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Enhancing UV Protection of Cotton through Application of Novel UV Absorbers

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ABSTRACT

Intimacy of textiles to human skin and consequent upsurge in global skin disorders because of elevated exposure to UV radiations has provided thrust to develop UV protective clothing. Vulnerability of cotton against UV radiations necessitates introduction of various approaches to elevate its UV protection. In this study, performance of two conventional UV absorbers, viz. benzophenone and its derivative 2,4 dihydroxybenzophenone was studied in terms of 'ultraviolet protection factor' (UPF) as well as color fastness, tensile strength, handle, etc. Performance of two novel UV absorbers, viz. avobenzone alone and in combination with octocrylene, was also evaluated for their ability to absorb UV radiation over a broader spectrum. The effect of UV finish with 2,4 dihydroxybenzophenone was found to be more pronounced compared to that with benzophenone; the UPF ratings increased up to 200 with avobenzone alone and in combination with octocrylene. The combination of the novel UV absorbers reduced the UV transmission considerably well below 1% in the UV-A and UV-B range along with good color fastness and marginal reduction in air permeability, handle and tensile strength.

Keywords: UV radiation, UV absorber, cotton, reactive dyes, UPF

1.1 Introduction

UV radiations (100-400 nm), an integral part of the solar spectrum (0.7-3000 nm), exerts detrimental effects on skin and phenomenal rise in skin disorders worldwide has triggered growth in developing ways to elevate protection of skin[1]. UV radiations are classified as UV-A (320-400 nm), UV-B (280-320 nm) and UV-C (100-280 nm) and the intensity and distribution of these depends closely on the angle of incidence[1,2]. UV-A radiations (320-400 nm) has long been recognized as major cause of pigmentation and premature ageing; UV-B radiations lead to various skin disorders and can bring about genetic variations; UV-C radiations are absorbed by the ozone in the stratosphere, however depleting ozone layer poses a threat to mankind. Being an interface between human being and environment, skin, consisting of three layers, viz. epidermis, corium and subcutis plays a decisive role in protection against UV radiations[1-6].

Clothing and sunscreens are instrumental against UV radiations; however, usage of textiles to enhance protection has gained thrust in recent times[5]. Intimacy of textiles to human skin and their distinct ability to reflect, absorb and scatter UV radiations has paved the way for developing textiles to counter adverse effects of UV radiations. UV shielding ability of fibers varies from one fiber to the other with cotton, wool offering less protection than polyesters and aromatic polyamides[4,6,7-11]. The ability of textiles to transmit UV radiations is assessed by the ultraviolet protection factor (UPF)[2,4,12]. UPF is the ratio of the extent of time required for skin to show redness (erythema) with and without protection under continuous exposure to solar radiations[13,14]. The most widely accepted standards related to testing and labelling of UV protective clothing are: AS/NZS 4399, ASTM D6603, ASTM D6544, UV standard 801 and AATCC 183[15,16].

Table 1 Ultraviolet protection factor ratings[1,4]

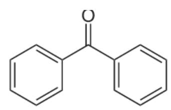
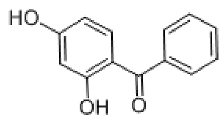
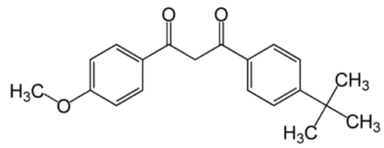
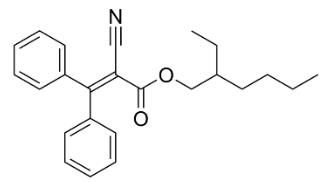
UPF Range	Protection Category	UV-R Transmission (%)
15-24	Good	6.7-4.2
25-39	Very Good	4.1-2.6
40-50, >50	Excellent	Less than 2.5

Factors affecting UV protection are numerous, viz. (i) porosity: higher porosity leads to higher UV transmission, (ii) thickness: heavier clothing mitigates UVR transmission, (iii) weight: thicker fabrics tend to transmit less UV radiations, (iv) wetness: wetness can bring about 30-50% reduction in UPF rating of a fabric, (v) relative humidity: increase in relative humidity causes swelling of fibers, which reduces the interstices and consequently the UV transmittance and (vi) stretch: stretch causes increase in porosity which allows more UV transmission[7,8,11,15,17].

UV protection in cotton can be improved by the use of (i) Dyes (ii) Fluorescent whitening agents and (iii) UV absorbers[18]. Dyes extend absorption spectra into UV region and dye structures with in-built UV absorbers find extensive use as these retain their protective properties for extended periods[5,19-24]. Fluorescent whitening agents can effectively act as UV absorbers but only at the UV-A range (350-400 nm)[19,25-29]. UV absorbers are of two types viz. inorganic and organic.

Popularly used inorganic UV absorbers include zinc oxide (ZnO) and titanium dioxide (TiO_2). TiO_2 and ZnO nanoparticles, apart from being costlier, provide excellent UV protection as large surface area maximizes interaction between fiber structure and applied nano particles[30-37]. Organic UV absorbers include hydroxybenzophenone derivatives, benzotriazoles, phenyl esters and cinnamic acid derivatives[29]. UV absorbers can inhibit photo-degradation too[38]. Some UV absorbers preferentially absorb most of the UV radiations reaching the substrate and other function by interacting with the photo-excited molecule before any other reaction occurs. Substituted benzophenones are the most effective in providing adequate protection against UV radiations. Suitable combinations of UV absorbers and antioxidants yield synergistic effects. [39].

Benzophenone absorbs UV radiations in UV-B range and its derivative 2,4 dihydroxybenzophenone absorbs strongly in the UV-A range[29]. The strong absorption in the near ultraviolet region of 2,4 hydroxybenzophenone is attributed to the conjugate chelation between the o-hydroxy and the carbonyl group. Avobenzone is known for its distinct ability to absorb UV radiations in the UV-A range and the combination of the avobenzone and octocrylene is associated with the increased stability of avobenzone and absorption of UV radiations in UV-A and UV-B range both[40]. The photochemistry of avobenzone involves mainly the formation of transient enol isomers. In the ground state, keto-enol equilibria exists where the intramolecularly hydrogen bonded enol 'chelated' form is largely favored (EC). This enol form shows a strong absorption band around 340–350 nm, while the keto form (K1) absorbs in the range 260–280 nm. [41].

Benzophenone 2, 4 dihydroxybenzophenone Avobenzone Octocrylene

In present work, undyed and reactive dyed cotton was finished with Benzophenone and 2,4 dihydroxy benzophenone and avobenzone separately. Because of solubility of these three chemicals in methanol, but that of octocrylene in isopropylmyristate (IPM), octocrylene was not separately used for finishing, rather because of its solubility in methanol solution of avobenzone at room temperature, it was rather used in combination with the latter. The UV protection factor (UPF) and other related properties of such finished fabrics was compared with those obtained from finishing with two conventional UV absorbers, viz. benzophenone and 2,4 dihydroxy-benzophenone.

1.2 Experimental

Thoroughly pretreated cotton fabric (epi: 92, ppi: 72, warp: 20's, weft: 30's and gsm: 120, UPF: 8.92, Air permeability:22.8 cc/cm^{2}/s, Flexural rigidity:96 mg/cm, Tensile strength: 323 N and whiteness index: 86) was used in this study. Half of the fabric samples were dyed with C I Reactive Orange 4, C I 18260 (Jaysynth Dye Chem, Mumbai) while rest half were left undyed and thereafter both the sets were finished with benzophenone, 2,4 dihydroxybenzophenone, avobenzone (Hi Media, Mumbai), and octocrylene (Galaxy Surfactants, New Delhi).
Reactive dyebaths were prepared for 1-5% shades at room temperature and liquor ratio 1:20. Cotton fabric was dyed in this bath for 30 minutes after which salt (50 g/l) was added; temperature was raised to 40-45^{o}C and dyeing was continued for further 60 min. Soda ash (8 g/l) was added for fixation over a period of 45 minutes. The bath was dropped; dyeings were cold washed, soaped at boil and thoroughly washed.

UV protective finish was imparted to dyed as well as undyed cotton separately with benzophenone, 2,4 dihydroxybenzphenone, avobenzone as well as combination of avobenzone and octocrylene by two methods, viz. padding and exhaust cum padding. Because of insolubility of these chemicals in water, methanol was used as the working medium. In padding method**,** liquor of UV absorbers (10-50 g/l) solubilized in methanol were prepared succeeded by padding at 80% pick up, dried at 65-70^{o}C and cured at 150^{o}C for 1 min. In exhaust cum padding method, baths were prepared with UV absorbers in methanol at varying concentrations (1-5%). Cotton fabric was immersed in this liquor at 30^{o}C and stirred continuously for 30 minutes after which it was padded, dried and cured as those were used in padding method.

Ultraviolet protection factor (UPF) of finished cotton was assessed by UV transmission analyzer (Labsphere, USA) using AATCC test method 183. Air permeability and tensile strength were evaluated using Air permeability tester (textest, Switzerland) and UTM (Zwick, Germany) with ASTM D 737 and ASTM D 5035 respectively. Color fastness was assessed according to AATCC Test Methods 16-2004 (light), 61-2007 (wash), 8-2007 (rubbing) using ATIRA Light fastness tester

(Paresh Engineering Works, Ahmedabad), Wash fastness tester (RBC Electronics, Mumbai) and Crockmeter (Paramount, Delhi) respectively.

1.3 Results and discussions

1.3.1 Influence of Benzophenone on UPF

Finishing of cotton with benzophenone through padding and exhaust cum padding led to considerable increase in the UPF ratings. While undyed cotton exhibited adequate protection beyond 20 g/l of the benzophenone, dyed cotton showed substantially better result in both the methods. Benzophenone (30 g/l) showed excellent protection for cotton dyed with reactive dye for 1% shade, while only 5 g/l of it showed protection beyond 50 for 5% shade, i.e. the deeper the shade, the lesser its requirement was. In exhaust cum padding method, the UPF ratings were directly proportional to the concentration of benzophenone. Up to 3% shade, excellent protection was obtained at high benzophenone concentrations; however, for 4% and 5% shades, the application of benzophenone at low concentrations was adequate. It is interesting to note that the benzophenone increased the UPF ratings substantially without affecting the whiteness of cotton (Table 2). The generalized trend of the UPF ratings obtained through padding and exhaust cum padding is depicted in Fig.1.

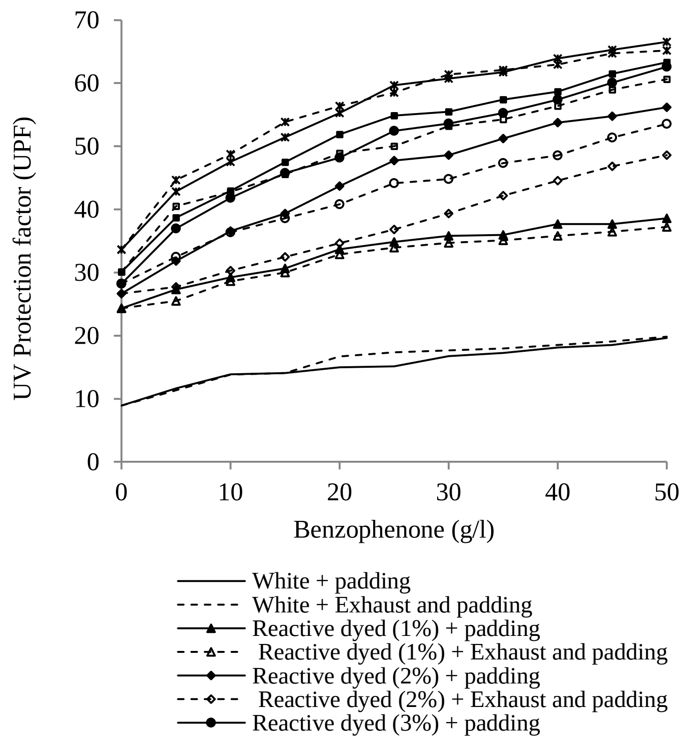


Fig. 1 Influence of Benzophenone on UPF of white and reactive dyed cotton

The UPF values shown in Fig. 1 were obtained against minimum transmission of UV radiation (i.e. maximum UPF) in the range of 280-320 nm, thus confirming ability of benzophenone to work effectively in UV-B range.

1.3.2 Influence of 2,4 dihydroxybenzophenone on UPF

Application of 2,4 dihydroxybenzophenone showed very high UPF on undyed cotton; increase in concentration developed yellowish appearance necessitating its use only at lower concentrations (Table 2). Dyed cotton showed a steep rise in the UPF ratings. Even just at 5 g/l against all shades, the protection was excellent and at higher concentrations the UPF ratings even exceeded 300. Exhaust cum padding technique showed less UPF ratings as compared to those obtained through padding. This may be attributed to the surface deposition of 2,4 dihydroxybenzophenone blocking most of the pores. Of all the UV absorbers used, 2,4 dihydoxybenzophenone showed the highest UPF ratings on both white and dyed cotton and this happens to be the only UV absorber to provide excellent UV protection on white cotton even at low concentrations (Fig. 2).

The combination of two conventional UV absorbers, viz. benzophenone and 2,4 dihydroxybenzophenone was not tried as 2, 4 dihydroxybenzophenone resulted in an increased yellowish appearance of the fabric thereby reducing the viability of the UV protective finishing operation on light shaded apparels intended for summer applications.

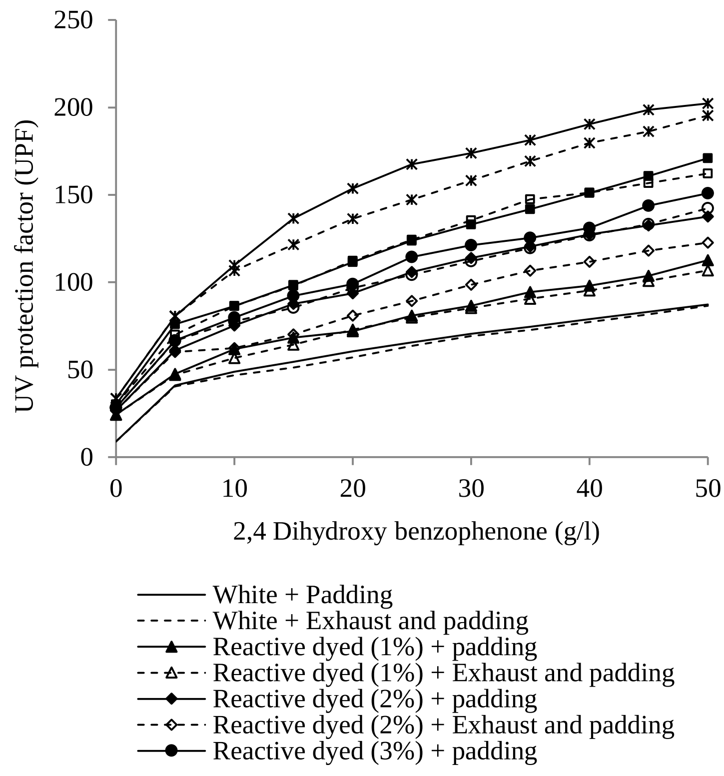


Fig. 2 Influence of 2,4 dihydroxy benzophenone on UPF of white and reactive dyed coton

The UPF values shown in Fig. 2 were obtained against minimum transmission of UV radiation (i.e. maximum UPF) in the range of 320-400 nm, thus confirming ability of 2,4 dihydroxybenzophenone to work effectively in UV-A range.

1.3.3 Influence of Avobenzone on UPF

Avobenzone provided excellent protection in UV-A range but the UPF rating in padding was less because at increasing concentrations there was accumulation of avobenzone molecules on cotton just after dipping. The excellent UV protection was achieved by padding at 10 g/l and 20 g/l for dyed as well as white cotton respectively (fig. 3). Increase in concentration of dye as well as avobenzone resulted in a linear increase in the UPF ratings. With exhaust cum pad technique there was steady increase in UPF ratings with white cotton and at 5% concentration the UPF was found to be 78.68. Avobenzone resulted in abrupt rise in UPF rating on dyed cotton. It is to be noted that avobenzone was highly effective at higher concentration on lighter shades; yellowness of white cotton was also negligible (Table 2).

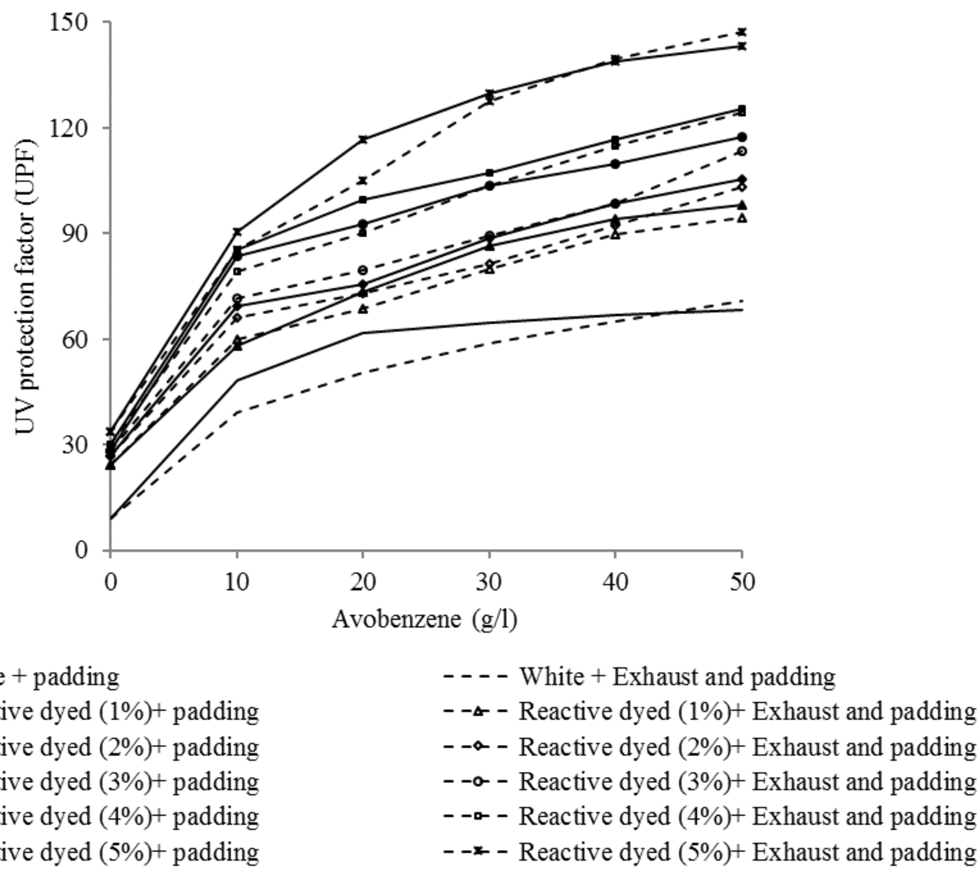


Fig. 3 Influence of Avobenzene on UPF of white and reactive dyed cotton

The UPF values shown in Fig. 3 were obtained against minimum transmission of UV radiation (i.e. maximum UPF) in the range of 320-400 nm, thus confirming ability of avobenzone to work effectively in UV-A range.

1.3.4 Combination of avobenzone and octocrylene

Synergistic effect of avobenzone and octocrylene showed protection on cotton with protection over the entire UV spectrum. Undyed cotton showed an increase in the UPF with the increase in the concentration of UV absorber without substantial change in whiteness (Table 2). Light dyed cotton offered adequate protection (Fig. 4).

In exhaust cum padding, the UPF were not as high as that for avobenzone probably because the interaction between the two and less concentration used in combination. On undyed cotton, combination of UV absorbers at their lowest concentrations resulted in abrupt increase in the UPF.

The UPF values shown in Fig. 4 were obtained against minimum transmission of UV radiation (i.e. maximum UPF) in the range of 280-400 nm, thus confirming ability of combination of avobenzone and octocrylene to work effectively in UV-A and B ranges both.

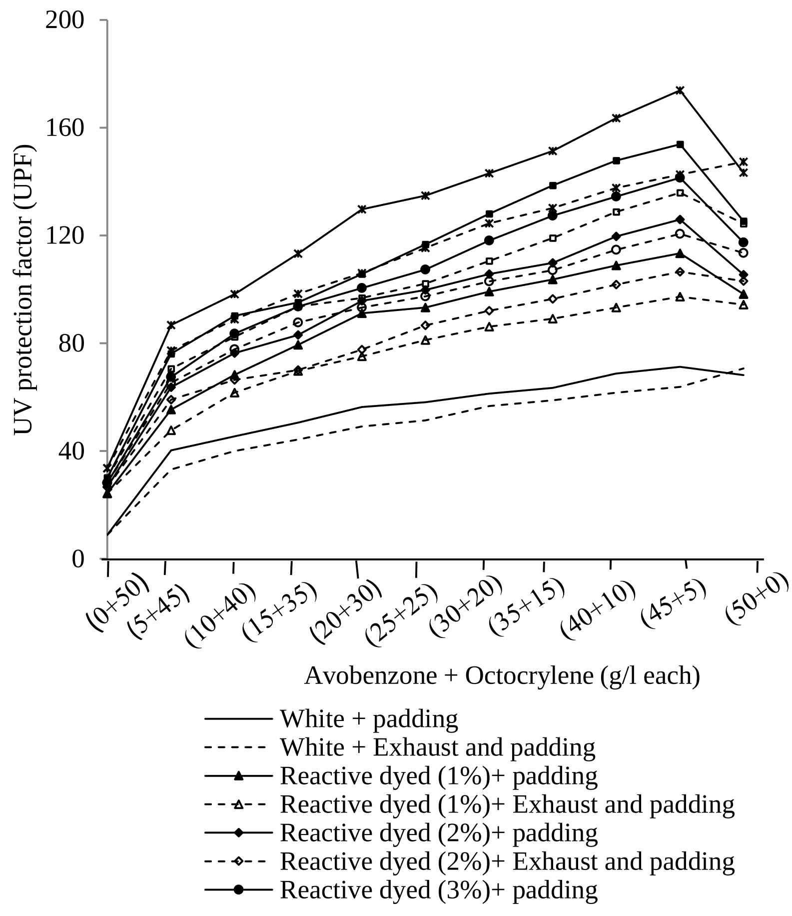


Fig. 4 Influence of combination of avobenzene and octocrylene on UPF of white and reactive dyed cotton

The comparative effectiveness of UV absorbers on undyed and reactive dyed (3% shade) cotton showed that benzophenone exhibited the lowest and its derivative 2, 4 dihydroxybenzophenone the highest UPF values for any given concentration of the respective UV absorbers and only for UV-A and UV-B ranges respectively. Avobenzone finished cotton possessed high UPF but it offered UV protection in the UV A range; in contrast, combined avobenzone and octocrylene resulted in imparting UV shielding on cotton over the complete UV spectrum (Fig. 5).

It is to be noted that avobenzone is soluble in methanol at 80°C, but addition of octocrylene caused solubility of avobenzone at room temperature.

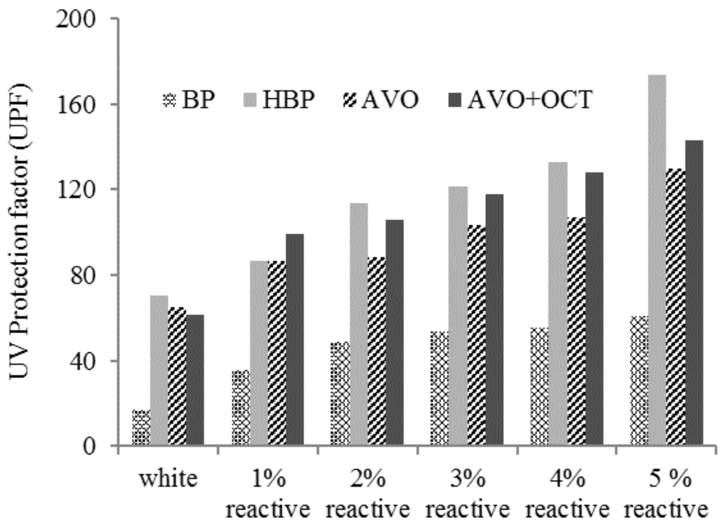


Fig. 5 Comparative performance of UV absorbers on white and dyed cotton (3% shade)

Table 2. Whiteness Index of cotton treated with UV absorbers

UV absorber	Whiteness Index				
	10 g/l	20 g/l	30 g/l	40 g/l	50 g/l
Benzophenone					
Padding	85.51	81.69	78.53	75.96	72.21
Exhaust cum padding	80.42	74.56	72.34	66.19	62.10
2, 4 dihydroxybenzophenone					
Padding	61.85	54.41	50.89	45.05	40.86
Exhaust cum padding	52.64	50.28	48.70	41.54	30.82
Avobenzone					
Padding	67.39	60.79	58.91	56.49	53.67
Exhaust cum padding	74.34	72.00	70.11	69.11	69.61
Avobenzone + Octocrylene					
Padding	71.28	68.68	65.47	62.39	58.41
Exhaust cum padding	62.34	59.60	56.69	52.78	53.85

1.3.5 Air Permeability

Increase in the concentration of benzophenone as well as depth of shade resulted in decrease in the air permeability. The reduction was more in case of dyed and finished cotton as compared to the undyed finished cotton. Exhaust cum padding showed better air permeability compared to that in padding which may be attributed to the interaction between the substrate and benzophenone reducing the pore size within the fabric structure (Table 3).

Table 3. Air permeability of anti-UV finished cotton

Uv absorber	Air permeability (cc/cm^2/s)					
	White	Reactive dyed				
		1 %	2 %	3 %	4 %	5 %
Benzophenone						
Padding						
10 g/l	22.0	20.2	19.3	19.4	19.3	18.6
20 g/l	21.2	18.6	18.8	18.4	18.5	17.4
30 g/l	19.3	17.8	17.8	17.4	17.9	16.4
40 g/l	18.6	17.2	16.6	16.8	16.8	16.8
50 g/l	18.1	16.4	16.3	16.0	15.6	15.6
Exhaust cum padding						
1 %	21.6	20.2	19.9	19.4	19.0	18.8
2 %	20.4	19.6	19.2	18.4	18.2	18.0
3 %	19.8	18.8	18.3	17.4	17.2	17.0
4 %	19.1	18.2	17.3	16.8	16.7	16.6
5 %	18.4	17.2	16.6	16.6	16.0	16.0
2, 4 dihydroxybenzophenone						
Padding						
10 g/l	22.4	20.6	19.8	19.6	19.0	18.6
20 g/l	22.8	20.2	19.3	19.2	18.8	18.2
30 g/l	21.4	19.6	18.8	18.6	18.2	17.6
40 g/l	20.8	18.6	18.4	18.2	18.0	16.8
50 g/l	20.4	18.0	17.9	17.6	17.2	16.2
Exhaust cum padding						
1 %	22.6	20.8	20.4	19.6	19.2	18.8
2 %	22.0	20.4	20.0	19.4	18.8	18.6
3 %	21.4	19.8	19.4	18.6	18.4	17.8
4 %	20.8	18.6	18.8	18.4	17.9	17.4
5 %	20.6	18.2	18.4	17.6	17.5	17.0
Avobenzone						
Padding						
10 g/l	20.8	19.9	19.6	18.3	18.1	16.9
20 g/l	19.0	18.7	18.0	17.8	17.6	16.4
30 g/l	*	18.6	17.9	17.6	17.4	16.3
40 g/l	*	18.3	17.8	17.4	17.0	15.7
50 g/l	*	18.1	17.4	16.9	16.3	15.1
Exhaust cum padding						
1 %	22.3	21.3	20.3	20.6	19.4	18.6
2 %	21.7	20.7	19.8	19.6	19.0	18.3
3 %	21.3	20.4	19.7	19.4	18.1	17.8
4 %	20.6	19.7	19.5	18.6	17.6	17.4

5 %	19.6	18.9	18.6	17.6	17.0	16.2
Avobenzone + Octocrylene						
Padding						
(10 +40)g/l	22.0	20.4	19.8	19.4	19.2	18.6
(20 +30)g/l	21.0	19.8	19.6	18.8	18.4	17.6
(30 +20)g/l	20.0	19.0	18.8	17.9	17.7	17.0
(40 +10)g/l	20.0	18.6	18.4	16.8	16.5	16.6
Exhaust cum padding						
(1.0+4.0)%	22.0	20.4	19.8	19.4	19.2	18.6
(2.0+3.0) %	21.0	19.8	19.6	18.8	18.4	17.6
(3 .0+2.0)%	20.0	19.0	18.8	17.9	17.7	17.0
(4.0+1.0) %	20.0	18.6	18.4	16.8	16.5	16.6

* Accumulation of avobezone on fabric during padding imposed difficulty to finish cotton.

The effect of 2,4 dihydroxybenzophenone was similar to that with benzophenone on white finished cotton with linear reduction in air permeability with increase in concentration of the former. Air permeability of undyed and finished cotton was more than that of dyed and finished as presence of dye molecules blocked pores in cellulose hindering the passage of air.

With increase in concentration, avobenzone proportionately reduced the air permeability of finished undyed and dyed cotton both. Large structure of avobenzone in association with higher shade happened to be the cause behind this. The air permeability was found to be less with avobenzone than that in 2,4 dihydroxybenzophenone but greater than benzophenone in the exhaust cum padding technique. It can also be inferred that the air permeability was reduced considerably with increase in concentration of shades.

Increase in concentration of both avobenzone and octocrylene in combination reduced air permeability though as compared to benzophenone and 2,4 dihydroxybenzophenone, this was marginal.

1.3.6 Flexural rigidity

Interaction between cotton and benzophenone resulted in linear increase of flexural rigidity with increase in concentration of benzophenone for both white as well as dyed cotton in both the padding methods. The order of flexural rigidity was found to be in order with depth of shade for dyed and finished cotton, i.e. the higher the depth the higher the flexural rigidity with undyed showed the minimum (Table 4).

Table 4. Flexural rigidity of anti-UV finished cotton

Uv absorber	Flexural Rigidity (mg/cm)					
	white	reactive dyed				
		1 %	2 %	3 %	4 %	5 %
Benzophenone						
Padding						
10 g/l	115.54	121.91	129.91	146.91	188.57	236.42
20 g/l	133.91	148.42	146.12	164.00	203.53	253.22
30 g/l	152.00	163.00	168.22	183.37	238.94	271.74
40 g/l	175.22	187.65	191.65	197.47	249.87	285.46
50 g/l	185.65	199.34	200.91	206.64	268.00	294.06

Exhaust cum padding						
1 %	113.42	121.39	133.81	139.22	187.17	224.65
2 %	124.00	143.38	149.79	151.65	209.87	234.70
3 %	145.22	156.71	164.89	167.87	238.46	241.00
4 %	167.22	169.57	173.46	179.67	249.37	257.21
5 %	178.65	183.87	182.57	189.06	259.03	268.03
2, 4 dihydroxybenzophenone						
Padding						
10 g/l	158.56	163.24	167.42	168.42	196.42	286.00
20 g/l	212.06	215.91	218.76	222.00	219.32	334.22
30 g/l	275.00	279.22	281.65	282.65	293.87	394.87
40 g/l	329.65	334.87	340.46	343.24	353.46	440.00
50 g/l	352.94	358.46	364.00	369.06	370.06	458.21
Exhaust cum padding						
1 %	135.95	143.91	152.91	153.91	186.42	235.42
2 %	170.91	182.42	186.42	185.00	200.28	253.22
3 %	189.38	197.22	203.00	207.45	214.24	269.96
4 %	199.04	214.65	218.87	222.87	232.46	287.46
5 %	213.87	222.46	225.83	232.00	243.00	302.06
Avobenzone						
Padding						
10 g/l	135.88	148.91	153.00	178.91	188.53	234.42
20 g/l	149.59	163.67	167.23	194.00	208.00	252.00
30 g/l	*	179.00	183.21	211.21	229.01	269.01
40 g/l	*	194.21	197.64	225.64	249.87	283.87
50 g/l	*	205.87	210.45	254.96	268.00	296.00
Exhaust cum padding						
1 %	115.89	126.57	132.97	143.91	190.76	234.42
2 %	131.92	137.46	146.42	163.03	209.53	253.22
3 %	153.42	158.00	160.83	179.22	222.93	279.83
4 %	166.22	171.87	184.87	190.87	248.81	289.46
5 %	179.87	183.87	192.46	203.06	260.06	300.06
Avobenzone + Octocrylene						
Padding						
(10 +40)g/l	202.32	209.88	208.91	210.91	216.91	315.42
(20 +30)g/l	286.91	284.44	290.56	293.70	305.74	393.21
(30 +20)g/l	368.00	374.00	375.00	375.35	378.03	434.67
(40 +10)g/l	424.79	431.64	439.64	447.64	451.87	527.46
Exhaust cum padding						
(1.0+4.0)%	196.32	205.88	207.91	210.91	214.91	305.42
(2.0+3.0) %	275.91	284.44	291.15	289.73	286.74	389.21
(3 .0+2.0)%	363.00	372.00	377.57	379.21	378.03	461.67
(4.0+1.0) %	417.79	424.64	430.64	437.64	446.87	494.46

* Accumulation of Avobezone on fabric during padding imposed difficulty to finish cotton.

The stiffness of cotton finished with 2,4 dihydroxybenzophenone increased with increase in concentration; however, at lower concentrations the increase was more pronounced. Increase in flexural rigidity may be attributed to the bond formation between cellulose and 2,4 dihydroxybenzophenone during curing.

Combination of avobenzone and octocrylene resulted in an increase in the flexural rigidity but at higher concentration the flexural rigidity of the fabric was very high thus making it uncomfortable to be worn next to skin. The difference between dyed cum finished cotton and white finished was not significant indicating the dye concentration did not substantially contribute towards flexural rigidity up to 4% shade for a given concentration of UV absorber.

1.3.7 Tensile behavior of finished cotton

Breaking force of cotton fabrics finished with benzophenone and 2,4 dihydroxybenzophenone is reported in table 4. With the increase in dye as well as benzophenone concentration there was gradual reduction in the breaking force and the reduction was directly proportional to the depth of shade at a given benzophenone concentration and vice-versa. Reduction in breaking force was substantial in case of exhaust cum padding as compared to padding due to the interaction between the substrate and benzophenone (Table 5).

Table 5. Tensile strength of anti-UV finished cotton

Uv absorber	Breaking force (N)					
	White	Reactive dyed				
		1 %	2 %	3 %	4 %	5 %
Benzophenone						
Padding						
10 g/l	313	299	290	285	280	266
20 g/l	304	292	283	280	272	260
30 g/l	297	286	278	272	264	253
40 g/l	290	277	272	266	254	244
50 g/l	281	269	265	259	240	236
Exhaust cum padding						
1 %	306	293	287	280	266	256
2 %	299	282	276	271	258	246
3 %	295	277	270	266	252	238
4 %	289	267	263	257	242	229
5 %	280	254	250	243	230	216
2, 4 dihydroxybenzophenone						
Padding						
10 g/l	311	301	290	285	277	260
20 g/l	302	294	283	280	270	253
30 g/l	295	287	273	274	262	248
40 g/l	291	279	268	265	253	239
50 g/l	284	268	262	257	244	230
Exhaust cum padding						
1 %	310	297	287	281	266	251
2 %	301	292	284	272	260	243
3 %	294	284	279	261	252	233
4 %	287	278	268	254	243	227
5 %	280	273	262	244	236	216
Avobenzone						
Padding						
10 g/l	301	289	285	274	268	262
20 g/l	293	281	276	269	260	256
30 g/l	*	276	270	259	252	250

40 g/l	*	260	258	248	240	239
50 g/l	*	251	244	238	230	228
Exhaust cum padding						
1 %	295	283	275	269	258	251
2 %	290	276	272	266	253	242
3 %	282	269	265	251	247	232
4 %	271	262	256	242	238	221
5 %	261	255	248	231	228	211
Avobenzone + Octocrylene						
Padding						
(10 +40)g/l	305	293	287	283	270	257
(20 +30)g/l	296	288	280	272	261	251
(30 +20)g/l	292	283	272	264	255	243
(40 +10)g/l	292	283	272	264	255	243
Exhaust cum padding						
(1.0+4.0)%	300	298	290	279	262	245
(2.0+3.0) %	290	289	284	270	256	239
(3 .0+2.0)%	284	280	276	260	249	223
(4.0+1.0) %	278	270	269	247	240	210

* Accumulation of Avobezone on fabric during padding imposed difficulty to finish cotton.

With the increase in concentration of avobenzone, the breaking load reduced to a great extent; however, the reduction in case of avobenzone finished dyed cotton was comparatively less. The result obtained in exhaust cum padding was similar to that with benzophenone and its derivative.

In padding, the breaking load was found to decrease with increase in concentration of avobenzone and octocrylene each in combination; though decrease in breaking load with avobenzone and octocrylene combination as compared to benzophenone and 2, 4 dihydroxybenzophenone was marginal. The breaking load in exhaust cum padding was more as compared to padding primarily because of the chemical interaction between the combination of avobenzone and octocrylene and cellulose. The breaking load was reduced considerably with increase in concentration of dye.

1.3.8 Colorfastness of finished cotton

The wash, light and rubbing fastness of finished cotton is shown in Table 6. Benzophenone exhibited the least light fastness as compared to the other UV absorbers thus limiting its use on apparel. Exhaust cum padding exhibited slightly better fastness over those with padding with all the UV absorbers. The rubbing fastness was also found to be good to excellent in most of the cases, dry rubbing 4.5-5 and 4 or above for wet rubbing.

Table 6. Color fastness of anti-UV finished fabric

	Wash Fastness		Rubbing Fastness		Light Fastness
	Staining	Fading	Dry Rubbing	Wet rubbing	
Reactive 1 %(UF)	3-4	3-4	4-5	4-5	5
Reactive 3 %(UF)	4	4	4-5	4-5	5
Reactive 5 %(UF)	4	4	4-5	4-5	5-6
Reactive 1 %(BPP)	3	3	4	4	3
Reactive 3 %(BPP)	4	4	4-5	4-5	3
Reactive 5 %(BPP)	4	4	4-5	4-5	3

Reactive 1 %(BPE)	4	4	4	4	3-4
Reactive 3 %(BPE)	4	4	4-5	4-5	3-4
Reactive 5 %(BPE)	4-5	4-5	4-5	4-5	4
Reactive 1 %(HBPP)	3	3	4	4	5-6
Reactive 3 %(HBPP)	3-4	3-4	4-5	4-5	6
Reactive 5 %(HBPP)	4	4	5	5	6-7
Reactive 1 %(HBPE)	3-4	3-4	4-5	4-5	6
Reactive 3 %(HBPE)	3-4	3-4	4-5	4-5	6-7
Reactive 5 %(HBPE)	4-5	4-5	4-5	4-5	7
Reactive 1 %(AP)	4	4	5	5	6-7
Reactive 2 %(AP)	4-5	4-5	5	5	7
Reactive 3 %(AP)	5	5	5-6	5-6	7-8
Reactive 1 %(AE)	4-5	4-5	5	5	6-7
Reactive 2 %(AE)	4-5	4-5	5-6	5-6	7
Reactive 3 %(AE)	5	5	5-6	5-6	7-8
Reactive 1 %(AOP)	5	5	6	6	7
Reactive 2 %(AOP)	6	6	6-7	6-7	7
Reactive 3 %(AOP)	6	6	6-7	6-7	8
Reactive 1 %(AOE)	5-6	5-6	6	6	7
Reactive 2 %(AOE)	5-6	5-6	6	6	7
Reactive 3 %(AOE)	6	6	6-7	6-7	6-7

*UF= Unfinished, BPP= Benzophenone padding, BPE= Benzophenone exhaust, HBPP= 2,4, dihydroxy benzophenone padding, HBPE= 2,4, dihydroxy benzophenone exhaust,
AP= Avobenzone padding, AE= Avobenzone exhaust, AOP= Avobenzone + Octocrylene padding, AOE= Avobenzone + Octocrylene exhaust.

1.4 Conclusions

Finishing of cotton with benzophenone increased the UPF substantially on both white as well as dyed cotton; however, the increase on dyed cotton was more than that on white. The limiting factor of benzophenone is its low light fastness. 2,4 dihydroxybenzophenone exhibited very high UPF with good fastness properties. However the yellowish appearance on white cotton imposes restriction on its use. Avobenzone offered excellent UV protection with minimal yellowish appearance. It was observed that finishing was a bit problematic with padding technique at higher concentrations due to accumulation of avobenzone just after the cotton was dipped in methanol. Avobenzone and octocrylene combination, by their distinct ability to absorb UV radiations over UV-A and UV-B range fulfilled the major objective of the study while exhibiting good colorfastness properties too. Solubility of avobenzone in methanol in presence of octocrylene at room temperature made the application simpler raising the hope of the commercial viability of this combination.

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