2. LITERATURE REVIEW

2.1 Protective Textiles

2.1.1 Introduction

Textiles have been used for human protection from time immemorial, primarily for protection from cold and rain. Primitive humans used hides and bark for protection. As civilisation advanced, wool felts in Northern Europe and woven cotton fabrics in India started to clothe the populations. Scientific advancements made in various fields have undoubtedly increased the quality and value of human life. It should however be recognized that the technological developments have also exposed us to greater risks and danger of being affected by unknown physical, chemical and biological attacks. One such currently relevant danger is from bioterrorism and weapons of mass destruction. In addition, we continue to be exposed to hazards from fire, chemicals, radiation and biological organisms such as bacteria and viruses. Fortunately, simple and effective means of protection from most of these hazards are available. Textiles are an integral part of most protective equipment. Protective clothing is manufactured using traditional textile manufacturing technologies such as weaving, knitting and non-wovens and also by specialized techniques such as 3D weaving and braiding using natural and man-made fibers. While all the textiles have some protective function, protective textiles are those that are specifically designed for specific hazards such as fire, impact, chemical, radiation, etc[1].

Protective clothing is now a major part of textiles classified as technical or industrial textiles. Protective clothing refers to garments and other fabric-related items designed to protect the wearer from harsh environmental effects that may result in injuries or death[2].

The variety of protective functions that needs to be provided by different textile products is considerable and diverse. It includes protection against cuts, abrasion, ballistic and other types of severe impact including stab wounds and explosions, fire and extreme heat, hazardous dust and particles, nuclear, biological and chemical hazards, radiation, high voltages and static electricity, foul weather, extreme cold and poor visibility. As well as people, sensitive instruments and processes also need to be protected. Thus, clean room clothing is an important requirement for many industries including electronics and pharmaceuticals.

In Europe and other advanced industrial regions, strict regulations have been placed upon employers through the introduction of legislation such as the Personal Protective Equipment (PPE) at Work Regulations (European Union). Under such legislation, it is not only necessary to ensure that the equipment and clothing provided is adequate to meet the anticipated hazards but it is also used effectively, that is that the garments are well designed and comfortable to wear. This has opened up a need for continuing research not only into improved fibres and materials but also into increasingly realistic testing and assessment of how garments perform in practice, including the physiology of protective clothing.

In many developing countries, there has not been the same legislative framework in the past. However, this is rapidly changing and future market growth is likely to concentrate less on the mature industrial markets than upon the newly industrialising countries of Asia and elsewhere. The protective clothing industry is still highly fragmented with much of the innovation and market development being provided by the major fibre and other materials producers. This could change as some global suppliers emerge, perhaps without their own direct manufacturing but relying on contract producers around the world, very much as the mainstream clothing industry does at present[3].

2.1.2 Classification

Classifying personal protective textiles is complicated because no single classification can clearly summarize all kinds of protection. Overlap of the definitions is common since there are so many occupations and applications that even the same class of protective clothing often has different requirements in technique and protection. Depending on the end use, personal protective textiles can be classified as:

a) industrial protective textiles;
b) agricultural protective textiles;
c) military protective textiles;
d) civilian protective textiles;
e) medical protective textiles;
f) sports protective textiles and
g) space protective textiles.

Personal protective textiles can be further classified according to the end-use functions such as:

a) thermal (cold) protection;

b) flame protection;
c) chemical protection;
d) mechanical impact protection;
e) radiation protection;
f) biological protection;
g) electrical protection and
h) wearer visibility.

Technological advances in the field of technical or high performance textiles have made it possible to engineer materials designed to meet specific needs. However, there is no `ideal' fabric that will provide protection against all hazards. Careful selection of appropriate textiles is crucial for the performance, use, care, and maintenance of protective clothing[4].

2.1.3 Materials and technologies

Depending on the end uses of the protective textiles there exists a wide variety of fabric manufacturing methods to meet the particular requirements. For protective clothing, protection provided by the material is the primary factor in its selection. In addition, factors such as comfort, durability, maintenance, cost, and design considerations may apply. Protective materials can be different in their protective capabilities. Adsorption, reaction, and barrier are three different mechanisms that have been identified[5] for their protective capabilities.

The main processes generally include (i) material manufacturing or selection; (ii) producing fabrics and other related items; (iii) finishing, and (iv) clothing engineering[6].

The past decade has witnessed an alarming increase in the incidence of skin cancer worldwide. Although wearing clothing to protect one's skin from the harmful rays of the sun is not new practice, this practice is of recent increasing interest. Governments around the world have begun to initiate action to educate their populations with respect to protection from solar ultraviolet radiation (UVR) exposure. Because fabric is composed of fibers that can absorb, reflect or scatter radiant energy, it has the ability to absorb and/or block most of the incident radiant energy and prevent it from reaching the skin. There is guarded optimism among manufacturers that the need for UV protective fabrics will grow as people live longer lives and are more active outdoors.

2.1.4 Basic standards for all types of protective clothing

Protective clothing should be as light as possible taking into account comfort, water vapour resistance, design, and protection level. It should provide the protection to the users from any type of hazards. Therefore, there is a basic need to maintain a standard for different type of protective clothings. In Europe the most important standards are strictly followed. They are:

· EN 340: 12-2003 Personal protective clothing ± general requirements

· EN 420: 09-2003 General requirements for gloves

At international level the standards correspond (but not identically) e.g., to

· ISO 13688: 1998 Personal protective clothing ± general requirements

· AS/NZS 2161.2:1998 General requirements (gloves)

· AS/NZS 4501.2:1999 General requirements (protective clothing)

The demand for further technical developments and elaboration of new standards is continuing to rise. Stricter legal requirements and the increased threat of insurance liability for employers will further the development and application of improved protective clothing.

According to the demands of the market many types of protective clothing have to fulfil more than one protective function simultaneously. The functional requirements for protective textiles form the basis for future research, which include the development of intelligent, so-called smart textiles. Smart textiles are likely to play a large part in the development of protective textiles in the next decade. Smart textiles can contribute to protection and safety in three ways:

- they are able to detect conditions that signal increased danger;
- they prevent accidents by sending out a warning when hazardous conditions have been detected;
- in the case of serious threats they can react by providing instantaneous protection.

Nanotechnology is one emerging field which can be used for protective clothing but the effect of nano particles on human beings should be studied thoroughly before using.

2.2 UV Protective Textiles

2.2.1 Introduction

Our skin is the largest and most important protective organ and interfacial contact zone with the atmosphere; 12-15% of body weight and constituted of three basic layers; epidermis (outer), corium (middle) and cutis (lower). It constitutes a vast surface area, and as such it is vulnerable to being damaged by excess sun exposure. The sun has rays that we cannot see or feel called UV radiation. UV radiation is the wavelength of sunlight that can damage the skin. The past two decades have witnessed an alarming increase in the incidence of skin cancer worldwide. Geethadevi & Maheshwari (2013) argues that primary reason is attributed to stratospheric ozone depletion caused by enormous use of CFCs as coolants[7]. As noted by Sarkar (2005) stratospheric ozone layer serves as the earth's main natural protection against harmful UV radiation from the sun. Because ozone is a very effective UV-absorber each one percent decrease in ozone concentration is predicted to increase the rate of skin cancer by two percent to five per cent[8, 9].

Other reasons for the skin cancer epidemic can be traced to lifestyle changes such as excessive exposure to sunlight during leisure activities. These activities include playing outdoors and swimming in the case of children, and golfing and fishing in the case of adults. In addition, fashion changes have dictated less coverage of the body while out in the sun, also increasing exposure despite sunscreen use to replace textile coverage. Gwendolyn and Patrica (2005) argues that limiting the skin's exposure to sunlight, especially during the hours of maximum intensity, 1000h to 1400h (10 am to 2 pm), is the best way to reduce the risk[10].

In the case of agricultural and other outdoor workers such as builders, law enforcement officers, industrial cleaners or waiters, exposure to the sun is an occupational hazard as they have no choice about the duration of their exposure to the sun[11, 12]. Outdoor workers and people undertaking recreational activities can receive 10 to 20% of the daily total ambient UVR and up to 30 to 40% of available ambient UVR, for the time period they are outside[13].

Persons working in the open atmosphere are prone to keatose, the precursor of skin cancer. Growing evidence of unusual depletion of stratospheric ozone and the increasing awareness of negative effects of ultraviolet radiation has encouraged the different research groups globally to take new research programme to focus on different aspects of UVR. The Australian radiation laboratory is credited to track back the research of UVR protection in

1980s. Dermatologists and anti-cancer organisations therefore warn against excessive exposure of the sun and call for prevention by means of suitable clothing and sun protective textiles[14]. The main aim of sun protective clothing is protection against erythema or sunburn from solar UVR.

2.2.2 Sun Exposure: What are the concerns?

Sunlight is the prime energy source and essential element for survival of human race. An appropriate amount of sun bath promotes the circulation of blood, invigorates the metabolism and improves resistance to various pathogens[15]. Sunlight triggers a series of beneficial chemical reactions in the skin which lead to the formation of vitamin D, a nutrient essential for health[16, 17].

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 280nm to 3000 nm, 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 radiation. 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. The intensity and distribution of ultraviolet radiation depend closely on the angle of incidence; hence vary with the location of the place, season and time of the day and when absorbed by the skin in excess of what are safe absorption levels, damages cellular DNA, Langerhans cells responsible for normal immunofunction as well as other processes which can lead to skin cells becoming cancerous[18, 19].

Prolong and frequent exposure of human being against sun causes different dermatological problems. The short-term exposure to ultraviolet radiation (UVR) causes sunburn and in medical science it is erythema. Prolong sunburn leads to photoageing of skin and results in terms of both nonmelanoma and melanoma skin cancer.

UV radiation levels vary depending on several factors such as: solar elevation, ozone, atmospheric air pollution, aerosols, dust, water vapour, clouds, altitude and surface reflection.

- Time of day – the higher the sun in the sky, the higher the UV radiation level. The sun is at its highest at around noon.
- Time of year – UV radiation levels are generally highest during the summer months.
- Geographic location – the sun's rays are strongest at the equator, where the sun is most directly overhead. The closer the equator, the higher the UV radiation levels.
- Altitude - UV radiation levels increase with altitude because there is less atmosphere to absorb the damaging rays.
- Clouds – heavy cloud cover usually reduces UV radiation levels.
- Environment – UV rays are reflected off surfaces such as snow, water, sand and concrete. This indirect UV radiation can significantly add to a person's overall exposure.
- UV Index, a measure of UV radiation levels

The global Solar UV Index[20] (see table 2.1) describes the level of solar UV radiation at the Earth's surface. It has been designed to indicate the potential for adverse health effects and to encourage people to protect themselves. The values of the index range from zero upward: 11+: the higher the index value, the greater the potential for damage to the skin and eye, and the less time it takes for harm to occur.

In many countries, the UV Index is reported along with the weather forecast in newspapers, on TV, and on the radio[21]. While the levels of UV radiation vary during the day, they reach a maximum around midday. The UV index is usually presented as a forecast of the maximum amount of UV radiation expected to reach the Earth's surface at solar noon. In countries close to the equator, the UV Index can reach up to 20. Summertime values in northern latitudes rarely exceed 8.

Table 2.1: UV Index

UV- Index	Danger Category
11	Extreme
8 to 10	Very High
6 to 7	High
3 to 5	Moderate
1 to 2	Low

UV Index Values	Exposure Categories
0-2	Minimal - Wearing a hat is sufficient protection.
3-4	Low - Wearing a hat and a sunscreen with SPF 15 is recommended
5-6	Moderate - Wearing a hat, a sunscreen with SPF 15 and staying in the shade is recommended.
7-9	High - In addition to the precautions recommended above, it is advised to stay indoors between 10 a.m. and 4 p.m.
10^{+}	Very High - In addition to the precautions recommended above, it is advised to stay indoors if possible.

UV Index	Category	Sunburn Time
over 9	extreme	less than 15 minutes
7-9	high	about 20 minutes
4-7	medium	about 30 minutes
0-4	low	more than 1 hour

UV radiation

The specific band of UV radiation (100-400nm) can be classified into three groups on the basis of wavelength[22].

i. Long length radiation span of wave length – 315- 400nm (UV-A);

ii. Middle length radiation span of wave length – 280- 315 nm (UV-B);

iii. Short length radiation span of wave length – 100-280nm (UV-C), extremely dangerous.

i.The UV-A region of light belongs to long span of wavelength 315-400nm and cause a transformation of melanin precursors in the skin, leading to a so-called rapid pigmentation, 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 on in the form of loss of elasticity accompanied by line sand wrinkles. Today it is also known that UV-A radiation can generate highly reactive chemical intermediates which indirectly damage DNA and in this way induces the skin cancer. 99% of the UV radiation that reaches the earth's surface is UV-A radiation and it is not absorbed by ozone. UV-A is the main cause of immune-suppression against a variety of infectious diseases (tuberculosis, leprosy, malaria, measles, chicken pox, herpes and fungal disease).

ii.The UV-B radiation – 'middle length radiation' comes in the range of 280-315nm and penetrate to a depth of a few millimetres 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[23, 24]. It damages the fundamental building element-DNA directly at molecular level as well as collagen fibres and vitamin A in the skin. UV-B radiation is mostly absorbed by ozone, although some reaches the earth. The amount of UV-B radiation received by a location is strongly dependent on: latitude and elevation of the location (average UV-B exposure at the poles is over a thousand times lower than at the equator), cloud cover (the reduction in UV-B exposure depends on cloud cover's thickness), and proximity to an industrial area (protection offered by photochemical smog, which absorbs UV-B). Incidence rates of Cutaneous melanoma in light skinned people in Norway are among the highest in the world. UV-B does not penetrate through the window glass and is most pronounced midday. UV-B radiation increases the melanin production as a means of protection which leads to a long lasting tan with 2-day lag phase after irradiation. It is known that, biologically, sunburn corresponds to a real damage to the genome in the skin cells and that although the effects may be reversed by repair processes permanent genomic damage can occur[25]. Because sunburns are primarily due to UV-B radiation, UV-B has been implicated as a potential contributing factor to the pathogenesis of cutaneous melanoma (CM)[26].

iii.The region 100-280nm is extremely dangerous, known as bacterial region characterised by strong bactericidal and sporecidal effects and belongs to UV-C radiation also known as 'hard radiation' which destroys DNA directly[27]. Stratospheric ozone layer in atmosphere absorbs UV-B and UV-C and to block it to reach on earth surface. This natural shield has been gradually depleted by man-made chemicals like chlorofluorocarbons (CFCs), hydro fluorocarbons (HCFCs) and other ozone-depleting substances (ODS), which are used widely in refrigerators, food containers, plastic foam, home insulation, etc. Table 2.2 shows the main differences between the UV-A, UV-B and UV-C radiation [28, 29, 30, 31, 32, 33, 34, 35]. A clear relationship exists between cumulative sun exposure and the development of NMSC (non-melanoma skin cancer), and a strong relationship exists between intense intermittent sunburn and the development of melanoma[36].

Table 2.2: Main differences between the UV-A, UV-B and UV-C radiation

UV-A radiation	UV-B radiation	UV-C radiation
λ = 400-315	λ = 315-280	λ = 280-100
Energy: 3.10-3.94 eV	Energy: 3.94-4.43 eV	Energy: 4.43-12.4 eV
Intensity:27W/m^2	Intensity:5W/m^2	Intensity:-
It has 1.7 times bigger mean energy than visible radiation*.	It has 2 times bigger mean energy than visible radiation*.	It has 4.1 times bigger mean energy than visible radiation*.
Its intensity represents the 7.9% of solar radiation**.	Its intensity represents the 1.5% of solar radiation**.	
Damages collagen fibres & accelerates skin ageing	Damages collagen fibres & accelerates skin ageing	Damages collagen fibres & accelerates skin ageing
Destroys vitamin A.	Destroys vitamin A. Initiates vitamin-D production.	Destroys vitamin A.
Responsible for tan.	Responsible for deeper tan of longer duration.	Responsible for sunburn.
Indirectly destroys DNA & contribute to skin cancer.	Directly destroys DNA & causes skin cancer.	Directly destroys DNA & causes skin cancer.
Suppresses immune system protection by some diseases or have positive effect by others.	Has negative or positive effect on immune system.	-
Penetrates under the skin.	Dangerous to the eyes,	Dangerous to the eyes,

*mean energy of visible radiation: 200 kJ/mol, **average solar radiation:342 W/m^2

2.2.3 What is a Sun tan?

The fundamental evidence that fabric protects against erythema is the condition called farmer's tan. The areas of skin not covered by fabric, often the lower arms and the neck, are the first to tan (darken) or burn (redden)[37].

Tanning results in permanently damaged collagen and elastin which leads to premature wrinkling, as well as multiplying the susceptibility of developing skin cancer, often decades after the sunburn or sun tan[38]. Table 2.3 shows that UV sensitivity of individual is deeply affected by the skin types.

Table 2.3: Effect of UV rays on different types of skin

Skin type (Appearance unexposed)	Critical dose mJ/cm^2	Self protection time (min)	Risk level
I - White	15 – 30	5 - 10	Burns easily, has the highest risk of premature skin ageing and greatest risk of developing skin cancer
II - White	25 – 35	8 - 12	Burn and only rarely tan
III - Brownish	30 – 50	10 - 15	Tan and occasionally burn
IV - Brown	45 – 60	15 - 20	Tan and occasionally burn
V - Brown	60 – 100	20 - 35	Sufficient levels of melanin and rarely burns, easily tan
VI – Dark Brown - Black	100 – 200	35 - 70	Sufficient levels of melanin pigment provide protection. Very rarely burns, easily tan

2.2.4 What is Sun protective clothing and UPF?

Textiles can provide simple and effective protection against damaging UV radiation because they are able to reflect, absorb and scatter solar wavelengths, but in the most cases it does not provide full sun screening properties (see figure 2.1). When UV radiation strikes a textile surface, some of the radiation is reflected at the boundaries of the textile surface. Another radiation element is absorbed when it penetrates the sample: more accurately, converted to a different energy form. The remaining part of the radiation passes through the fabric and reaches the skin: this part is referred to as transmission[39].

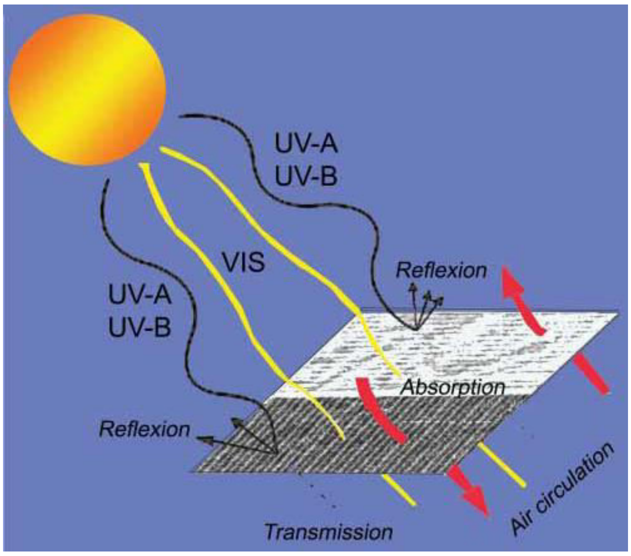

Figure 2.1: UV radiation in contact with textile fabric[40]

Grancaric A M, Penava Ž, Tarbuk A. (2005) studied the influence of fabric construction on ultraviolet skin protection expressed as the ultraviolet protection factor (UPF). They investigated the effect of fabric density and cover factor using twelve woven fabrics from the same cotton fibres and yarn count, but different in type of weaving and fabric density. UPF and UV-A and UV-B transmission were measured using transmission spectrophotometer Cary 50 Solarscreen (Varian) according to the AATCC Test method 183-2000. It was found that as higher fabric density resulted in a higher fabric surface mass and a higher fabric cover, UV-A, and UV-B transmission decrease and UV protection increases. Woven fabrics shrunk during alkali scouring, resulting in increased fabric density and cover factor and UV protection. Plain-woven cotton fabrics showed better UV protection than twill and Satin woven fabrics due to the higher filling factor (Table 2.4). Not only the weave but also the warp and weft density, yarn structure and fineness, play an important role in UV protection[24].

Table 2.4: Air permeability, AP, UV-A and UV-B transmission, T(λ) $_{UVA+UVB}$ and UPF values of the raw and scoured woven fabrics

LABEL	RAW			SCOURED		
	AP [l/h mm WC cm²]	T(λ) UVA+UVB	UPF AATCC	AP [l/h mm WC cm²]	T(λ) UVA+UVB	UPF AATCC
P1	16.36	4.16	56.96	8.67	3.96	62.85
P2	51.43	35.24	5.71	37.89	22.18	9.23
P3	60.00	28.18	7.22	36.00	13.40	15.72
P4	36.00	22.33	10.71	21.18	11.11	17.49
K1	15.00	2.55	111.10	9.23	3.54	113.52
K2	45.00	33.33	6.06	36.00	15.15	13.84
K3	60.00	23.85	8.53	27.69	12.86	16.09
K4	45.00	26.76	7.57	41.50	14.68	14.13
A1	12.41	1.99	140.52	9.47	1.81	166.15
A2	90.00	37.95	5.29	60.00	18.85	10.51
A3	72.00	21.37	9.50	51.43	12.49	16.84
A4	90.00	25.40	7.95	60.00	9.48	12.38

Ultraviolet Protection Factor (UPF) value

The rating system for fabrics specifies an Ultraviolet Protection Factor (UPF) value, which can be thought of as a time factor for the protection of Caucasian skin compared to exposure without any protection[41]. The rating system is determined as a result of the total ultraviolet transmission through the fabric and the skin's response to the rays. The instruments for measuring fabric transmission includes broadband radiometers, spectroradiometers, or spectrophotometers, and Xenon lamps[42]. The preparation of the fabric prior to the UV transmission test includes the exposure of specimen to laundering, simulated sunlight and chlorinated pool water and to present in a state that simulate the conditions at the end of two years of normal seasonal use, so that the UV protection level finally stated on the label estimates the maximum transmittance of the garment fabric during a two-year life cycle. First, the amount of ultraviolet transmission of the fabric must be calculated by measuring the UV spectral transmittance of the fabric using a spectrophotometer[43]. Spectral transmittance refers to the amount of ultraviolet radiation that penetrates the fabric and fibres at each wavelength. For the purposes of this effort, the spectral transmittance is measured only for the UV-A and UV-B wavelengths, i.e. 290-400 nanometres.

The UPF factor allow for people to identify the effectiveness of a fabric to inhibit ultraviolet radiation and range from 15 to 50. It is expressed as the ratio of extent of time required for the skin to show redness (erythema) with and without protection, under continuous exposure to solar radiation. 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$\pm$ 2 hours of continuous exposure.

The higher the UPF level, the greater the protection provided by the fabric. The ASTM procedure has been developed to simulate ageing of the fabric, which is applied before the AATCC test is conducted, thus allowing for a measure of the UPF level after wear, as stretch or other factors may have a significant impact on the UPF level of the fabric.

AATCC 183:2004 method defines the UPF rating for a fabric/textile as the ratio of UV measured without the protection of the fabric (compared to) with protection of the fabric. For example, a fabric rated UPF 30 means that if 30 units of UV fall on the fabric only 1 unit will pass through. A UPF 30 fabric that blocks or absorbs 29 out of 30 units of UV is therefore blocking 96.7% UV. If a person would show visible erythema (sunburn) after five minutes of exposure, fabric with a UPF of fifty extends that to five minutes times the protection factor, i.e. 250 minutes, or roughly four hours[44].

UPF is similar to SPF (Sun protective factor) used to rate sunscreens but UPF is the rating used to measure the amount of UV rays that pass through fabrics when exposed to UV radiation. Unlike SPF that traditionally uses human sunburn testing in a laboratory environment, UPF measures both UV radiation transmittance using a laboratory instrument (spectroradiometer) and an artificial light source and translates these results using a mathematical expression based upon the sunburn action spectrum (erythema action spectrum) integrated over the relevant UV spectrum. Theoretically, both human SPF testing and in vitro laboratory instrument testing measure a product's relative ability to protect against minimal sunburn compared to skin that is not protected. Developed in 1998 by Committee RA106, the testing standard for sun protective fabrics in the United States is the American Association of Textile Chemists and Colorists (AATCC) Test Method 183. This method is based on the original guidelines established in Australia in 1994.

In general, high-weight, dark coloured and thick fabrics absorb a higher amount of UV rays than light-weight, light-colour and thin fabrics. This fact represents a severe limitation regarding the manufacture of summer clothing, since summer garments are, per definition, represented by light-weight constructions. Dubrovski P D & Golob D. (2014) presented the effects of woven fabric construction and color on the ultraviolet protection factor. Weave type, fabric tightness, cover factor, volume porosity and colour of lightweight summer woven fabrics were investigated in this research. Colour had the biggest influence on the ultraviolet protection factor of fabrics, whereas woven fabric construction was essential when light pastel colored fabrics were used as ultraviolet protection (Figure 2.2). The work provides guidelines for engineering woven cotton fabrics with sufficient ultraviolet protection[33].

But the most intense UV radiation is observed in summer season. So the potential of skin damage (skin burn, skin cancer), in whatever form, therefore is the highest in summer. The objective regarding UV protection, especially for beach and sports wear and even for light-weight summer work wear therefore has to be the creation of light-weight, light-coloured fabrics, which are comfortable to wear in hot season and additionally offer an optimum UV shielding ability under almost occurring wear conditions. Design considerations such as long sleeves and collars are also very important in sun protective clothing in an effort to maximize the amount of body coverage and thus the protection provided.

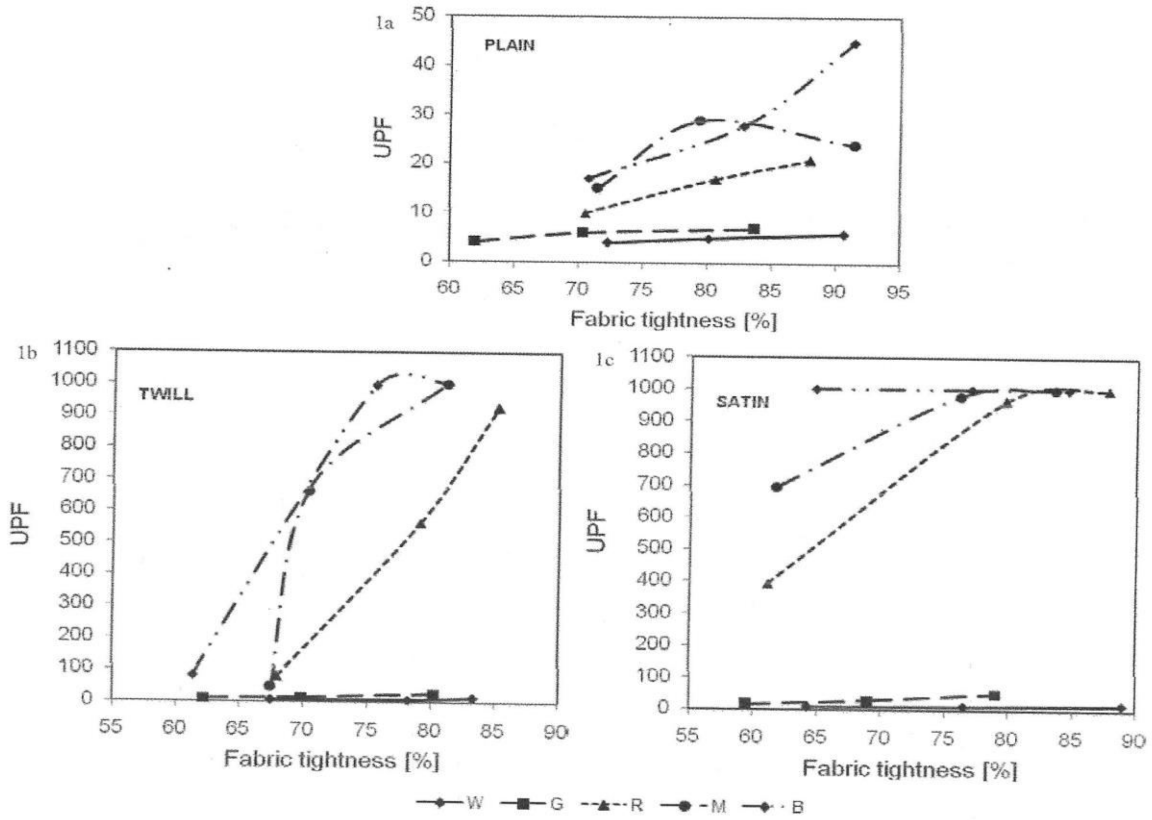

Figure 2.2: The results of UPF measurements regarding the fabric tightness (1a. plain fabrics; 1b. twill fabrics; 1c. satin fabrics)

2.2.5 Assessment of ultraviolet protection of textiles

There are two basic methods, namely *vivo* and *vitro* used to assess the amount/ degree of sunburn protection provided by various fabrics (ultraviolet protective factor):

Vivo Method

In vivo method is one that closely parallels the method used to assess the effectiveness of sun screen lotions, that is to determine the sun protection factor (SPF) of the lotion. 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. 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. Generally, xenon arc solar simulators are used, with filters to absorb wavelengths below 290 nm and to reduce visible and infrared radiation. Cost and ethical dilemmas impede and often exclude this form of testing. Stanford[45] and Gies[46] and their co-workers described in vivo test methods based on MED testing. However, the most frequently performed in vivo test method is in vivo confirmation of the UPFs measured in vitro. Based on skin prototype, MED is determined using incremental UV-B doses on the upper back of a subject and is read after 24 hours. To measure the MED of protected skin, a textile is placed over the skin on the other side of the back. The incremental UV-B doses for determining the MED of unprotected skin are multiplied by the UPF determined in vitro, with the product being the incremental UV-B doses for MED testing of the protected skin. Cost and impracticability are limitations of the in vivo test methods. Some in vivo tests have used polysulfone dosimeters as small portable badges monitoring UV doses on mobile subjects[47].

Vitro Method

Direct and diffuse UV transmittance through a fabric is the crucial factor determining the UV protection of textiles. Radiometric UV transmission tests use a broadband UV light source filtered for UV-B or combined UV-A and UV-B spectral regions to illuminate a fabric sample. The total UV transmission through the textile is measured by a radiometer. For correct measurement, this test method requires a UV source that closely matches the solar spectrum, with detectors that respond similarly to human skin. Nevertheless, this technique is simple and suitable when relative variation in UPF needs to be measured.

The in vitro method is also called the instrumental method, because a spectrophotometer is used. This method has an in vivo component to it. The two major steps in this procedure are transmittance testing and calculations based on the transmittance data collected. To obtain transmittance data, a fabric swatch is placed in a spectrophotometer equipped with an integrating sphere. The procedure is to direct a beam of radiation composed of one wavelength in the UV light and of known quantity perpendicular to the surface of the fabric swatch and to measure the amount of radiation transmitted through the fabric. The sending of beams of radiation continues until all wavelengths in the UV range (or in some tests the wavelengths at 2 or 5 nm intervals) have been directed to the fabric face and transmittance data collected. Once the transmittance data have been collected (usually by measuring the UV transmittance of several swatches of the same fabric to take into account variation in fabric uniformity), they are used to calculate percent transmittance values (percent UVA, percent UVB, or a total percent transmittance value, or a percent penetration value (1/UPF). As suggested by the AS/NZS and European standard, the spectrophotometer should be fitted with a UVR transmitting filter for wavelengths of less than 400 nm to minimize errors caused by fluorescence from whitening agents. For UPF determination, at least 4 textile samples must be taken from a garment, 2 in the machine direction and 2 in the cross-machine direction[48].

Percent transmittance

The calculation of total UV percent transmittance for a fabric is the ratio of the amount of radiation transmitted to the amount of radiation directed perpendicular to the fabric swatch surface. The calculation of the percentage of UVB transmitted through the fabric is the same, except only the data from the UV rays in the UVB region are used. Likewise, the calculation of the percentage of UVA transmitted involves only the data when UVA was directed at the fabric surface. Percent transmittance data do not take into account that certain wavelengths in the UV range are more responsible for skin damage than others.

Fabric – ultraviolet protection factor value

The calculation of a UPF value is accomplished by combining the transmittance data collected that established the relative power of UV wavelengths to cause the skin to redden. These later data, data collected using human subjects, are given in the erythemal action spectra. The importance of using the erythemal action spectra data in a protection calculation is that fabrics that allow greater portion of the most powerful skin reddening rays to be transmitted will receive a numerical value lower than a fabric that allows less of the powerful skin reddening rays through, even when both fabrics transmit the same amount of radiation.

If, E_λ is the erythemal effectiveness of ultraviolet radiation (spectral intensity of radiation); S_λ, the spectral relative biological efficiency in watts per square meter; T_λ, the spectral permeability of the protective item; i.e. textile fabric, $\Delta\lambda$ ranges of wavelength in nm, then UPF can be calculated according to the Equation (2)[49, 40, 50, 51, 52, 53]:

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

The numerator of the above equation describes the quantity of the UV radiation, which reaches the skin if unprotected. The denominator describes the quantity of the UV radiation reaching the skin protected by a garment[76]. The in vivo and in vitro methods are in agreement if the ratio of the MED of protected skin to the MED of unprotected skin results in the original in vitro UPF.

Erythema Action Spectra

The erythema action spectrum is obtained by irradiating test subjects with monochromatic ultraviolet radiation of various wavelengths[77]. 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. From these results, the erythemal effectiveness, the reciprocal of the critical dose of a given wavelength is determined. E_λ is defined as the inverse value of W_λ times an arbitrary constant C_0:

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

Erythemal effectiveness of light is thus proportional to harmfulness. Calculations to determine UPF as defined by AS/NZS 4399:1996, AATCC 183:2004 and EN 13758 involve measurement of the percent transmission of a fabric sample across the UV spectrum weighted by the erythemal weighting factors at different wavelengths. The AS/NZS 4399:1996 method is particularly convenient because it does not specify any preconditioning of the fabric and involves only measurements on dry fabric[54, 55].

2.2.6. UV protection care labelling

Initiatives for developing standards related to UV protection started in the 1990s, and standards related to the preparation of fabrics, testing and guidance for UV protection labelling have been formulated by different agencies[56]. The in vitro UPF method is the major technique of measurement of the photoprotection of textiles in all countries. UPF is a measure of total UV blocked, both UV-B and UV-A. The total UV transmission through the textile is measured by a radiometer. For accurate measurement, this test requires a UV source that closely matches the solar spectrum, with detectors that respond similarly to those of human skin. The technology is simple and suitable when a relative variation in UPF must be measured.

Care labelling similar to fabric and garment care labels has been developed for UV protection, and standard procedures have been established for the measurement, calculation, labelling methods and comparison of label values of textile products[57]. Since 1981, the skin Cancer Foundation, an international body, has offered a Seal of Recommendation of the photo-protective products which includes sunscreens, sunglasses, window films and laundry additives, in accordance with AATCC TM 183-2000 (transmittance or blocking of erythemal weighted ultraviolet radiation through fabrics) or AS/NZS 4399 (sun protective clothing evaluation and classification). The ASTM Standard for sun protective clothing and swimwear which is considered the industry standard in rating such sun protective clothing[58, 59, 60, 61] are shown in the table 2.5 below:

Table 2.5: UPF ratings

UPF	Protection category	% UV radiation blocked
15 or 20	Good protection	93.3-95.9
25, 30 or 35	Very good protection	96.0-97.4
40, 50 or 50+	Excellent protection	97.5-99+

This determination is based on UPF ratings derived from the AATCC and ASTM test methods. In addition, they caution that only clothing which covers a significant portion of the body, such as to the neck, elbows, and knees, can be rated as sun protective. AATCC 183 should be used in conjunction with other related standards including American Society for Testing and Materials (ASTM) D 6544 and ASTM D 6603. ASTM 6544 specifies simulating the life cycle of a fabric so that a UPF test can be done at the end of a fabric's life cycle – which is when most fabrics provide the most reduced level of UV protection[62, 63, 64]. BS 7914N (1998) specifies method of test for penetration of erythemally weighted solar ultraviolet radiation through clothing fabrics[65]. EN 13758-1 (2001) specifies method of test for apparel fabrics[66].

Similarities and differences among clothing standards

The calculation and expression of results is similar in EN 13758-1, AATCC-183 and AS/NZS 4399. All three standards report results as a UPF rating. When samples are found to have a UPF rating over 50, EN 13758-1 reports them as >50 whereas ASTM D6603 and AS/NZS 4399 report them as 50+.

EN 13758-1 (and BS 7914) stipulates that fabric samples are to be conditioned at a specified temperature and humidity before testing. AS/NZS 4399 does not specify any conditioning. ASTM D6603 specifies that the fabric samples should be conditioned with laundering, UV exposure and chlorinated pool water equivalent to two years of normal use.

EN 13758-1 and AATCC-183 uses a solar spectrum measured in Albuquerque whereas AS/NZS 4399 uses a solar spectrum measured in Melbourne. UPF results calculated with either spectrum do not differ significantly.

EN 13758-1 and AATCC-183 provide for reporting of measurements made when the fabrics are wet and /or stretched. AS/NZS 4399 currently specifies testing and labelling requirements whereas EN 13758-1 is concerned only with testing. ASTM D6603 specifies USA labelling requirements.

The various standards require that UPF rated clothing be labelled as fitting into a particular range of protection, rather than stating a single measured number. AS/NZS 4399:1996, for example, calls for the measured value to be rounded down to the nearest multiple of five. At the limits, ratings below fifteen are not recognized and any measured value above fifty may only be labelled as 50+. ASTM D6603 requires both a numeric UPF value and a description of the garment as providing good, very good or excellent UV protection. These terms are based on UPF values of 15-24, 25-39 and >40 respectively. European standard EN 13758—2:2003 rates the protection category of textiles in the UPF range above 40 as excellent; UPF range 30-40 is considered as very good while UPF range 20-29 is defined as good UV protection. According to it, only textiles with a UPF greater than 30 are labelled as UV protecting material. When the fabric UPF is greater than 40, only UPF 40+ should be reported.

Contrary to popular belief, not all textile materials offer adequate UV protection, the UPF value of a third of typical summer clothing sold, is less than 15. The main purpose of the textiles designed to protect from UV radiation, is significantly to reduce the open area portion, consequently implying an increase in the portion of covered skin. The optimal combination of thickness, fabric area density, mass per unit area, knitted structure, in addition to yarn type and yarn linear density, allow production of textile products with high UV protection properties[91]. As transmittance of UV light drops below 2%, the calculated UPF increases dramatically with very small reductions in transmittance. For this reason, standards do not permit labelling with numbers higher than 50.

Standards also require that clothing made of different fabrics, or different colours of the same fabric, have each area tested separately. The garment must then be labelled according to the lowest level of protection afforded. Labelling standards differ from those that define a process for determining the UPF/SPF for the fabrics, because they direct the conversion of the fabric UPF values generated in vitro testing to a single label UPF value, which in turn determines a classification category of the fabric/product. Labelling standards provide different directions for determining label information including the state of the fabric (e.g. new or laundered) at the time of transmittance testing, so it is important to look for the standard number on the product label.

This labelling allows the consumer to compare the amount of protection provided by various textiles, and to purchase the product that best meets their sun protection needs. This UV-label system, supplements other required labelling of garments, including permanent care labels and fibre content composition labels. It is important to emphasize that the UPF value to be placed on a garment label needs to be the lowest UPF value expected during consumer use over a two-year period. For synthetic fabrics, this UPF value will typically be obtained for the prepared-for-testing specimens after they have been laundered 40 times and exposed to 100 fading units of UV-radiation, to simulate conditions to lower the UPF during consumer use. For other fabrics, knits in particular, the fabric manufacturer must stretch the fabric to standard width for the garment manufacturer. This stretching process reduces the UPF of the fabric dramatically because the optical porosity is increased. Because the first laundering of such fabrics will shrink the fabric and reduce the optical porosity of the fabric, the UPF will be restored after laundering. For cotton or cotton-blend knit fabrics, the laundered-once UPF value will typically be lower than the prepared-for-testing value, because optical porosity continues to decline over the life of the garment while calculated UPF values increase.

Differences in basis of claims

One of the active debates about classifying garments as UV-protective is whether classification should include:

Only those garments made of fabrics having or exceeding an agreed to minimal level of sunburn protection and covering at least as agreed to minimum skin surface area; and those garments made of fabric having or exceeding an agreed-to minimal level of sunburn protection with no requirement for area of garment skin coverage. Both basis for making a claim have been adopted.

Another critical difference in basis of claims that a garment/fabric is sunburn protective lies in the condition of the fabric swatches of the fabric at the time of testing. The ASTM 6603 labeling document specifies that the fabric swatches must be prepared for testing. What this means is that fabric is subjected to 40 launderings and many hours of UV radiation exposure.

If the fabric will be used in swimwear, it also must be subjected to chlorinated pool water. Procedures for these exposures are specified in ASTM 6544-the preparation of textiles before ultraviolet transmittance testing. The rationale for this swatch preparation step is to ensure that the lowest amount of protection during a normal life of the fabric is used in making the sunburn protection claim. In other words, the wearer of the garment is assured that the label amount is the least to be expected.

Manufacturers and certifiers

Fabric and garment manufacturers who wish to label their garments or a line of their garments as being sun protective tend to do using a label of a certifier. For example, in Australia/ New Zealand, the certifier is the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). In the United States, the major certifier is the International Testing Association for Applied UV Protection. Another certifier is the Skin Cancer Foundation, which provides a certification seal for those products that meet its certification requirements. Certifiers may use the standards produced by national and international standard-setting organizations. Often they set their own testing and labelling procedures and standards. The certifier's name usually appears on the garment label.

2.2.7 Effect of UV Radiation 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. The penetration of UV radiation in nylon causes photo oxidation and results in decrease in elasticity, tensile strength and a slight increase in the degree of crystallinity. 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[68]. Elevated temperature and UVB radiation on cotton plants result in severe loss of bolls[69]. 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. Similar to homochain polymers there are several hetero chain polymers also that are highly susceptible to photo degradation: polyesters, polyamides and polyaramids, polyethers, polyimides, polyurathanes and polysulphides. High strength fibres; zylon, dyneema and Kevlar losses strength upon exposure to UV radiation.

2.2.8 Are Sunscreens and Sunblocks enough?

Health organizations worldwide are recognizing that using sunscreens and sunblocks exclusively are not reducing the rates of skin cancer in the general population. Age groups that in past rarely suffered from skin cancer, such as children and teenagers, are developing skin cancer despite a lifetime of sunscreen and sunblock usage. Part of the reason of this is that sunscreens/sunblocks are rarely used frequently enough. In addition, patches of skin can be left exposed and unprotected. However, they have disadvantages in use such as discomfort, requirement for frequent reapplication and potential hypersensitivity. Furthermore, some recent epidemiologic studies showed that use of sunscreens increased the risk for developing nevi and melanomas[70]. Using cosmetics with an SPF (Sun protection factor) or a natural sunblock, such as titanium dioxide or zinc oxide in larger particle size (not micronized to ultrafine or fine levels) contribute to skin protection, but are not sufficient by themselves to provide adequate coverage. Sunscreen lotions available contains natural skin damage fighting ingredients like green tea and organic sunflower oil, mineral pigments and filters to deflect UV rays. Sunscreen as a means of sun protection has many limitations; it can easily wear off and most people do not apply sufficient amounts. Therefore, sunscreen should not be used as the primary means of sun protection but only in combination with other 'sunsafe' measures and behaviours. Sunscreen lotion should be applied of at least SPF (Sun protection factor) 15 liberally and re-applied every two hours or after swimming, playing or exercising outdoors. In 2011, the Journal of Clinical Oncology published a randomized clinical study of over 1,600 people showing that regular sunscreen use reduced the incidence of melanoma by 50-73%[7]. The use of textiles in now recommended by many health organizations to decrease the impact of skin cancer on the general population.

2.2.9 How can textiles protect the skin?

In the past, ancient and ethnic cultures did not have access to lab-derived cosmetic formulations to protect their skin. Textiles were easily accessible and effective in skin protection. When one examines cultures that live in typically hot, sunny places, certain similarities are evident in their common use of textiles.

2.2.10 UV Resistance

It is widely held misconception that any clothing provides adequate sun protection. Clothing is associated with several factors which governs the effectiveness of UVR protection. UV resistance in textiles refers to a fibre's or fabric's ability to resist UV radiation. This can be important for the preservation of the fibre as UV rays cause of degradation to textile fibres, as UV rays excite the polymer molecules and break polymer chains thereby resulting in significant damage to the fibre depending on the UV intensity and the duration of exposure.

Textile items can be used to provide protection to a product or wearer from UV radiation, but to do so effectively the textiles requires the ability of resisting UV transmission through the constituent fibres or the penetration of the radiation through the fabric interstices. This means the fibres themselves should be UV resistant and the fabric structure should have good breathability but low optical transparency. The energy of UV radiation received by a textile can be divided into the following three components: the energy reflected, absorbed and transmitted by the textile product; the latter irradiates the human organism directly.

The UV resistance of textiles may therefore looked at from two perspectives:
That as a functionality to protect the textile article itself from degradation; generally achieved by the inherent characteristics of the fibre, which can be natural or an engineered quality in a synthetic fibre, attained by particular additives to the polymer such as titanium dioxide or carbon black.

When ultraviolet radiation hits the textile materials, different types of interactions occur depending upon the substrate and its conditions[71, 72]. The UV radiation transmitted through a textile fabric consists of the waves that pass unchanged through the pores of the fabric and scattered waves that have interacted with the fabric[73]. Several different effects occur when UV radiation hits a textile surface, causing the UV radiation to be broken down into several components. Part of the radiation is reflected at the boundaries of the textile surface; another part is absorbed when it penetrates the sample, that is, it is converted to a different energy form. Yet another part of the radiation travels through the fabric and reaches the skin; this part is referred to as the “transmission” [74].

To protect a wearer or item from UV radiation; combination of fibre selection and engineering of the fabric structure, and if higher levels of protection are required special finishes can be applied to the fabric surface.

Kathirvelu S. et al. (2009) studied the synthesis and characterization of nanosized zinc oxide particles and their application on cotton and polyester/cotton fabrics for the protection against

UV radiation. The nanoparticles were produced in different conditions of temperature (90^0 or 150 ^{0}c) and reaction medium (water or 1, 2 –ethanediol). Fourier transform infrared spectroscopy, transmission electron microscopy and x-ray powder diffractometry have been used to characterize the nano particles composition as well as their shape, size and crystallinity. The effectiveness of the treatment was assessed using the standardized tests, such as UV-vis spectrometry and the calculation of the UPF both before and after washing of the treated samples. It was found that the performance of ZnO nano particles as UV-absorbers can be effieciently transferred to fabric materials through the application of ZnO nano particles (Table 2.6). The UV tests indicated a significant improvement in the UV absorbing activity in the ZnO-treated fabrics[52].

Kursun, S. and Ozcan, G. (2010) treated swimwear fabrics with the same knitting construction and different fiber composition (80% PET+20% /Elastane, 80% PA+20% Elastane) with suitable dyestuffs and UV absorber agents at different concentrations (figure 2.3). Then, all the treated swimwear fabrics were tested for UV absorbance (AS/NZS 4399), colour fastness to rubbing (EN ISO 105- X12), light fastness (TS 1008 EN ISO 105-B02), colour fastness to perspiration (acidic and basic-TS EN ISO 105 E04), colour fastness to sea water (EN ISO 105 E02), and colour fastness to chlorinated water (EN ISO 105 E03) to evaluate the effect of their treatment parameters (such as UV absorber agent, dye concentration) on the UV protection characteristics of the swimwear fabrics[75].

Table 2.6: UPF values of different samples for UV-A and UV-B radiations

Sample	UPF value	
	UV-A	UV-B
Untreated		
Cotton (woven)	1.05	1.07
Cotton (knitted)	0.98	1.00
P/C blend (woven)	2.30	5.50
P/C blend (knitted)	1.80	4.40
Treated		
Cotton (woven) with Z_1	4.92	5.23
Cotton (woven) with Z_2	8.45	10.29
Cotton (knitted) with Z_1	4.00	4.70
Cotton (knitted) with Z_2	8.80	9.50
P/C blend (woven) with Z_1	10.23	15.76
P/C blend (woven) with Z_2	11.80	16.20
P/C blend (knitted) with Z_1	9.62	14.53
P/C blend (knitted) with Z_2	11.10	15.87

Z_1—ZnO nanoparticles synthesized through Synthesis 1.
Z_2—ZnO nanoparticles synthesized through Synthesis 2.

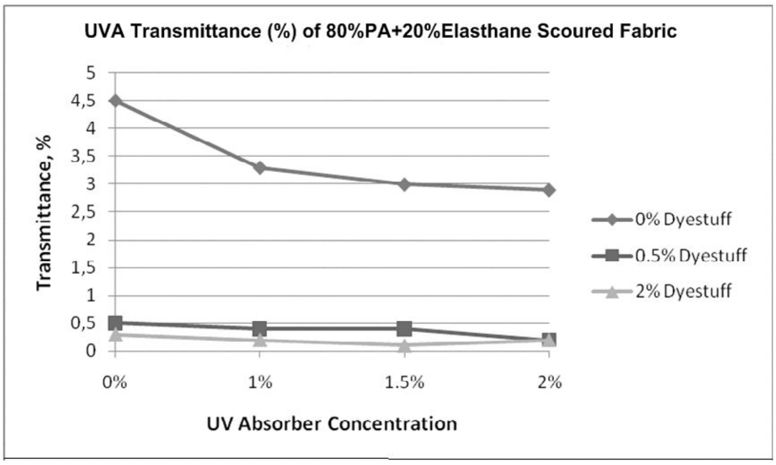

Figure 2.3: Effect of UV absorber concentration on the UV protection of fabrics

Zhou Y and Crews, P.C (1998) subjected eight types of summer-weight fabrics to 20 home launderings using detergents with and without an optical brightening agent (OBA). Results showed that OBAs used in laundering improved the UVR blocking ability of cotton fabrics and cotton/polyester blend fabrics, but not fabrics comprised entirely of polyester and nylon. The implication of the study is that a UPF rating can be significantly improved by repeated laundering of the garment in a detergent containing an OBA[76].

Sarkar and Vora (2011) analysed lyocell fibre – the cellulose fibe made from wood pulp and produced by direct dissolution, for its protective properties against UV radiation and disease –causing microbes and found that an optimum UV absorber – UV Suncell (r) (Huntsman Textile Effects, Charlotte, NC) concentration of 2% of the weight of the fabric was sufficient to improve the UV properties of lyocell fabric to an excellent degree (Table 2.7) [77].

Table 2.7: UPF values of lyocell fabric after finishing with the UV absorber

UV absorber concentration (% weight of fabric)	Ultraviolet Protection Factor (UPF)		
	After treatment	After laundering	After light exposure
Unfinished fabric	0.6	-	-
1	45.9	-	-
2	51.9	51.2	51.6
3	55.3	-	-
4	81.8	-	-

2.2.11 Selection criteria

There are a number of factors that influence the level of ultraviolet protection provided by a fabric. In order of importance these are: weave (tighter is better), colour (darker is better), weight (also called mass or cover factor-heavier is better), stretch (less is better) and wetness (dry is better). Wet processing of textiles (bleaching, usage of UV absorber, and coloration) also influences the UVR protection function of textiles and some refurbishment activities like wetness, stretch, heat or chemical treatments. The combined effect of these parameters (fibre, yarn, fabric, and wet processing treatment) complicates the subject of UVR protection by clothing. Table 2.8 indicates that the influence of a UV absorber on the UV blocking effect of uncoloured polyester fabrics is very high[78].

Table 2.8: UPF & transmittance % of polyester fabrics treated with UV absorber

Sample	Treatment	UPF	
		Without Cibafast HLF	1.5% Cibafast HLF
U	no	26.7	660.9
1	Acid	28.3	609.3
2	Alkaline	27.8	586.3
Or_p	Acid	57.6	894.0
	alkaline	54.4	798.5
Or_d	Acid	230.0	1820.4
	alkaline	219.3	1546.9
R_p	Acid	38.8	724.4
	alkaline	39.3	834.9
R_d	Acid	161.9	1212.8
	alkaline	147.2	1193.9
B_P	Acid	54.1	659.8
	alkaline	50.7	671.9
B_d	Acid	311.8	646.0
	alkaline	284.2	676.6

Fabric construction and UV Protection

Researchers have referred to fabric porosity by a variety of terms, including cover factor, tightness of weave and fabric openness. Scientists quantify the cover factor of fabrics using either image analysis or direct transmittance data. The complementary relationship is called fabric porosity and provides data about the percent of fabric surface area not filled by fibre. Cover factor is a highly important fabric parameter, because it determines the probability of a UV ray striking a fibre. The accepted rule is that the higher the cover factor the greater the UPF regardless of fabric structure. Fabric construction parameter (ends/inch & picks/inch or courses/inch & wales/inch and linear density of yarns) 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.

If one had a set of fabrics composed of fibres that absorbed all the radiation that struck them, but each fabric has a different cover factor, then the relationship between cover factor and SPF/UPF value would be as shown in Table 2.9:

Table 2.9: Relationship between cover factor/porosity and sun and ultraviolet protection factor values[79]

Cover factor (%)	Porosity (%)	Max theoretical fabric SPF/UPF
80	20	5
90	10	10
93.4	6.6	15
95	5	20
97.5	2.5	40
98	2	50
99	1	100
99.5	0.5	200

The data show that UPF increases rapidly as percent cover factor increases in small increments. Pailthorpe, a textile scientist from Australia note 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):

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

The greater the probability that UV radiation directed at the fabric surface will strike a fibre and therefore be reflected or absorbed by the surface fibre or other fibres as it continues its journey through the maze of fibres comprising the yarn leads to decreased transmittance (higher UPF). Conversely, the higher the percent porosity of the fabric, the greater the probability that rays directed perpendicular to the fabric surface (as is the case in transmittance testing) will pass directly through the pores in the fabric (where there is no UV absorbing material.

Percentage UV radiation transmission and UPF can be calculated using the following equations:

% UVR transmission = 100 – cover factor (5)

UPF = 100 / (100 – cover factor) (6)

Application of equations (5) and (6) show that the cover factor of a fabric must be greater than 93% to achieve a minimum UPF rating of 15. Also, once the cover factor exceeds 95%, very small increases in cover factor lead to dramatic improvements in the protective ability of the fabric. It should be noted, however, that fabrics with the same cover factor can have widely different UPF ratings, particularly if their fibre chemistries are different.

Cloth cover is a measure of the fraction of area covered by both the warp and weft threads in a given fabric and calculated simply by using thread count and yarn number according to an equation by Booth and Pollitt[101].

Cloth cover = Cover $factor_{warp}$ + Cover $factor_{weft}$ – [Cf_{warp} * Cf_{weft}) / 28] (7)

The above equation was developed for a plain weave fabric and the basic premise is that the cover factor would be 28 if all yarns just touched each other. In practice, cover factors can range from 8 to 28 for commercially available fabrics. However, Crews et al. found that cloth cover was not a precise estimator of fabric porosity and therefore not a reliable predictor of UVR transmission through a fabric.

Another method of quantifying porosity is determining percent cover by image analysis. Percent cover is defined as the percentage area occupied by warp and filling yarns in a given fabric area. This method reported by Crews et al[80] involves magnifying a microscopic image of a fabric obtained using a light microscope and a video camera on a video monitor screen for a magnification of 130X. The monochrome image of the magnified fabric is then captured with a video capture card, converted to pixels on the computer screen, and analyzed with image analysis software. Each pixel represents a monochromatic value between 0 and 255. The area of fabric occupied by yarns is considered to be those areas represented by black pixels, i.e., monochromatic values between 0 and 75. Percent cover is then determined according to equation (8).

Cover (%) = (Number of black pixels / Total number of pixels) x 100 (8)

For example, it is recommended that fabric porosity of UV protective textiles should not be less than 1.5% in the stretched state. Some believe that fabric porosity for undyed, woven fabrics is the best indicator of a fabric’s ultraviolet protection levels.

The construction or weave of the fabric is the most important factor affecting UVR transmission[81]. The arrangement of yarns and fibres determined by fabric construction can influence the compactness of the structure, together with the open space within the fabric[82]. Dimitrovski et al (2010) observed that the absorption portion in the areas covered with two yarns amounts to about 65% and in area covered with one yarn is around 44% of the total UV radiation[83]. Wong et al, (2013) observed that fabrics with tuck stitches have larger fabric pores than the other fabrics, which allow more UVR to pass through fabric directly[84]. The tighter the weave of a fabric, i.e. the less space between the yarns, the more protection it will provide the wearer from ultraviolet rays. Dark blue jeans have a UPF of 1700[85, 86]. A high degree of correlation exists between UPF and fabric porosity, but is also influenced by the nature of fibres.

Dependence of radiation transmission on the permeability of fabrics

It was observed that dependencies exist between the air permeability and radiation transmission, including light transmission. This results from the fact that both quantities depend on the structure of the textile product, especially the inter-thread distances. This feature is caused by the weave phase of the woven fabric, the twist, thickness and hairiness of the thread, as well as by the cover factor of the woven fabric. The air permeability and UV transmission are often considered from the same point of view regarding the use properties of the fabric. Recently, it was noticed that good barrier properties against radiation can be found in fabrics constructed from polyester microfibers, but unfortunately its air permeability is small. On the other hand, a large twist coefficient at a great pitch of the threads leads to an increase in the inter-thread channels in the woven fabric, resulting in the air permeability and UV transmission also rising. The barrier properties of a fabric with respect to its structure can also be considered from the point of view of its porosity.

Gabrijelčič H. et al (2009) analysed the influence of the fabric surface cover factor and fabric colour values on the degree of UV ray transmittance and the UV protective factor (UPF). The research was carried out on lightweight coloured fabrics woven in sateen weave with different densities of warp and weft threads and with different colours in the weft. Measurements of the UPF were performed using the “in vitro” method in the range of UV-A and UV-B ray wavelengths, from 280 to 400 nm. The results of the research confirm the importance of the fabric surface openness for the UV protective factor and expose the influence of the fabric face and reverse sides as well as of colour values L*, C*ab, hab of warp and weft threads on the UPF in sufficiently closed woven constructions. Namely, constructions with less than the 5% surface openness offer excellent protection (UPF above 50), whereas constructions with less than 10% surface openness offer good to very good protection (a UPF above 20). At coverage higher than 95%, the fabrics analysed could be generally divided into three groups with respect to the effectiveness of their UV protection: fabrics of darker colours (black, blue) with extremely high UPF values, fabrics of chromatic lighter colours (yellow, red, green) with UPF values half of those of darker colours in general, and white fabrics (bleached) in which the desired UPF values are not reached regardless of the degree of the cover factor (figure 2.4).

Fabric tightness or relative fabric density is another parameter which represents the fabric structure or how tight the fabric is woven, similar as cover factor. Researchers have shown that fabrics woven in sateen weaves provide the best UV protection (in comparison with twills and weaves similar to plain weave). This can be explained by the composition of sateen weaves, which have the highest cover factor due to the specific arrangement of interlacing points, and also a different shape of pores from twills and weaves similar to plain weave[87]. It is known that by satin weave it is possible to achieve higher warp/weft density than with twill or plain weaves, so the limit density as well as actual density will be higher[88]. Consequently,

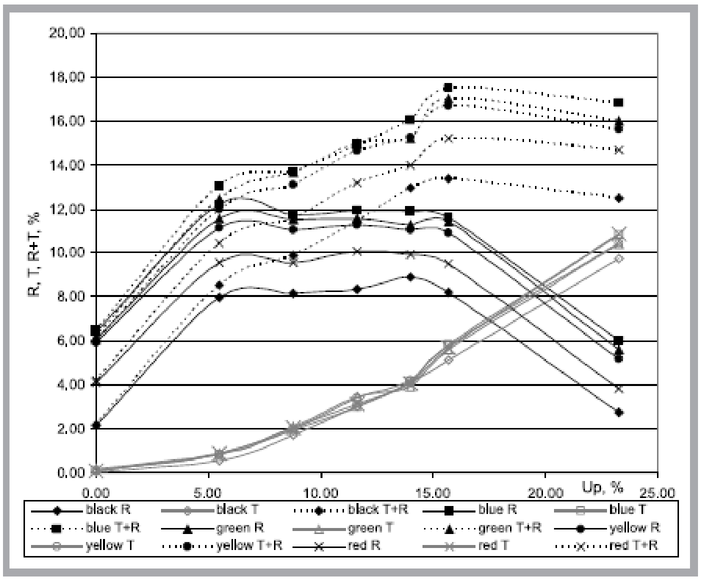

Figure 2.4: Diagram of reflectance R, transmittance T & the sum of the reflectance & transmittance R+T of samples made of coloured threads

the macropores will be smaller and UV radiation will have less free space to pass through than in twill or plain weaves. Differences between plain and twill weaves are attributable to the floating of weft yarns, over one and under two of the warp threads creating greater cover/density in twills[89]. The relative importance for ultraviolet protection is given by; cover %> nature of fibre> fabric thickness. UPF shows better correlation with fabric weight and thickness than porosity[90]. Therefore, fabrics with maximum number of yarns in warp and weft give high UPF.

Fabric depth of shade

The description of a fabrics colour may be specified, in a non-scientific way, by its hue (e.g. red, orange, yellow, blue, or green) and its depth of shade. This discussion begins with the wisdom of using fabric depth of shade to estimate fabric UPF. Fabric depth of shade is related to the lightness or darkness of the colour (hue) of a fabric. For example, a red dye can be used to make fabrics ranging in shade from light pink to dark red, the shade differing because of the concentration of the dye in the fabric. Similarly, a black dye can be used to make fabrics ranging in shade from light gray to intense black. Although it is true that the darker the shade of fabrics dyed with the same dye, the higher the UPF of the fabric (provided the dye used has capability of absorbing in the UV region of the electromagnetic spectrum), fabric depth of shade is an impractical selection factor for consumers to use, because the comparison probably will not be between or among fabrics that were dyed with the same dye. Because dyes, even those that dye the fabric to the same hue, differ in ability to absorb UVR, fabrics of the same hue and depth of shade will have different UPF values, sometimes dramatically different values.

Dyed fabrics protect more than undyed ones and their protection levels rise with the increase in dye concentration. In general, light colours reflect solar radiation more efficiently than dark ones, but part of the radiation penetrates more easily through the fabric thanks to multiple scattering[91].

Vital dependencies were noted between the colour of the woven fabrics, that of the warp and weft threads, and the kind of dyestuff used with respect to the absorption of UV radiation. Generally, reactive and pigment dyes increase the absorption[92, 93].

The colour of a dye is dependent on the absorbing properties of the dye in the visible band of the electromagnetic spectrum (380-770 nm). The absorption band of all dyes, however, extends into the UV radiation band (290-400 nm) and hence dyes act as effective UVR absorbers. The UPFs of the various colours are determined by the transmittances below 40 nm and can vary substantially. According to colour physic principles, dark colours of the same fabric type (blue, black, red, etc.) all absorb more strongly than lighter pastel shades (white, oatmeal, pale blue, light green etc.) and will consequently have higher measured UPFs, e.g. blue, UPF=80; green UPF =81; red, UPF =157; black, UPF=256 and consequently achieve UPF ratings of 50+ in the excellent protection category[94]. This can be compared with the lighter colours such as natural, UPF=6, and pale blue, UPF=13, both less than UPF 15, which is insufficient to achieve a UPF rating. The oatmeal UPF=16 and the white UPF=22 both have low-rated UPFs of 15 and 20, respectively. The same effect due to colour is also true for polyester materials (identical weave, weight, etc.). One of the first reports regarding the effect of colour on UV radiation transmission was by Gies et al. (1994) who stated that for fabrics of identical weight and construction, darker coloured fabrics scored higher UPF ratings than lighter shades[95]. A more comprehensive study examining the ability of dyes to reduce UV transmission through fabrics based on dye concentration in the fabric and transmittance in solution was carried out by Srinivasan and Gatewood (2000) who studied the effect of fourteen direct dyes on the UPF of a bleached print cloth. At 1.0% dye on weight of fabric, all dyed fabrics had UPF values above 15 compared to an UPF value of 4.1 for the undyed fabric. The results also indicated that dyes applied at 1.0% on weight of fabric gave higher UPF values than dyes applied at 0.5% on weight of fabric concentration[96]. They further noted that transmission / absorption characteristics of dyes in the UV band were a better predictor of UV protection than the colour of the dyestuff itself.

Colour depth will affect both the absorption and the reflectivity of UV photons by the fabric with dye molecules proposed as having a specific role. Whether colour depth modifies the effect of other variables known to affect UPF (such as fabric structural properties), and in both UVA and UVB regions, is currently unclear.

In conclusion it must be remembered that while colour can dramatically increase a fabric's protective ability, the dyestuffs responsible for the protection must be colourfast to washing, perspiration, sunlight, crocking and bleaching for the life of the fabric.

Fabric colour: hue

Hue, brightness and saturation are attributes used to describe visually assessed colour. Hue refers to the wavelength of light stimulating cones in the eyes with all colour composed of proportions of blue, green and red stimuli. Brightness is dependent on the limnenance and reflectivity (the more lumens emitted by an object the brighter the colour) while saturation is the amount of white present (a fully saturated colour has no white). The question is whether one can relate fabric colour (hue) to UPF. The answer is no[97, 98]. Natural colour pigment and waxes in natural fibres act as UV absorber. Naturally coloured cotton has higher UV absorption capacity[99, 100, 101, 102, 103, 104, 105].

Type of fibre

Ultraviolet protective factor is strongly dependent on the physical and chemical structure of the fibres. Fibres influence the barrier properties of fabrics by the kind of the fibre matrix, their porosity as well as the geometrical form and dimension of the fibres. The fibre matrix, especially its chemical structure, the presence of cumulated associated double bonds, among others have the greatest impact on the barrier properties. The fibre diameter and fibre localisation in the yarn also have an influence on the barrier properties that change the fabric structure. Commonly, the smaller the fibre diameter, the better the protection properties are, which is due to the decrease in the inter-fibre and inter-yarn distances[106].

The physiochemical type of fibrous material and fabric openness are other driving parameters to decide the UVR protection of clothing. It has been found that fibres containing conjugated aromatic system like PET are more effective for UVR absorption. Cellulose fibers (cotton, flax, jute, viscose) have no double bonds in their chemical structure, thus they have a low intrinsic UV protection properties of textile fabrics made thereof. Most researches into UV protection properties of natural fibres have focused on cotton[107]. To get high UV protection from a cotton fabric the cotton density (weight) needs to be very heavy and / or chemicals added to the finished garment (this can cause skin irritation). This in turn compromises the strength of fibre and airflow. In hot and humid conditions, the cotton garment becomes clammy, heavier and wetter and uncomfortable. Because cotton is a natural substance, the fibre tend to breakdown quicker with each wash thereby reducing the UV protection. Most lightweight cotton garments have an approximate UV rating of only 5 – this means that rays can easily penetrate the garment and cause sunburn to the wearer and reduces a further 50% when wet[108]. Cotton fibres in themselves reflect or absorb a little UV radiation. This is particularly true once they have becomes wet- the fibres then become almost see-through. In addition, cotton fibres are kidney-shaped in diameter, for example within one fibre the diameter can be very variable. When this is combined with twisted fibre structure, quite large holes appear in woven or knitted fabrics, through which the UV radiation can penetrate unhindered to the skin below. Spectroscopic studies showed that cotton has a relatively high ultraviolet transmission in the range of 280nm - 400nm. Algaba et al (2004) further found that[109] bleached cotton fabrics with very compact fabric structures exhibits high degree of permeability to ultraviolet radiation. The same fabric consisting of cotton in grey state provides higher UPF, because of the presence of natural pigments, pectins and waxes contained, which act as ultraviolet absorbers[110, 111].

Different fibre types provide different levels of ultraviolet protection. For example, cotton, wool and silk have inherent characteristics that cause them to be better absorbers of ultraviolet rays[112]. Protein fibres also have mixed effects in allowing ultraviolet radiation. Exposure to sunlight damages the quality of silk's colour, strength and resiliency in both dry and wet conditions[113]. Mulberry silk is deteriorated to a greater extent than muga silk. Bleached silk and bleached PAN show very low UPFs of 9.4 and 3.9 respectively. Silk fabrics are usually finer and have a medium ultraviolet transmission. Bleached silk fabrics were found to have four times higher UVR transmission than comparable unbleached silk fabrics[114]. Natural silk has a relatively high UV protection factor, because, like modern synthetic fibres, it contains matting components that reflect and absorb UV rays. The regular fibre structure, with small gaps in woven or knitted fabrics, also prevents the UV radiation from reaching the skin. Depending on the colour, the UPF may be 20 to 30. There is a good reason why in India, for example, silk sarongs are worn wrapped in several layers, which significantly increase the UV protection factor[115].

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. However, the strong absorption of jute is due to the presence of lignin, which acts as a natural absorber.

All studies were unanimous in the assertion that Polyester fibres whose structure is based on aromatic components absorb the UV-A and UV-B regions than aliphatic polyamide fibres. 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. The ultraviolet transmissions of different materials are as follows:
Cotton bleached > Cotton grey > Polyamide > Silk > Wool > Polyester.

Blending of polyester and cotton in a fabric would provide significantly better protection than cotton alone. Such a blend would provide increased absorbency and thus increased comfort for clothing in warm weather.

Fabric stretch

One of the aspects to be taken into account when discussing protection against ultraviolet radiation is the fact that most of the prevailing standards consider only the measurement of the UPF of the fabrics when they are dry and unstretched. However, some applications of textile apparel involve an exposition to ultraviolet radiation in wet state (e.g. swimsuit) an in a stretched state (tight garments). The measurement of UPF of dry and unstretched samples of these fabrics can lead to error, as the protection factor is likely to decrease considerably because of the wearing conditions of these garments.

Stretching a textile cause an increase in fabric porosity, with a consequent decrease in UPF. The less stretch a fabric has, the more likely it is to provide a greater degree of protection from ultraviolet rays. Knitted fabrics, in particular, are more likely to allow for the penetration of the sun's rays than woven fabrics. Tight fitting fabrics provide less protection than more relaxed, loose-fitting garments. Exceptions to these are fabrics made from Lycra fibres, which are consistently rated highly for protection against ultraviolet rays. The blending of Lycra with synthetic fibre gives the double advantage of protection against UV radiation due to chemical nature of fibre (aromatic compound) and highly stretchable Lycra fibre gives higher cloth cover.

Fabric weight

Fabric construction is the primary determinant of fabric porosity, followed by fabric weight. Thicker and heavier fabrics afford a greater degree of protection than thinner fabrics, providing that both fabrics are constructed with the same weave. Light fabrics such as silks and bleached cottons allow UV rays through. The value of UPF increases with increase in fabric density and thickness for similar construction and is dependent on fabric porosity[116].

Moisture and Swelling

The presence of water also impacts the ability of a fabric to protect the wearer against the sun. When textiles become wet, by air hydration, perspiration, or water, UV transmission through the fabric can significantly change, with a marked reduction of UPF observed for textiles made from cotton and cotton blends. The fabric scatters light less when wet, causing it to be more transparent. Such effects of wetness depend on the fibre used, how absorbent it is, and the fabric structure. Wetness may cause a 30-50% reduction in a fabric's UPF rating. Structure is particularly important because some fabric structures allow for more interstitial water. In the case of moisture, the influence is largely dependent on the type and hygroscopicity of fibres and conditioning time, which result in swelling phenomena[117]. 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. Cotton, wool, and silk are very absorbent fibres which may cause a decrease in their protective qualities whereas synthetic materials are non-absorbent and repel water, thus increasing their protective qualities. 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 capillary absorption and in turn less ultraviolet transmittance. For cotton, although an effect similar to viscose was expected, the finishing treatment might prevent the fabric from swelling. There is incidence of better degree of correlation between hygroscopic fibres and their UPF values[118]. Polyester has a low absorption and swelling capacity and that is why the UPF can't be related to humidity. Generally, elastane clothes retain higher levels of UV protection when wet than cotton or natural fibres.

Overall, wetness tends to reduce the effectiveness of protection against ultraviolet radiation, but it has been documented to increase effectiveness in some instances. Repeated washing can improve the UPF of clothes, especially cotton, by shrinking gaps in the weave.

Effect of maintenance & usage on UV protection

Stretching or fading during use and laundering can affect the level of protection provided by a fibre. While shrinkage may initially help to counteract such effects, extended wear will decrease UPF ratings because it reduces weight and thickness. Laundering has actually been found to increase the UPF levels, which can be attributed to fluorescent whitening agents commonly found in detergents. Fluorescent whitening agents tend to absorb the light in the ultraviolet and violet region (usually 340-370 nm) of the electromagnetic spectrum and re-emit light in the blue region (typically 420-470 nm), thus contributing to their overall effectiveness in increasing UPF levels. However, old, threadbare or faded clothes may have a lower UPF rating[119]. With wear and use, several factors can alter the UV protective properties of a textile, including stretch, wetness and degradation due to laundering.

Additives

The barrier properties of synthetic fibres, such as polyester or polyamide are commonly improved by the addition of ceramic nano-additives in the majority of SiO_2. The simplest type of additive, is the addition of the delusterant pigment TiO_2 which acts as an UV absorber[120].

Since TiO_2 incorporated during fibre manufacturing the effect is permanent. Treatment with Ultraviolet absorbers is another efficient method of increasing UPF. Ultraviolet absorbers are organic/inorganic colourless compounds with strong absorption in the ultraviolet wavelength range of 290 nm- 360 nm. 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. Alternatively, isomerisation can occur and the UV absorber may then fragment into non-absorbing isomers. The presence of inorganic pigments in the fibres results in more diffuse reflection of light from the substrate and provides better protection[121]. In order to improve UV protection 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[122].

Certain additives and finishes, such as Rayosan®, which is marketed by Sandoz, and fluorescent whitening agents, Tinofast CEL, and Tinofast PS, can be added to fabrics to increase ultraviolet protection. It has been found that 0.5% micro titanium dioxide and 0.4% titanium dioxide can improve the scattering of ultraviolet radiation. Chemical treatments and resin coatings are known to increase the UPF, but these can also decrease with wear and sometimes may affect the hand of the fabric. Presumably, delustered fibres have better protection against ultraviolet radiation. 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[123].

Introducing nanoparticles in textile finishing, led to UV protection by coating the surface of textiles and clothing with TiO_2 and Zinc oxide, and nowadays, a natural zeolite clinoptilolite. Zinc oxide nanoparticles have a very narrow size distribution (20 nm-40 nm) and minimal aggression, which result in higher levels of ultraviolet radiation blocking. For example, one sun protective company has embedded zinc oxide (ZnO), a natural mineral compound with well-established sun protection properties, into fibres of natural cotton and bamboo to create ZnO SUNTECT® fabric[124].

Man-made fibres with UV Protection

Conventional man-made fibres with UV protection contain 5 to 10% ceramic substances, above all titanium dioxide, which is integrated in PET, PA and PAN fibres. Ceramic materials have an absorption capacity in the UV region between 280 & 400 nm, and reflects visible and IR rays. They provide an excellent UV protection of over 90% and have a cooling effect of several degrees celcius.

Dimitrovski K., Sluga F. & Urbas R (2010) in order to determine the key parameters contributing to the closeness of the structure and offer suitable UV protection, made an analysis of monofilament woven fabric structure. Monofilament fabric samples used in the production of high-module screen-printing meshes, characterized by the excellent dimension stability of the structure, the properties of which change with varying diameters of the monofilaments and the fabric density, were chosen for this research. The values of absorption and the ultraviolet protection factor (UPF) were calculated (Table 2.10). The values calculated on the basis of a determined mathematical model matched well with the measured values and they can together represent the basis for successful planning of fabrics with suitable UV protection properties[83].

Table 2.10: Measured values of UV transmission (T) and reflection (R), and the calculated values of absorption (A) and ultraviolet protection factor (UPF) with the values of portion of area covered with one and two yarns in the material structure an transmission through the material (Tm)

Sample	UPF	T [%]	R [%]	A [%]	K_{Tm}	K_{Rm}	K_{Am}	T_m [%]*	a_1 [%]	a_2 [%]
1	2.37	54.22	13.72	32.06	0.293	0.212	0.495	18.98	48.24	16.52
2	3.08	45.95	16.17	37.88	0.273	0.218	0.510	20.27	49.99	24.33
3	3.71	41.76	16.53	41.71	0.267	0.208	0.525	21.22	49.56	29.90
4	4.84	35.83	18.12	46.05	0.255	0.210	0.535	21.96	46.75	39.38
5	4.78	36.02	18.68	45.30	0.256	0.217	0.527	22.01	46.84	39.15
6	5.79	33.01	18.81	48.18	0.246	0.212	0.542	21.83	44.52	44.30
7	2.92	47.02	15.44	37.54	0.271	0.212	0.517	19.68	49.90	22.76
8	3.87	39.25	17.36	43.39	0.239	0.218	0.544	19.05	49.48	30.32

* T_m [%] = $T - a_{o.}$

2.2.12. Future trends

The preceding discussion outlines the need for UV protective textiles and the complexities associated with making a textile impervious to ultraviolet radiation. What is not certain, however, is the magnitude of the market for UV textiles. According to most industry experts, people have been led to believe over many decades that sunscreen lotions are an equivalent alternative to covering up with clothing. Currently the market is limited to audiences that are very aware of the risks of skin cancer due to UV exposure. It is apparent that campaigns to increase public awareness of the harmful risks of UV exposure and education regarding the beneficial effects of UV textiles have to be mounted to develop the UV textiles market. Nevertheless, there is guarded optimism among manufacturers that the need for UV protective fabrics will grow as people live longer lives and are more active outdoors. A much positive approach to expanding the UV textiles market is through building trust in UV labels and claims of UV protective properties in textile materials by way of stringent quality-control programs.

Woven fabrics can provide simple and convenient protection against harmful effects of UVR if the necessary attention is paid to their engineering in the phase of a new product development. There are several factors influencing UV protection properties of woven fabrics like yarn construction (fibre type, twist, yarn packing factor), fabric construction with its primary (type of weave, yarn fineness, warp/weft density, relative fabric density or fabric tightness) and secondary (cover factor, open porosity, mass, thickness, volume porosity) parameters of fabric geometry, additives (dye, pigment, delusterant, optical brighteners, UV absorbers), laundering and wearing conditions (stretch, wetness). The proper combination of mentioned factors allows production of passive woven fabrics with high UV protection properties, which may reduce risk associated with UV overexposure.

Some hardcore environmentalists shun sun-protective clothing because it is usually made from polyester, lycra or nylon, all which are petroleum-derived and are can contain some nasty chemicals. So more focus should be on use of breathable sun protective fabrics which are designed from hygroscipic fibres.

Soon such smart textiles will be developed which will warn the subject how long he/she could be on the sun, what is the average UV index in a particular position, what is the UPF of wearing fabric in a particular moment, when subject should use the shadow, etc.

2.3 Moisture Management

2.3.1 Introduction

Moisture management is an important aspect of fabric meant for apparels, which decides comfort level. An important feature of any fabric: how it transport, store, and dispose liquid water and moisture from the surface of the skin to the atmosphere through the fabric is often referred to as Moisture Management, which is a complex process influenced by a variety of fabric characteristics, e.g. type of fibre (hydrophilic and hydrophobic), porosity, and thickness, absorption capacity, evaporation [125, 126].

Moisture management could be defined as "the controlled movement of water vapor and liquid water (perspiration) from the surface of the skin to the atmosphere through a fabric"[127]. To evaluate the moisture management of a textile one has to know about both the basic temperature regulation of the human body, and about the properties of the textile required by this regulation.

Temperature regulation of the body

The human body has different ways of trying to maintain its temperature. For example, in a cold environment, blood circulation in the arms and legs is reduced, in order to minimize heat exchange with the surrounding atmosphere. If the body warms up, the blood circulation increases in an attempt to release surplus heat, and we start to sweat. During perspiration water (containing salt and other substances) is transmitted through the pores of the skin, from which it then evaporates. Through the cold which is generated during evaporation, the warmth surplus is consumed – in this way the body cools down again, and its temperature is re-adjusted.

Function and problems of clothing

Clothing is supposed to protect humans- in accordance with their environment – from cold, heat, wind and weather. If possible, it should fulfill this function without inhibiting the evaporation of humidity caused by perspiration (good moisture management), and thus not interfering with the temperature regulation of the body.

When we start to sweat, our body humidity is more or less absorbed by the textile we are wearing. If the humidity remains in the fabric and is not transported to the surface for evaporation, cooling cannot occur. The body warms up and even more sweat is produced. After its exercise, the body cools down and sweating ceases. However, any humidity retained in the clothing evaporates after awhile, even if the body does not need to be cooled any more. Then we start to freeze.

Liquid water released by the body is known as sensible perspiration. To be removed from the body it must be wicked through the fabric structure and then evaporate from the outside of the fabric. When it evaporates heat is removed which helps to control the temperature of the body[128].

During exercise, both insensible perspiration and sensible perspiration are produced, but the latter increases in response to rising body temperature producing liquid at the surface of the skin. Moisture vapour can pass through openings between fibres or yarns. This action prevents perspiration from remaining next to the skin. In hot conditions, trapped moisture may heat up and lead to fatigue or diminished performance. In cold conditions, trapped moisture will drop in temperature and cause chilling and hypothermia.

Moisture transmission through textiles has a great influence on the thermo-physiological comfort of the human body which is maintained by perspiring both in vapour and liquid form. Recently there is an increasing demand for sportswear and sports related textiles due to significant increases in interest of people in active indoor and outdoor leisure pursuits. If moisture cannot evaporate from the skin, both the skin temperature and discomfort increase. An ideal sportswear must transfer perspiration from the body followed by evaporating the moisture rapidly and keeping the body warm[129]. The most effective fabrics will spread moisture over a wide area to maximize the surface area available for evaporation and hence cooling.

The ability of a fabric to allow perspiration in its vapour form to pass through it is measured by its moisture vapour permeability in grams of water vapour per square metre per 24 hours. The clothing worn should allow this perspiration to be transferred to the atmosphere in order to maintain the thermal balance of the body. When a wearer begins to perspire, the liquid moisture management properties of the material are more important than vapour moisture management properties[130].

Moisture management has the following functions-

Regulation of body temperature – when the human body core temperature exceeds 37^{o}C, sweat is produced. Transporting the sweat away from the skin and evaporating it to the atmosphere, reduces body temperature.

Control of cloth weight increase- absorbing the moist generated by the body increases cloth weight, making it uncomfortable and with a negative effect on performance. Moisture management avoids this effect[131].

When a textile product incorporates thermally active materials or specially designed fibres, it can provide enhanced thermal and moisture management performance in addition to the existing passive characteristics of the structure to keep the body in the comfort state. Fabric liquid moisture transport properties in multi-dimensions, called moisture management properties influence the human perception of moisture sensations significantly.

2.3.2 Principle of Operation

The Moisture Management Tester (MMT) is an instrument to test the liquid moisture management capabilities of textiles such as knitted and woven fabrics. The liquid moisture management properties of a textile are evaluated by placing a fabric specimen between two horizontal (upper and lower) electrical sensors each with seven concentric pins. A predetermined amount of test solution (synthetic sweat) that aids the measurement of electrical conductivity changes are dropped onto the center of the upward-facing test specimen surface. The test solution is free to move in three directions: radial spreading on the top surface, movement through the specimen from top surface to the bottom surface, and radial spreading on the bottom surface of the specimen. Moisture Management Tester is designed to sense, measure and record the liquid moisture transport behaviours in these multiple directions.

During the test, changes in electrical resistance of specimen are measured and recorded. The electrical resistance readings are used to calculate fabric liquid moisture content changes that quantify dynamic liquid moisture transport behaviours in multiple directions of the specimen. The summary of the measured results are used to grade the liquid moisture management properties of a fabric by using predetermined indices.

The Moisture Management Tester utilizes the electrical resistance technique, which is based on the substantial difference in electrical conductivity of air (non-wetted fabrics) and water (wetted fabrics): as the liquid wicks through and / or absorbs into the fabric sample, the electrical resistance of the sample reduces. The Moisture Management method assumes that the value of the electrical resistance change depends on two factors: the components of the water content in the fabric, thus when the influence of the water components is fixed, the electrical resistance measured is only related to the water content in the fabric. It is important to note that the electrical resistance of wet textile fabrics also depends on the fabric fiber composition and content, fiber polymer (where fibres themselves exhibit differential electrical conductivity or virtually no conductivity), and also different fiber sorbtion properties, thus the Moisture Management testing method has to be considered in context of the fiber conducive properties. The fabric being tested was placed between the two sensors. An amount of test solution (synthetic sweat) is to be introduced onto the top side of the fabric.

The MMT measures the liquid transfer in one step in a fabric sample in multi-directions; outward on the top (next to skin) surface of the fabric, through the fabric sample from the top to the bottom (opposite) surface, and outward on the bottom surface. Gravity unquestionably has an influence on the transfer of moisture through the fabric from the top surface to the bottom surface, but as the tests are conducted under the same conditions, the influence of gravity could be considered constant for all fabrics. The possible presence of air gaps between the skin and the fabric, and also the possible 'boundary' wetting resistance between the skin and the fabric during real wear are not taken into consideration in the study[132, 133, 134, 135].

2.3.3 Moisture transport mechanism

The moisture transport process of clothing under humidity transience is one of the most important factors influencing the dynamic comfort of a wearer in practical wear situations[136]. However the moisture transport process is hardly a single process; it is always coupled with heat transfer process under dynamic conditions due to energy changes involved with the phase change of water molecules[137]. Clothing's heat and moisture transfer performance is affected not only by material properties, such as fabric thickness, weight and air permeability, the air gap between the skin and the material but also by design, open or closed, size and accessory and how a garment is worn[138]. The nature and thickness of the materials reduce the permeability of clothing and, consequently, inhibit the evaporation of moisture from the body. The clothing weight, as well as its stiffness, thickness and bulkiness, can increase the wearer's metabolic heat production during activity as well as restrict heat exchange between the body and the environment. Due to the tenor body activity, the body can put out as much as 1 L sweat an hour; therefore, the fabric worn next to skin will get wet. This moisturized fabric reduces the body heat and makes the wearer uncomfortable. So, the fabric worn next to the skin should assist for the release of moisture quickly to the atmosphere.

The fabric worn next to the skin should have two important properties. The initial and the foremost property is to absorb perspiration from the skin surface, and the second is to transfer the moisture to the atmosphere and make the wearer feel comfortable.

The most important factors which affect moisture transport are: fibre type; cloth construction or weave; weight or thickness of the material and presence of chemical treatments. There are three possible ways the moisture may migrate: through the fiber interiors, along the surfaces of the fibers, or through the air spaces between the fibers and the yarns.

As long as the water remains in the vapor state, bulk transport of liquid by capillary action can be neglected, and these routes may be described by the following three mechanisms: a) molecular diffusion through the polymeric phases, b) surface diffusion of absorbed molecules along the fibers and c) molecular diffusion through the air spaces of the fabric. Perspiration moisture collects in and passes through clothing as worn. Both the collection and passage of this moisture is influenced by the properties of clothing fabrics. The measurement of moisture properties related to comfort in wear is very important.

Generally, in responding to external humid transients; a piece of dry fabric exhibits three stages of transport behavior. Two fast processes are dominated in the first stage: water vapor diffusion and liquid water diffusion in the air filling the inter-fiber voids in which steady states can be reached in a fraction of a second. Throughout this period, water vapor diffuses into the fabric because of the concentration gradient across the two surfaces. In the meantime, due to the surface tension force, the liquid water starts to flow out of the regions of higher liquid content to the drier regions.

The second stage, which is a relatively slow process features the moisture sorption of fibers and takes a few minutes to a few hours to be completed, depending on the hygroscopicity of the fibers. In this period, water diffuses into the fabric by sorption of water into the fibers, which increases the relative humidity at the fiber surfaces. After liquid water diffuses into the fabric, the surfaces of the fibers are saturated because of the film of water on them, which again enhances the sorption process. Throughout these two transient stages, the heat transfer process is coupled with the four different forms of moisture transfer due to the heat release or absorption during sorption/desorption and evaporation/condensation, which, in turn, are affected by the efficiency of heat transfer.

At last, the third stage is reached as a steady state, in which all four forms of moisture transport and the heat transfer process become steady and the coupling effects among them become less significant[139]. The liquid moisture flow through textile materials is controlled with two processes, i.e. Wetting and wicking.

Wetting of a fabric can occur from either the external environment of the wearer or from the internal environment when the wearer is perspiring. Wetting is the initial process, involved in fluid spreading; it is controlled by the surface energies of the involved solid and liquid. Wetting is a complex process further complicated by the structure of fibrous assembly. The curvature of fibres, crimps on fibres and orientation and packing of fibres in fibrous materials make the evaluation of wetting phenomena of fibrous assemblies more complicated. The curvature and roughness of contact surfaces are two critical factors for the wetting phenomena in fibrous materials, which are porous media of intricate, tortuous and yet soft, rough structure. A liquid that fully wets a material in the form of a smooth planar surface may not wet the same material when presented as a smooth fibre surface, let alone a real fibrous structure. Clothing comfort also depends on the wetting behavior of fibrous structure.

The mechanism by which moisture is transported in textiles is similar to the wicking of a liquid in capillaries. Capillary action is determined by two fundamental properties of the capillary: its diameter; and surface energy of its outside face.

The smaller the diameter or the greater the surface energy, the greater the tendency of a liquid to move up the capillary. In textile structures, the spaces between the fibres effectively form capillaries. Hence, the narrower the spaces between these fibres, the greater the ability of the textile to wick moisture. Fabric constructions, which effectively form narrow capillaries, pick up moisture easily. Such constructions include fabrics made from micro fibres, which are packed closely together. However, capillary action ceases when all parts of a garment are equally wet.

The surface energy in a textile structure is determined largely by the chemical structure of the exposed surface of the fibre, as follows:

- Hydrophilic fibres have a high surface energy. Consequently, they pick up moisture more readily than hydrophobic fibres;
- Hydrophobic fibres, by contrast, have low surface energy and repel moisture.

In general, wicking takes place when a liquid travels along the surface of the fibre but is not absorbed into the fibre. Physically, wicking is the spontaneous flow of a liquid in a porous substrate, driven by capillary forces.

Good moisture absorption and release can be found in fibers with greater specific surface area. Such rapid transportation of moisture or diffusion of sweat in the form of steam from the body towards the outside enables good moisture absorption and release, thus maintaining dryness and comfort of the fiber properties. Natural fibers such as cotton and viscose are hydrophilic, meaning that their surface has bonding sites for water molecules. Therefore, water tends to be retained in the hydrophilic fibres, which have poor moisture transportation and release. On the other hand, synthetic fibers such as polyester are hydrophobic, meaning that their surface has few bonding sites for water molecules. Hence, they tend not to get wet and have good moisture transportation and release. Neither natural nor synthetic fibres can perform well in both moisture absorption and release at the same time. To achieve such would require moisture absorption and release finishing through which the structural design and quality of fibres are modified so that the textile products thus manufactured can have good performance in absorbing, transporting and dissipating moisture[140].

Detailed knowledge of the moisture transmission properties of a fiber assembly is prerequisite for improving the comfort of apparel materials. It has been theorized by many researchers that the flow of fluid in a fabric is largely governed by the network structure of fabric and not by the fibre type. In any system, where capillarity causes relative motion between a solid and a liquid, the shape of the solid surfaces is an important factor, which governs the rate and direction of liquid flow. The rate of travel of liquid water is governed by the fibre arrangement in yarns, which controls capillary size and continuity[141]. The assumption that the fibre type does not contribute to capillary flow is not an entirely true statement, because fibre type also contributes to the overall structure. Fibre type, under certain circumstances, can drastically change the structure of the yarn by changing the wicking properties of the fabric[142]. Together with wetting and wicking mechanisms, the drying behavour of fabrics was also studied by some scholars who were interested in the comfort properties of fabrics.

2.3.4 Work of other researchers

There have been a number of research studies conducted over last three decades to establish the parameters that affect the UV permeability of the textile garment. Some studies concluded that the compactness and weight of the fabric are most relevant parameters, while others claim that dark colour shades offer more protection. Fabric cover factor, fabric shade depth, and fabric hue are three selection criteria that can have a significant influence on the sun protection provided to fabric-covered skin[143].

Wilson C A & Parisi A V. (2006) investigated the effect of fabric type, colour, fit and wetness on transmission of solar erythemal ultraviolet radiation under laboratory conditions using a spectrophotometer and simulated wear using a multivariate experimental design. Garments were also evaluated under conditions of simulated use in Queensland, Australia using polysulphone dosimeters, placed against the 'skin' at selected sites on the torso and on the adjacent outer-surface of the covering garment. During simulated wear the fabric type, fit and colour were the main variables affecting UVB transmission through the garments (figure 2.5). They concluded that to optimize protection, dark fabrics with good cover should be constructed into garments with positive design ease, and be selected and worn as loosely-fitting styles that maximize the surface area covered[144].

Zhou, L., Feng, X., Du, Y. and Li, Y. (2007) developed a special moisture management wool–cotton fabric that can easily transfer the inner microclimate liquid sweat out while keeping the inside feeling dry, which can be used in sports wear design[145]. Figure 2.6 shows a comparison among the six kinds of fabric in terms of the accumulative one-way transfer index and the overall moisture management capacity.

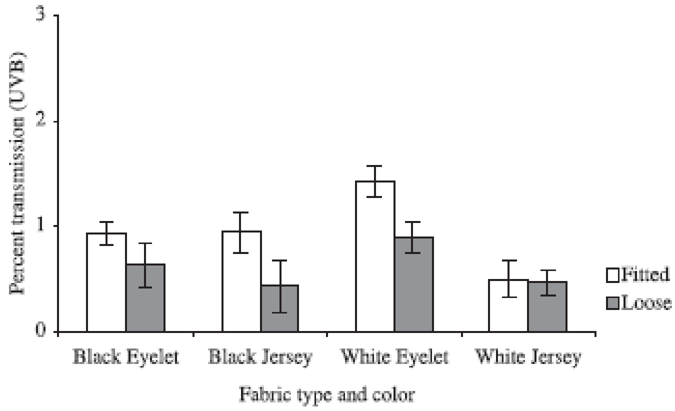

Figure 2.5: Percentage transmission of UVB through eyelet and jersey T-shirts during simulated wear according to fabric type, colour and fit (mean transmission respective of wetness)

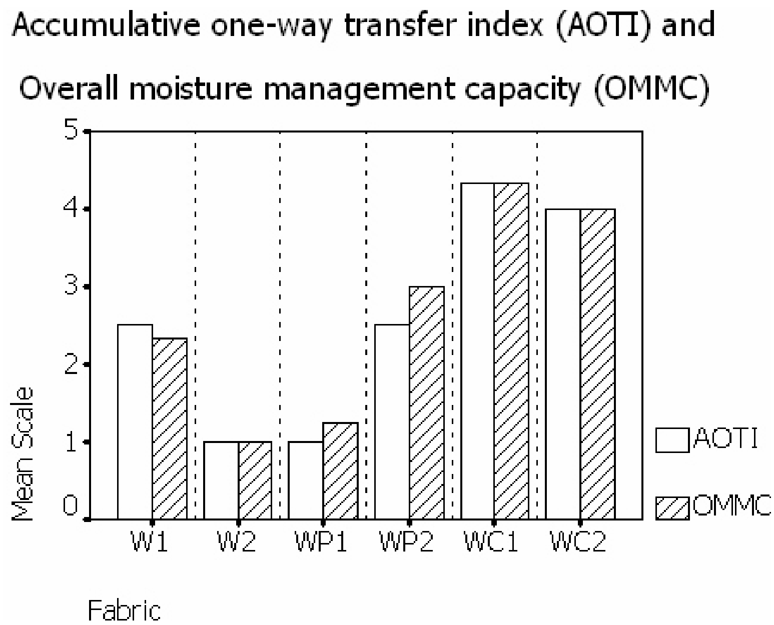

Figure 2.6: Accumulative one-way transfer index & Overall moisture management capacity

Algaba I M, Riva A., Pepió M (2007) carried out study on undyed woven fabrics manufactured with three different cellulosic fibers (Cotton, Modal and Modal Sun) and with three different structures. A statistical model for each fiber type was formulated, which allowed the prediction of the UPF according to the UPF of the original fabric (unstretched and dry), the tension and the wetness (Table 2.11). The models confirmed that, for all the fiber types, wetness and tension had a significant influence on the UPF of the fabrics[146].

Table 2.11: Minimum estimated weight to reach the different protection categories.

Category of protection	Minimum	Minimum weight, g/m^2		
Minimum UPF	UPF	Cotton	Modal	Modal Sun
Good Protection	15	Not reachable	(235)	163
Very good protection	25	Not reachable	Not reachable	172
Excellent protection	40	Not reachable	Not reachable	184

Wang, S.X. et al. (2007) tested two kinds of clothing systems, a traditional clothing system (clothing A), and a specially designed moisture management clothing system (clothing B). Both clothing systems have the same four-layer structure (underwear, vest, coat, and outer jacket), but with use of different functional fabrics. The experiments were conducted in a climate chamber where the temperature was controlled at –15 °C. Eleven young male subjects took part in wear trial experiments, in which they were dressed in clothing A or B and walked on a treadmill. The humidities and temperatures at the skin surface and at different layers of the clothing system were measured together with measurements of thermal and moisture sensations (figure 2.7). The experimental results showed that the moisture management property of fabrics significantly affected the moisture diffusion and temperature distributions in the cold protective clothing systems, and influenced the thermal and moisture sensations[147].

Wilson C A. et al.(2008) studied how selected variables affected transmission of ultraviolet radiation (UVR) through fabrics and whether these variables interacted to modify transmission. Using a spectrophotometer the effect of i) fabric type (two knitted, two woven), color (black and white), wetness (dry, damp, wet), and extension (relaxed, extended (10 × 10%, 10 × 20%)), and ii) fabric type and layering (1, 2, 3 layers) of white fabrics, on UVR (290–400 nm), UVA (315–400 nm), UVB (290–315 nm), and ultraviolet protection factor (UPF) rating was investigated. Differences among variables were identified using univariate and repeated measures ANOVA, and interactions among variables identified and described. Selecting dark colours, limiting extension and layering fabric were shown to be effective ways of increasing UV protection and UPF by decreasing transmittance. (figure 2.8)[148].

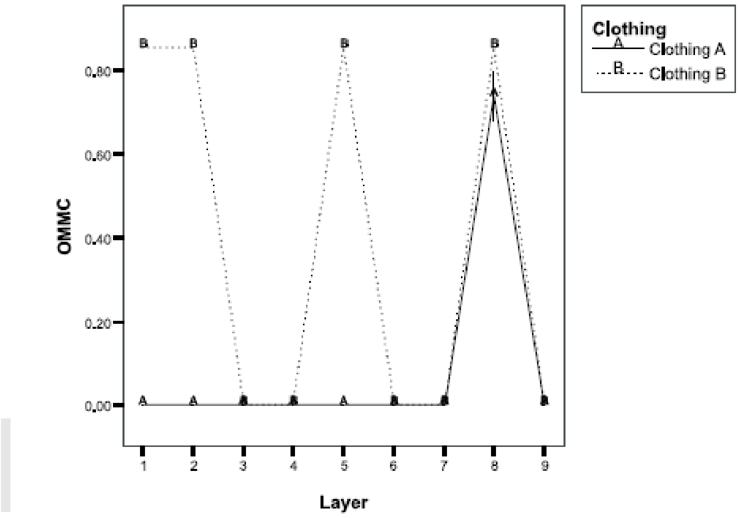

Figure 2.7: A comparison of the OMMC of each layer between the two kinds of clothing system

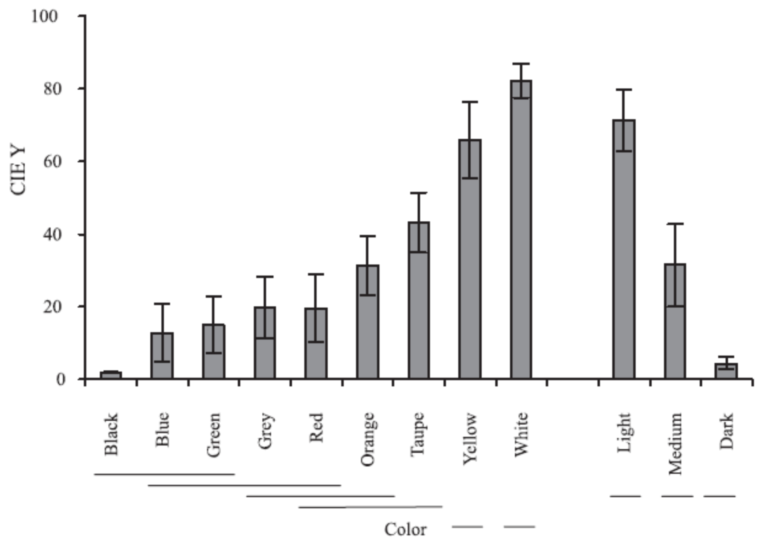

Figure 2.8: CIE L* (lightness) and Y (brightness) values for fabrics categorized into colour groups

Wilson C A. et al. (2008) examined sensory and instrumental methods for quantifying colour of fabrics and investigated the relationship between fabric colour and UV transmittance. The colour of 175 samples was visually categorized by human judges into colour groupings and measured instrumentally according to the CIE XYZ and CIE LAB systems using a spectrocolorimeter. The relationship between colour and UV-A, UV-B and UVR transmittance was examined and the most appropriate method for describing the relationship between UV protection and colour was determined. Colour depth rather than colour per se affected mean UV transmittance with dark fabrics confirmed as being most effective. L* (lightness), Y (brightness), were found to be equally effective descriptions of the 'colour'/transmittance relationship (figure 2.9). Manufacturers seeking to colour fabrics so as to minimize UV transmittance should select colours with CIE L* of approximately < 38 or CIE Y of approximately < 28. Medium and high transmittance levels were less clearly related to CIE values[149].

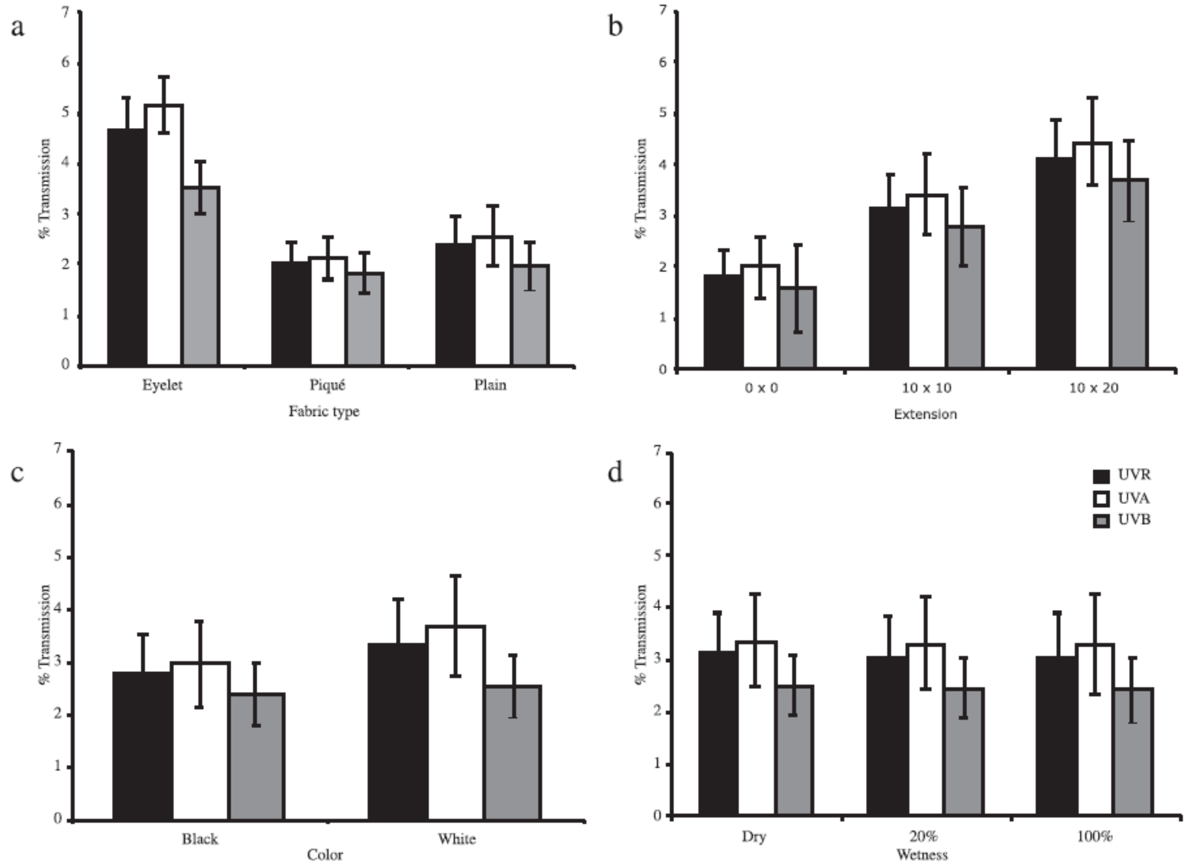

Figure 2.9: Effect of fabric type, extension, colour, and wetness on mean UVR, UVA and UVB transmission (mean for each variable calculated over all other variables).

Sampath et al (2011) studied the thermal comfort characteristics of selected knitted fabrics by analyzing the thermal behaviour of moisture management finished (MMF) fabrics, in order to find the suitability of the product for different climatic conditions. The knitted fabrics made from yarns of micro-denier polyester filament, spun polyester, polyester/cotton, filament polyester, and 100% cotton were used for the study. Thermal characteristics such as thermal conductivity, thermal resistance, thermal absorptivity, relative water vapor permeability, and water vapour resistance were analyzed for the MMF fabrics. The test results indicated that the knitted fabrics produced from different nature of yarns have greater influence on thermal characteristics, when they were converted into fabrics. The MMF treatment have significant effect on thermal behaviour of micro-denier polyester knitted fabrics with respect to thermal conductivity, thermal absorptivity, water vapour permeability, and water vapour resistance. Among the five fabrics, it was observed that micro-denier polyester fabrics gives faster heat transfer, quicker evaporation of sweat from the skin through the fabric, and also cooler feeling at initial touch (figure 2.10)[126].

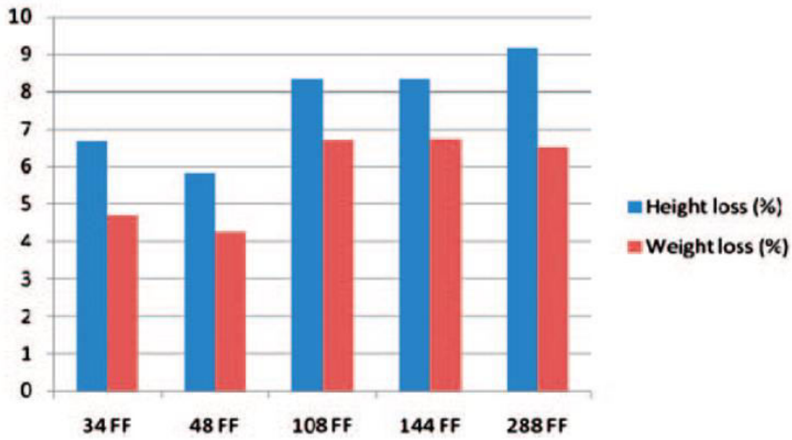

Figure 2.10: Moisture vapour transfer of the fabrics.

Urbas et al (2011) worked was to establish whether very good to excellent UV (ultraviolet) protective properties of fabrics can be obtained through a suitable fabric construction and yarn colour, at the same time ensuring suitable air permeability. A comparison of different fabric structures and colours was attempted to enable the assessment of the impact of the mentioned parameters on both, UV protective properties and air permeability of fabrics. The research indicated excellent UV protection (>60) in all samples. Table 2.12 contains the obtained measurement results of air permeability of all samples from the face and back side after the statistical consideration, as well as the colour values of samples in the CIE Lab colour system.

UV protection depended on their construction and in a sufficiently closed structure, also on the colour of the used yarn. There was no significant difference between the samples in blue and red. In addition to excellent UV protection, four samples (one double-weft and three double fabrics) also demonstrated very high air permeability, which was 3–5 times higher than in the one-layer sample, which demonstrated the best UV protective properties. The research has shown that fabrics with a very high ultraviolet protective factor value and good air permeability can be made by using a suitable construction and yarn colours that sufficiently absorb UV light; the latter being particularly important for light summer cotton clothes[150].

Table 2.12: Measured and statistical values of air permeability, colour values on front (f) and back (b) side of samples with blue (B) and red (R) weft, colour differences and UV values of samples.

		Colour values of samples						UV (290–400 nm)			
Samples	Air permeability (l/m^2s)	L*	a*	b*	C*	h (°)	ΔE^*_{ab}	UPF	T (%)	R (%)	A (%)
1B – f	243.40	25.32	8.72	−32.86	34.00	284.90	27.54	205.51	0.57	8.36	91.07
1B – b	234.60	43.80	2.69	−13.35	13.62	281.40		158.32	0.68	21.90	77.42
2B – f	817.60	30.51	6.17	−27.08	27.77	282.80	0.59	63.01	1.81	10.82	87.38
2B – b	829.00	30.33	6.02	−27.62	28.27	282.30		66.92	1.69	10.94	87.37
3B – f	216.60	32.41	5.57	−25.94	26.53	282.10	0.66	92.40	1.20	12.05	86.75
3B – b	207.20	31.82	5.70	−26.22	26.83	282.30		86.17	1.27	11.90	86.84
4B – f	1067.60	31.18	6.18	−27.60	28.29	282.60	7.52	97.74	1.20	10.82	87.98
4B – b	1112.00	24.39	7.55	−30.52	31.44	283.90		102.37	1.17	7.58	91.26
5B – f	931.40	30.36	7.46	−30.85	31.74	283.60	7.80	81.36	1.46	10.96	87.58
5B – b	916.00	27.64	4.99	−23.96	24.48	281.80		74.03	1.58	8.42	89.99
6B – f	614.40	29.97	5.15	−25.05	25.58	281.60	6.68	101.04	1.18	10.41	88.41
6B – b	534.40	28.44	7.48	−31.12	32.01	283.50		88.54	1.33	11.56	87.11
1R – f	233.40	38.56	44.31	14.25	46.55	17.83	39.23	286.19	0.38	5.53	94.09
1R – b	247.60	46.86	11.08	−4.87	12.10	336.30		268.17	0.39	19.29	80.32
2R – f	856.60	39.34	34.51	7.68	35.35	12.55	2.41	61.54	1.78	7.91	90.30
2R – b	884.00	39.53	36.59	8.88	37.65	13.65		61.58	1.79	7.96	90.25
3R – f	231.40	41.01	33.76	6.36	34.35	10.67	3.72	96.09	1.11	9.52	89.37
3R – b	222.00	41.04	30.39	4.77	30.77	8.92		91.90	1.15	9.58	89.27
4R – f	996.80	40.80	36.08	8.42	37.04	13.13	5.95	116.52	0.96	7.99	91.05
4R – b	1072.00	36.53	39.07	11.27	40.66	16.10		114.51	0.99	5.19	93.82
5R – f	864.80	42.36	41.00	10.75	42.38	14.70	13.81	102.19	1.12	8.15	90.74
5R – b	847.80	34.57	30.57	6.14	31.18	11.36		93.92	1.21	6.53	92.26
6R – f	601.00	40.89	28.24	3.52	28.46	7.10	12.04	108.19	1.04	7.78	91.18
6R – b	500.20	40.42	38.57	9.68	39.77	14.09		101.31	1.11	9.65	89.24

Čuden A P and Urbas R (2011) evaluated the impact of elastane on UV protection properties of viscose and polyacrylonitrile knitted structures. The investigation illustrated that wet relaxed elasticized knits show good UV radiation protection with UPF 20-40. In contrast, non-elasticized viscose and polyacrylonitrile knits are inappropriate for UV radiation protection (figure 2.11). Polyacrylonitrile knits investigated ensure better UV protection than viscose knits[41].

Sampath, M.B., Mani, S., and Nalankilli (2011) made single jersey knitted fabrics from polyester filament yarn. Five different fabrics were made from 150 denier polyester yarns constituting different number of filaments, namely, 34 filaments, 48 filaments, 108 filaments, 144 filaments, and 288 filaments. Moisture management finish was applied to the five types of single jersey knitted fabrics and the effect of filament fineness on comfort characteristics of moisture management finished polyester knitted fabrics was analyzed to achieve suitability for making sportswear.

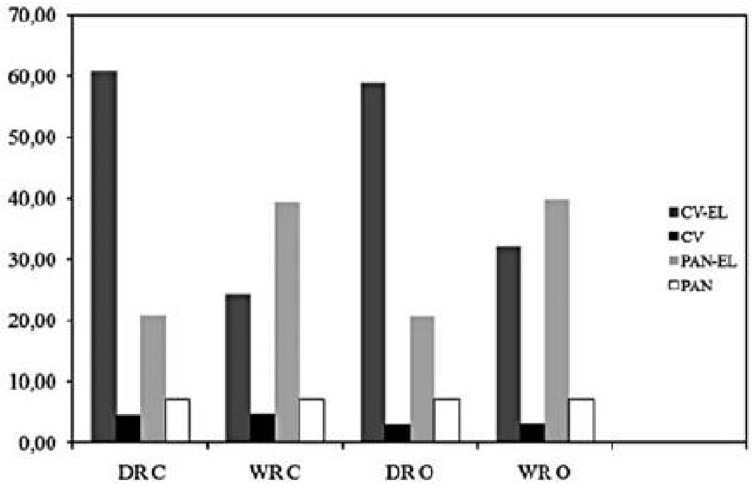

Figure 2.11: UPF of elasticized & non-elasticized viscose & polyacrylonitrile knits

Figure 2.12 shows the water spreading area has increased from 34 filament fabric to 288 filament fabric though they differ in fabric geometry. From the tests, it was observed that Filament fineness and surface area of yarn play a vital role in deciding the comfort characteristics of the fabric, as also moisture management finish treatment which enhances it[151].

Stankovic S B. et al. (2014) investigated the influence of yarn twist and surface geometry on these properties of fabrics. The gray-state plain cotton knitted fabrics were produced from yarn differing in twist level under controlled conditions, so as to obtain as similar as possible construction of the fabrics. These plain knitted (single jersey) fabrics were spectrophotometrically assessed and UV protection factor was calculated. The results

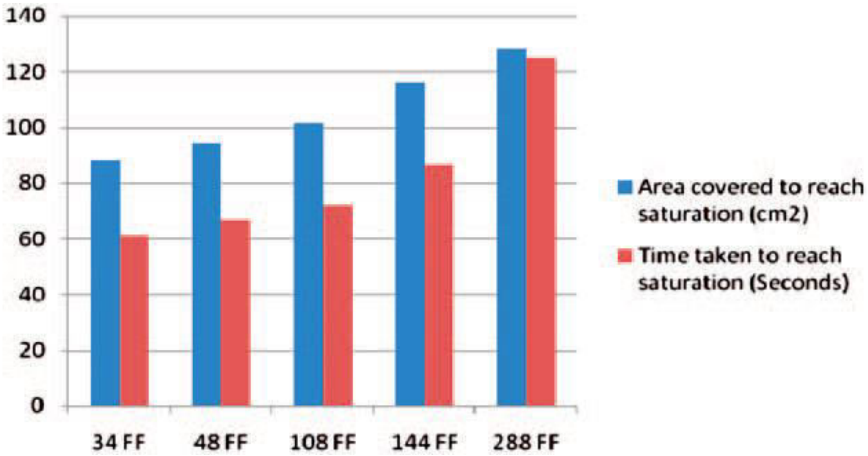

Figure 2.12: Area spread and time taken to reach saturation point.

obtained indicated that yarn twist considerably influenced the UV protection properties of the knitted fabrics by influencing yarn compactness and surface properties, which in turn influenced the open porosity of the fabric (Table 2.13)[34].

Table 2.13: Construction characteristics, physical properties and UPF results of the grey-state plain cotton knitted fabrics after water treatment

Parameter, unit		KY1	KY2	KY3
Area shrinkage, %		8.6	10.5	13.8
Stitch density	Course, cm^{-1}	6.9	6.8	7.1
	Wale, cm^{-1}	12.0	12.5	12.0
	Surface, cm^{-2}	82.8	85.0	85.5
Thickness, mm		1.248	1.256	1.268
Mass per unit area, g/m^2		446.2	453.0	458.4
Bulk density, g/cm^3		0.358	0.361	0.362
Porosity, %		76.2	76.0	75.9
Transmission, %	UVA	0.156	0.074	0.192
	UVB	0.146	0.070	0.190
	UVR	0.151	0.072	0.191
UPF		622.688	1008.739	450.538
Rated UPF		40+	40+	40+
$UPF_{treated}/UPF_{gray}$		6.5	6.4	7.8

Payá J.C. et al (2016) focussed on establishing a new methodology for determining the ultraviolet protection factor value using an ultraviolet lamp and detector. They evaluated a total of 72 samples prepared by using a standardized warp of 150 denier and warp density (60h/cm) and varying the parameters such as the weave, the colour, the weft, weft density and the fabric weight. It was found that the new method is totally reproducible and had a correlation of 95.27% between the data obtained by it and the spectrophotometric method (figure 2.13)[152].

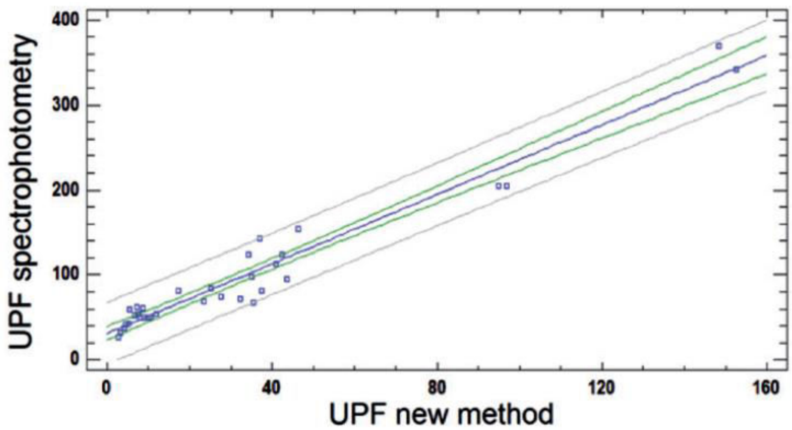

Figure 2.13: Statistical linear modelling of the spectrophotometric and new measuring system.

Research has been investigating the influence of raw material, structure (and consequently physical characteristics, i.e. mass per unit area, thickness, bulk density, porosity, etc.), colours of yarns, as well as the effect of different finishing additives that block the penetration of UV rays through textiles. Most researches into UV protection properties have focused mainly on synthetic fibres such as polyester, nylon and in natural fibres - cotton. Not much work has been carried out on regenerated fibres. Experts believe that cotton production is limited by 28 million tons in 2020 due to a reduction of arable land and limitations in water availability as cotton is grown in warm climates – irrigation of freshwater is often prerequisite. Due to these limitations of growth for cotton, cellulosic fibres are perfect alternatives for filling that gap. Cotton and man-made cellulosic fibres are both based on the same polymer-cellulose-which provides moisture uptake as an essential factor for comfort. There is lack of studies dealing with the effect of fibre composition.

The main objective of this work was to (i). engineer a blended yarn of correct linear density from different blend ratios; (ii). To develop woven fabric which provides adequate protection from UVR present in the sunlight specially for workwear along with required comfort property.