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UV Radiation Protective Clothing

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Abstract: The incidence of skin cancer has been rising worldwide due to excessive exposure to sunlight. Elevated exposure to ultraviolet radiation component of sunlight results in skin damages; such as sunburn, premature skin ageing, allergies and skin cancer. Medical experts suggest several means of protection of human skin against ultraviolet radiation; use of sunscreens, avoidance of the sun at its highest intensities, wearing clothing that covers as much of the skin surface. However, this paper gives an insight about how textile clothing can be efficiently utilized for protecting human skin from the harmful ultraviolet radiations. The various influential clothing parameters, offering resistance to penetration of ultraviolet radiation through the fabrics are briefly summarized. The determinant factors of ultraviolet radiation are elaborated. The effect of ultraviolet radiations on textile materials is discussed.

Keywords: Fabric construction, protective clothing, skin diseases, ultraviolet absorber and ultraviolet radiation.

1. INTRODUCTION

Sunlight is the prime energy source and essential element for survival of human race. Sun radiation has a continuous energy spectrum over wavelength range of about 0.7 nm to 3000 nm and the effective spectrum of the solar radiation reaching on the surface of earth spans from 280 nm to 3000 nm [1], where the wavelength of ultraviolet spectrum lies between 290 nm to 400 nm. Ultraviolet radiation constitutes to 5% of the total incident sunlight on earth surface (visible light 50% and IR radiation 45%). Even though, its proportion is quite less, it has the highest quantum energy compared to other radiations. This energy of ultraviolet radiation is of the order of magnitude of organic molecule's bond energy; hence, it has tremendous detrimental effect on human skin [2, 3]. The intensity and distribution of ultra-violet radiation depend closely on the angle of incidence; hence they vary with the location of the place, season and time of the day [4]. The incidence of skin cancer has been increasing at an alarming rate over the past several decades. While there are many factors involved in the onset of melanoma and non-melanoma skin cancers, overexposure to ultraviolet radiation has clearly been identified as an important factor [5]. The long wavelength (320 nm-400 nm) ultraviolet rays (UV-A) cause a transformation of melanin precursors in the skin, leading to so-called rapid pig-mentation, which sets in within a period of a few hours, but this is only a very minimal and of short duration. However, it penetrates deeply into the dermis or true skin, leading to premature ageing, showing up in the form of loss of elasticity accompanied by lines and wrinkles. The shorter wavelength (290 nm-320 nm), but higher energy ultraviolet rays (UV-B) penetrate to a depth of a few millimeters into the skin, causing the formation of a relatively stable pigment in the cells of the outer layer of the skin. This can lead to acute chronic reactions and damages; such as skin reddening (erythema) or sunburn. The shortest wavelength (10 nm-290 nm) ultraviolet rays (UV-C), which are highly damaging to human skin are filtered out by the ozone layer and do not reach on the surface of earth [2, 6].

Skin is the largest organ in the human body; 12-15% of body weight and constituted of three basic layers; epidermis (outer), corium (middle) and cutis (lower). The skin is the interfacial contact zone of human being with the atmosphere and acts as a protective barrier. While the visible light and infrared radiations can penetrate all the three layers, the ultraviolet radiations are absorbed completely by the epi-dermis and the corium. The longest wavelength ultraviolet radiations can penetrate deeper than the shorter radiations [4]. The ozone layer of the atmosphere acts as a very effective ultraviolet absorber. The stratospheric ozone layer is steadily decreasing due to growing consumption of conventional fuels in last few decades; hence, its decrease has led to increased ultraviolet radiation reaching on the surface of earth and has thus enlarged the risks of the negative effects of sunlight. Recognizing these facts, it is highly essential to protect exposure of skin from excessive amounts of ultraviolet radiation. Medical experts suggest several means of protection against ultraviolet radiation; use of sunscreens, avoidance of the sun at its highest intensities, wearing clothing that covers as much of the skin surface. In recent years, research on textile materials has been paying tremendous attention towards the development of new generation clothing; varying the material & design of cloth, chemical treatments and embedding with ultraviolet absorbers for improving the protection of human skin.

2. DETERMINANT FACTORS OF ULTRA VIOLET RADIATION

2.1. Ultraviolet Protective Factor (UPF)

Ultraviolet protective factor measures the effectiveness of textile fabrics in protecting the human skin from ultraviolet radiations. It is expressed as the ratio of extent of time required for the skin to show redness (erythema) with &

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without protection, under continuous exposure to solar radiation [7]. The UPF is calculated using the Equation (1);

$$UPF = \frac{MEDprotectedskin}{MEDunprotectedskin} \quad (1)$$

Where, *MED* is the minimal erythemal dose or quantity of radiant energy needed to produce the first detectable reddening of skin after 22 ± 2 hours of continuous exposure. The various ratings of UPF are mentioned in Table **1**. There are two basic methods, namely *vivo* and *vitro* used for determination of ultraviolet protective factor.

Table 1. Ultraviolet Protective Factor Ratings [8]

UPF Range	Protection Category	Effective UV-R Transmission (%)	UPF Rating
15-24	Good	6.7-4.2	15, 20
25-39	Very Good	4.1-2.6	25, 30, 35
40-50, 50+	Excellent	Less than 2.5	40, 45, 50, 50+

2.1.1. Vivo Method

In this method, test subjects, whose skin is covered with textile clothing together with an adjacent unprotected skin, is irradiated with a standardized lamp, whose spectrum of light is as closely as possible resembles with that of sunlight. The UPF is then determined from the quotient of the time it takes for skin reddening to occur with and without textile material [9]. Measurements of this method are time consuming and the spectrum of light chosen for measurement is not exactly similar to the spectrum of sunlight, hence, not very suitable for developing textile clothing for sun protection [1].

2.1.2. Vitro Method

If, E_λ is the erythemal effectiveness of ultraviolet radiation (spectral intensity of radiation); S_λ, the spectral relative biological efficiency; T_λ, the spectral permeability of the protective item; i.e. textile fabric, $\Delta\lambda$ ranges of wavelength, then UPF can be calculated according to the Equation (2) [9];

$$UPF = \frac{\sum E_\lambda . S_\lambda . \Delta\lambda}{\sum E_\lambda . S_\lambda . T_\lambda . \Delta\lambda} \quad (2)$$

2.2. Erythema Action Spectra

The erythema action spectrum is obtained by irradiating test subjects with monochromatic ultraviolet radiation of various wavelengths [1, 9]. For each wavelength, a critical light dose, W_λ in J/m^2, for producing delayed erythema is determined. Erythemal effectiveness is related to W_λ by the Equation (3), as mentioned below [9]. From these results, the erythemal effectiveness, the reciprocal of the critical dose of a given wavelength is determined [1]. E_λ is defined as the inverse value of W_λ times an arbitrary constant C_0 :

$$E_\lambda = \frac{C_0}{W_\lambda} \quad (3)$$

Erythemal effectiveness of light is thus proportional to harmfulness. The erythemal effectiveness of ultraviolet light is shown in Fig. (**1**). It is clear from the figure that, wavelength of 280 nm -300 nm is 1000 times more harmful than wavelength 340 nm.

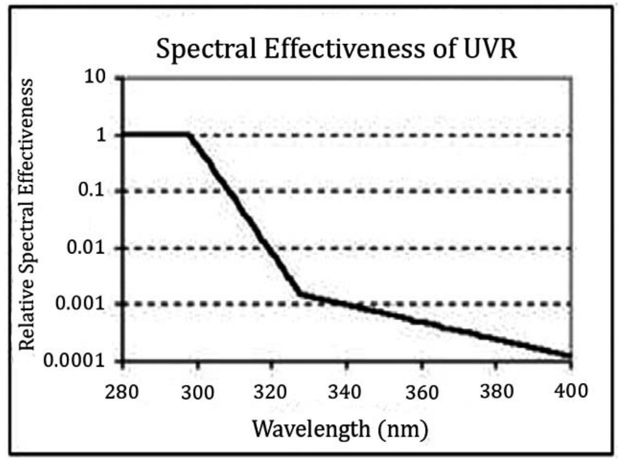

Fig. (1). Relationship between wavelength and relative spectral effectiveness.

3. EFFECT OF UV RADIATIONS ON TEXTILE MATERIALS

UV radiation is one of the major causes of degradation of textile materials, which is due to excitations in some parts of the polymer molecule and a gradual loss of integrity, and depends on the nature of the fibres [10-19]. The penetration of UVR in nylon causes photo oxidation and results in decrease in elasticity, tensile strength and a slight increase in the degree of crystallinity [14, 16]. In the absence of UV filters, the loss in tensile strength appears to be higher in the case of nylon (100% loss), followed by wool, cotton and polyester, with approximately 23%, 34% and 44% respectively after 30 days of exposure [17]. Elevated temperature and UVB radiation on cotton plants result in severe loss of bolls [18]. There are numerous homo chain polymers that are susceptible to degradation due to ultraviolet radiation; polyolefins, polyketones, poly (vinyl alcohol), polycarboxylic acids, polyacrylonitrile, poly (vinyl chloride) and polystyrene [20, 21]. Similar to homochain polymers there are several hetero chain polymers also that are highly susceptible to photo degradation: polyesters, polyamides and polyaramids, polyethers, polyimides, polyurethanes and polysulphides [20]. High strength fibres; zylon, dyneema and kevlar losses strength upon exposure to UV radiation [22].

4. CLOTHING ATTRIBUTES AFFECTING UPF

When ultraviolet radiation hits the textile materials, different types of interactions occur depending upon the substrate and its conditions [7, 23-33]. The ultraviolet protection provided by apparel is a function of the construction of fabric; thickness, porosity, extension of the fabric, chemical characteristics; physico-chemical nature of fibre, dyeing and finishing treatment given to the fabric, moisture content of the fabrics and presence of ultraviolet absorbers [25, 27, 28, 31, 34].

4.1. Structure of Fabric

Sun protective woven or knitted fabrics have higher cover factor than traditional fabrics [35]. As the cover factor is expected to have positive influence on the protection to ultraviolet radiation, researches have carried out regression analysis and observed that there exists positive coefficient of correlation between cover factor of fabric and its UPF value. Fabric construction parameter (ends/inch & picks/inch or courses/inch & wales/inch) is a primary determinant component of cover factor. Woven fabrics usually have higher cover factor than knitted fabrics, because of frequent interlacement of yarns. Pores between yarns are generally larger in knitted fabric than in woven fabric. Many summer fabrics are "open" structures with low cover factors. Pailthorpe, a textile scientist from Australia noted that by increasing the mass per unit area (using coarser count), while maintaining constant construction parameters (ends/inch & picks/inch) and fibre composition would result in an increased cover factor and hence, subsequently increase in UPF. The pores between yarns are smaller, thus more radiation is blocked. Pailthorpe envisions an ideal fabric in which the yarns are completely opaque to ultraviolet radiation and the pores between the yarns are very small. With light penetrating only through the pores, ultraviolet transmission is related to porosity of the ideal fabric as expressed in Equation (4) [36];

$$UPF = \frac{100}{Porosity\%} \quad (4)$$

The highest possible UPF is therefore 100, when the porosity is 1% (Table **2**). In the case of a voile fabric having a porosity of 25%, the maximum UPF that can be expected is 4. For poplin with 1% porosity, the maximum UPF is 100 [1]. Dry finishes have potential to alter the porosity of the ideal fabric, but yarns are not opaque to ultraviolet radiation and hence the UPF of a fabric is always lesser than the ideal fabric [36].

Table 2. Porosity and Maximum Theoretical UPF [37]

Porosity (%)	Maximum theoretical UPF
10	10
5	20
2	50
1	100

The value of UPF increases with increase in fabric density and thickness for similar construction and is dependent on fabric porosity [4]. A high degree of correlation exists between UPF and fabric porosity, but is also influenced by the nature of fibres [37]. The relative order of importance for the ultraviolet protection is given by; cover %> nature of fibre > fabric thicknessc [38]. UPF shows better correlation with fabric weight and thickness than porosity [39]. Therefore, fabrics with the maximum number of yarns in warp and weft give high UPF. Woven fabrics usually exhibit high cloth cover than knitted fabrics due to the manner in which the yarns are interlaced/arranged [7]. Thick rib structures of hemp and linen can allow 10.52%-12.70% and 9.03%-11.47% of UV-A and UV-B radiations respectively [29]. However, knitted structure made from a blend of synthetic fibres with Lycra offers the best protection against solar radiation [33] and warp-knitted structures are capable of screening up to 80% of the solar radiation & bright glares. The blending of Lycra with synthetic fibre gives the double advantage of protection against UV radiation due to the chemical nature of fibre (aromatic compound) and highly stretchable Lycra fiber gives higher cloth cover. Double knit structures give significantly higher UV protection than single knit structures. In double knit structures; interlock gives the highest level of UV protection, followed by 1x1 rib structure, full milano and full cardigan [40]. Stretching reduces the UPF rating of the fabric during wear, as the effective porosity% is increased [27]. However, the fabric porosity can be modified through many dry finishing processes through overfeed on the stenter, compressive shrinkage processes such as compacting and sanforising, which are normally used to obtain dimensional stability, incidentally decreasing the porosity% results in increased value of UPF. Gentle milling employed in the case of lightweight wool fabrics can also reduce the porosity% and subsequently the UPF [26].

4.2. Physio-chemical Nature of Fibre

Ultraviolet protective factor is strongly dependent on the physical and chemical structure of the fibres. The chemical nature of the fibres influences the UPF, due to variation in ultraviolet transparency [4]. Natural fibres like cotton, silk, and wool have lower degree of absorption of ultraviolet radiation than synthetic fibres [41, 42]. Spectroscopic studies showed that cotton has a relatively high ultraviolet transmission in the range of 280 nm-400 nm [4]. Bleached cotton exhibits high degree of permeability to ultraviolet radiation. The same fabric consisting of cotton in the grey state provides a higher UPF, because of the presence of natural pigments, pectins and waxes contained, which act as ultraviolet absorbers [2, 43]. Raw natural fibres like linen and hemp possess a UPF of 20 and 10 to 15 respectively and are not perfect ultraviolet protectors even with lignin content [29]. However, the strong absorption of jute is due to the presence of lignin, which acts as a natural absorber. Protein fibres also have mixed effects in allowing ultraviolet radiation. Silk fabrics are usually finer and have a medium ultraviolet transmission [1, 4]. In contrast to this, wool fabrics have a higher absorption and lower transmission of ultraviolet radiation. Wool absorbs strongly in the region of 280 nm-400 nm and even beyond 400 nm. Polyester fibres absorb more in the UV-A & UV-B regions than aliphatic polyamide fibres. Polyester fibres, on the other hand, whose structure is based on aromatic components, exhibit a strong absorption effect in the shorter wavelength of ultraviolet region. This is reinforced by the absorptivity of delustering agent; e.g. Titanium dioxide, which heavily reduce the fibre's permeability over the spectrum of ultraviolet region [4]. The aliphatic polyamide fibre is relatively permeable to ultraviolet radiation [2, 4]. The ultraviolet transmissions of different materials are as follows:

Cotton bleached > Cotton grey > Polyamide > Silk > Wool > Polyester

4.3. Dyeing and Finishing

The dyes used to color textiles can have a considerable influence on their permeability to ultraviolet radiation. Depending on their chemical structure, the absorption band of many dyes extends in to the ultraviolet spectral region. As a result, such dyes acts as ultraviolet absorbers and increases the UPF of the fabric. As a general rule, it can be said that for the same fabric structure and dye, the darker the shade, the higher the UPF value. Studies at the University of Alberta also suggest that darker colored fabrics can offer more protection than lighter colored fabrics [44]. In principle, fabrics dyed with black and dark blue exhibit maximum ultraviolet radiation protection. If the UPF of a dark dyed fabric should be found to be inadequate, in most cases the fabric structure is unsuitable, because its porosity is too high. Since fluorescent brighteners absorb in the ultraviolet region, especially longest wavelength ultraviolet rays, they also reduce the ultraviolet permeability of textiles. Clothing engineered for ultraviolet protection may use high concentrations of premium dyes that disrupt ultraviolet light. Such dyes include "conjugated" molecules that disrupt ultraviolet radiation. The higher the concentration of such dyes, the darker the garment becomes, but ultimately the color has no influence on ultraviolet radiations. Pigment-dyed fabrics, which include a resin that creates a powdery look and feel, get high marks for ultraviolet protection [8].

The ultraviolet protection abilities of the textile materials are considerably influenced depending upon the type of dye or pigment, the absorptive groups present in the dyestuff, depth after dyeing, the uniformity and additives [4, 16, 23, 27, 30, 31, 43, 45, 46]. In a given fabric, higher transmission of ultraviolet radiation is observed in the case of bright fibres (viscose) than dull fibres [46]. A protective effect can be obtained by dyeing or printing, which is better than using heavyweight fabrics which are not suitable for summer conditions. Darker colors of the same fabric type (black, navy, dark red) absorb ultraviolet radiation much more strongly than the light pastel colors for identical weave with UPF in the ranges of 18-37 and 19-34 for cotton and polyester respectively [16, 23]. Some direct, reactive and vat dyes are capable of giving a UPF rating of higher than 50 [27]. Some of the direct dyes substantially increase the UPF of bleached cloth, which depends on the relative transmittance of the dyes in the UV-B region. In many cases, a UPF calculated using a direct dye solution appears to be higher than that of the fabric after dyeing, mainly because the actual concentrations are mostly less than the theoretical concentration. Dyes extracted from various natural resources also show the UPF within the range of 15-45 depending on the mordant used [47]. Cellulosic fabrics transmit UV-A and UV-B equally with the transmittance ratio (TA/TB) of 0.9. When dyed with the reactive dyes, the UPF increases from 4.7 to 5.0-14.0, depending upon the concentration, which is not sufficient to satisfy the minimum requirements [31]. Some of the vinyl sulphone dyes and monochlorotriazine dyes possess ultraviolet radiation absorption characteristics, which also increase with the concentration. Cellulosic fabrics dyed with these dyes show reduced ultraviolet radiation transmission from 24.6% to 10-20% and 27.8% to 8-22% for UV-A and UV-B respectively. When mixtures of these dyes are used, the UPF increases synergistically. Some combinations of disperse reactive mix can give prolonged ultraviolet protection with a UPF of 50+ for polyester/cotton blends [48].

Optical brightening agents or fabric whitening agents are used at the finishing operations, as well as in the wash cycles, and their effect on UPF has been demonstrated extensively in the past [4,27,42,48-52]. Optical brightening agents are often applied to enhance the whiteness of textiles by ultraviolet excitation and visible blue emission. The phenomenon of excitation and emission is caused by the transition of electrons involving p-orbitals from either conjugated or aromatic compounds [48]. Most optical brighteners have excitation maxima within the range of 340 nm-400 nm. Optical brightening agent can improve the UPF of cotton and cotton blends, but not of fabrics that are 100% polyester or nylon [27]. The presence of optical brightening agent to the extent of 0.5% in the fabrics having polyester/cotton blended yarn of blend proportion 67:33, can improve the UPF from 16.3 to 32.2, which is more or less closer to that obtained using the UV absorbers with 0.2% (UPF 35.5). Washing the fabrics leads to a loss of UPF in the case of OBA-treated fabrics and the UPF reaches the level of that in untreated fabric after 10 washes, which shows the semi-permanent nature of the finish and protection [48]. Another limitation of many optical brightening agents is that they mostly absorb in the UV-A part of the day sunlight spectrum but have a weak absorption in UV absorption around 308 nm, which plays an important role in skin diseases [51, 53].

4.4. Moisture and Swelling

The ultraviolet protection factor of wet garment is significantly lower than that of the same garment measured in the dry state. Water in the interstices of the fabric reduces the scattering effect and therefore, increases its ultraviolet radiation permeability. Wetness may cause a 30%-50% reduction in a fabric's UPF rating. The ability of textile fibres to provide ultraviolet protection varies depending upon the structure and other additives present in the fibres [2, 29, 32, 54]. Besides, the construction parameters and wear conditions of the textile materials, moisture and additives incorporated in processing also affect the UPF of the textile materials [25, 27, 29, 45]. In the case of moisture, the influence is largely dependent on the type & hygroscopicity of fibres and conditioning time, which result in swelling phenomena [55]. The relative humidity% / moisture content of fibres affect the UPF of the fabric in two ways; namely the swelling of fibres due to moisture absorption, which reduces the interstices and consequently the ultraviolet transmittance. On the other hand, the presence of water reduces scattering effects, as the refractive index of water is closer to that of the textile polymer and hence there is a greater ultraviolet transmission vis-à-vis a lower value of UPF [27, 29]. A typical cotton fabric could transmit 15-20% ultraviolet radiation, rising to more than 50%, if the garment is wet. The ultraviolet radiation transmission should be lower than 6% and 2.5% for adequate and extremely good protection respectively [25]. Dependence of humidity is more pronounced in silk and viscose fibres, of which viscose has a higher water absorption and swelling capacity, while silk has poor swelling properties. Even though silk has poor swelling properties, it's very fine in nature and has a greater number of fibres in the cross-section of yarn, results in higher swelling due to capillary absorption and in turn less ultraviolet transmittance. Finishing treatments given to the fabrics to reduce swelling, which reduces the transmittance of ultraviolet rays. There is incidence of better degree of correlation between hygroscopic fibres and their UPF values [45].

4.5. Ultra Violet Absorbers

Ultraviolet absorbers are organic/inorganic colorless compounds with strong absorption in the ultraviolet wavelength range of 290 nm-360 nm [10, 11, 17, 25, 30, 34, 46, 48, 49, 56-60]. UV absorbers incorporated into the fibres convert electronic excitation energy into thermal energy, function as radical scavengers and singlet oxygen quenchers. The high-energy, short-wavelength ultraviolet radiation excites the UV absorber to a higher energy state; the energy absorbed may then be dissipated as longer-wavelength radiation [25]. Alternately, isomerisation can occur and the UV absorber may then fragment into non-absorbing isomers. Sunscreen lotions contain UV absorbers that physically block ultraviolet radiation [7, 25, 61]. Chemically, several classes of ultraviolet absorbers are available. The important groups of ultra violet absorbers are; 2-hydroxybenzo-phenones, 2-hydroxypheny benzotriazoles, 2-hydroxy-phenyl-s-triazines [62]. The most widely used UV-B screens; 2-ethyl hexyl-4-methoxy cinnamate with high refractive index, make a substantial contribution to the RI matching of skin, i.e. 'refractive index matching' [61]. An effective UV absorber must be able to absorb throughout the spectrum to remain stable against ultraviolet radiation and to dissipate the absorbed energy to avoid degradation or loss in color [17]. Organic UV absorbers are mainly derivatives of o-hydroxy benzophenones, o-hydroxy phenyl triazines, o-hydroxy phenyl hydrazines [10, 11, 25]. The orthohydroxyl group is considered essential for absorption and to make the com-pound soluble in alkaline solution. Some of the substituted benzophenones penetrate into synthetic fibres much like disperse dyes [17]. Commonly-used UV absorbers are 2-hydroxy benzophenones, 2-hydroxy phenyl benzotriazoles, 2-hydroxy phenyl-striazines and chemicals such as benzoic acid esters and hindered amines [56]. The strong absorption in the near ultraviolet range of 2, 4 dihydroxy benzophenone is attributed to the conjugating chelation between the orthohydroxyl and carbonyl groups. Organic products like benzotriazole, hydro benzophenone and phenyl triazine are primarily used for coating and padding processes in order to achieve broad protection against ultraviolet radiations [34]. Suitable combinations of UV absorbers and antioxidants can yield synergistic effects [49]. Benzophenone derivatives have low energy levels, easy diffusibility and a low subli-mation fastness. Orthohydroxy phenyl and diphenyl triazine derivatives have an excellent sublimation fastness and self-dispersing formulation can be used in high temperature dyeing in pad-baths and also in print pastes [59]. UV absorbers incorporated into the spinning dope prior to the fibre extrusion and dye bath in bath dyeing, improve the light fastness of certain pastel shades and the weatherability of spun-dyed fibres [55, 63]. UV absorbers to the extent of 0.6%-2.5% treated to the fabric are sufficient enough to provide adequate ultraviolet radiation protection [64]. The presence of UV absorbers in polyester, nylon, silk and wool protects the fibres against sunlight-induced photo degradation. On wool, UV absorbers can retard the photo-yellowing that occurs upon exposure to sunlight [25]. Triazine class-hindered amine light stabilisers are used in polypropylene fibre to improve the ultraviolet stability. The addition of HALS (0.15%) is sufficient to improve the stability substantially. Even pigmented polypropylene requires ultraviolet stabilisers, if the fibres are exposed to ultraviolet radiation during their services [58]. High-energy UV absorbers suitable for polyester include derivatives of o-hydroxyphenyl diphenyl triazine, suitable for dye baths, pad liquor or print paste. UV absorbers have refractive indices of about more than 2.55, by virtue of which maximum covering capacity and opacity is achieved [34]. The presence of inorganic pigments in the fibres results in more diffuse reflection of light from the substrate and provides better protection [11, 13, 34, 43, 55, 64, 65]. TiO_2 added in the spinning dope for matt effects in the fibres also acts as UV absorber [10]. Titanium dioxide and ceramic materials have an absorption capacity in the ultraviolet region between 280 nm-400 nm and reflects visible and IR rays and these absorbers are also added as dope additives [66]. For maximum effect, the particles have to be monomolecularly distributed and are often applied in one bath [34, 11, 64, 67]. Nanoscale titanium gel particles strongly bound to the cotton fabrics can give a UPF $\geq$ 50, without impairing the tensile properties. Brighter viscose yarns provide the highest ultraviolet transmittance compared to the dull pigmented viscose yarns, modal yarns [68]. Zinc oxide nanoparticles have a very narrow size distribution (20 nm-40 nm) and minimal aggregation, which can result in higher levels of ultraviolet radiation blocking [65]. The mixture of (67/33) titanium dioxide (TiO_2) and zinc oxide (ZnO) on cotton and nylon fabrics produces significantly higher absorption of ultraviolet radiation than the effect of individual components [13]. Micro-fine nylon fabrics treated with 1.5% TiO_2 & having 0.1% porosity are capable of giving UPF greater than 50 [42]. Incorporating UV absorber in dyeing decreases the dye uptake slightly, except in post-treatment application [56]. Many commercial products and processes have been developed to produce fabrics with a high level of UPF, using various dope additions and topical applications for almost all types of fabrics produced from cellulosic fibres, wool, silk and synthetic fibres [1, 17, 24, 34, 57, 68-71]. Most of the commercial products are compatible with the dyes and other finishing agents applied to the textile materials and these agents can be applied using simple padding/ exhaust method/ pad-thermo fix and pad-dry-cure methods [17, 46, 70-72].

Hilfiker *et al*. have studied the effect of thickness & porosity of the fabric and concentration of ultraviolet absorbers in treated fabric on ultraviolet radiation protection. The parameters involved are; d = thickness of the material, $A_0(\lambda)$ = absorbance of material of unit thickness without any pores and without ultraviolet absorbers, P = porosity, ε_m = molar extinction coefficient of ultraviolet absorbers, c = concentration of ultraviolet absorbers in fabric in mass per volume, MW = molar mass of ultraviolet absorber. The various assumptions are made in their study are; thickness of the fabric is uniform, molar extinction coefficient of the ultraviolet absorbers in the fabric is the same as in the solution, Beer-Lambert's law is obeyed, i.e. the UV absorbers are monomolecular dispersed and the change of scattering behavior of the fabric after addition of the ultraviolet absorbers is negligible. With these assumptions, the transmittance of the fabric containing ultraviolet absorbers can be measured by the equation (5) [9]:

$$T(\lambda) = P + (1-P)\times 10^{-\frac{\{A_0(\lambda)d+\varepsilon_m(\lambda)dc\}}{MW}} \quad (5)$$

The porosity of the fabric can be determined by measuring the directed transmittance of the fabric. As light passing through the pores are not scattered, putting the fabric in a suitable UV/VIS-spectrometer can do the measurement. The detector in such an apparatus must be small and far away from the sample; only the transmitted light, which has the same direction as the incident light is detected.

5. COMMERCIAL UV PROTECTIVE CLOTHINGS

Solartex Sun Gear, a leader in sun protection products since 1998, offers various UV sun protective products including sunscreen, spf clothing, sun protective clothing, rash guard shirts, swim shirts, sun protection swimwear, uv suits, sunsuits & sun hats, for babies, infants, toddlers, boys, girls, children, men, ladies & adults from Australian manufacturers such as Stingray and Sun Emporium. They also carry Sunbusters and Iplay UV swimwear and sun protection wear. All Solartex UV apparel carries an SPF Skin Protection of UPF 50+ (UPF is the SPF equivalent for UV clothing and UPF 50+ is the highest rating available) and virtually all items are chlorine resistant as well, so that they last much longer than ordinary sun protective wear. They also carry sun hats from Sunday Afternoon, Physician Endorsed, Wallaroo hats, and San Diego Hats [73]. Coolibar's SUNTECT® brand fabrics are used for manufacturing of complete range of clothing of kids, women & men and have a guaranteed UPF factor of 50+ [74]. BluKuda, the new brand of clothing of Sun-Togs, brings professional design and fashion to sun protection clothing and UV Swimwear using top quality fabrics - chlorine-resistant swim fabrics and technical leisure fabrics. BluKuda range of UV protective clothing and UV Swimwear complies with Australian and New Zealand standards (AS/NZS 4399) and USA standard (ASTM-D6603-USA) offering a superb UPF 50+ protection (the maximum Ultraviolet Protection Factor available for UV clothing/UV Swimwear) [75]. EcoStinger® specializes in sun protective clothing wear, Stinger suits, sunblock full body cover swimsuit coverups, uv protection swimwear and sun hats for women, men, kids and juniors. EcoStinger fabric is made in Italy, and is verified to provide excellent UV protection blocking >97.5% of the sun UV radiation, as well as providing protection against box jellyfish stingers [76]. The Solar Protective Factory (SPF) provides various brands of clothing; SPF, GEO-TRAVELER, Columbia Sportswear, Cabana Life, Dorfman Pacific, Lejay, Rayban, Sportif, Tuga, Aquaweave®, SPF® Ultra, Sierra Summits, Cocoons, econscious, Native, Revo, Wallaroo Hats, UV Natural, GA-DAY™, Duck & Hyde, Blue Lizard, CW-X, Frubi, Panoptx, Sigg, Tilley Hats and XGO [77].

6. CONCLUSIONS

UV radiation causes degradation of textile materials, due to excitations in some parts of the polymer molecule and a gradual loss of integrity. Sun protective woven or knitted fabrics have higher cover factor than traditional fabrics. The ultraviolet protective factor of fabric is strongly dependent on the physical and chemical structure of the fibres. Natural fibres like cotton, silk, and wool have lower degree of absorption of ultraviolet radiation than synthetic fibres. Darker colored fabrics can offer more protection than lighter colored fabrics for the same fabric structure and dye. Fabrics dyed with black and dark blue exhibit maximum ultraviolet radiation protection. Optical brightening agent can improve the UPF of cotton and cotton blends, but not of fabrics that are 100% polyester or nylon. The ultraviolet protection factor of wet garment is significantly lower than that of the same garment measured in the dry state. Ultraviolet absorbers are organic/inorganic colorless compounds with strong absorption in the ultraviolet wavelength range of 290 nm-360 nm and block the ultraviolet radiation reaching the human skin, when incorporated in the fabrics.

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