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ABSTRACT

The toxicity of the pyrolysis gases from six elastomers was investigated, using the screening test method developed at the University of San Francisco. The elastomers were polyisoprene (natural rubber), styrene-butadiene rubber (SBR), ethylene propylene diene terpolymer (EPDM), acrylonitrile rubber, chlorosulfonated polyethylene rubber, and polychloroprene.

Changing from a rising temperature program (40°C/min) to a fixed temperature program (immediate exposure to 800°C) resulted in shorter times to animal responses. This effect is attrituted in part to more rapid generation of toxicants.

The rising temperature and fixed temperature programs produced exactly the same rank order of materials based on time to death. Acrylonitrile rubber exhibited the greatest toxicity under these test conditions; carbon monoxide was not found in sufficient concentrations to be the primary cause of death.

INTRODUCTION

Elastomers are a class of materials which are used in a wide variety of applications, many of which involve possible exposure to fire. Information on their relative toxicity is therefore of considerable potential value. Earlier work at the University of San Francisco showed that elastomers exhibited a range of toxicity (1), and that test conditions affected test results and could affect relative rankings (2).

This paper presents the results of studies of the toxicity of the pyrolysis gases from six elastomers. A gradual heating rate, intended to simulate the pre-flashover conditions of a developing fire, was provided by the rising temperature program at 40°C/min. A rapid heating rate, intended to simulate the post-flashover conditions of a fully developed fire, was provided by the fixed temperature program at 800°C.

The plan of investigation consisted of the following steps: first, performance of experiments on the synthetic polymers using both the fixed temperature and rising temperature programs; second, analysis of the animal responses to determine the effect of temperature program on animal response times and on time intervals between specific responses, for the different polymers; third, comparison of the animal response times with the response times reported for known concentrations of the toxicants expected from specific polymers; fourth, comparison of the toxicant concentrations required to produce the observed effects with the concentrations of those toxicants determined by gas analysis of the chamber atmospheres.

MATERIALS

The elastomer samples evaluated in this study were identified as follows:

Polyisoprene, natural rubber, smoked sheet, raw polymer

Styrene-butadiene rubber, SBR #1502, raw polymer

Ethylene propylene diene terpolymer (EPDM), raw polymer, Nordel 1440, Du Pont

Acrylonitrile rubber, raw polymer, Hycar 1042, B. F. Goodrich.

Chlorosulfonated polyethylene rubber, raw polymer, Hypalon 40, Du Pont.

Polychloroprene, raw polymer, Neoprene GNA, Du Pont.

APPARATUS

A Lindberg horizontal tube furnace is used for pyrolysis. The sample material is pyrolyzed in a quartz boat centered in a quartz tube, closed at one end with a cap and connected at the open end to the animal exposure chamber.

The animal exposure chamber is of a design developed and patented by NASA and is made of clear polymethyl methacrylate so that continuous observation of the animals is facilitated. The activity of the free moving mice in the chamber allows observation of natural, unrestrained behavior which can be recorded by the average lay person. This spontaneous activity appears to result in fairly uniform distribution of the gases throughout the chamber volume.

The polymethyl methacrylate is superior to glass in ease of fabrication, light weight, resistance to shock, and inertness to hydrogen fluoride, which is a pyrolysis effluent from some synthetic polymers. The chamber has a total free volume of 4.2 liters, and is made of an upper dome section and a lower base section, both with a diameter of 203 mm (8 in).

The upper dome section is removable, and is connected to the base section by means of a conventional toggle snap ring; the joint is sealed by an O-ring. Access to the chamber is provided by two horizontal cylinders of different diameter mounted on the dome section. The larger horizontal cylinder, having a diameter of 59 mm (2.38 in), is fitted with an adapter to accomodate the open end of the pyrolysis tube. The smaller horizontal cylinder, having a diameter of 39 mm (1.56 in), is fitted with an adapter to accomodate the probe of a Beckman process oxygen analyzer, and serves also as the entry port for the test animals. A perforated polymethyl methacrylate plate across the larger horizontal cylinder prevents movement of the mice into the pyrolysis tube.

The upper end of the dome section is provided with apertures and a clear polymethyl methacrylate cylinder having a cover plate; the cover plate is connected to a bubbler to permit venting of pressure exceeding 25 mm (1 in) of water and prevent entry of fresh air, and is provided with fittings for a thermometer and for gas sampling.

PROCEDURE

The pyrolysis tube, pyrolysis boat, animal exposure chamber, and all fittings and adapters are thoroughly cleaned and dried before each test. The pyrolysis boat is weighed without and with the sample under test. A sample weight of 1.00 g is normally used for screening studies, and was used in this study.

The test animals are received in plastic cages, with each test group in its own cage. Each animal is removed, inspected for freedom from abnormalities, weighed, and marked on some part of the body with different colors of ink for identification. Four Swiss-Webster male mice, 25 to 35 g body weight, are used for each test. Four appears to be the optimum number of mice which can be used for each test without excessive oxygen consumption during the test period, as well as the largest number which can be satisfactorily observed by a single operator.

Each experiment is repeated two or more times. This replication provides measures of variation between test animals and between experiments.

The mice are placed in the animal exposure chamber and given a minimum of 5 min to accustom themselves to their surroundings. The entire system is sealed (except for the safety vent) and all joints are checked for proper seating. The pyrolysis tube containing the sample is introduced into the furnace, which is preheated to 200°C in the case of the rising temperature program, or 800°C in the case of the fixed temperature program. In the case of the rising temperature program, the furnace is turned on at the start of the test at the predetermined heating rate of 40°C/min; when the furnace approaches or reaches 800°C, this temperature is maintained by either automatic or manual control until the end of the test. The test period is 30 min, unless 100% mortality occurs earlier; the test is terminated upon the death of the last surviving animal, and any samples for gas analysis are taken at that time before the system is opened.

Time to first sign of incapacitation is defined as the time to the first observation of loss of equilibrium (staggering), prostration, collapse, or convulsions in any of the test animals.

Time to staggering is defined as the time to the first observation of loss of equilibrium or uncoordinated movement in a specific test animal.

Time to convulsions is defined as the time to the first observation of uncontrolled muscular movements in a specific test animal.

Time to collapse is defined as the time to the first observation of loss of muscular support in a specific test animal.

Time to death is defined as the time to the observed cessation of movement and respiration in a specific test animal.

Temperatures and oxygen concentrations in the animal exposure chamber are recorded at 1-min intervals throughout the entire test period.

After the test is terminated and the animals are removed from the chamber, the pyrolysis boat containing the sample is removed, allowed to cool, and weighed to permit calculation, by difference, of the weight of sample pyrolyzed. Surviving animals are observed daily for a 14-day period after the test, and any significant changes from normal appearance, behavior, or weight are noted.

RESULTS AND DISCUSSION

Animal Responses

The results of toxicity tests on six elastomers are presented in Tables 1 and 2. Test results using the fixed temperature program are presented in Table 1, and test results using the rising temperature program are presented in Table 2. The values given for individual tests, as indicated by a test reference, are mean $\pm$ standard deviation within experiment (between animals); the mean values given for individual elastomers are mean $\pm$ standard deviation between experiments.

The mean values for the different elastomers, listed in order of increasing time to death for each temperature program, are presented in Table 3. The values given are mean $\pm$ standard deviation between experiments, with n being the number of experiments.

The reductions in times to animal responses resulting from the change from the rising temperature program to the fixed temperature program are presented in Table 4.

Changing from the rising temperature program to the fixed temperature program resulted in shorter times to animal responses. This effect is attributed in part to more rapid generation of toxicants. For all six elastomers, reductions in times to convulsions, collapse, and death averaged 10.15 $\pm$ 0.65 min.

The more rapid heating rate had the greatest effect on time to first sign of incapacitation and time to staggering with acrylonitrile rubber and polyisoprene, and the least effect with polychloroprene and chlorosulfonated polyethylene rubber.

The rising temperature and fixed temperature programs produced exactly the same rank order of materials based on time to death. The order of decreasing toxicity was acrylonitrile rubber, chlorosulfonated polyethylene rubber, ethylene propylene diene terpolymer, polyisoprene, polychloroprene, and styrene-butadiene rubber.

The time intervals between convulsions and death, and between the first sign of incapacitation and death, are presented in Table 5. The time intervals between convulsions and death were not significantly affected by the change in temperature program in the case of polyisoprene, styrene-butadiene, ethylene propylene diene terpolymer, and chlorosulfonated polyethylene rubber. The time intervals between the first sign of incapacitation and death were consistently shorter with the fixed temperature program than with the rising temperature program.

Chamber Gas Analyses

The recorded oxygen concentrations in the animal exposure chamber during the test consistently decreased with time; the oxygen concentrations obtained by gas analysis at the time of death of the last surviving animal are therefore the lowest concentrations encountered by the test animals.

Although the oxygen concentrations obtained during the test by the polarographic membrane technique provided reliable information on trends, the oxygen analyzer used frequently malfunctioned and the readings were sometimes at considerable variance from the data obtained using a gas chromatograph with thermal conductivity detector. Interference from other compounds and smoke deposits were possible causes of the discrepancies observed. The values obtained by gas chromatography are considered more reliable and are used in this paper.

The concentrations of methane, carbon monoxide, and oxygen in the animal exposure chamber at the time of death of the last surviving animal are presented in Table 6. Because these analyses are essentially isolated spot values which provide no information about concentration trends, only limited conclusions can be based on these data (3). However, because a closed system is used to prevent entry of fresh oxygen and escape of toxicants, it seems reasonable to assume that the oxygen concentrations are the lowest encountered and that the methane and carbon monoxide concentrations are the highest encountered.

The gas analyses were limited in extent, with samples taken from only 15 tests with the rising temperature program and 7 tests with the fixed temperature program. The oxygen concentrations averaged 16.5 $\pm$ 0.6 per cent with the rising temperature program and 19.0 $\pm$ 1.1 per cent with the fixed temperature program; the values given are mean $\pm$ standard deviation. The higher oxygen concentrations observed with the fixed temperature program are believed to be due to the shorter times to death and hence reduced oxygen consumption by the test animals.

The concentrations of methane ranged from 600 to 14,300 ppm with the fixed temperature program and from 1,200 to 18,200 ppm with the rising temperature program. Where comparable data for specific elastomers were available, methane concentrations tended to be higher with the fixed temperature program. Because 15,000 ppm (1.5 per cent) of methane displaces only sufficient air to reduce oxygen concentration by 0.3 per cent, the contribution of methane as a simple asphyxiant in this study was not considered significant. The contribution of these concentrations of methane to hazard with regard to flammable mixtures (4) may be more significant but is outside the scope of this study.

Carbon monoxide concentrations reached the 10,000 ppm (1 per cent) level only with polyisoprene, styrene-butadiene rubber, and ethylene propylene diene terpolymer. With acrylonitrile rubber using both the fixed temperature and rising temperature programs, carbon monoxide concentrations were below 5,500 ppm; these CO concentrations, by themselves, could not have resulted in death in less than 8 min (5), and therefore do not account for the 4.3 min time to death observed with acrylonitrile rubber using the fixed temperature program.

The carbon monoxide concentrations from ethylene propylene diene terpolymer and chlorosulfonated polyethylene rubber using the fixed temperature program were high enough to explain the times to death observed, on the basis of the earlier carbon monoxide study (5).

Chamber Atmosphere Temperatures

The recorded temperatures in the animal exposure chamber during the test did not exceed 28.5°C in any of the experiments. In only five of the experiments did the chamber temperature exceed 27.0°C. These temperatures are not considered to have a significant effect on animal responses.

CONCLUSIONS

A more rapid heating rate generally produced shorter times to death, as anticipated. The two heating rates used produced exactly the same rank order of materials based on time to death.

Acrylonitrile rubber exhibited the greatest toxicity under these test conditions, and carbon monoxide was not found in sufficient concentrations to be the primary cause of death.

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Table 1. Toxicity Test Data on Elastomers: USF Method F: 800°C fixed temperature, no forced air flow

test reference	time to first sign of incapacitation min	average time to staggering min	average time to convulsions min	average time to collapse min	average time to death min	weight of animals g
polyisoprene, natural rubber						
ANS-1285	7.83	8.95 ± 1.36	8.27	9.34 ± 0.87	11.23 ± 1.18	32.75 ± 1.3[illegible]
KLK-3	9.10	9.98 ± 0.97	10.23	10.55 ± 0.93	12.58 ± 0.66	34.20 ± 3.[illegible]
ANS-1289	8.00	8.85 ± 0.80		9.53 ± 0.39	11.45 ± 0.99	29.45 ± 2.81
mean	8.31 ± 0.69	9.26 ± 0.63	9.25 ± 1.39	9.81 ± 0.65	11.75 ± 0.72	
styrene-butadiene rubber						
ANS-1286	9.87	10.30 ± 0.48	10.48	11.37 ± 0.97	15.77 ± 1.99	31.93 ± 2.47
ANS-1290	9.32	10.06 ± 0.76	10.37	11.04 ± 0.75	12.70 ± 1.74	30.60 ± 1.64
KLK-4	9.47	10.55 ± 0.89	11.34 ± 0.09	11.11 ± 1.10	12.98 ± 7.01	30.70 ± 2.45
mean	9.55 ± 0.28	10.30 ± 0.25	10.73 ± 0.53	11.17 ± 0.17	13.82 ± 1.70	
ethylene propylene diene terpolymer						
KLK-6	7.45	7.69 ± 0.33	8.46 ± 0.40	8.25 ± 0.30	10.63 ± 0.09	33.83 ± 3.42
KLK-8	7.03	7.36 ± 0.25	8.32 ± 0.39	8.42 ± 0.18	11.48 ± 1.17	33.78 ± 1.65
KLK-10	6.63	7.83 ± 0.81	8.77 ± 1.16	8.63 ± 0.09	9.72 ± 1.15	31.53 ± 2.05
mean	7.04 ± 0.41	7.63 ± 0.24	8.52 ± 0.23	8.43 ± 0.19	10.61 ± 0.88	

values given are mean ± standard deviation

Table 1. Toxicity Test Data on Elastomers: USF Method F: 800°C fixed temperature, no forced air flow (continued)

test reference	time to first sign of incapacitation min	average time to staggering min	average time to convulsions min	average time to collapse min	average time to death min	weight of animals g
acrylonitrile rubber						
KLK-7	1.97	2.12 ± 0.13	3.04 ± 0.14	2.51 ± 0.14	4.18 ± 0.22	30.88 ± 3.97
KLK-9	2.23	2.34 ± 0.14	3.11 ± 0.32	2.65 ± 0.0	4.31 ± 0.35	30.55 ± 4.56
KLK-11	2.12	2.12	3.02 ± 0.39	2.22 ± 0.14	4.53 ± 0.84	37.35 ± 0.95
mean	2.11 ± 0.13	2.19 ± 0.13	3.06 ± 0.05	2.46 ± 0.22	4.34 ± 0.18	
chlorosulfonated polyethylene rubber						
KLK-1	8.22	9.30 ± 1.59	8.33	10.06 ± 1.47	11.92 ± 1.88	28.83 ± 3.04
ANS-1287	3.83	7.37 ± 3.08	7.70 ± 2.66	7.91 ± 2.66	8.89 ± 2.41	30.38 ± 3.42
KLK-12	9.22	9.22	6.90 ± 3.49	11.02	7.94 ± 3.80	35.08 ± 3.15
mean	7.09 ± 2.87	8.63 ± 1.09	7.64 ± 0.72	9.66 ± 1.59	9.58 ± 2.08	
polychloroprene						
KLK-2	9.57	10.40 ± 1.17	11.87	10.94 ± 1.18	12.25 ± 0.45	31.23 ± 1.84
ANS-1288	8.60	9.91 ± 1.15	9.72	10.34 ± 0.95	11.75 ± 0.95	30.78 ± 1.03
KLK-5	10.40	10.75 ± 0.58	11.04 ± 0.79	11.33 ± 0.66	12.61 ± 1.30	33.40 ± 1.01
mean	9.52 ± 0.90	10.35 ± 0.42	10.88 ± 1.08	10.87 ± 0.50	12.20 ± 0.[illegible]3	31.80 ± 1.40
values given are mean ± standard deviation						

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Table 2. Toxicity Test Data on Elastomers: USF Method B:
200-800°C rising temperature, 40°C/min, no forced air flow

test reference	time to first sign of incapacitation min	average time to staggering min	average time to convulsions min	average time to collapse min	average time to death min	weight of animals g
polyisoprene, natural rubber						
MTL-13	10.38	16.62 ± 4.30	20.58 ± 1.35	20.02 ± 1.15	24.01 ± 2.88	28.75 ± 0.29
JES-2	18.25	19.62 ± 1.34	20.18 ± 1.13	20.67 ± 0.71	21.77 ± 1.46	26.40 ± 0.84
MTL-35	17.42	17.44 ± 0.02	18.16 ± 0.54	18.35 ± 0.56	20.60 ± 0.93	26.55 ± 1.37
mean	15.35 ± 4.32	17.89 ± 1.55	19.64 ± 1.30	19.68 ± 1.20	22.13 ± 1.73	
styrene-butadiene rubber						
MTL-14	8.63	10.80 ± 2.37	20.34 ± 0.30	20.08 ± 0.25	22.69 ± 0.64	26.92 ± 1.66
MTL-28	18.17	18.17	19.19 ± 1.00	20.30 ± 2.14	23.14 ± 3.22	26.88 ± 2.92
KLK-13	20.40	21.15 ± 0.53	22.68 ± 2.86	23.34 ± 1.72	26.50 ± 1.65	30.80 ± 2.46
mean	15.73 ± 6.25	16.71 ± 5.33	20.74 ± 1.78	21.24 ± 1.82	24.11 ± 2.08	
ethylene propylene diene terpolymer						
MTL-15	8.93	9.79 ± 0.87	16.98 ± 0.91	17.85 ± 0.90	19.74 ± 1.22	27.38 ± 1.89
MTL-29	14.57	15.34 ± 1.04	18.10 ± 1.09	16.76 ± 0.53	21.01 ± 1.44	24.50 ± 1.63
JAS-9	8.97	9.68 ± 0.72	19.72	19.01 ± 0.59	21.24 ± 0.94	26.05 ± 0.82
mean	10.82 ± 3.24	11.60 ± 3.24	18.27 ± 1.38	17.87 ± 1.13	20.66 ± 0.81	

values given are mean ± standard deviation

Table 2. Toxicity Test Data on Elastomers: USF Method B:
200-800°C rising temperature, 40°C/min, no forced air flow (continued)

test reference	time to first sign of incapacitation min	average time to staggering min	average time to convulsions min	average time to collapse min	average time to death min	weight of animals g
acrylonitrile rubber						
MTL-19	9.33	9.98 ± 0.91	10.98 ± 0.61	11.13 ± 0.75	14.89 ± 2.59	27.10 ± 1.75
JES-1	9.63	9.73 ± 0.14	12.25 ± 1.10	10.94 ± 0.72	16.82 ± 2.28	28.28 ± 3.16
JES-7	9.55		12.68 ± 2.56	13.76 ± 1.85	15.85 ± 3.43	32.58 ± 2.42
mean	9.50 ± 0.16	9.86 ± 0.18	11.97 ± 0.88	11.94 ± 1.58	15.85 ± 0.97	
chlorosulfonated polyethylene rubber						
MTL-21	6.67	7.83 ± 1.16	17.05 ± 4.82	19.23 ± 2.43	20.01 ± 2.48	26.72 ± 0.74
JES-4	8.18	8.86 ± 1.21	14.68 ± 5.00	21.72	16.12 ± 6.06	29.33 ± 3.33
MTL-34	9.82	9.98 ± 0.22	21.08 ± 0.79	21.26 ± 0.89	22.12 ± 1.07	22.52 ± 0.50
mean	8.22 ± 1.58	8.89 ± 1.08	17.60 ± 3.24	20.74 ± 1.32	19.42 ± 3.04	
polychloroprene						
MTL-22	9.70	9.98 ± 0.28	20.71 ± 1.24	22.19 ± 1.34	25.21 ± 3.22	27.80 ± 0.90
JES-3	16.68	18.08 ± 2.24	19.73 ± 1.74		21.14 ± 2.52	26.18 ± 0.33
MTL-33	6.48	10.88 ± 4.38	21.42 ± 1.42	21.50 ± 0.94	23.12 ± 1.40	22.72 ± 0.26
mean	10.95 ± 5.21	12.98 ± 4.44	20.62 ± 0.85	21.84 ± 0.49	23.16 ± 2.04	
values given are mean ± standard deviation						

Table 3. Toxicity Test Data on Elastomers, Listed in Order of Increasing Time to Death

elastomer	time to first sign of incapacitation min	time to staggering min	time to convulsions min	time to collapse min	time to death min	number of tests
USF Method B: 200-800°C rising temperature, 40°C/min, no forced air flow						
acrylonitrile rubber	9.50 ± 0.16	9.86 ± 0.18	11.97 ± 0.88	11.94 ± 1.58	15.85 ± 0.97	3
chlorosulfonated polyethylene rubber	8.22 ± 1.58	8.89 ± 1.08	17.60 ± 3.24	20.74 ± 1.32	19.42 ± 3.04	3
ethylene propylene diene terpolymer	10.82 ± 3.24	11.60 ± 3.24	18.27 ± 1.38	17.87 ± 1.13	20.66 ± 0.81	3
polyisoprene, natural rubber	15.35 ± 4.32	17.89 ± 1.55	19.64 ± 1.30	19.68 ± 1.20	22.13 ± 1.73	3
polychloroprene	10.95 ± 5.21	12.98 ± 4.44	20.62 ± 0.85	21.84 ± 0.49	23.16 ± 2.04	3
styrene-butadiene rubber	15.73 ± 6.25	16.71 ± 5.33	20.74 ± 1.78	21.24 ± 1.82	24.11 ± 2.08	3
USF Method F: 800°C fixed temperature, no forced air flow						
acrylonitrile rubber	2.11 ± 0.13	2.19 ± 0.13	3.06 ± 0.05	2.46 ± 0.22	4.34 ± 0.18	3
chlorosulfonated polyethylene rubber	7.09 ± 2.87	8.63 ± 1.09	7.64 ± 0.72	9.66 ± 1.59	9.58 ± 2.08	3
ethylene propylene diene terpolymer	7.04 ± 0.41	7.63 ± 0.24	8.52 ± 0.23	8.43 ± 0.19	10.61 ± 0.88	3
polyisoprene, natural rubber	8.31 ± 0.69	9.26 ± 0.63	9.25 ± 1.39	9.81 ± 0.65	11.75 ± 0.72	3
polychloroprene	9.52 ± 0.90	10.35 ± 0.42	10.88 ± 1.08	10.87 ± 0.50	12.20 ± 0.43	3
styrene-butadiene rubber	9.55 ± 0.28	10.30 ± 0.25	10.73 ± 0.53	11.17 ± 0.17	13.82 ± 1.70	3

values given are mean ± standard deviation

Table 4. Reduction in Times to Animal Responses as a Result of Change from Rising Temperature Program to Fixed Temperature Program

elastomer	difference, min, in time to					
	incapacitation	staggering	convulsions	collapse	death	mean
acrylonitrile rubber	7.39	7.67	8.91	9.48	11.51	9.97 ± 1.37
chlorosulfonated polyethylene rubber	1.13	0.26	9.96	11.08	9.84	10.29 ± 0.68
ethylene propylene diene terpolymer	3.78	3.97	9.75	9.44	10.05	9.75 ± 0.31
polyisoprene, natural rubber	7.04	8.63	10.39	9.87	10.38	10.21 ± 0.30
polychloroprene	1.43	2.63	9.74	10.97	10.96	10.56 ± 0.71
styrene-butadiene rubber	6.18	6.41	10.01	10.07	10.29	10.12 ± 0.15
mean for animal response (n = 6)			9.79 ± 0.49	10.15 ± 0.72	10.51 ± 0.62	
overall mean (n = 18)						10.15 ± 0.65

Table 5. Time between Convulsions and Death and between Incapacitation and Death as a Function of Elastomer and Heating Rate

elastomer	difference, min, in time between			
	convulsions and death		incapacitation and death	
	rising temp.	fixed temp.	rising temp.	fixed temp.
acrylonitrile rubber	3.88	1.28	6.35	2.23
chlorosulfonated polyethylene rubber	1.82	1.94	11.20	2.49
ethylene propylene diene terpolymer	2.39	2.09	9.84	3.57
polyisoprene, natural rubber	2.49	2.50	6.78	3.44
polychloroprene	2.54	1.32	12.21	2.68
styrene-butadiene rubber	3.37	3.09	8.38	4.27

Table 6. Gas Chromatographic Analyses of Chamber Atmospheres at Time of Death of Last Surviving Animal

test reference	methane ppm	carbon monoxide ppm	oxygen per cent
USF Method F			
ethylene propylene diene terpolymer			
KLK-6	14,200	12,800	18.3
KLK-8	12,100	10,700	19.2
KLK-10	14,300	17,700	18.4
mean	13,533 ± 1,242	13,733 ± 3,592	18.63 ± 0.49
acrylonitrile rubber			
KLK-9	600	2,400	20.4
KLK-11	5,400	5,400	19.8
mean		3,900 ± 2,121	20.10 ± 0.42
chlorosulfonated polyethylene rubber			
KLK-12	10,500	8,100	19.6
polychloroprene			
KLK-5	-	6,400	17.1
overall mean (n = 7)			18.97 ± 1.11
values given are mean ± standard deviation			

Table 6. Gas Chromatographic Analyses of Chamber Atmospheres at Time of Death of Last Surviving Animal (continued)

test reference	methane ppm	carbon monoxide ppm	oxygen per cent
USF Method B			
polyisoprene			
JES-2	6,100	9,700	15.9
MTL-35	5,750	11,200	16.4
mean	5,925 ± 247	10,450 ± 1,061	16.15 ± 0.35
styrene-butadiene rubber			
MTL-14	1,200	9,500	17.0
MTL-28	5,000	11,400	16.3
mean	3,100 ± 2,687	10,450 ± 1,344	16.65 ± 0.49
ethylene propylene diene terpolymer			
MTL-15	5,000	11,000	17.0
MTL-29	8,600	16,300	16.0
JAS-9	18,200	9,700	17.7
mean	10,600 ± 6,823	12,333 ± 3,496	16.90 ± 0.85
acrylonitrile rubber			
MTL-19	3,400	3,800	17.4
JES-1	4,400	5,300	17.1
mean	3,900 ± 707	4,550 ± 1,061	17.25 ± 0.21
chlorosulfonated polyethylene rubber			
MTL-21	4,100	7,700	16.3
JES-4	-	5,700	16.8
MTL-34	5,500	7,600	16.0
mean	4,800 ± 990	7,000 ± 1,127	16.37 ± 0.40
polychloroprene			
MTL-22	6,100	8,800	15.9
JES-3	-	7,900	15.4
MTL-33	6,750	5,250	16.5
mean	6,425 ± 460	7,317 ± 1,845	15.93 ± 0.55
overall mean (n = 15)			16.51 ± 0.64
values given are mean ± standard deviation			

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16. Abstract

The toxicity of the pyrolysis gases from six elastomers was investigated, using the screening test method developed at the University of San Francisco. The elastomers were polyisoprene (natural rubber), styrene-butadiene rubber (SBR), ethylene propylene diene terpolymer (EPDM), acrylonitrile rubber, chlorosulfonated polyethylene rubber, and polychloroprene.

Changing from a rising temperature program (40°C/min) to a fixed temperature program (immediate exposure to 800°C) resulted in shorter times to animal responses. This effect is attributed in part to more rapid generation of toxicants.

The rising temperature and fixed temperature programs produced exactly the same rank order of materials based on time to death. Acrylonitrile rubber exhibited the greatest toxicity under these test conditions; carbon monoxide was not found in sufficient concentrations to be the primary cause of death.

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