

TO R. Chartier
AT Assonet
FROM V. C. Pitts
AT New Haven
SUBJECT Polyvinyl Chloride - Decomposition
Project 8541-000
NHHS 74-38, S. 3

14+22
DATE May 10, 1974

COPY TO H. Bialecki
I. Capuano
R. Henderson
C. H. Hofrichter
R. E. Maizell
B. I. C.
T. R. C.

INGA INDEXED

The attached new material on thermal degradation of polyvinyl chloride has been collected since Mrs. Floto's memo of February 15, 1974. Do you wish us to continue collecting and forwarding such references or should we discontinue this program?

Virginia C. Pitts
V. C. Pitts

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TECH. INFO. SERV. NEW HAVEN

(37) Polyvinyl Chloride decomposition

OLI 7499

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OLI 7500

extreme or apparently inappropriate test conditions, but by so doing, if limiting behaviour can be identified, due account of this can be made in the design specification and the chances of successful performance can be improved.

Acknowledgement

The author wishes to thank Mr P.I. Vincent for his help and comments during discussion of this paper.

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Toxic products from plastics materials in fires

W.D. Woolley BSC, PHD, MIFIREE

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Abstract: Over one-half of the fatalities in fires are caused by smoke and toxic gases. Work is in progress at the Fire Research Station to study the production of toxic gases when plastics materials are decomposed under controlled laboratory conditions involving pyrolysis at temperatures up to 1000°C and in full-scale fires using a special compartment with a variable ventilation slit (door) leading to a corridor. When heated above about 190°C, PVC releases the toxic gas hydrogen chloride. At 300°C this dehydrochlorination is rapid and quantitative. In fires involving wood and PVC fuels the main toxic products are carbon monoxide and hydrogen chloride and the contribution of hydrogen chloride to the over-all toxicity depends upon the fuel loadings and ventilation. Pyrolysis of flexible polyurethane foam at about 300°C releases a polymeric 'yellow smoke' which decomposes at temperatures above 800°C in nitrogen (500°C in air) to give a range of nitrogen-containing compounds, particularly hydrogen cyanide. Fires involving industrial loads of foam show that temperatures in excess of 1000°C (sufficiently high to decompose the yellow smoke) are attained within a few minutes. During the early stages of the fire the toxic hazard from hydrogen cyanide can approach the same order of magnitude as that from the carbon monoxide.

1 Introduction

Last year in the United Kingdom approximately 1000 persons died as a direct result of fire. Evidence indicates that over one-half of the fatalities were caused by the combined effects of smoke and toxic gases and that the remainder were due to burns and other injuries. In addition, many thousands of persons were involved in potentially hazardous fire situations.

The effects of smoke and toxic gases can be considered separately. The main effect of smoke is that it reduces visibility and hence hinders escape, whereas the effect of toxic gases, coupled with oxygen depletion of the atmosphere and heat exposure, is to kill. Certain toxic gases at sub-lethal levels can directly hinder escape by producing

severe eye and inhalation irritancy. Other toxic gases that are odourless kill rapidly without warning.

This paper will outline the current work being carried out at the Fire Research Station to study the release of toxic products when building and furnishing materials are involved in fires. As examples the paper will report the results of two well known and topical materials, namely polyvinyl chloride (PVC) and polyurethane foam.

Essentially, the research is divided into two main areas involving, first, small-scale laboratory decomposition experiments under simulated fire conditions, and, secondly, full-scale fire tests. It is relevant in this report to discuss the experimental facilities and procedures and then give a broad survey of the results.

2 Experimental procedures OLI 7501

2.1 Laboratory experiments

In the laboratory studies, small samples of material are decomposed in a furnace system under the conditions likely to be encountered in fires, i.e. temperatures up to and in excess of 1000°C in environments ranging from air to a serious deficiency of oxygen. This is in fact a study of the

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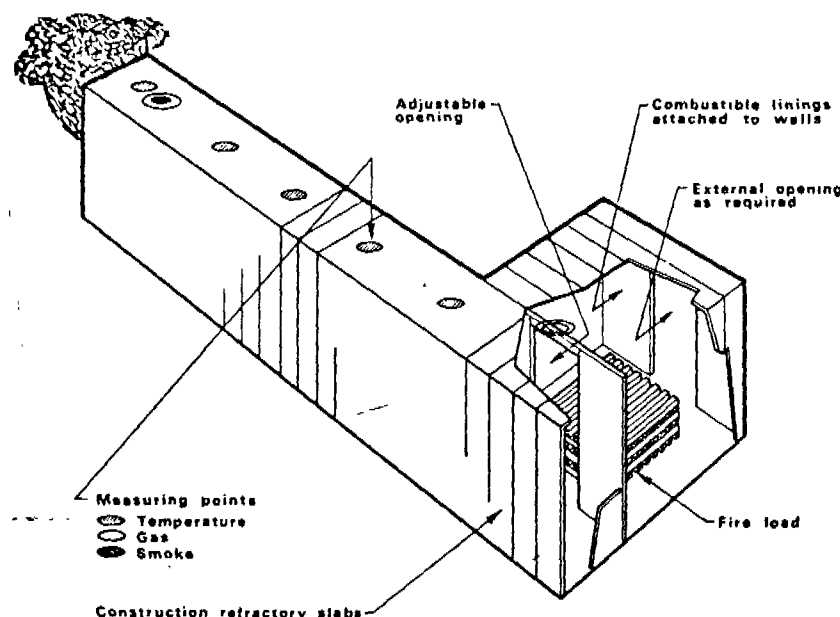


FIG 1 Compartment and corridor for fire tests

thermal and thermal-oxidative decomposition of materials. The volatile products released from the decomposition are collected in a refrigerated trap coupled on-line to a research gas-chromatograph/mass-spectrometer unit. In this way the products released under various decomposition conditions can be identified quantitatively and qualitatively. From this information it is possible to make an appraisal of the toxic species likely to be encountered in fires.

As shown later in this report, a further important feature of the laboratory studies is the elucidation of the decomposition mechanisms and the evaluation of decomposition kinetics. Information obtained from laboratory tests is vital in the design and evaluation of experiments involving the full-scale fire rig.

2.2 Full-scale fire experiments

A schematic diagram of the experimental fire compartment with corridor is shown in FIGURE 1; it consists of a compartment (approximately 3 × 3 m in area and 2.5 m high) with a variable ventilation slit (door) leading to a corridor (1.3 m wide and 12.6 m long). Basically it is designed to represent a fire situation in a compartment adjacent to an escape route. The rig can be loaded directly with plastics materials or alternatively lined with plastics wall linings (either inside the compartment or inside the corridor) with a cellulosic fuel crib. Alternatively, specific items (eg chairs or beds) can be introduced directly into the compartment for tests.

The rig is fully instrumented for monitoring the compartment and corridor gas temperatures, for measuring the smoke evolution and for sampling gases at various points for subsequent analysis of toxic products. Carbon monoxide and oxygen concentrations in the fire gases are monitored in all tests. Other toxic species are monitored as required.

3 Results

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3.1 Polyvinyl chloride

3.1.1 Laboratory tests. PVC is now widely used in buildings both in the structure and in the furnishings. Concern has been expressed that when involved in fires PVC releases a number of highly toxic species such as

phosgene. Recent work at the Fire Research Station has done much to eliminate the concern over phosgene.¹

The release of the toxic gas hydrogen chloride from the thermal decomposition of PVC is now well established. This dehydrochlorination becomes significant at temperatures above about 190°C, and the higher the temperature the more rapid is the release of hydrogen chloride. Air tends to increase the rate of dehydrochlorination for a given temperature. At high temperatures there is a virtually quantitative release of all the available chloride as hydrogen chloride.

From consideration of the kinetics of dehydrochlorination² for a typical rigid (unplasticized) PVC it has been shown that the extent of dehydrochlorination for a given temperature is given by

$$(100-P)^{-1} = 0.1 + \frac{1}{2}kt \quad (1)$$

where P is the extent of dehydrochlorination (as a percentage of the theoretical),

t is the decomposition time in minutes, and

k is the rate constant, given by

$$\log_{10}k = 15.27 - 9.13 \times 10^3 (1/T) \quad (2)$$

for inert atmospheres and

$$\log_{10}k = 12.93 - 7.86 \times 10^3 (1/T) \quad (3)$$

for air atmospheres. T is the decomposition temperature in degrees absolute. The times for various percentages of dehydrochlorination in inert and air atmospheres as calculated from eqns 1, 2 and 3 are given in TABLE 1.

Table 1 Calculated time for 20–60 per cent of theoretical dehydrochlorination in nitrogen and air between 200° and 300°C

TEMPERATURE °C	EXTENT OF DEHYDROCHLORINATION					
	20%		40%		60%	
	NITROGEN	AIR	NITROGEN	AIR	NITROGEN	AIR
200	min	min	min	min	min	min
220	251.4	114.9	619.8	283.3	1237.8	565.8
240	41.4	24.3	102.1	60.0	204.0	119.8
260	7.9	5.8	19.4	14.3	38.7	28.6
280	1.69	1.55	4.16	3.82	8.31	7.62
300	0.41	0.45	1.00	1.12	2.00	2.23
	0.11	0.14	0.27	0.36	0.53	0.71

Under non-isothermal dehydrochlorination conditions (ie where the temperature rises as a function of time) as in fires, a time interval summation process has been used for calculating the total hydrogen chloride released as a function of time from a knowledge of the temperature/time profile of the PVC.

The equation for this process is

$$(100 - P_n)^{-1} = 0.1 + \frac{1}{2} \Delta t \sum_{i=1}^{i=n} k_{(mi)} \quad (4)$$

where P_n is the total hydrogen chloride (as a percentage of the theoretical) released at the end of the n th interval, Δt is the time interval in minutes and $k_{(mi)}$ is the rate constant at the mean temperature of the i th interval as calculated from eqn 2 or 3.

A comparison between the experimental and calculated dehydrochlorination of PVC subjected to a temperature rise from 190° to 286°C in about 20min is given in FIGURE 2. As can be seen, there is good agreement between the experimental and theoretical behaviour except that the experimental curve lags behind the theoretical curve. This lag is due to the experimental collection delay. The potential of this method in studies of real fire situations is at present being evaluated.

After dehydrochlorination of PVC has taken place, the residue has a conjugated polyene structure which itself decomposes to give a complex mixture of products; these have been identified by gas chromatography and mass spectrometry¹ as consisting of saturated and unsaturated hydrocarbons with a predominance of aromatic materials, particularly benzene. The presence of air during decomposition acts as a catalyst and increases the yields of the hydrocarbons but without the formation of any oxy-

genated organic species. Oxidation does of course produce oxides of carbon.

From the laboratory studies it is concluded that the main toxic risk from PVC arise from carbon monoxide and hydrogen chloride. Contrary to certain popular belief, there are no significant quantities of phosgene, chlorine or organic halides. The hydrocarbons themselves make little contribution to over-all toxicity but the aromatics are clearly precursors of smoke formation.

3.1.2 Full-scale tests. A typical full-scale fire test, to study the behaviour of PVC in fires, involves a wooden crib (127 kg) as the main fuel source in the compartment, the walls being lined with 100 kg of rigid PVC, and having a ventilation slit 700mm wide. A comparative experiment is carried out with wood alone (127 kg) in the compartment.

FIGURE 3 shows the gas temperatures in the compartment as a function of time for these tests. The experiment with PVC gives a higher temperature for a longer period than wood alone, due to the extra heat contribution from the PVC. Typical concentrations of carbon monoxide and hydrogen chloride recorded during these tests are given in FIGURE 4. The concentration scales are adjusted in the ratio of 2:1 to show equivalent toxicities since carbon monoxide is directly hazardous to life at 3000 ppm and hydrogen chloride at 1500 ppm. With hydrogen chloride there is the added problem that it is a

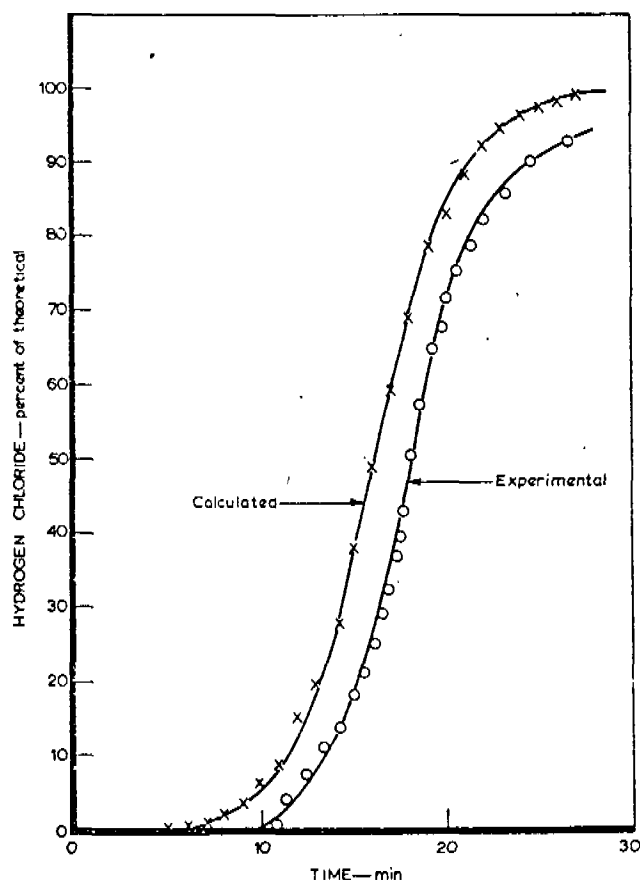


FIG 2 Calculated and experimental dehydrochlorination

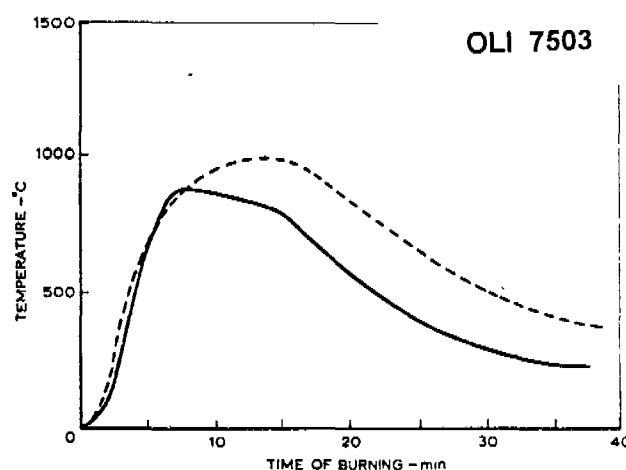


FIG 3 Gas temperatures for wood and PVC fires

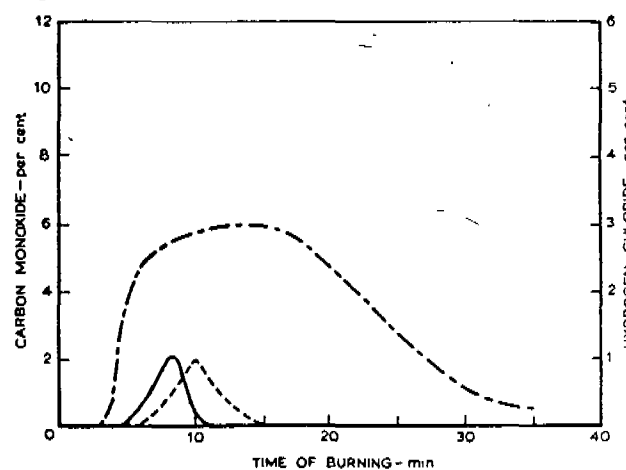


FIG 4 Toxic gas production from wood and PVC fires

— Carbon monoxide (wood)
 --- Carbon monoxide (wood and PVC)
 -.- Hydrogen chloride (wood and PVC)

severe eye and inhalation irritant, and concentrations as low as 100 ppm have been reported as intolerable to breathe.³

From tests of this kind a number of broad conclusions can be reached for fires involving wood and PVC fuels:⁴

- If the ventilation is low the fire develops slowly; carbon monoxide production is important and hydrogen chloride is released relatively late and slowly.
- With high ventilations the fire develops rapidly; carbon monoxide production is relatively low and hydrogen chloride is released relatively early and rapidly.
- If PVC is present in the fire load (eg as in furnishings) hydrogen chloride will be released earlier and more rapidly than if the PVC is present as a wall lining.

3.2 Polyurethane foams

3.2.1 Laboratory tests. Polyurethane foam is used in flexible form in furnishings and in rigid form in certain applications within the structures of buildings.

There has been concern that toxic products containing nitrogen (such as hydrogen cyanide) could be released in fires involving polyurethane foams, although until recently there has been little information to substantiate this view. In fact, early decomposition studies have tended to support the view that virtually no nitrogen-containing materials are released during thermal decomposition and that the nitrogen content of the foams remains in the non-volatile residue.

The first consideration in studies of the decomposition behaviour of polyurethane foams was to monitor the nitrogen losses during thermal decomposition and to compare these with the corresponding weight losses. This was effected by decomposing samples of both rigid and flexible polyurethane foams in a furnace for 15-min intervals at fixed temperatures and analysing the residues by elemental ultramicroanalysis (for the determination of the weight percentages of carbon, hydrogen and nitrogen). FIGURE 5 shows the comparisons between the weight and nitrogen losses for a typical MDI rigid polyurethane foam (prepared from diphenyl methane 4,4'-diisocyanate) showing a general decomposition behaviour with only little evidence of any extra nitrogen retention in the residue.

FIGURE 6 shows the equivalent data for samples of TDI polyester and polyether flexible foams (prepared from tolylene diisocyanate). In each case there is identical behaviour and a preferential loss of a nitrogen-rich material, and at 300°C there is a virtually complete loss of the nitrogen content of each foam with a corresponding weight loss of about 30 per cent. Because of this behaviour and of the wide use of TDI flexible foams within buildings, recent research efforts have been devoted to the flexible foams and will be extended to rigid foams at a later date.

It is now known that the behaviour of the TDI flexible (polyester and polyether) polyurethane foams represents a depolymerization process,⁵ namely that the foams decompose to give the parent polyol and TDI. Fortunately the TDI (a highly toxic material) is not released in 'free' form but mainly as a yellow smoke (probably a polymeric form of TDI) which has been isolated in the laboratory. The yellow smoke from the polyester foam appears to be identical with that obtained from the polyether material. Its elemental composition is approxi-

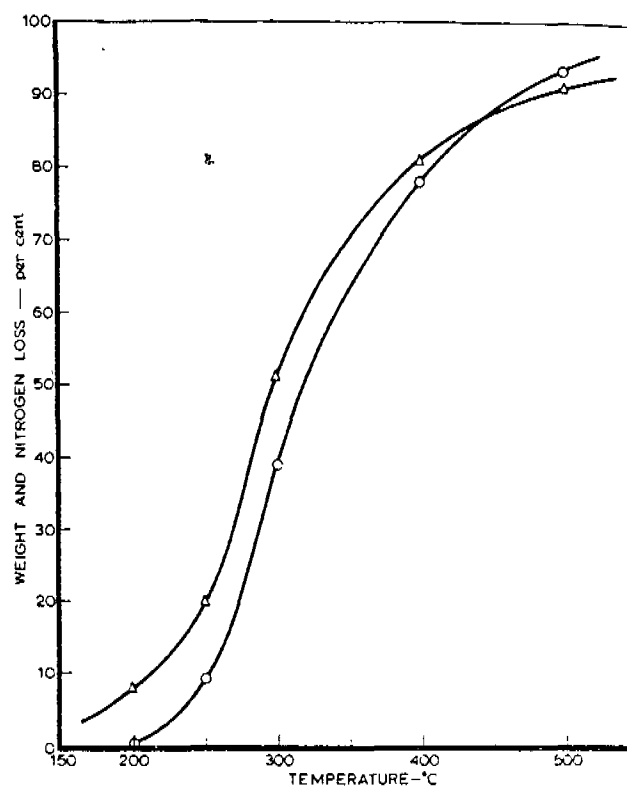


FIG 5 Decomposition data for MDI rigid polyether foam

○ Nitrogen loss
△ Weight loss

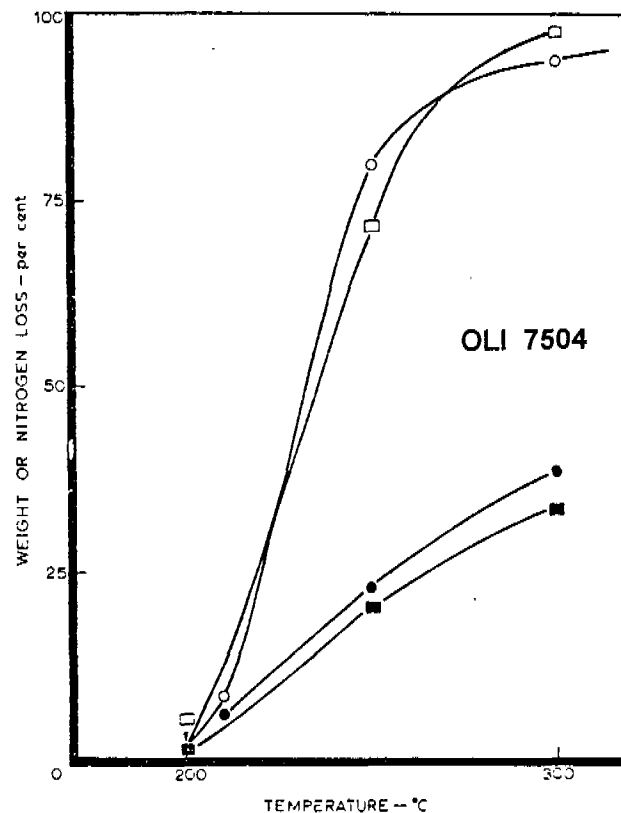


FIG 6 Decomposition data for TDI flexible polyether and polyester foams

○ Nitrogen loss, polyester ● Weight loss, polyester
□ Nitrogen loss, polyether ■ Weight loss, polyether

mately 64 per cent carbon, 6 per cent hydrogen and 17.5 per cent nitrogen, the remainder being oxygen. The yellow smoke is relatively stable to thermal decomposition and will volatilize unchanged from furnace systems at

temperatures up to 800°C but will decompose readily above that temperature.

Chromatograms (flame ionization detection) of the decomposition products of the yellow smokes obtained from the polyester and polyether foams and decomposed at 850°C are shown in FIGURE 7. The similarities between the 'finger print' chromatograms are evident and confirm the chemical similarities between the two smokes. The identifications of the decomposition products obtained by coupled gas-chromatography/mass-spectrometry are listed in TABLE 2. The main nitrogen-containing materials are hydrogen cyanide, acetonitrile, acrylonitrile, pyridine and benzonitrile, and of these hydrogen cyanide predominates. The yields of hydrogen cyanide increase with temperature, and at 1000°C (maximum temperature used) approximately 70 per cent of the theoretically available nitrogen of each polyurethane foam is released, via the yellow smoke intermediate, as hydrogen cyanide. The yields of cyanides obtained either directly from the decomposition of the foams or indirectly from the decomposition of an equivalent weight of yellow smoke are in good agreement. In air atmospheres the decomposition proceeds by the same yellow smoke intermediates as those observed during pyrolysis experiments. Further, the intermediates release the same nitrogen-containing materials (of which hydrogen cyanide again predominates) but they decompose at a much lower temperature.

The yields of hydrogen cyanide from the polyester yellow smoke, decomposed either directly or via the decomposition of the foam in inert and air atmospheres, are shown in FIGURE 8.

Table 2. Identifications of the decomposition products of the yellow smokes by mass spectrometry (see Fig 7)

PEAK NOMENCLATURE	MASS-SPECTROMETRIC INTERPRETATION
a	Nitrogen*
b	Carbon dioxide
c	Ethylene
d	Ethane
e	Water
f	Propane
g	Hydrogen cyanide
h	Not identified
i	Butyne or butadiene
j	Acetonitrile
k	Acrylonitrile
l	Propionitrile
m	Methyl acrylonitrile or vinyl acetonitrile
n	Benzene
o	Methyl acrylonitrile or vinyl acetonitrile
p	Not identified
q	Pyrrole
r	Pyridine
s	Toluene
t	Methyl pyridine
u	Methyl pyridine
v	Cyclooctatetrene or styrene
w	Vinyl pyridine
x	Benzonitrile or benzamide
y	Not identified
z	Indene
A	Methyl cyanobenzene†
B	Methyl cyanobenzene†
C	Not identified
D	Not identified
E	Naphthalene
F	Quinoline or isoquinoline
G	Not identified

*Furnace carrier gas.

†Other possibilities, phenyl acetonitrile or indole.

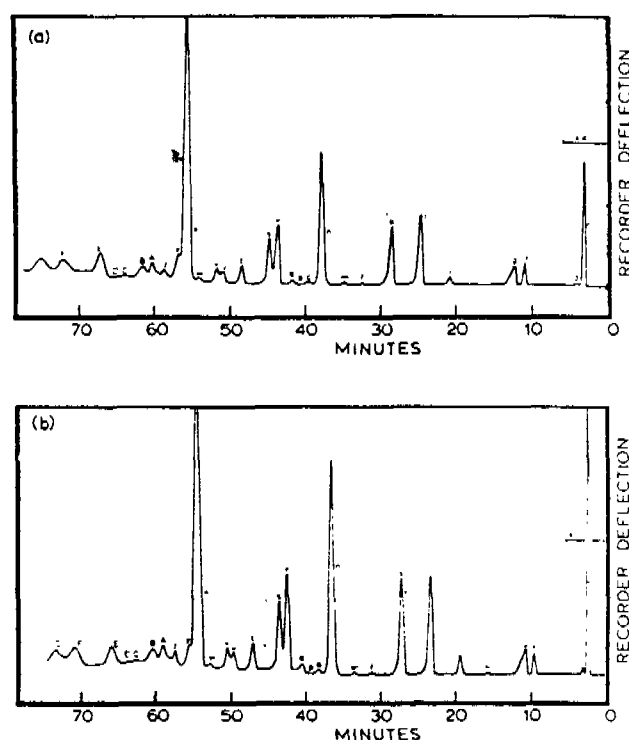


FIG 7 Chromatograms of the decomposition products of yellow smokes at 850°C
(a) from polyether foam
(b) from polyester foam
(For identifications see Table 2)

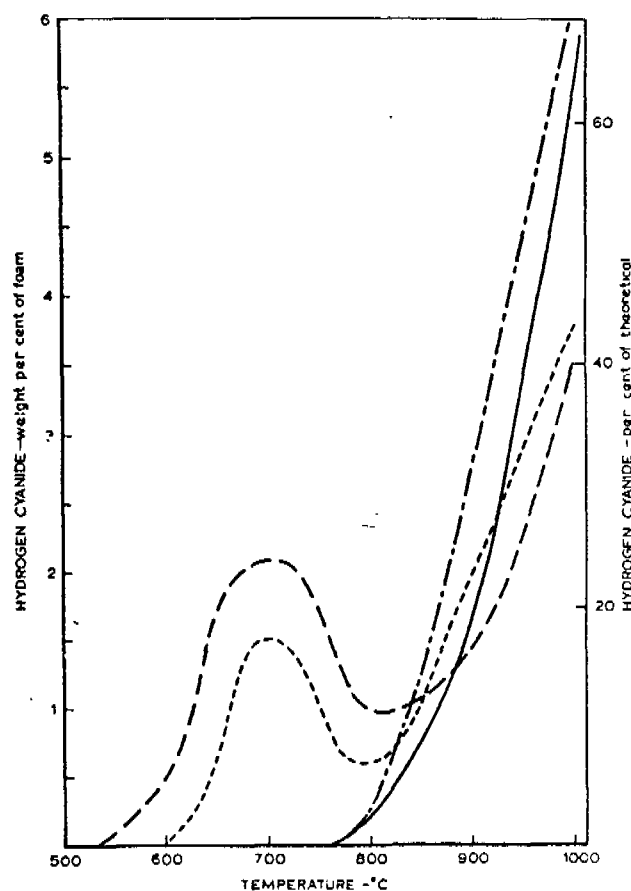


FIG 8 Yields of hydrogen cyanide from polyester yellow smoke and foam in nitrogen and air
— Yellow smoke, nitrogen - - - Yellow smoke, air
- - - Foam, nitrogen . . . Foam, air

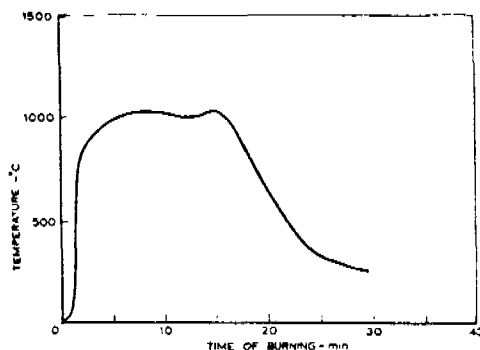
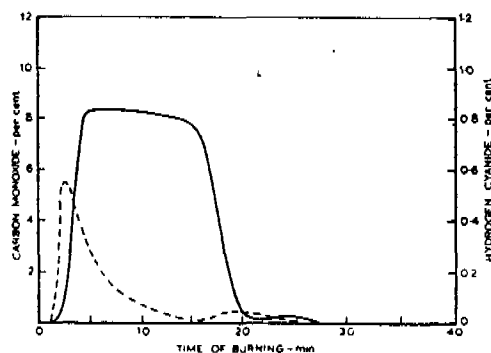


FIG 9 Gas temperature for polyurethane fire

Current work is directed towards studies of the production of oxides of nitrogen in air atmospheres and the possible release of free TDI from the foams.

3.2.2 Full-scale tests. A number of full-scale fires involving industrial loads of flexible polyether polyurethane foams have been carried out in the test rig. FIGURE 9 shows the temperature within the compartment for a foam test of 135 kg (ventilation slit 1.15 m wide) which is typical of the general fire behaviour of these foams and shows a rapid temperature rise followed by a 'steady-state' burning condition. Because of the rapid temperature rise the yellow smoke can survive in the compartment only during the first few minutes of the test. Subsequently, decomposition takes place within the hot gaseous zone of the compartment. Samples of the fire gases have been extracted from the compartment during the 'steady state' burning and have been analysed in the laboratory. As expected, hydrogen cyanide, acetonitrile, acrylonitrile, benzene, pyridene, toluene and benzonitrile have been detected from the decomposition of the yellow smoke. Further, the relative proportions of these materials are in good agreement with the values expected on the basis of the temperature and oxygen concentration within the compartment.

The concentrations of carbon monoxide and hydrogen cyanide (plotted on scales of equivalent toxicities as estimated from toxicological literature^{6,7}) are shown in FIGURE 10. Hydrogen cyanide is taken as being directly hazardous to life at 300 ppm; carbon monoxide is hazardous at 3000 ppm and the scales of FIGURE 10 have been adjusted in the ratio of 10:1. In the early stages of the fire the hazard from cyanides can approach the same order of magnitude as that from the carbon monoxide. The reason for the rapid decline in the hydrogen cyanide

FIG 10 Toxic gas production from polyurethane fire
— Carbon monoxide
--- Hydrogen cyanide

yields after about five minutes is uncertain; it may be associated with an initial and relatively rapid loss of yellow smoke, which subsequently decomposes leaving a polyol residue which continues burning almost as a liquid.

4 Discussion

As has been indicated in this report, the study of toxic gas production from even a single material requires an extensive research programme covering the full range of temperatures and atmospheres likely to be encountered in fires. Basically this programme involves the qualitative and quantitative analysis of the chemical nature of the products formed during both small-scale laboratory experiments and full-scale fire tests. This analysis identifies only by chemical nature. There is no instrumentation available which will measure toxicity or irritancy.

The assessment of the toxicity of the chemical products is made on the basis of published data^{3,6} obtained from human and animal exposures when available. Such data are very limited, and when applied to fire gases they do not necessarily indicate the true over-all toxicity for a number of reasons, particularly

- that the toxicities of certain chemical species may be as yet unknown;
- that there may be interactions (synergisms) between the effects of different toxic species, and that mixtures of toxic materials may be more hazardous than expected.

The Fire Research Station has therefore recently placed a contract for toxicity studies with the Chemical Defence Establishment at Porton. This work, which is now forming an important addition to the laboratory and full-scale tests, is aimed at evaluating by animal experiments the toxicities of the fire gases from both wood and a number of important plastics. In this way it is hoped to establish whether the toxicities of the fire gases can be attributed to the carbon monoxide present and hence to determine whether there is a significant contribution from other toxic species.

Animal experiments of this kind also give the opportunity to study synergistic effects of toxic species and to consider other important physiological effects of fire gases such as irritancy.

In addition to the Porton contract the Fire Research Station has placed substantial contracts at the Industrial Materials Research Unit (IMRU) of Queen Mary College and at the Rubber and Plastics Research Association (RAPRA) at Shawbury. The work at IMRU involves important fundamental studies of the smoke formation from plastics involved in fires. At RAPRA, the fire hazard of plastics in furniture and furnishings is being considered, and the work initially involves ignition and fire development measurements followed by smoke and toxic gas production from complete items of furniture (composites) rather than individual plastics components.

Acknowledgements

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THERMAL DEGRADATION OF POLY(VINYL CHLORIDE). I. APPARATUS
FOR INVESTIGATION FOR EARLY STAGES OF THERMAL DEGRADATION
ABBAS, KENT B. / SORVIK, ERLING M.
DEP. ORG. CHEM. / CHALMERS UNIV. TECHNOL. / GOTEBOG
SWED.
J. APPL. POLYM. SCI.
JAPNAB, VOL 17 ,ISS 12 , YR 1973, PGS 3567- 76
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THERMAL DEHYDROCHLORINATION KINETICS PVC
CONDUCTIMETRIC DETN HYDROGEN CHLORIDE

800027610N VOL=80 ISS=06 SEC=35 WT= 9 CA447CARD 6
THERMAL DEGRADATION OF POLY(VINYL CHLORIDE). II. DEGRADAT
ION MECHANISM BASED ON DECOMPOSITION ENERGETICS
GUPTA, V. P. / ST. PIERRE, L. E.
DEP. CHEM. / MCGILL UNIV. / MONTREAL / QUE.
J. POLYM. SCI., POLYM. CHEM. ED.
JPLCAT, VOL 11 ,ISS 8 , YR 1973, PGS 1841- 50
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PVC THERMAL DEGRDN KINETICS
CHLOROPROPENE VINYL CHLORIDE COPOLYMER

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DEGRADATION OF POLY(VINYL CHLORIDE). III. KINETICS OF THE
RMAL DEHYDROCHLORINATION CATALYZED BY SLOW-DIFFUSING HYDROG
EN CHLORIDE
CARENZA, M. / MOISEEV, YU. V. / PALMA, G.
LAB. FOTOCHIM. RADIAZ. ALTA ENERG. / CONS. NAZ. RIC.
PADUA / ITALY
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JAPNAB, VOL 17 ,ISS 9 , YR 1973, PGS 2685- 94
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HYDROGEN CHLORIDE DEGRDN CATALYST
CATALYST DEHYDROCHLORINATION PVC

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PYROLYSIS OF POLY(VINYL CHLORIDE). FORMATION OF AROMATIC C
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HYDROGEN CHLORIDE PVC PYROLYSIS
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OXIDE METAL PVC PYROLYSIS
CHLORIDE METAL PVC PYROLYSIS

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800060368N VOL=60 ISS=12 SEC=35 WT=18 CA447CARD 7
THERMAL DECOMPOSITION OF A VINYL CHLORIDE-PROPYLENE COPOLYMER
MYAKOV, V. N. / TROITSKII, B. B.
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PROPYLENE COPOLYMER DECOMPN
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800048535G VOL=80 ISS=10 SEC=35 WT=16 CA447CARD 1
EFFECT OF SOME METAL CHLORIDES ON THE THERMAL DECOMPOSITION
OF POLY(VINYL CHLORIDE) AND POLY(VINYLDENE CHLORIDE)
MYAKOV, V. N. / TROITSKII, B. B.
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//KEYWORDS//
PVC THERMAL DECOMPN
POLYVINYLDENE CHLORIDE THERMAL DECOMPN
DEHYDROCHLORINATION MECHANISM PVC
MERCURIC CHLORIDE DEHYDROCHLORINATION PVC
FERRIC CHLORIDE DEHYDROCHLORINATION PVC
TIN TETRACHLORIDE DEHYDROCHLORINATION PVC
TITANIUM TETRACHLORIDE DEHYDROCHLORINATION PVC
INITIATOR DEHYDROCHLORINATION PVC
CATALYST DEHYDROCHLORINATION PVC

79C126883Q VOL=79 ISS=22 SEC=35 WT= 9 CA447CARD 5
STUDY OF THERMAL DECOMPOSITION OF POLY(VINYL CHLORIDE)-TYPE
POLYMERS USING MODEL SUBSTANCES. V. PYROLYSIS OF CIS-5-C
HORO-3-HEPTENE AND CIS- AND TRANS-5-ACETOXY-3-HEPTENE IN T
HE GAS PHASE
CHYTRY, V. / OBEREIGNER, B. / KRIVINKOVA, O.
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//KEYWORDS//
PVC THERMAL STABILITY
VINYL ACETATE POLYMER STABILITY
CHLOROHEPTENE PYROLYSIS KINETICS
ACETOXYHEPTENE PYROLYSIS KINETICS
DEGRDN PVC
HEPTENE DERIV PYROLYSIS KINETICS

OLI 7508

790126895V VOL=79 ISS=22 SEC=35 WT= 9 CA447CARD 6
THERMAL DEGRADATION OF POLY(VINYL CHLORIDE) IN THE PRESENCE
OF POLY(METHYL METHACRYLATE)
EKSTRIN, F. A. / KULIKOVA, A. E. / LYUTOVA, T. M.
SHILOV, G. I.
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THERMAL DEGRDN PVC POLYMETHACRYLATE

780072822D VOL= 78 ISS= 12 WT= 9 CA447CARD 20
THERMAL DEGRADATION AND COLOR SHADES OF POLY(VINYL CHLORIDE
) (SPECTROSCOPIC STUDY)
SMIRNOV. L V
PLATONOVA. N V
KULIKOVA. N P
GRACHEV. V I
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HEAT DEGRDN PVC
IR PVC DEGRDN
UV PVC DEGRDN
COLOR STABILITY PVC

780072872U VOL= 78 ISS= 12 WT= 9 CA447CARD 27
THERMAL STABILITY TESTING OF POLY(VINYL CHLORIDE)
MITTERBERGER, DIETER
HOLD. FUDOLF
FARBWERKE HOFCHST A -G
GENDORF
GUMMI. ASBEST. KUNSTST
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OLI 7509

800083782G VOL=80 ISS=16 SEC=35 WT=11 CA447CARD 9
STUDY OF THE THERMAL DEGRADATION OF POLY(VINYL CHLORIDE) BY
THERMAL ANALYSIS AND ESR SPECTROMETRY
SHIMOKAWA, SHIGEZO / OHNO, YASUHIRO / SOHMA, JUNKICHI
HIRANO, HARUMUCHI / ENDOH, KAZUO
FAC. ENG. / HOKKAIDO UNIV. / SAPPORO / JAPAN
NIPPON KAGAKU KAISHI
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800083781F VOL=80 ISS=16 SEC=35 WT= 9 CA447CARD 8
COMBUSTIBILITY OF POLY(VINYL CHLORIDE). II. PYROLYSIS OF
POLY(VINYL CHLORIDE) CONTAINING PHOSPHATES
YOSHINAGA, SHUNICHI / MATSUMOTO, MASARU
NAGAISHI, TOSHIYUKI / HARA, YASUTAKE / OSADA, HIDEYO
FAC. ENG. / KYUSHU SANGYO UNIV. / FUKUOKA, / JAPAN
NIPPON KAGAKU KAISHI
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PVC SODIUM PHOSPHATE PYROLYSIS
PYROPHOSPHATE SODIUM PVC PYROLYSIS
HYDROGEN PHOSPHATE PVC PYROLYSIS

800083835B VOL=80 ISS=16 SEC=35 WT= 9 CA447CARD 14
THERMAL DECOMPOSITION OF SOLID POLYMERS
BOUCHER, E. A. / EVERETT, D. H. / MILLARD, P. L.
SHARMA, K. R.
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POLYVINYLIDENE CHLORIDE DEHYDROCHLORINATION KINETICS
POLYMETHYL VINYL KETONE DEHYDRATION
MORPHOL POLYMER THERMAL DEGRDN

800071239X VOL=80 ISS=14 SEC=35 WT= 9 CA447CARD 5
THERMAL DEGRADATION AND STABILIZATION OF POLY(VINYL CHLORIDE). XV. ACTIONS AND EFFECTS OF ORGANOBORON COMPOUNDS ON THE THERMAL DECOMPOSITION OF POLY(VINYL CHLORIDE)
MORIKAWA, TAKESHI / AMANO, TAKAO
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KOBUNSHI KAGAKU
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BORATE ESTER PVC DEGRDN
BORANE ORGANO PVC DEGRDN
ORGANOBORON COMPD PVC DEGRDN
HYDROBORATION PVC ORGANOBORANE COMPD

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