RGC 139398

WW4/F/211

SAWTRI

SPECIAL PUBLICATION

A Review of Fire Accidents, Flammability and the Toxicity of Burning Textiles

by

N.J.J. van Rensburg

SOUTH AFRICAN
WOOL AND TEXTILE RESEARCH
INSTITUTE OF THE CSIR

P.O. BOX 1124
PORT ELIZABETH
REPUBLIC OF SOUTH AFRICA

WOL NO 59
ISBN 0 7988 2425 5
SAWTRI SPECIAL PUBLICATION
September 1982

A REVIEW OF FIRE ACCIDENTS, FLAMMABILITY AND THE TOXICITY OF BURNING TEXTILES

by N. J. J. VAN RENSBURG
SOUTH AFRICAN WOOL & TEXTILE RESEARCH INSTITUTE
PORT ELIZABETH

ABSTRACT

The effect of fire and its products (heat, smoke and irritant or toxic gases) on the human being, as well as the reponse of people in a fire situation, are reviewed. Some data on the causes of fire injuries are given and the factors causing injury or death in a fire are discussed. Open flames and smoking are the main causes of fires and in most cases textile products are the primary agent ignited. Only about one-third of all deaths caused by fire are the direct result of burns, while two-thirds are caused by toxic gases liberated by the fire. The products formed by the combustion of textile fibres and the relative toxicity ratings of a number of textiles are discussed in this paper.

INTRODUCTION

The Fire Protection Association of South Africa reported that fire losses for 1980 reached an all-time record of R134 million[1]. At least 126 people died as a result of burns and asphyxiation in fire incidents[2] in South Africa in 1980. This figure does not take into account persons who died of their injuries some time after admission to hospital, and according to figures released by the Department of Statistics more than 400 people lose their lives in fires and fire related incidents annually in South Africa.

FIRE OCCURRENCE AND FIRE INJURIES

A breakdown of data on fires in the USA shows that most fires occur in residential buildings (about 32%)[3]. A similar tendency is found in South Africa, where about 38% of all fires occur in dwellings, outbuildings or flats[2]. Table I gives a breakdown of the fire calls attended by fire brigades in South Africa in 1980.

An analysis of residential fires in the USA revealed several noteworthy characteristics[4]. Firstly, these fires occurred mostly *in living areas,* namely the living room, bedroom and kitchen. Secondly, the majority of fires originated when *textile containing products,* such as upholstery or bedding, were ignited. Thirdly, about two-thirds of the residential fires occurred *at night*.

TABLE I

THE OCCURRENCE OF FIRES IN SOUTH AFRICA IN 1980[2]

	% of total
Dwellings, outbuildings, flats	38
Hotels, cafès, cinemas, churches, hospitals	5
Offices, shops, stores, warehouses, educational	12
Industry	13
Cars, busses, garages, ships, trains	32

Table II shows an interesting comparison between South Africa and the USA in terms of the causes of residential fires[2,4]. In the USA smoking is by far the largest cause of fatal residential fires. In South Africa, on the other hand, smoking ranks third after open flames and electrical faults. It is rather alarming to note, that open fires and smoking caused about 40% of all residential fires in South Africa in 1980. In other words, more than 800 of the calls received by fire brigades in 1980 for residential fires were caused by open fires or smoking.

TABLE II

THE MAIN CAUSES OF RESIDENTIAL FIRES[2,4]

Cause of fire	% of total	
	South Africa	USA
Open flames	27	—
Electrical faults	17	8
Smoking	13	56
Cooking	10	7
Arson	8	4
Heating	5	14
Others	20	11

Some interesting data on the sources of ignition, fire injuries and deaths which occurred in the city of Syracuse in the state of New York were collected over a period of 4 years by McDonald and co-workers[5]. Matches and smoking materials accounted for more than half of all injuries. In most cases textile products were the primary agent ignited, followed by flammable liquids. It is interesting to note that household textiles accounted for 71% of the textile products ignited and apparel for the remainder. Furthermore, the agent ignited and the age of the injured person were related. Apparel items were most frequently ignited by the young (0-9 years) and the elderly (65 + years). In other words, persons who have the lowest chance of escaping injury or death show the highest incidence of fire accidents[5].

Table III shows the severity of fire injuries, as analysed in the Syracuse study[5]. It can be seen that about 17% of the fire injuries resulted in death, while a further 50% of the cases were so serious that they had to be treated in a hospital. Obviously these figures reflect the conditions experienced by the people during exposure to the fire.

TABLE III

SEVERITY OF FIRE INJURY[5]

Severity of Injury	%
Fatality at scene or death on arrival at hospital	8
Fatality after hospital treatment	9
Hospital admission — survived	41
Treated and released	10
No hospitalisation required	26
Disposition unknown	6

It is very important to remember, however, that it is not the fire (flames and heat) only, but also other products, such as smoke and toxic gases, which can cause injury or death.

It is commonly accepted that direct contact with flames or high temperatures is the major cause of fire injury and death. According to data published in the literature, however, this is not the case. Kimmerle[6], for example, pointed out that death or injury is frequently due to a combination of several factors. In the cases where the main cause of death could be established, however, he noted that burns were not the major factor.

Table IV gives the major causes of deaths in fires reported in 1970 for Japan[6], while Table V gives the figures for Illinois in the USA[3]. It is interesting to see that gas poisoning and suffocation caused about 60% of the deaths, while burns caused 30-40% of the deaths. In other words, about two-thirds of the fire deaths were caused by the gases produced by the fire and not by the fire itself. This is a very important aspect of fire injuries and death and it must be emphasized that an escape from the fire itself does not necessarily imply that the person is safe, because he may still be overcome by gases and smoke while he is quite a distance away from the fire.

TABLE IV

MAJOR CAUSES OF DEATH IN FIRES IN JAPAN, 1970[6]

Cause of Death	%
Burns	30
Carbon monoxide poisoning/suffocation	59
Heart failure	1
Bruises, bone fracture	1
Suicide	8
Others	1

TABLE V

CAUSES OF FIRE DEATHS — ILLINOIS, 1970[3]

Cause of Death	%
Burns	39
Toxic gases — carbon monoxide	3
other gases	57
Not specified	1

THE HUMAN BEHAVIOUR IN THE CASE OF A FIRE

It is important to remember that a fire can spread vey rapidly, as can its products, such as heat, smoke and toxic gases. Cases are known where a fire which started on the first floor of a building forced people out of the twentieth floor within 12 minutes[7]. In some studies on fires in bedrooms it was found that ignition and burning occurred so rapidly that the contents of the room were destroyed completely within 8 minutes[8]. Finley and co-workers[9] reported that in the case of garment fires the peak temperature was reached within 30 seconds after ignition. (The peak temperatures recorded were normally very high and would produce severe third-degree burns). It is clear that the human being does not have much time to act in the case of a fire. The behaviour of the human being in the case of a fire threat situation will therefore have a major effect on the severity of any fire injuries which may be sustained.

Jin[10] carried out some studies on the emotional instability of human beings caused by smoke produced by fires. The author used a steadiness tester to measure the extent of the subjects' emotional instability caused by smoke, simultaneously measuring their heart rates, walking speeds, and respiratory rates as a function of increasing smoke density. He found that for people not familiar with the inside of the building, the threshold visibility largely depended on emotional instability resulting from the reduced visibility and irritation caused by smoke. For people familiar with the inside of the building the threshold density was dependent mainly on the extent which they could physiologically tolerate irritation and suffocation. Jin found that the heart rate increased, walking speed decreased and the respiration of the test persons became progressively disturbed as the amount of smoke increased. He concluded that the threshold visibility for people familiar with the inside of a room was about 4 metres, while for those who were not the threshold visibility was about 13 metres.

A similar study was carried out by Bryan[7] and he found that the perception of an individual of a potential fire threat depends on physiological, cultural and psychological factors. Furthermore, previous experience and educational factors also play a rôle. Physiological variables include age, sex and physical abilities. Cultural variables are very important, and an individual in the rôle of father or husband, may become very vulnerable when a family member is in danger. The physiological variables that determine behavioural response in a fire occurrence involve the emotional condition of the individual.

For example, Bryan found that five times as many women as men who were questioned after a fire incident reported that their first action was to get to their family. Furthermore, Wood[11] found that males were less likely to leave the building when compared with females, and once a male did leave the building he was more likely to re-enter the burning building than a female.

In a further publication Bryan[12] gave some interesting statistics on the alerting mechanisms involved in fire incidents. The results, given in Table VI show that more than 30% of the people involved became aware of the fire after they smelled smoke. Warnings by members of the family or others amounted to a further 30% of the cases. Rather surprisingly, a relatively low percentage of people became aware of the fire by visual observation of the flames or smoke, especially when the distance between the people and the fire is considered. Table VII shows that more than 60% of the people were within 6 metres of the fire when they first became aware of it[12].

TABLE VI

THE FIRST ACTION WHICH MADE PEOPLE AWARE OF A FIRE[12]

Action	%
Smelled smoke	31,8
Notified by others	17,3
Noise	14,4
Notified by family	14,1
Saw smoke	10,3
Saw fire	6,8
Other	5,3

TABLE VII

THE DISTANCE BETWEEN PEOPLE AND THE FIRE WHEN THEY FIRST BECAME AWARE OF IT[12]

Distance (m)	%
0-3	40,3
3-6	23,7
6-9	16,2
9-12	3,1
12-15	8,4
15-30	4,4
30-45	0,8
> 45	3,1

Buchbinder[13] studied human activity patterns and injury severity in fire incidents involving apparel. He found that activities preceding an apparel fire accident were related to age, sex and the severity of the burn injury. Men were primary involved in accidents with flammable liquids, gases or electricity while women were more susceptible to direct flame ignition. The majority of cases studied had burns over 20% of the total area of their body. When flammable liquids were involved, there tended to be fewer minor injuries and more moderately serious injuries than in other materials. Age and defensive capability were major factors determining the extent of fire injury, with persons over 65 and those with limited ability suffering most.

TOXICOLOGICAL ASPECTS OF FIRE HAZARDS

(1) TEMPERATURE

The effect of temperature on the human body is shown in Table VIII:

TABLE VIII

PHYSIOLOGICAL EFFECTS AT VARIOUS TEMPERATURE LEVELS[14]

Temperature	Effect
28°C	Acceptable maximum temperature of activity
38°C	Danger of heat prostration and heat stroke
43°C	Heat balance can not be maintained for long
65°C	Central circulation failure. Hyperpotassemia
100°C	Very rapid skin burns in humid air
125°C	Nasal breathing difficult
150°C	Mouth breathing difficult
180°C	Irreversible injury to dry skin in 30 seconds

Very high temperatures have been recorded in fires in buildings and the survival time under these conditions can be extremely short. Figure 1 shows the maximum tolerance time as a function of temperature[15]. It is clear that above 200°C the human being has little chance of survival, unless special protective clothing is worn. Prager[16] found that the maximum temperature reached during the burning of upholstery on chairs ranged from 200°C to 900°C, depending on the material used for the upholstery.

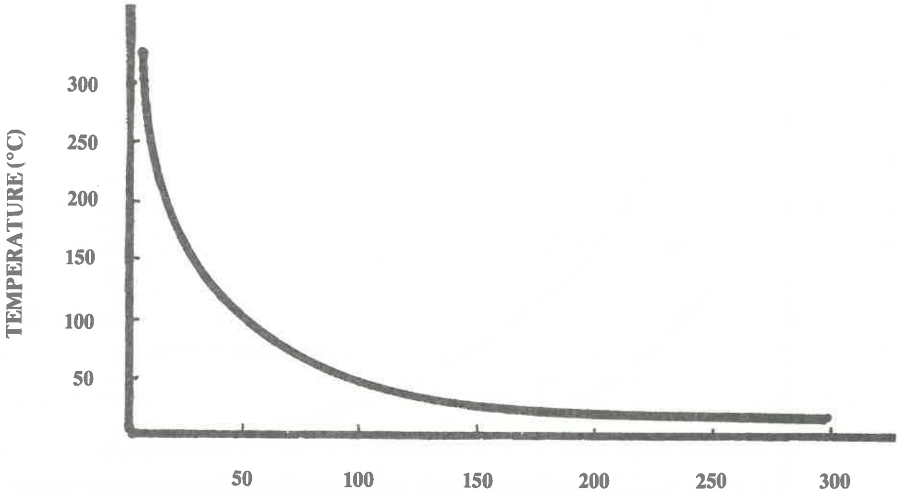

FIGURE 1

Maximum tolerance time as a function of temperature.

Body burns are normally classified as 1st, 2nd and 2rd degree[17]. A first degree burn is but an inflammatory response of the body to heat. In a 2nd degree burn there is partial destruction of secondary skin appendages (hair follicles, sweat glands, etc.,) and the wound can heal by itself. In a 3rd degree burn the secondary appendages have been destroyed completely, and the wound can only heal by the ingrowth of skin from the non-burned edges. The severity or depth of a burn is classed as 1st, 2nd and 3rd degree, while the extent of the burn is expressed according to the "rule of nine", where one arm is 9%, a leg front is 9%, etc. A healthy adult may survive a 10 to 15% 3rd degree burn without much difficulty. However, if a third degree burn involves 50% of the body surface, the mortality rate is about 50%. If a burn involves 70% or more of the body surface the chance of survival is nil. Crikelair[17] stated that there is no first aid treatment for a severely burned patient. First and second degree burns involving 10% or less body area are relatively easy to treat and do not require hospitalisation, while 2nd and 3rd degree burns involving 50% or more of the body area require prolonged hopital care. It appears, therefore, that the cost of a burn accident is largely dependent on the severity of the burn injury.

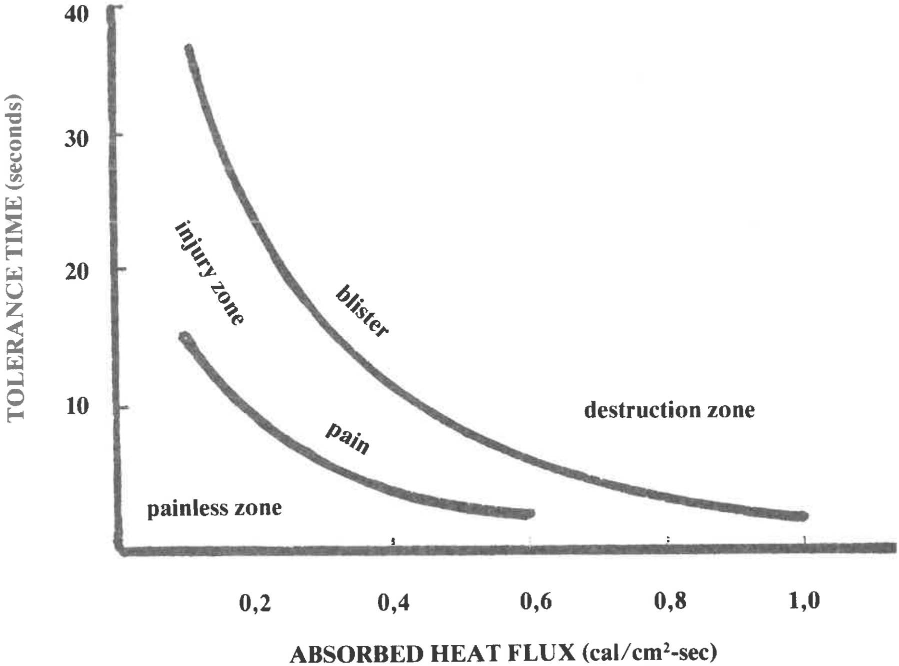

FIGURE 2

The relationship between heat-flux and human skin tolerance time

The relationship between heat-flux and human tissue response up to second degree burn has been established by Stoll and Chianta[8]. Their results are shown in Figure 2. A flux of 0,4 cal/cm^2-sec will produce pain in about 2 seconds and a blister in 5-6 seconds. Fluxes ranging from 0,3 to 1,0 cal/cm^2-sec are typical of those obtained on the faster burning fabrics[19]. It seems that fabrics comprising a wide variety of different types of fibres all are capable of producing at least second-degree burns. In fact, studies showed that burning fabrics can cause epidermal and dermal damage up to 8 mm in depth. Sweat glands are found approximately 2-3 mm beneath the surface and are quite sensitive to heat. They were often found to be damaged even when the surrounding tissues appeared unharmed[19].

Martin[20] reported that the mortality in the case of burning clothes is significantly higher than that of other fire accidents. Mortality in all cases where burning clothing or nylon nightdresses were the sole source of heat, amounted to 43%. As a result of this it was said that if a person's home catches fire, he can probably escape with his life and skin, but if his pyjamas catch fire, he will probably lose his skin and possibly his life!!

The values for the heat of combustion and maximum flame temperature of textile fibres can vary considerably. Table IX shows that heat of combustion and flame temperature are not necessarily correlated. For example, cotton has a relatively high flame temperature, but a low heat of combustion, which means that it will burn rapidly. Polyester, on the other hand, will behave in the opposite manner.

TABLE IX

THE HEAT OF COMBUSTION AND MAXIMUM FLAME TEMPERATURE FOR VARIOUS TEXTILE FIBRES[21]

Fibre	Heat of Combustion (kJ/g)	Temperature (°C)
Cotton	18,9	860
Wool	21,0	680
Polyester	24,8	700
Polyamide	29,4	875
Polyacrylic	36,1	850
Polypropylene	44,1	840

(2) SMOKE

Smoke is defined as the airborne solid or liquid particles which are generated when a material is decomposed by heat or burning[22]. Smoke is generally associated with the following hazards.

TABLE X

SMOKE HAZARDS[3]

Property	Hazard
Opacity	Hinders escape and rescue
Lachrymatory irritant	Induces panic
Toxicity (direct)	Incapacitates (kills)
Toxicity (indirect)	Causes anoxia
Heat	Sears respiratory system

Smoke can reduce the visibility very rapidly, and thus it can hinder escape from a building. Studies have shown that illuminated exit signs 3,5 metres away from observers were totally obscured by smoke within 5 to 12 minutes after the start of the fire[7].

It has been reported that acute inhalation of smoke can lead to suffocation due to the fact that it prevents absorption of oxygen. Furthermore, very hot smoke can, regardless of its chemical composition, destroy tissue[6]. Mohler found that victims of an airline crash, killed by neither the impact nor the fire itself, but rather by the smoke, had high levels of carbon monoxide in their cardiac blood, as well as widespread presence of soot particles extending down to the smallest cavities of the lungs[23]. In an interesting study Hillenbrand and Wray[8] collected the particles formed during a fire in a room in filters and found that they amounted to as much as 5 000 g/m^3 .

Various materials differ significant in their rates of smoke production. The smoke generation coefficients of a number of materials are as follows:

TABLE XI

SMOKE GENERATION COEFFICIENTS AT 700°C[24]

Product	Smoke generation coefficients (cm^2/g)
Plywood	28
Polyester	83
Acrylic	270
Polyvinyl chloride	390
Polyurethane	900

Smith[25] carried out an interesting calculation on the smoke "hazard load" in a furnished room of 3m x 4m x 2,5 m . His results are given in Table XII, which shows that textiles contribute the major part of the smoke hazards load in the room. Furthermore, it is known that the presence of about $3{,}2 \times 10^3$ particles/m^3 air will reduce the visibility (i.e. the maximum distance a standard exit sign can be read) to only 50cm . The results in Table XII indicate that, theoretically, the visibility in this room could drop to well below that level in the case of a fire.

TABLE XII

THE SMOKE HAZARD LOAD OF A FURNISHED ROOM[25]

Component	Surface area (m^2)	Smoke volume ("Particles")	% of Total
Carpet	10,0	238,000	63
Ceiling tile	11,0	18,000	5
Wall panel	9,0	4,800	1
Upholstery	4,0	117,000	31
Total smoke hazard load = $13{,}8 \times 10^3$ particles/m^3			

(3) TOXIC EFFECTS OF GASES AND VAPOURS

(a) Irritants

Some typical irritants formed by fibres are hydrogen chloride and ammonia.

(b) Asphyxiants

The main gases involved in asphyxiation are oxygen, carbon dioxide, carbon monoxide and hydrogen cyanide[6,15,26].

(i) Oxygen (O_2)

The effect of reduced levels of oxygen in the air on the physiological behaviour of the human being is shown in Table XIII.

TABLE XIII

PHYSIOLOGICAL EFFECT OF REDUCED LEVELS OF OXYGEN[6]

% Oxygen in Air	Symptoms
20	Normal
17	Respiration volume increases, muscular coordination diminishes
12-15	Shortness of breath, dizziness, quickened pulse, efforts fatigue quickly, muscular coordination for skilled movements lost
10-12	Nausea and vomiting, exertion impossible, paralysis of motion
6-8	Collapse and unconsciousness occurs
< 6	Death in 6 to 8 minutes

It is important to remember that burning products normally consume oxygen, and if a fire occurs inside a building the oxygen content of the air can drop very rapidly. Table XIII shows that when the oxygen content of air drops to below 16%, the human being is in danger, because he may make a faulty decision as a result of the decrease in his mental alertness. When the oxygen content of the room is below 12% paralysis can occur.

The question now arises as to how rapidly the oxygen content in a room decreases in the case of a fire. Hillenbrand and Wray[8] reported that it can drop to below 16% within 2 minutes.

(ii) Carbon dioxide (CO_2)

Compared to other gases carbon dioxide is not very dangerous. The effect of increased levels of carbon dioxide on the human being is shown in Table XIV.

TABLE XIV

THE EFFECT OF VARIOUS CONCENTRATIONS OF CO_2 ON THE PHYSIOLOGICAL BEHAVIOUR OF THE HUMAN BEING[6]

Concentration of CO_2 in Air (p.p.m)	Symptoms
250-350	Normal concentration
900-2000	Without effect
18 000	Ventilation increased by 50%
25 000	Ventilation increased by 100%
50 000	Symptoms of poisoning after 30 minutes, headache, dizziness
90 000	Fatal within 4 hours
120 000	Immediate unconsciousness, death in minutes

(iii) Carbon monoxide (CO)

Carbon monoxide is the most common harmful gas produced by fires and it is extremely toxic. It is colourless, tasteless and almost odourless and is therefore difficult to detect. Carbon monoxide is a haematin poison and reduces the oxygen in the arterial blood. It has a 300 times higher affinity for haemoglobin than oxygen[6,27]. The relation between carbon monoxide concentration and the response in human beings is shown in Table XV:

TABLE XV

THE EFFECT OF CARBON MONOXIDE ON THE HUMAN BEING[6]

Concentration of CO_2 in Air (p.p.m)	Symptoms
100	No poisoning, even for long periods
300	Distinct poisoning after 2-3 hours
500	Hallucinations felt after 30-120 min
1000	Death after 2 hours inhalation
3000	Fatal in 30 minutes
> 8000	Immediate death by suffocation

(iv) Hydrogen cyanide (HCN)

Hydrogen cyanide is produced from various nitrogen containing products during burning. It is a deadly poison and has in fact been used in the gas chamber in the USA. Its effect on the human being is shown in Table XVI.

TABLE XVI

THE EFFECT OF VARIOUS CONCENTRATIONS OF HCN ON THE HUMAN BEING[6]

Concentrations of HCN in air (p.p.m)	Symptom
1-5	Threshold of odour
100	Death after 1 hour
110-135	Fatal after 30-60 minutes
181	Fatal after 10 minutes
280	Immediately fatal

Apart from the gases mentioned above, a large number of other gases can also be liberated during combustion. Several of these, such as nitrogen dioxide (NO_2), sulphur dioxide (SO_2), hydrogen sulphide (H_2S) and acrolein ($CH_2 = CHCHO$) are lethal in concentrations of 200 p.p.m. or higher.

It is important to note that a combination of two or more of the products of combustion can lead to either antagonistic or synergistic effects. That is, a mixture of two gases can give either a smaller or a larger effect than that expected from the two individual gases. Autian[27], Kimmerle[6] and others, have stated that the physiological and toxicological effects of single compounds produced in fires have not yet been fully clarified. Obviously the effects of a combination of these products on the human being is most complicated and although tests with animals (mainly rats and mice) are being used, there is still some controversy about the relevance of some of the tests. However, human volunteers for fire tests are not very common, and we therefore have to rely on these laboratory tests for the present.

TOXICITY OF BURNING TEXTILES

The relative toxicity rankings of a number of textile and other polymeric materials, as reported by Hilado and Cumming[31], are given in Table XVII.

TABLE XVII

RELATIVE TOXICITY RANKINGS OF BURNING MATERIALS[31]

Material	Time to death (min)
Modacrylic/rayon (70/30) fabric	4,6
Wool fabric	7,6
Polyester fabric	9,4
Leather	10,2
Cotton fabric	11,9
Nylon fabric	13,1
Polyurethane foam	13,8
Polyvinyl chloride	16,8
Polystyrene	20,0

The results given above were obtained by a specific test on mice and it is known that the relative ranking of the materials may vary, depending on the test conditions. In general, however, some of the materials are consistently amongst the most toxic, whilst others, such as polystyrene are consistently amongst the least toxic.

Hilado and Lopez[28] studies more than 100 upholstery fabrics and concluded that the fabric types could be ranked as follows in order of increasing toxicity: nylon, cotton, polyester, wool. Certain other research workers[29], however, are not in agreement with this ranking, and have pointed out that the ranking depends very much on the type of test and the specific test conditions employed. Benisek[30], for example, emphasised that great care should be taken when interpreting results of small scale tests, particularly where time to animal response is taken as criterion for toxicity ranking.

It is wellknown that hydrogen cyanide and nitrogen dioxide are of the most toxic gases, as is shown by the LC_{50} values for human beings, in Table XVIII. (The LC_{50} value is defined as the concentration of the toxic gas in the atmosphere being inhaled by the test object that will produce death in 50% of the cases within a defined period).

TABLE XVIII

PREDICTED LETHAL GAS CONCENTRATIONS FOR HUMANS[31]

Toxicant	LC_{50} (p.p.m) (30 minutes)
NH_3	55 000
CO	8 300
SO_2	8 000
HCℓ	7 700
HF	4 600
HCN	200
NO_2	180

A comparison between various textile fibres in terms of the amounts of toxic gases (carbon monoxide, hydrogen cyanide and hydrogen chloride) produced during pyrolysis is given in Table XIX.

TABLE XIX

AMOUNTS OF TOXIC GASES PRODUCED BY THE PYROLYSIS OF FIBRES AT 600°C[32]

Fibre	% Gas formed		
	CO	HCN	HCℓ
Cotton	22	—	—
Polyester	15	—	—
Wool	15	1	—
Nylon	13	1,2	—
Acrylic	7	2,6	—
Modacrylic	7	1,5	5
Aromatic polyamid (Nomex)	2	0	—

It is interesting to note that Schumacher and Breysse[33] estimated that, at 800°C, one kilogram of polyacrylonitrile (i.e. acrylic fibre, which is used extensively in knitteds) would produce enough hydrogen cyanide to give a concentration of 217 p.p.m. in a 28 m^3 room. This concentration of HCN would be fatal to any human being within a few minutes.

Apart from the toxic gases, a very large number of other products are normally formed by the combustion of textile fibres. In most cases more than 20 different products have been identified. Some typical products which are formed during the combustion of fibres are methane, ethylene, ammonia and a number of aldehydes[33].

It must be emphasised that even flame-retardant treated textiles may be pyrolysed or decomposed without burning by the heat of the fire from another item, and in this manner contribute to the accumulation of toxic products.

SUMMARY

A review of the literature has shown that the field of flammability and the toxicology of textiles is a very complex one. In fact, more that 3 500 papers have been published on flammability over the past 10 years, and more than 200 of those have dealt specifically with toxicological aspects of flammable textiles. The combustion or pyrolysis of textiles leads to the formation of a large number of products, some of which are very toxic. The relative amounts of toxic gases formed by textiles in a fire depends on various parameters, such as temperature and the availability of oxygen. Various laboratory tests, which have been developed for the evaluation of the relative toxicity of textiles, however, are not always in agreement. Apart from toxic gases, the heat and smoke produced by fibres are also hazardous.

The production of toxic gases by textiles in fires, forms only one aspect of this very complex field, and although toxicity is a highly emotional subject, it should not be considered to be more important than various other flammability characteristics, such as ease of ignition, spread of flame and heat release.

It should also be pointed out that most textiles can be treated with flame-retardant chemicals to reduce their flammability, or alternatively inherently flame retardant fibres can be used and thus the potential dangers associated with flammable textiles can be reduced considerably. Finally, the good old proverb "Prevention is better than cure", is most applicable in the case of fire accidents.

REFERENCES

1. Anon, *Fire Protection,* **8** (No. 2), 1 (June, 1981).
2. Anon, *Fire Protection,* **8** (No. 2), 7 (June, 1981).
3. Gaskill, J. R., *J. Fire Flam.,* **4**, 279 (1973).
4. Damant, G. H., *J. Consumer Prod. Flam.,* **5**, 20 (1978).
5. McDonald, K., Dardis, R. and Smith, B. F., *J. Fire Flam.,* **2**, 173 (1971).
6. Kimmerle, G., *J. Combust. Toxicol.,* **1**, 4 (1974).
7. Bryan, J. L., *J. Fire Flam.,* **6**, 17 (1975).
8. Hillenbrand, L. J. and Wray, J. A., *J. Consumer Prod. Flam.,* **1**, 115 (1974).
9. Finley, E.L., McDermott, F. G. and Carter, W. H., *J. Consumer Prod. Flam.,* **1**, 19 (1974).
10. Jin, T., *J. Fire Flam.,* **12**, 130 (1981).
11. Wood, P. G., The behaviour of people in fires, British Joint Fire Research Organization, Fire Research Note 953, (Nov., 1972).

12. Bryan, J. L., *J. Fire Flam.,* **7**, 319 (1976).
13. Buchbinder, L. B., *J. Consumer Prod. Flam.,* **1**, 4 (1974).
14. Pryor, A. J. and Yuill, C. H., An investigation of the hazards of Combustion Products in building fires, SWR 1, Project No.3-1237-3 South-West Research Institute, San Antonia (1963).
15. Montgomery, R. R., Reinhardt, C. F. and Terrill, J. B., *J. Combust. Toxicol.,* **2**, 179 (1978).
16. Prager, F. H., *J. Consumer Prod. Flam.,* **5**, 3 (1978).
17. Crikelair, G. F., *Textile Flammability and Consumer Safety, GDI Occasional Publications* No. 45, Zurich, 1969.
18. Stoll, A. M. and Chianta, M. A., *Aero-space Med.* **39**, 1092 (1968).
19. Chainard, M. P., Knodel, D. C. and Arnold, H. W., *Text. Res. J.,* **43**, 166 (1973).
20. Martin, E. P., Textile Flammability and Comsumer Safety, GDI Publications, No. 45, Zurich, 1969.
21. Einsele, U., *Melliand Textilber.,* **53**, 1395 (1972).
22. Bauer, R. G., *J. Fire Retard. Chem.,* **5**, 200 (1978).
23. Mohler, S.R., Aeromedical Research Program, First Annual Report to Industry, *Fed. Aviation Admin.,* Dept. of Transportation (13th June, 1967).
24. Tsuchiya, Y., Sumi., K., *J. Fire Flam.,* **5**, 64 (1974).
25. Smith, E. H., *J. Consumer Prod. Flam.,* **2**, 58 (1975).
26. Saito, F., *J. Combust. Toxicol.,* **4**, 32 (1977).
27. Autian, J., *J. Fire Flam.,* **1**, 239 (1970).
28. Hilado, C. J. and Lopez, M. T., *J. Consumer Prod. Flam.,* **4**, 40 (1977).
29. Benisek, L., *J. Combust. Toxicol.,* **5**, 101 (1978).
30. Benisek, L., *J. Coated Fabrics,* **11**, 41 (1981).
31. Hilado, C. J. and Cumming, H. J., *J. Combust. Toxicol.,* **4**, 415 (1977).
32. Muller, R. and Couchoud, P., *Melliand Textilber.,* **57**, 807 (1976).
33. Schumacher, R. L. and Breysse, P. A., *J. Combust. Toxicol.,* **3**, 393, (1976).

Published by
The South African Wool and Textile Research Institute,
P.O. Box 1124, Port Elizabeth, South Africa,
and printed in the Republic of South Africa
by Nasionale Koerante Beperk, P.O. Box 525, Port Elizabeth.

© Copyright reserved

ISBN 0 7988 2425 5