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Acute Toxicity of the Combustion Products from Various Kinds of Fibers

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Summary: Acute toxicity of the combustion products from various fibers was evaluated in animal experiments. The materials used were cotton, gauze, acetate, rayon, polyester (PE), polychlal (PC), polyvinylidene chloride (PVDC), silk, wool, polyacrylonitrile (PAN), and modacryle (MA). Rats, mice, and rabbits were exposed to gases released from these materials, heated with an electric heater. In experiments with rabbits animals inhaled gases through a tracheal cannula under urethane narcosis. As indices for toxicity, the time at which animals were impaired severely, was used in rat experiments while the death time was used in experiments with rabbits and mice. The concentrations of O_2 and CO in the exposure room were determined continously, blood COHb and cyanide values were also estimated.

Gases from fibers containing nitrogen impaired severely and killed the animals earlier than any other materials. Blood analyses revealed the presence of high values of cyanide in PAN, MA, and silk experiments. HCN was considered to be responsible for the high toxicity of gases from these materials. In the case of wool, despite of high toxicity of its combustion products, blood cyanide and COHb values were not very high.

Gases from cotton, gauze, and rayon impaired severely and killed the animals relatively early in the exposure period. Toxicity of combution products from these materials was attributable to CO on the basis of gas and blood analyses. Acute toxicity of PE and acetate gases, being less than that of cotton, gauze, rayon under the present experimental conditions, was explained mainly by CO.

Neither severe impairment nor death occurred during exposure in PC and PVDC experiments.

Zusammenfassung: In Tierversuchen wurde die akut toxische Wirkung von Gasen untersucht, die bei der Verbrennung von Fasermaterial entstehen. Es wurden hierzu folgende Materialien verwendet: Leinen, Gaze, Azetat, Kunstseide, Polyester (PE), Polychlal (PC), Polyvinylidanchlorid (PVDC), Seide, Wolle, Polyacrylonitril (PAN) and Modacryl (MA). Ratten, Mäuse und Kaninchen wurden den Gasen ausgesetzt, die durch Erhitzen der betreffenden Fasern oder der Kombination von zwei Faserarten entwickelt wurden. Bei den Versuchen mit Kaninchen inhalierten die mit Urethan narkotisierten Tiere die Gase durch eine Trachealkanüle. Als Kriterien für die Toxizität des jeweiligen Gases wurde bei Ratten die Zeit gewertet, bis zu der schwere Beeinträchtigungen im Verhalten (Vergiftungserscheinungen) beobachtet wurden. Bei Mäusen und Kaninchen wurde die Zeit bis zum Eintritt des Todes gemessen. In der Kammer, in der die Tiere den Gasen ausgesetzt wurden, wurde fortlaufend die Sauerstoff und CO-Konzentration gemessen, bei den Tieren CO-Hämoglobin und die Cyanid-Konzentration im Blut.

Stickstoff-haltige Fasern vergifteten und töteten die Tiere durch die entwickelten Gase früher als andere Materialien. Blutanalysen ergaben relativ

hohe Cyanidwerte bei Versuchen mit PAN, MA und Seide, HCN wird daher die hohe Toxizität dieser Gase zugeschrieben. Bei Wolle, deren Verbrennungsgase ebenfalls sehr toxisch sind, wurden jedoch nicht sehr hohe Cyanid- und COHb-Werte gemessen.

Die Verbrennungsgase aus Leinen, Gaze und Kunstseide führten relativ schnell zu schweren Vergiftungserscheinungen und Tod der Versuchstiere, wobei die Toxizität in erster Linie auf das gebildete CO zurückzuführen ist, wie dies Gas- und Blutanalysen ergaben. Auch die Toxizität der Gase von PE und Azetat, die zwar geringer ist als die erstgenannten, beruht auf der Entstehung von CO.

Weder Vergiftungserscheinungen noch Todesfälle ließen sich im Fall von PC und PVDC beobachten.

Key words: Combustion products from various fibers - CO, combustion products - HCN, combustion products

INTRODUCTION

Recent development in polymer chemical industry has brought many products into daily use, but together with them it has introduced products with potential danger of releasing toxic substances that could have never been expected in fires before. Besides the introduction of the products with such potential hazards, efforts to seal buildings for air-conditioning and changes in mode of travel, in which a tightly closed environment is required, contribute largely to the increase in the loss of lives in accidental fires. Even a minor fire can easily cause O_2 depletion, or the release of toxic gases. The introduction of fire-retardant and relatively safe products in terms of the combustion products should be considered seriously.

So far little information is available on potential hazards of combustion products of various polymers on the basis of animal experiments. The present experiments were performed to obtain basic data for such problems and are concerned with the evaluation of the toxicity of combustion products from various kinds of fibers on the basis of gas, blood, and behavioral analyses.

MATERIALS AND METHODS

Experimental animals

Male Wistar-strain rats weighing about 180 g, male dd-strain mice of about 18 g, and male albino rabbits weighing about 2,000 g were used. The experiments on rats represent the principal part of the experiments.

Experimental materials

The fibers used were 1. cotton, 2. acetate, 3. rayon, 4. polyester (PE), 5. polychlal (PC, a copolymer of vinyl chloride with vinyl alcohol), 6. polyvinylidene chloride (PVDC), 7. silk, 8. wool, 9. polyacrylonitrile (PAN), 10. modacryle (MA, a copolymer of acrylonitrile with vinyl chloride), and 11. gauze. All fibers except gauze were obtained form Nippon-Boen-Kyokai and gauze was a commer-

cial product. In rat experiments, all kinds of materials were used. In experiments with mice (1, 2, 5, 8, 10), and rabbits (1, 5, 7, 8, 9), materials were limited to five (in parentheses). Each material was cut to pieces of about 3.5 x 3.5 cm and 10 g of sample were used in rat and mouse experiments, the sample weight was doubled in experiments with rabbits. In mixed-sample experiments in rats, in which two kinds of material (PAN+cotton, and PAN+PC) were heated simultaneously, 5 g of each material, the sum total 10 g, were applied.

Experimental apparatus

The scheme of an experimental apparatus is illustrated in Fig. 1. The apparatus consists of a combustion room and an exposure room. The combustion room is made of a 30x30x50 cm, transparent box of acrylic resin, in which a sample in a cylindrical stainless-cage, serving as a furnace, is heated with an electric heater of 300 w. In mixed-sample experiments the furnace was divided into two parts at the bottom of it, and each sample was placed individually. The temperature during heating was recorded with a thermoelectric thermometer (Yokogawa Electric Company), with a tip of the thermocouple laid on the bottom of the furnace. The maximal temperature of the furnace during heating was about 450° C without a sample and it was attained about 20 minutes after heating. The maximal temperature with sample exceeded 500° C with exception of acetate. Increasing the sample weight to 20 g elevated the maximal temperature. In the lower part of a side wall of the combustion room there is a hole for air supply (1 cm diameter) and on the upper part of an opposing side wall is an another hole of 3.5 cm in diameter, from which combustion products flow into the exposure room through a 50 cm-long flexible plastic tube. The exposure room (36x36x10 cm) is made of transparent acrylic resin and can be made air-tight with a removable lid of the same material. There is a hole on each side wall of the exposure room. The two smaller holes of 1.5 cm in diameter were used for O_2 concentration determination and in experiments with rabbits, which inspired through this hole by a tracheal cannula gases in the exposure room. The two larger holes of 3.5 cm were used as inlet and outlet for gases. At the outlet, a small portion of gases was carried through a thin plastic tube to a gas analyzer for CO at a rate of 0.2 l/min by an airpump.

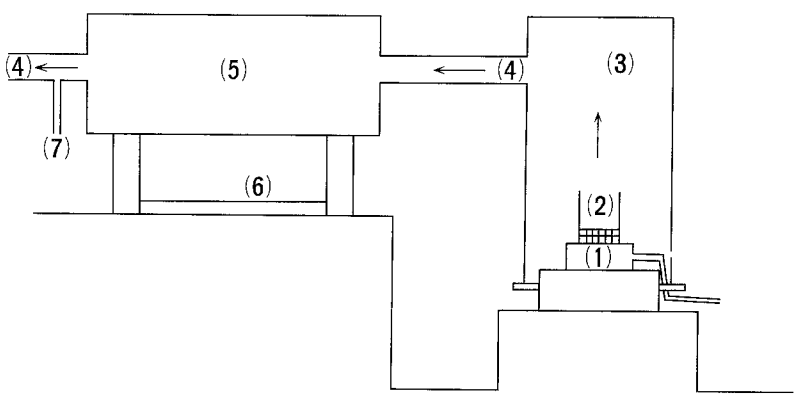

Fig. 1. Schematic diagram of an experimental apparatus (1) electric heater (2) furnace (6.5 cm in diameter, 9 cm in height). (3) combustion room. (4) flexible plastic tube. (5) exposure room. (6) mirror. (7) plastic tube to CO analyzer. For detailed explanation, see text

One rat was exposed to the combustion products at a time. In mouse experiments a compartmentalized stainless-cage of 30x30x9 cm with 5 mice was placed in the exposure room.

In rabbit experiments, the animal was made to breathe the gases of the exposure room by a tracheal cannula. In experiments with rats and mice, the exposure room was laid above an experimental table, as shown in Fig. 1., and beneath the chamber a mirror was laid for observation of the animal's behaviour.

Experimental conditions

In all experiments the exposure time was 30 min. In experiments with rats, the animal was regarded as severely impaired showing any of the conditions described later and was taken out immediately from the exposure room for blood sampling. The conditions used for taking out the rat from the room consist of the following four criteria: 1. The rat struggles to advance only to lay itself down flat, its hind legs struggling and kicking vainly. 2. The rat falls into convulsion. 3. The rat cannot maintain normal posture. 4. The rat does not respond to external stimuli and remains motionless. The rat was decapitated and blood was collected in a heparinized beaker. The rats which were not impaired during exposure were also decapitated after the experiment for blood sampling.

In mouse experiments death was judged from cessation of respiratory movement.

Rabbits were anesthetized by intravenous injection of 25% urethane in saline and fixed in a supine position on an operation board for subsequent procedure. A tracheal cannula was inserted and connected through a plastic tube to the exposure room. For blood sampling a polyethylene catheter was introduced into the carotid artery. Blood was collected with a heparinized syringe and the syringe with blood sample was stored in an ice bath, the tip of the needle was sealed off with a piece of rubber. For blood lactate determination a small part of the blood was taken immediately from the syringe. After deproteinization with perchloric acid the supernatant solution was stored in an ice bath until analysis. Blood was collected at 5 minutes intervals in cotton and PC experiments, but it was not so regularly collected in PAN, silk, and wool experiments. The amount of blood obtained by single sampling ranged from 0.5-4 ml, according to the object of determination. The death of the rabbit was judged from cessation of respiration and of heart beating.

In addition to the experiments with combustion products, experiments with rats include acute HCN inhalation test. The aim was to determine blood cyanide level and to relate cyanide concentration to the toxicity of the combustion products. The rat was in a desiccator exposed to HCN liberated from NaCN by sulfuric acid. Righting reflex of the rat was tested by rotating the desiccator and the animal was taken out from the vessel when it no longer showed the reflex.

Gas, and blood analyses

Exposure room CO concentration was determined continously with an infrared gas analyzer (Horiba, L1A-2B). The instrument was calibrated prior to analysis with zero gas (0% CO in N_2), and span gas (1.8% CO in N_2), respectively. The full scale of the analyzer was 0-2%. O_2 concentration was monitored continously with an O_2 analyzer (Beckman). The calibration of the instrument was made with atmospheric air. Blood COHb concentration was determined according to the method of VAN KAMPEN *et al.* (1) with slight modifications. The procedure of whole blood cyanide determination followed that of FELDSTEIN *et al.* (2) with a slight modifications. In combustion experiments with nitrogen-free material blood cyanide determination was omitted except for gauze experiments. Blood lactate level was determined enzymatically with the lactate test kit (Boehringer, Mannheim). Determination of pH, pO_2, and pCO_2 was carried out with combianalyzer U (Esch-

weiler) at 37° C. Prior to analysis the instrument was calibrated with standard pH solutions (pH 6.84 and pH 7.38), and standard gases (O_2: CO_2: N_2 = 2.08: 2.05: 95.87, and 11.8: 5.93: 82.27). The time from sampling until analysis did not exceed 40 minutes. The acidity of the blood was expressed in terms of hydrogen ion concentration, (H^+) in nM/l. On completion of an experiment the residual ash was weighed and a combustion rate was calculated according to the following equation:

$$\frac{\text{weight of sample-weight of ash}}{\text{weight of sample}} \times 100.$$

In mixed-sample experiments the combustion rate was calculated separately on individual material.

RESULTS

The time course of exposure room CO and O_2 concentrations is illustrated in Figs. 2 and 3 on selected materials. Maximal CO and minimal O_2 levels are presented in Table 1 with respect to all materials. The concentration of CO was very high in cotton, and gauze experiments and both materials showed almost the same concentration curves. The concentration began to rise abruptly about 6-7 minutes after heating and the level of about 1% was attained at about 10 minutes and the curve showed still an increasing tendency. In 20 g experiments with cotton the situation was almost the same. The concentration became much higher and the CO level exceeded 2% 15 minutes after heating of the material and the concen-

Table 1. *Summarized data for the exposure room gas concentrations. The maximal CO and minimal O_2 concentrations are expressed in ranges with respect to every material*

Material	Weight (g)	Maximal CO(%)	Minimal O_2 (%)
Cotton	10	1.26 - 1.5	17.8 - 18.2
Cotton	20	2.0<	14.0 - 14.7
Rayon	10	1.1 - 1.3	17.6 - 18.3
Acetate	10	0.34 - 0.6	18.8 - 19.6
Polyester	10	0.29 - 0.53	15.6 - 19.1
Polychlal	10	0.12 - 0.45	18.3 - 20.0
Polychlal	20	0.59 - 0.85	17.1 - 18.0
Polyvinylidene chloride	10	0.10 - 0.33	16.3 - 19.8
Gauze	10	1.4 - 1.7	17.8 - 19.2
Wool	10	0.12 - 0.21	19.9 - 20.0
Wool	20	0.30 - 0.43	18.6 - 19.5
Silk	10	0.24 - 0.42	18.5 - 19.3
Silk	20	0.38 - 0.65	16.5 - 17.8
Polyacrylonitrile	10	0.01 - 0.04	20.3 - 20.9
Polyacrylonitrile	20	0.02 - 0.09	20.3 - 20.4
Modacryle	10	0.02 - 0.04	20.0 - 20.9
Polyacrylonitrile + Cotton	10	0.63 - 0.85	19.3 - 20.4
Polyacrylonitrile + Polychlal	10	0.01 - 0.04	19.8 - 20.3

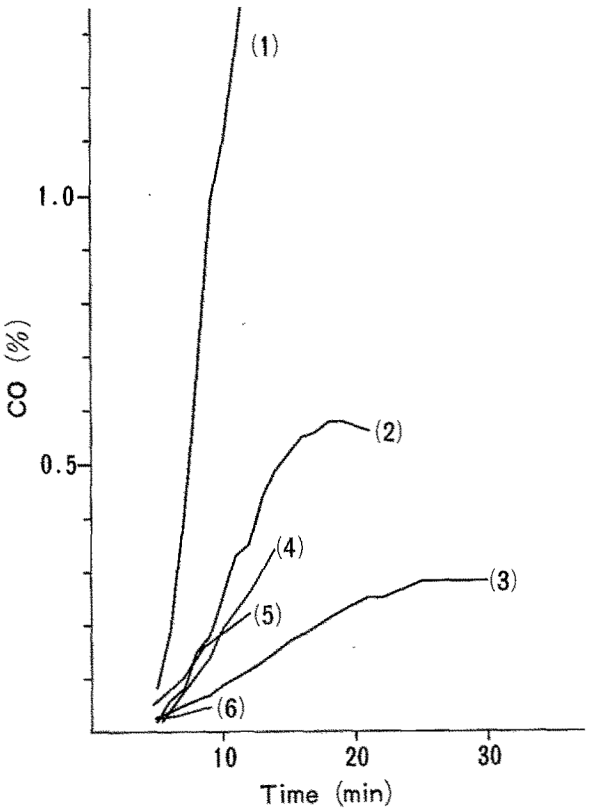

Fig. 2. Time course of the exposure room CO concentration with selected materials in rat experiments. One typical curve is drawn for each material. (1) cotton (2) acetate (3) PC (Polychlal) (4) silk (5) wool (6) PAN (Polyacrylonitrile)

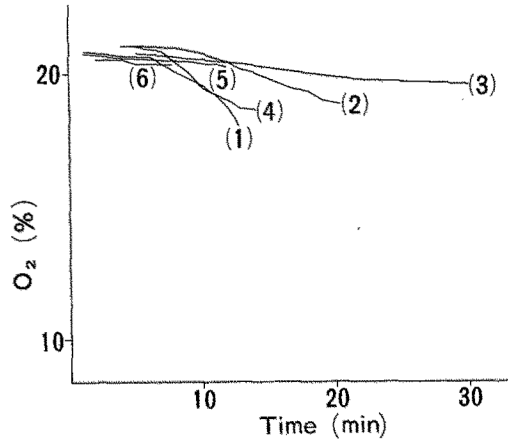

Fig. 3. Time course of O_2 concentration of the exposure room with selected materials in rat experiments. One typical curve is drawn for each material. (1) cotton (2) acetate (3) PC (Polychlal) (4) silk (5) wool (6) PAN (Polyacrylonitrile)

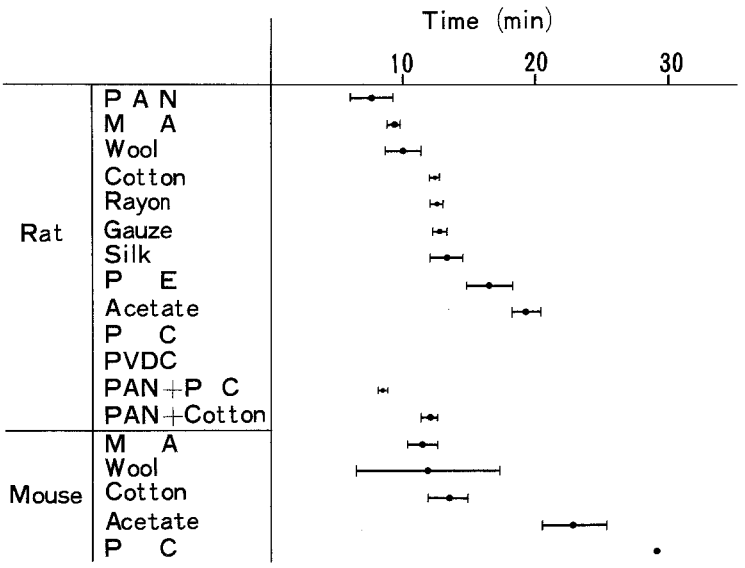

Fig. 4. Time, at which rats were impaired severely, and the death time of mice. Each time is shown in mean ± s.d. on every material. For detailed explanation for "impaired severely", see text

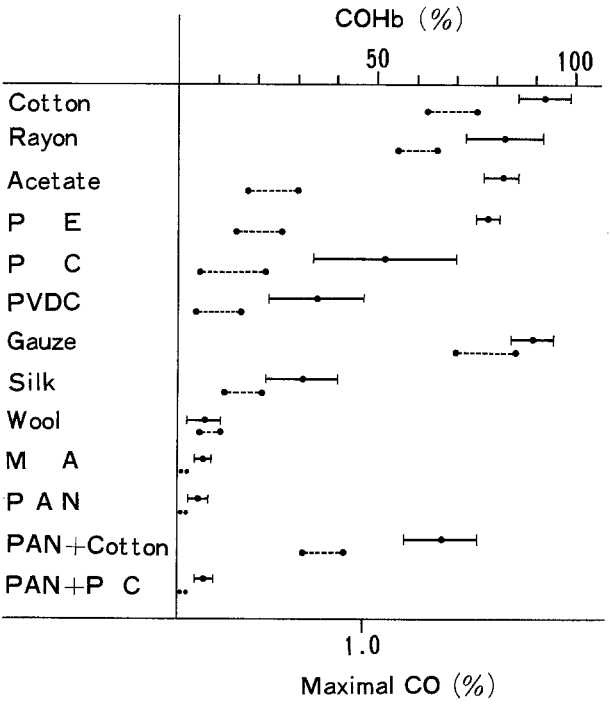

Fig. 5. COHb levels of rats and maximal CO concentration in the exposure room. COHb level, expressed in solid line, is shown in mean ± s.d. The maximal CO concentration is expressed in dotted line

tration remained above 2% for about 10 minutes. Rayon showed the same pattern as cotton and gauze with respect to CO, but the maximal concentration did not reach the level of cotton (Table 1). The CO level of 1% was not attained in any of PE, PC, and PVDC in 10 g experiments. The concentration curves of PE deserve attention. In 4 of 5 experiments with this material ignition occurred about 7 minutes after heating, and continued for about 1 minute. After ignition CO concentratiion increased and O_2 level decreased relatively abruptly. No ignition occurred in any other materials except PE. CO concentration in exposure room was relatively low in material containing nitrogen (Fig. 2 and Table 1). Under the heating conditions applied silk released more CO than wool. The lowest CO concentration was recorded in PAN and MA experiments. In PAN the highest level of CO was less than 0.1% in both 10 g and 20 g experiments (Table 1). In mixed-sample experiments with PAN+cotton, the maximal CO level reached 0.85%. The relatively high CO concentration is probably due to cotton. On the contrary, in PAN+PC, the maximal CO level was as low as 0.1%. This concentration of CO seems to be too low for the presence of PC, which had reached the maximal level of about 0.43% in 10 g experiments. This low concentration of CO can be explained by the relatively short experimental period. PC does not liberate much CO in an early stage of combustion, as shown in Fig. 2.

O_2 concentration in the exposure room began to decrease gradually about 10 minutes after the start of combustion (Fig. 3). In experiments with cotton, gauze, and rayon, exposure room O_2 concentration decreased to a level of 17% (Table 1). The lowest O_2 level occurred in PE experiment with ignition (15.6%). In PC, PVDC, silk, and wool experiments O_2 concentration did not decrease remarkably during exposure. In experiments with PAN and MA, O_2 concentration in the exposure room was maintained at about normal value. Doubling the sample weight caused a further reduction in O_2 concentration in every material.

The number of rats impaired severely during exposure was as follows: cotton (5/5, numerator and denominator designate the number of rats impaired and used, respectively), rayon (5/5), acetate (4/5), PE (4/5), PC (0/5), PVDC (0/5), gauze (5/5), wool (6/6), silk (5/5), PAN (6/6), MA (6/6), PAN+cotton (6/6), and PAN+PC (4/4). The impaired rats had lost ability to right themselves, with the exception of a rat, which was subjected to a PE experiment.

In PC and PVDC experiments, no rat was impaired severely during exposure.

The first criterion, the rat's inability to advance, was mostly applied in judgement of severe impairment. The results of the applications of respective criterion were as follows: cotton (first, second, third, fourth = 5, 1, 0, 0), rayon (5, 0, 0, 1), acetate (4, 0, 0, 0), PE (3, 0, 0, 0), gauze (5, 0, 0, 0),

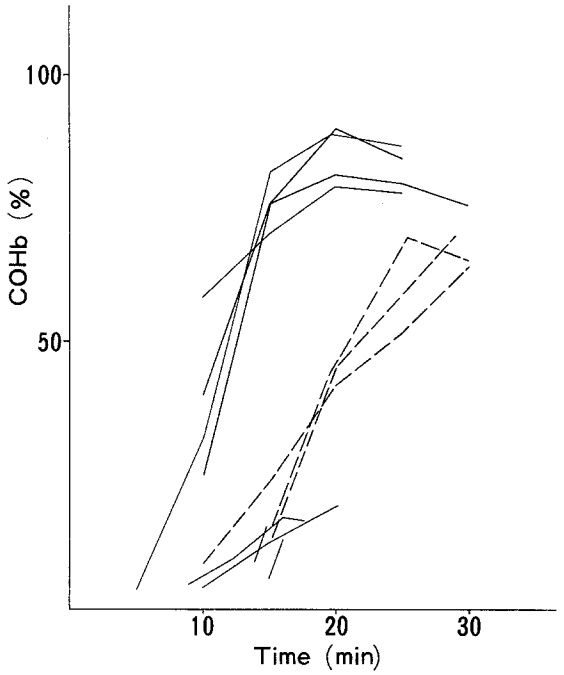

Fig. 6. Time course of blood COHb levels of rabbits in experiments with 20 g of samples. Upper group of solid lines indicates the curve in cotton experiments, lower group the curve in silk, dotted lines indicate the results of PC (Polychlal) experiments

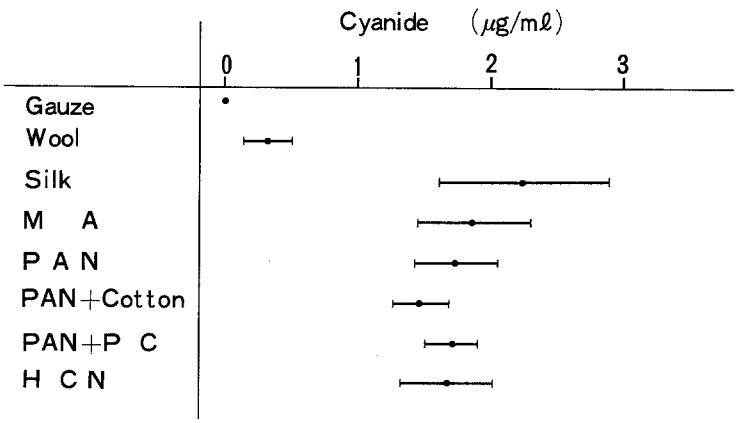

Fig. 7. Blood cyanide levels of rats. The cyanide levels are expressed in mean± s.d.

silk (4, 1, 0, 2), wool (5, 3, 1, 0), PAN (2, 2, 2, 0), MA (2, 2, 1, 0), PAN+ cotton (4, 3, 0, 2), and PAN+PC (4, 1, 0, 0). As some rats showed more than two symptoms in a close time intervals, the sum of the items applied is not equal to the number of the rats impaired.

All mice died within 30 minutes of exposure in cotton, wool and MA experiments. Eight of 20 mice died in experiments with acetate and 19 of 20 survived in experiments with PC.

The time, at which rats were impaired severely, and the death time of mice are shown in Fig. 4. The nitrogen-containing materials, PAN, MA, and wool, impaired rats most rapidly. Rats were impaired within 15 minutes by PAN+cotton, cotton, rayon, gauze, and silk. In PE and acetate experiments, the time was much delayed. Impairment of rats in PE experiments occurred exclusively in those with ignition. Gases, not identified, from acetate had the property of irritating the eyes and the corneas of rats became turbid during exposure.

Mice were killed relatively early in MA, wool, and cotton experiments.

In rabbit experiments the combustion products from PAN, silk, and wool killed all the animals within exposure, and the mean death time was 14, 15, and 17 minutes respectively. In cotton experiments 3 of 4 rabbits were killed, and the death time averaged 27 minutes. No death occurred in PC experiment.

Blood COHb concentration in rats is shown in Fig. 5, together with the maximal CO concentration in the exposure room. The higher the CO in the exposure room, and the longer the exposure time, the higher was the COHb level. The cotton experiments yielded the highest mean COHb value exceeding 90%. COHb values of more than 75% were obtained in gauze, rayon, acetate, and PE experiments. The COHb concentrations were moderate in experiments with PC, PVDC, and silk. In wool, PAN, and MA groups, COHb values were verly low. In mixed-sample experiments with PAN+cotton, the presence of cotton increased the mean level to 70%.

The time course of COHb concentration in rabbits is shown in Fig. 6 on selected materials. COHb values increased with CO concentration in the exposure room. In cotton experiments the value of 80% was exceeded at 20 minutes and in PC experiments COHb attained the value of 60% at the end of exposure. COHb concentrations were below 10% in both wool and PAN experiments.

With respect to blood cyanide considerably high values were obtained in silk, MA, and PAN experiments. Blood cyanide concentrations of rats are shown in Fig. 7. In contrast to very low, almost 0, values in gauze experiments, the blood of rats exposed to the combustion products from silk, PAN, and MA, respectively, showed high values of cyanide. Silk experiments yielded the highest cyanide concentration. Blood cyanide value in PAN+cotton was low compared with that in experiments with PAN alone. Blood cyanide value in wool was apparently low, compared with that of silk. Cyanide concentration in blood of rats exposed to HCN was lower than that of silk experiment. The time course of blood cyanide concentration in rabbit experiments is shown in Fig. 8 on three materials. In

PAN experiments considerably high blood cyanide levels were attained in an early stage of exposure, and the time, at which blood cyanide level began to increase abruptly, was apparently more delayed in silk experiments than in PAN. The blood cyanide concentration exceeded the value of 2.50 μg/ml in both PAN and silk experiments, the value in silk was slightly higher. Blood cyanide concentration was below 0.4 μg/ml in wool experiments.

Hydrogen ion concentration of the blood of rabbits in experiments with cotton and PC is shown in Fig. 9. In both materials the time, at which (H^+) began to increase (in cotton at about 10 minutes, and in PC 20 minutes), corresponded to the time, at which COHb exceeded the value of about 50%. The rate of increase and the final value were higher in cotton than in PC. The time, at which (H^+) began to increase, was shorter in experiments with PAN, silk, and wool than in experiments with cotton and PC. In PAN, and silk experiments the (H^+) became higher with increasing cyanide concentration. The time course of blood lactate showed similarity in pattern to that of (H^+).

Arterial O_2 and CO_2 tensions, which were not measured in all rabbits, were maintained at approximately normal ranges until the end of exposure.

The combustion rate in 10 g experiments is shown in Fig. 10. The group with large rate consists of materials containing neither nitrogen nor chlorine, such as cotton, rayon, PE, gauze, and acetate. These materials showed combustion

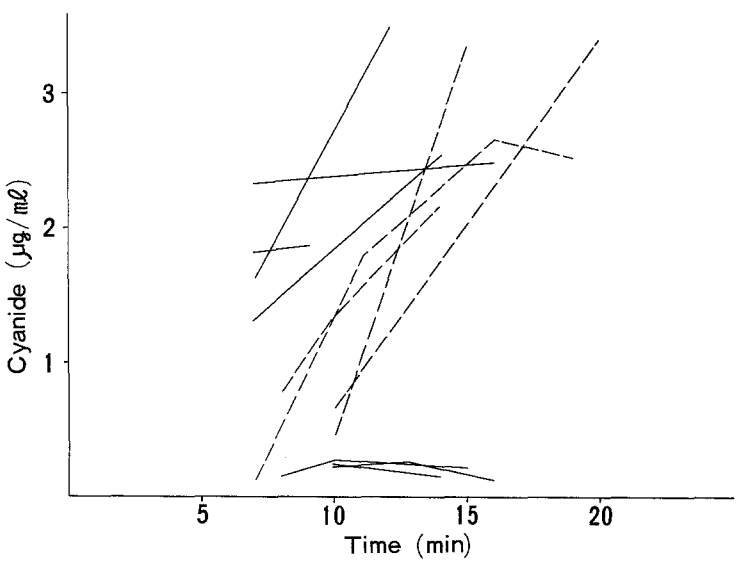

Fig. 8. Time course of the blood cyanide levels in rabbit experiments. Upper group of solid lines indicates the curves of PAN (Polyacrylonitrile) experiments, lower group those of wool; dotted lines indicate the results of silk experiments

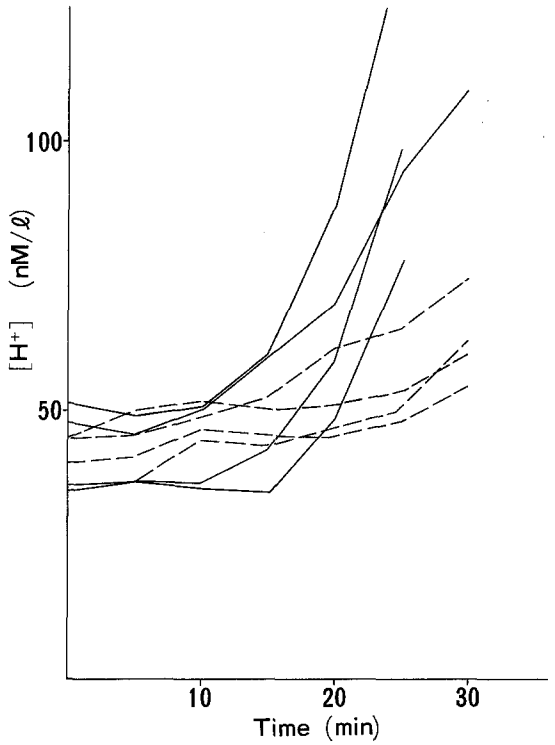

Fig. 9. Time course of blood hydrogen ion concentration in rabbits with 20 g of samples. Solid lines are the results of cotton experiments, dotted lines are those of PC (Polychlal) experiments

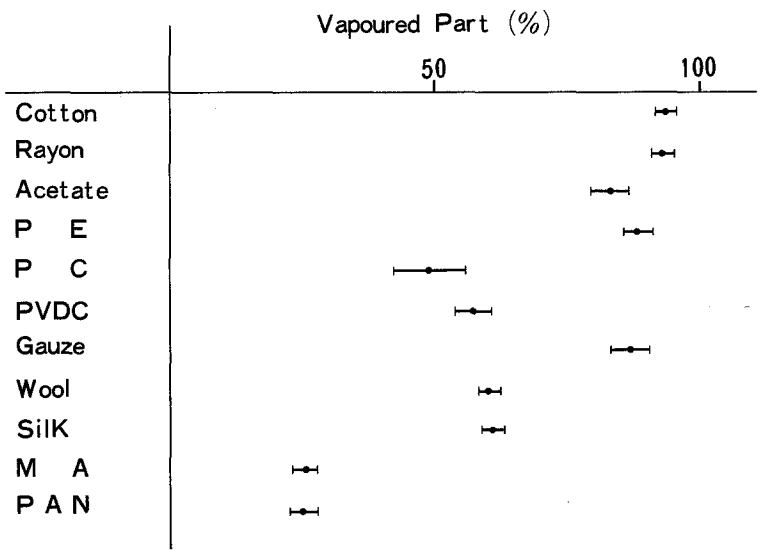

Fig. 10. The combustion rates of materials. The rate is expressed in mean± s.d. For detailed explanation of the combustion rate, see text

rates above 80%. About 50-60% of the sample were evaporated in wool, silk, PC, and PVDC. The combustion rate was the lowest in PAN and MA groups. The results of the mixed-sample experiments and 20 g experiments did not differ significantly from those of 10 g experiments.

DISCUSSION

There are principally two methods in evaluating the toxicity of combustion products. The first is gas-analysis, and the second is a biological method. In the gas-analysis method the combustion products derived from materials under various conditions are identified and determined, and the toxicity of the material, from which gases evolved, are evaluated by referring to the toxicological literatures. The concept of the "TUF" (Time of useful function, the time available for escape from toxic atmosphere resulting from fire) by GAUME *et al.* (3, 4, 5) and the "Toxicity index" by TSUCHIYA *et al.* (6) are based essentially on the gas-analysis method. Generally speaking, this method has several drawbacks; firstly, it is practically impossible to identify and determine all the components of combustion products with even sophisticated instruments and it may be possible to miss a substance with very high toxicity. Secondly, on the basis of the gas-analysis method alone the biological effects of mutual actions of gases are difficult to evaluate. Of many gases there may be some which interact with another to enhance its toxicity. Such an example is already reported (7). Thirdly, the potential danger of particles (8), which may suffocate the animals, is not taken into consideration,

In the biological methods depending upon responses of animals exposed to the combustion products, the experimental variations due to individual differences, which are considered to be inherent in biological experiments, can be treated statistically and the drawbacks involved in the gas-analysis method can be covered up.

In the biological method, the first consideration is the selection of an index for the assessment of toxicity. Although death and/or death time of the animals can be used for this purpose, it could be more suitable to adopt the index representing the loss of ability for escape, in view of the importance of early escape from the toxic atmosphere in real fires. The mouse's habit of rotating an exercise wheel has been applied for this purpose (5), the number of rotation was related to the degree of intoxication.

Although the behavior of animals can be recorded almost automatically without being disturbed by smoke using those methods, in the present study emphasis

was placed on direct observation of the animals exposed to gases without special apparatus, considering the possibility that mere findings obtained may serve as the index representing the loss of ability for escape. As long as the direct observation method is applied the present exposure room seems to be of convenient size and further enlargement of the exposure room could make the observation of the animals more difficult. It is unlikely that there was significant difference with respect to the severity of damage among four criteria, as in all rats taken out from the room under the diagnosis of being severely impaired there was no righting reflex with exception of one rat.

The toxicity of the combustion products of cotton and gauze are exclusively due to CO. In these materials COHb value as high as 75% were obtained in rats and rabbits, and the changes in acid-base balance of rabbits are considered to be secondary to hypoxia due to CO poisoning. Arterial O_2 tension was maintained at about normal range until the end of the experiment, however, it is known that in the presence of CO transport of O_2 from Hb to tissues is more difficult. The toxicity of gases evolved from rayon, acetate, and PE was found mainly due to CO, as COHb values of animals subjected to these materials were also high. Besides CO, other gases which may be produced by incomplete combustion of these materials may have to be taken into consideration for the evaluation of the toxicity. It was characteristic that PE bubbled when heated and the products from acetate produced irritation of the eyes. With respect to synthetic, chlorine-containing materials, PC and PVDC, CO concentration was higher in PC than in PVDC. Although no rat was impaired severely during exposure to gases from these materials, further observation of the animals may be necessary for possible after-effects, because probable inhalation of acid gases such as HCl may have injured the respiratory tracts.

In the present study high toxicity of the combustion products from nitrogen-containing materials was demonstrated, and blood analyses revealed that HCN was responsible for this high toxicity, with the exception of wool. The present results are in agreement with those of SUMI *et al.* (9). In their experiments acrylic fiber had exceedingly high "Toxicity Index".

The combustion products from PAN and MA showed the highest toxicity in the present study. With these materials CO was produced only poorly and O_2 level in the exposure room was maintained at approximately normal levels. The main substance responsible for high toxicity was HCN, which was clearly shown in blood analyses. These materials have acrylonitrile groups ($-CH_2 \cdot CHCN-$) in their chemical structure and HCN is considered to be released directly. In addition to CO, silk produced considerable amounts of HCN. With respect to

blood cyanide concentration, it had higher values than PAN. The blood cyanide levels of rats exposed to gases from PAN, MA, and silk higher than those of rats exposed to HCN can probably explained by the fact that the rats in HCN experiments were taken out immediately after the loss of righting reflex, while the rats exposed to the combustion products had lost the reflex when judged severely impaired. The combustion products from wool killed and impaired rabbits and rats early in the exposure period, however, both blood COHb and cyanide values were much lower than those of silk. Although almost equal amounts of HCN were expected to be produced from silk and wool on the basis of the approximately equal nitrogen contents, this was not the case. The difference in amount of HCN released under the present experimental conditions may be due to difference in the structure of protein in both materials. Silk contains no sulfur, on the other hand, wool contains considerable amount of sulfur-containing amino acid. Therefore, in interpreting the acute toxicity of gases from wool, other products than HCN and CO should be taken into consideration.

The process of combustion and pyrolysis of high-polymers such as fibers are very complex, depending on many variables. It is practically very difficult to obtain reproducible data. Even in the closely controlled and instrumental combustion experiment of plastics by BOETTNER *et al.* (10), experimental deviations of ± 25% were considered inevitable. Although the present results are on the basis of only one experimental condition, it is considered that they demonstrated clearly high toxicity of combustion products from various fibers.

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