# Application of Energy Considerations to Ultraviolet Protection of Clothing, Environmental Protection of Textile Filters and Textile Screens for Industrial Safety

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Textile materials and clothing have been used since antiquity by human beings for the purposes of protection, comfort and adornment. Recent times have witnessed a steadily increasing emphasis on the role that clothing can play to guard against skin cancer and in particular malignant melanoma caused by excessive exposure to ultraviolet solar radiant energy.

Technical textiles especially nonwoven filters play a significant part in the reduction of carbon emissions from coal fired electricity generators and energy intensive industrial processes such as the production of aluminium by electrolysis. In addition, when these technical textile materials are efficiently used for filtration purposes by controlled cleaning, electrical power or energy losses are greatly reduced which in turn lowers the emission of ‘greenhouse gases’ into the atmosphere especially carbon dioxide.

In all industrial processes involving the generation of large amounts of heat energy such as power stations and industrial chemical reactors, it should be possible to use the energy absorption properties of technical textile materials in order to design industrial screens to guard against injury caused by an explosion resulting from excessive temperatures in a runaway reaction.

In all these applications of textile materials and clothing, it is necessary to consider the interaction between the structure and physical properties of the textile material and the generation, transmission, conversion and absorption of energy. These considerations are becoming more important because of the steadily increasing emphasis on health, environmental protection and industrial safety in today’s world.

## Ultraviolet protection of clothing

It is often believed by the general community that sun creams and light weight summer clothing (including hats and sunglasses) provide total protection from the adverse health effects of solar ultraviolet radiation on the human skin. This presumption, however, is far from the truth.

Recent statistics reveal that in Australia over one thousand people die from skin cancer each year. In addition, two-thirds of Australians are directly affected by skin cancer of one kind or another during their lifetime (4). The occurrence of the most dangerous form of skin cancer i.e. malignant melanoma in Australia is very high for both males and females. High incidence rates also occur in other countries such as USA and New Zealand. The Australian statistics represent the highest incidence of skin cancer world-wide. Furthermore, the incidence of skin cancers continues to increase world-wide according to the World Health Organisation (WHO).

The medical dermatology profession recognises that the dominant factor causing these high rates of skin cancer is the cumulative exposure to the sun's ultraviolet radiation. There is clearly a need for test methods and standards to specify the protection provided by clothing from the harmful effects of solar radiant energy, which is generally classified as ultraviolet A (UVA) 315-400 nm wavelength and the more harmful ultraviolet B (UVB) 280-315 nm wavelength.

The two main ways of assessing the UV protection of clothing are in vivo or in vitro test methods. In vivo testing measures the actual protection afforded by the garment from human skin erythema by means of a xenon solar simulator as the source of UVA and UVB radiant energy. For in vivo testing, the sun protection factor (SPF) determines the ultraviolet protection by adopting the minimum erythema on human skin as the end point (3, 5).

The transmission of ultraviolet radiation through the textile material or garment is measured by in vitro testing using a spectrophotometer or spectroradiometer which actually detects the percentage transmission in wavelength intervals of 5 nm for the 280 to 400 nm wavelength range of the UV spectrum. Both the direct and diffuse UV radiation transmitted through the garment are detected and measured.

The ultraviolet protection factor of clothing (UPF) derived from the in vitro test method (5) as defined in Australia / New Zealand standard AS/NZS 4399 (1996), 'Sun protective clothing – evaluation and classification'. This standard has recently been adopted by the International Commission on Illumination - Technical Report CIE 172: 2006 (3). The UPF provides a single numerical value which is representative of the whole UVA and UVB wavelength energy spectrum. The UPF gives the greatest weighting to the biologically most harmful UVB wavelength band.

The UPF classification or rating scheme set by the Australia / New Zealand standard AS/NZS 4399 (1996) is summarised in table 1. The limit for UPF labelled clothing in Australia is currently 50+.

Table 1: UPF Classification or Rating Scheme

| UPF Range | UVR protection category | Effective UVR transmission % | UPF Ratings |
|---|---|---|---|
| 15 to 24 | Good protection | 6.7 to 4.2 | 15, 20 |
| 25 to 39 | Very good protection | 4.1 to 2.6 | 25, 30, 35 |
| 40 to 50, 50+ | Excellent protection | ≤ 2.5 | 40, 45, 50, 50+ |

Almost all structural parameters of a textile material especially the fabric cover factor or weight, have a direct influence on the fabric ultraviolet protection factor. The most important fabric properties in this context are: fabric cover factor (or weight), fibre type, yarn construction, fabric construction, finishing processes, colour, UV absorbers, wash and wear, fabric stretch and wetting (or hydration). The effects on UPF of these fabric parameters have been studied at University of New South Wales and are described in detail by Pailthorpe and his co-workers (4, 5) and are summarised in the International Standard CIE 172 (2006) (3).

In order to achieve a desired UPF rating for a textile material, it is always necessary to control all the textile parameters which influence the transmission of ultraviolet radiation through the material, especially the fabric cover factor. If we define an 'ideal' textile material as one in which the constituent yarns are completely opaque to the transmission of ultraviolet radiation, then the UPF of this ideal fabric is given by:

$$UPF = \frac{100}{100 - (CoverFactor)} \ldots \qquad \text{eqn. (1)}$$

Table 2 shows the UPF values calculated from eqn. (1). It can be seen that very small changes in the fabric cover factor give substantial improvements in the UPF of the textile material especially for values of cover factor greater than 95%. It follows that a small increase in the fabric cover factor will produce a substantial improvement in ultraviolet protection of clothing.

Table 2: UPF Values Calculated From Fabric Cover Factor

| Cover Factor | Fabric UPF |
|---|---|
| 90.0 | 10 |
| 93.3 | 15 |
| 95.0 | 20 |
| 97.5 | 40 |
| 98.0 | 50 |
| 99.0 | 100 (50+) |
| 99.5 | 200 (50+) |

For example, consider a textile manufacturer producing batches of fabric having a mean cover factor of 98.5% with a quality control range of ±1.0 %. There would be substantial variation in the UPF values for these fabric batches ranging from a minimum value of 28 (corresponding to a cover factor of 96.5%) to a maximum UPF value of 66 (corresponding to a cover factor of 98.5%)

with a mean UPF value equal to 40 corresponding to the average cover factor of 98.5% (still assuming yarns which are opaque to transmission of ultraviolet radiation).

It is clear from this discussion that in order to produce high UPF ratings for textile materials, it is necessary for textile designers and manufacturers to maintain stringent quality control systems which enable textile materials to be produced within a narrow range of cover factor.

It is also noteworthy that highly UPF rated textile materials having high cover factor are generally less permeable to air and water vapour. Therefore, a high fabric UPF rating should be balanced by considering the comfort properties of summer weight clothing. There is considerable scope for innovative fabric structures and finishing processes (including the incorporation of UV absorbers) in order to achieve these aims in the marketplace.

## Environmental protection of industrial textile filters

An industrial fabric filter consists of a textile material which may be woven, needlefelt or knitted structure most commonly in the shape of a long cylinder called a filter bag which ranges in length up to 10m and 30 cm in diameter. There may be several thousand filters in the supporting structure called the bag house in an industrial plant.

The dirty gas emissions are passed through the fabric filter, separating the dust particles from the gas stream in order to satisfy environmental emission regulations. These filters are most commonly used in coal fired power stations, iron and steel works, copper and lead smelters, aluminium electrolysis refining plants and for the collection of nuisance gases. In Australia, there are many metal smelters and power stations which depend heavily on fabric filters for environmental pollution control purposes.

Dust particles are initially captured by the individual fibres when the filter is new. Gradually a dust cake builds up on the filter. The major dust collection mechanism is a sieving action which is performed by the dust cake itself. The fabric acts primarily as a support for the dust cake which does most of the filtering.

As the dust cake builds up, the pressure drop across the dust cake increases causing more energy to be expended in order to maintain the flow of gas through the filtration system. If the volume flow rate of gas is to be maintained at acceptable levels, then the filter must be continually cleaned to restore the pressure drop and flow rate to their original levels.

Thus the cleaning process is critical and ultimately it determines the performance of the filter and minimises the energy losses. Three of the most common cleaning mechanisms used for fabric filters are the shaker, reverse air and pulse jet systems.

For effective cleaning of the filter, the dislodgement applied by the cleaning mechanism must be greater than the adhesion force which holds the dust cake on to the fabric. The balance between the force being applied by the cleaning mechanism and the force required to remove a dust cake is a crucial factor in influencing fabric filter performance.

A model has been reported (1) which predicts the cleaning characteristics of a pulse jet filter in terms of its residual flow rate and filter bag pressure drop. Measurements during cleaning of fabric acceleration, pulse jet pressure and dust cake adhesion are incorporated in the model. The assumptions in the model are summarised in table 3.

Table 3: Assumptions Made in the Model for Performance of a Pulse Jet Filter

| Assumptions |
|---|
| The filter reaches an equilibrium so that the dust added during a cycle equals the dust removed by the cleaning process.<br>Dust dislodgement is achieved purely as a result of fabric acceleration / deceleration.<br>The distribution of the force of adhesion of the dust cake to the fabric is log-Normal.<br>Cleaning of the fabric is dichotomous. The dust cake is either completely removed or not at all.<br>The dust cake is evenly distributed over the fabric surface just prior to cleaning.<br>Flow through the fabric is the same in both the forward and reverse directions. |

In pulse jet filters, it is generally agreed that fabric deceleration provides the tensile force that dislodges the dust, typically in the range of 50g to 250g. Reverse flow can also represent a secondary mechanism of dust dislodgement. The model of pulse jet filter performance predicts the relationship between the maximum fabric cleaning acceleration and the pulse over-pressure.

The adhesion, pulse over-pressure and fabric deceleration measurements were incorporated into the pulse jet cleaning model so that the residual volume flow rate could be predicted for a given filter bag pressure drop. A computer model was developed that predicts the residual flow rate at a given bag pressure drop. Predictions of this computer model have been applied in practice to the optimisation of pulse jet filter operation in Australian power stations and metal smelters in order to:

Minimise environmental pollution in the power generation industry;

Protect individuals from inhalation of smoke, chemical, biological and radiological aerosols;

Minimise energy losses caused by excessive dust cake build-up on the filter fabric thus reducing the emission of greenhouse gases to the atmosphere such as carbon dioxide; and

Recover valuable products from fumes in smelting and refining operations.

## Textile screens for industrial safety

Safety in industry is a high priority. Considerable progress has been made to reduce the risk of industrial accidents, which nevertheless still happen occasionally. For example, the large majority of thermal runaways in the chemical industry is due to human factors, in particular mistakes in loading of the reagents and imperfect maintenance. However, a significant number of accidents result from an incomplete knowledge of the processes or reagents being used.

Let us consider for example the case of a technical problem such as a temperature breakdown or a deposit on the walls of an engine, which would decrease its coefficient of heat exchange. In these situations, heating related to the reaction is no longer compensated by the system of cooling and hence the temperature can increase and thus the reaction can ‘runaway’. The runaway system is then likely to initiate secondary reactions or decomposition which in turn can also become runaway reactions. The phenomenon then adopts unverifiable proportions causing a thermal explosion.

An important tool to improve the safety of industrial workers near a chemical reactor could be, for example, the protection provided by textile screens that are activated in the situation where the temperature increases in an uncontrolled manner (2). This kind of textile screen protection could be programmed to fall from the height of the reactor creating a soft but resistant absorbing barrier against the force of the explosion and also protection against projectiles.

There are two fundamental considerations concerning this kind of textile screen protection. The first consideration is the texture of the fibrous material which depends on the local stress. The second factor to be considered is the shape of the textile screen which depends on the way in which the stress is to be diffused.

For the first problem, we need to evaluate which textile material would provide maximum absorption of energy due to the local stress while also providing resistance to disintegration caused by the high energy localisation in projectiles emanating from the explosion. This energy can sometimes be near the fusion point of the fibre. The protective textile screen must therefore comprise fibres of relatively low cost which are capable of absorbing large quantities of energy prior to fusion or disintegration. The texture of the screen ideally would consist of multilayers of textile material which represents an area for extensive research.

Considering the second problem, we include the principal parameters that generate the optimal shape of the textile screen when an industrial explosion takes place. It is necessary to evaluate by means of optimisation techniques, the functional derived from the ‘energetic’ factors and their constraints. Energetic factors during the explosion and the way in which the explosion happens may be modeled to find the best answer to the problem.

# Conclusion

We have considered three very different situations whereby textile materials are used for some kind of protective screening purpose either in everyday clothing or industrial applications. Quantitative models have been derived by analysing the processes of energy transmission, generation and absorption in order to optimise the role of the textile material for the different applications.

The transmission of very high energy ultraviolet solar radiation through textile materials especially for light summer clothing depends principally on the fabric cover factor in addition to other secondary fabric properties such as fibre type, yarn and fabric construction, finishing processes, colour, UV absorbers, wash and wear, stretch and hydration. The cumulative exposure of human skin to ultraviolet radiation, especially the very high energy UVB wavelength range, is the major factor which determines the incidence of skin cancer in particular the very dangerous form of malignant melanoma. Standard test methods and quality control considerations for high rating ultraviolet protection of clothing are being developed.

Industrial power stations and metal smelters depend very heavily on textile filter bags for the minimisation and control of environmental pollution and the emission of greenhouse gases into the atmosphere caused by their operation. A computer model which optimises the build-up of the dust cake on the surface of an industrial fabric filter can be used to control the operation of a pulse jet filter system in industry in order to achieve these aims.

Energy absorption properties of textile materials can also be employed to design an industrial textile screen which serves as a protective barrier for industrial workers against an explosion arising from thermal runaway reactions in a chemical plant. The design of a protective textile screen necessitates the analysis of the maximum energy generated when cooling mechanisms break down enabling the occurrence of a thermal runaway and associated explosion and projectile emissions to be isolated by the screen to a confined area of the plant.

In these apparel and industrial applications, the fundamental properties of fibrous textile materials provide the basic screening control mechanisms which are required. These examples together with many other practical situations are becoming more highly recognised today as society places increasing emphasis on human health, safety, energy conservation and reduction of environmental pollution and atmospheric greenhouse gases.

# References

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