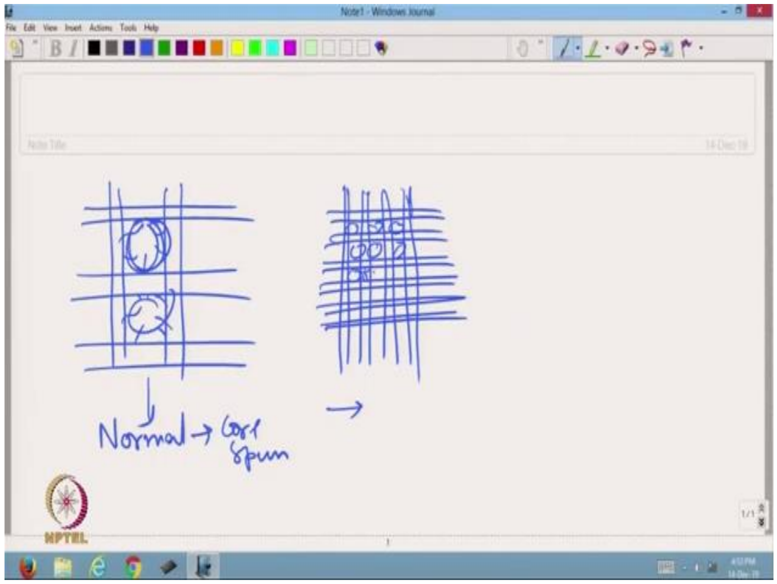

So we have, this is low level of cover and when we talk about the high level of cover by increasing the picks per inch, so these are the openings here the openings are smaller. Now for normal to core spun there will be increase in cover percent and due to that the UPF will also increase. But here at higher level of cover due to flattening there will be increase in cover and UPF will increase.

But the presence of hairiness with the open structure, the effect of hairiness will be insignificant, but when the fabrics are compact, that presence of hairiness will be will have significant impact on the UPF. That is why the UPF increases more during flattening when the cover percent is high. So here the cover percent is high the impact is 19% this impact is mainly due to the hairiness present.

At low cover most of the UV is transmitted through the pores and thus the effect of core yarn plays very minor role, at high cover transmission is low thus even a small increment of cover leads to further reduction in transmission and significant increase in UPF.

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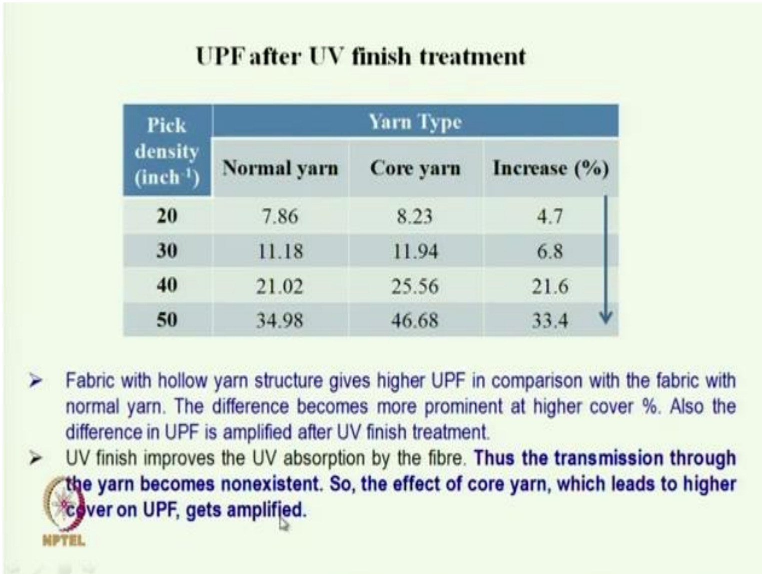

So that is with UV finish ultraviolet finish treatment here, the enhancement the increase is much higher than the untreated. So earlier it was the untreated fiber untreated fabric but here this is you will finish treatment fabric with hollow yarn structure gives higher UPF in comparison with the fabric with normal yarn the difference become more prominent at higher cover factor also the difference in UPF is amplified after UV finish treatment.

So this is clear here it’s difference is magnified the UV finish improves the UV absorption by the fiber itself thus the transmission through the yarn becomes non-existent because the fiber also absorbs the UPF, so the effect of core yarn which leads to higher power factor gets amplified. So here also the UV finishing it helps in the absorption by the fiber, so whatever flattening took place it gets amplified when the fiber starts absorbing the UV.

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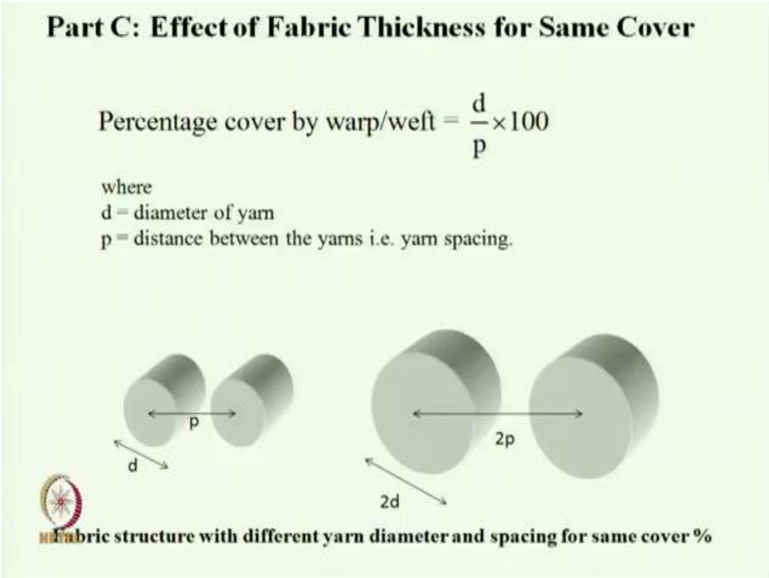

And, our next study will be the effect of fabric thickness keeping the cover factors same, so that we will discuss in the next class, till then thank you.