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Toxicity Evaluation of the Combustion Gases Released from Residential Container Fires

Hong Kim[1*], Ki-Chang Jung[1], Jeong-Hun Kim [2], Hyung-Ju Park[2], Jung-Yun Lee[2]

[1]Department of Safety System Engineering, Hoseo University, Asan 336-795, Korea
[2] Department of Safety Engineering, Graduate School of Hoseo University, Asan 336-795, Korea

Abstract

The recent fire accident in an elementary school of chonan city in Korea causes the media focus on the fire safety of residential container building. In this study, real fire tests were conducted in this kind of building. Combustion products including O_2, CO_2, CO, NO_x, SO_x, HCl, HCN were measured, blood samples of lab rats were analyzed in terms of Co-Hb, Glucose, AST(GOT), ALT(GPT), in order to investigate the hazard-reduction effects of employing gas mask and filter during the fire emergency of residential container buildings. According to the test results, whether employing the filter causes a sheer difference in the toxicity of the fire-induced gases, and the importance of wearing a gas mask was evidently demonstrated.

1. Introduction

Nowadays, polymer materials are mainly used for building interior decoration. According to the fire statistics, the fire death toll caused by the toxic gases released from the combustion of polymers largely outnumbered ones caused by the fire itself. The smoke and toxic gases released from the polymer fire can block the vision when building occupants evacuate, cause respiratory difficulty and suffocation, thus impede the building evacuation in a fire emergency. The inhalation of these toxic gases can also cause damages or sequelae to respiratory and internal organs of human body, therefore has to be inhibited in a proper manner.

The interior wall for this kind of buildings consists of the materials, which are highly combustible as sandwich panels made from polyurethane foam and expanded polystyrene [1-4]. A fire disaster in the residential containers that were employed as the dormitory in an elementary school located in chonan city, Korea, evidently demonstrated this threat.

Corresponding Author- Tel.: +82-41-540-5721;
Fax: +82-41-540-5728
E-mail address: kimhong@office.hoseo.ac.kr

In this study, combustion gases analysis and blood test of Sprague Dawley(SD) rats were employed to evaluate the practicality and insulation property of a filter mounted on the fire gas mask produced by S company in Korea.

2. Experiment

2.1 Set-up of residential container

The container in this study is the size of 6m(W)×3m(D)×2.3m(H) widely having used in Korea on a following Figure 1. Inside the container is furnished with the common residential furniture, and the fire load in this container is set at 42.31kg for scientific analysis. [5-7]

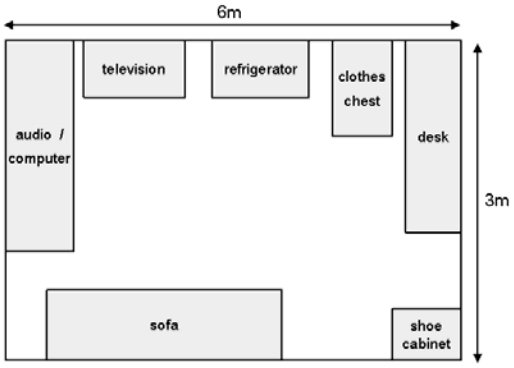

Figure 1. Schematic of upholstered furniture in the container.

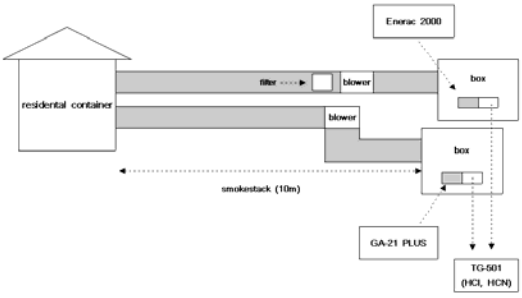

Figure 2. Schematic of experimental set-up.

2.2 Installation of smokestacks

In order to determine the concentrations of combustion gases, there are two smokestacks, each of 10,000mm long and 75mm wide, installed in the container as indicated in Figure 2. The inlet of the smokestacks is placed at 1.5m high, where the nose of an adult male is supposed to be at. Each smokestack is equipped with a blower at the inlet and a box at the outlet. One box is mounted with a filter, while the other one isn't. The flow speed of the blower is set at 30ℓ/min, which is the maximum intake that the filter can handle.

Table 1. Measurement equipment for combustion gases (with/without filter protection)

Combustion gases	With filter	Non-filter
O_2 CO_2 CO NO_x SO_x	Enerac 2000	Madur company (GA-21Plus)
HCl HCN	GrayWolf company DirectSense™ (TOX PPC Kit, TG-501)	

Ten rats that are 9 weeks after birth were put into each box. The blood of rats inside the box with filter protection was sampled every 5 minutes, while the blood of rats inside the box without filter protection was sampled every 2 minutes. The analyzing methods, reagents and testing devices in terms of the type of enzyme are shown in Table 2.

Table 2. Analysis method, reagent and equipment for enzymes

Enzymes	Method	Reagent	Analyzer
Co-Hb	UV Spectro-meter	-	H.P.
Glucose	Enzyme method	-	-
AST (GOT)	UV	Sinyang company,	Hitachi 7600

ALT (GPT)	UV	Korea	110

3. Results and Discussions

3.1 Measurements of combustion gases

Figure 3 shows the time-dependent O_2 concentration. When it is 1 minute after ignition, the O_2 concentration drops to 16%, which is the lethal concentration for human body, while 5 minutes after ignition, the O_2 concentration drops to the minimum value of 3.45%.

Figure 4 shows the time-dependent CO_2 concentration. When it is 2 minutes after ignition, the CO_2 concentration exceeds 5%, which can cause unconsciousness and death after long-term exposure. When it is 5 minutes after ignition, the CO_2 concentration shows a peak value of 9.7%. It can be seen from both figures that CO_2 concentration increases along with the drop of O_2 concentration, and that the drop of O_2 concentration before the increase of CO_2 concentration indicates the inability of building occupants to perform an evacuation. Among the combustion gases passing through the filter, O_2 is recorded to a minimum concentration of 19.5%, and CO_2 is recorded to a minimum concentration of 1.9%, which, in contrast to the gases not passing through the filter, shows no significant changes from the normal levels.

Figure 5 shows the time-dependent CO concentration. When it is 1 minute after ignition, the CO concentration exceeds 400ppm, which is the TLV-STEL of CO, and 9 minutes 30 seconds after ignition, the highest CO concentration of 5395ppm is recorded. For the combustion gases passing through the filter, after 13 minutes elapse since ignition, the CO concentration starts showing a climbing tendency, and reaches the highest value of 379.5ppm when 17 minutes and 30 seconds elapse. The increase of CO concentration is believed to result from the decline of the filter's performance.

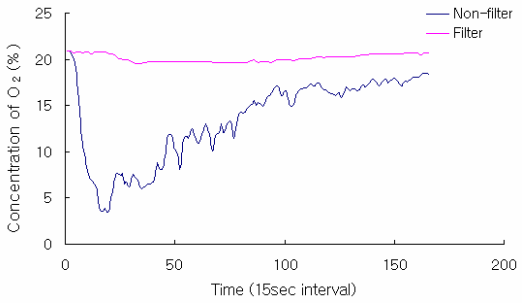

Figure 3. Variation of O_2 concentration during the container fire.

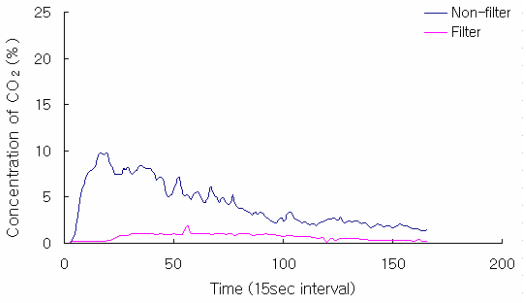

Figure 4. Variation of CO_2 concentration during the container fire.

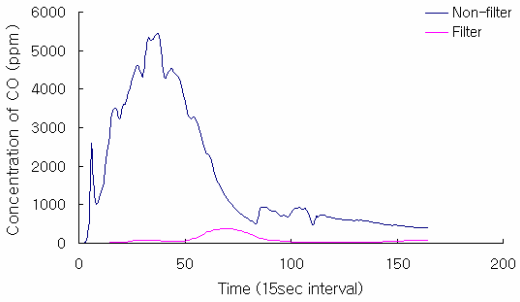

Figure 5. Variation of CO concentration during the container fire.

Figure 6 shows the time-dependent NO_x concentration. When it is 5 minutes and 30 seconds after ignition, the NO_x concentration reaches the highest value of 223ppm in the box without filter protection, while reaches 57.9ppm in the box protected by the filter. As can be seen from Figure 7, 2 minutes and 30 seconds after ignition, the SO_x concentration reaches the highest value of 467ppm in the box without filter

protection, while reaches 4ppm in the box protected by the filter.

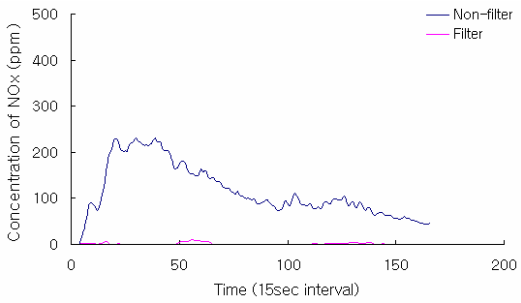

Figure 6. Variation of NO_x concentration during the container fire.

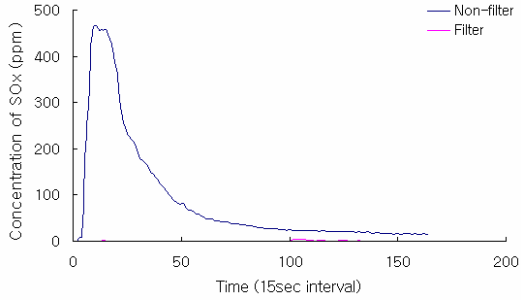

Figure 7. Variation of SO_x concentration during the container fire.

Figure 8 shows the time-dependent HCl concentration. The HCl concentration in the box without filter protection reaches 62.3ppm when it is 2 minutes after ignition, while in the box protected by the filter, the concentration reaches 5.9ppm when it is 15 minutes after ignition. And from Figure 9, the HCN concentration in the box without filter protection reaches 117.8ppm, while in the box protected by the filter, the concentration reaches 0.2ppm, when it is 7 minutes after ignition. Both the concentrations of HCl and HCN exceed their TLV-STELs(5ppm and 10ppm) after ignition.

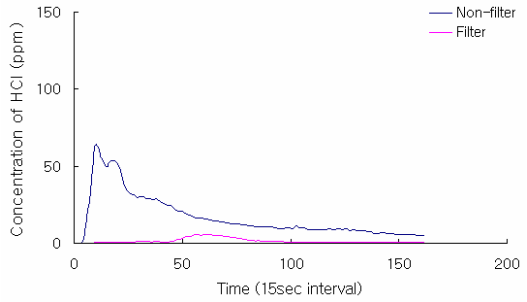

Figure 8. Variation of HCl concentration during the container fire.

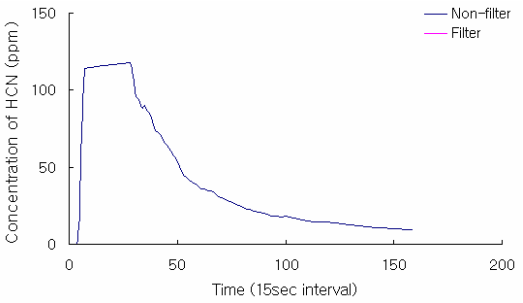

Figure 9. Variation of HCN concentration during the container fire.

3.2 Results of rodent blood test

Figure 10, 11 shows the results of blood test in the box without filter protection. From these figures, the peak concentration of Co-Hb is recorded to 12±4%. The glucose concentration in blood keeps rising until 12 minutes elapse since ignition, and is recorded to a peak value of 423mg/dL. The glucose concentration exceeds the reference level of 200mg/dL in healthy blood, thus may cause irregularity of human body. AST(GOT) and ALT(GPT) are respectively recorded to each of concentration 134~230IU/L, 40~86IU/L.

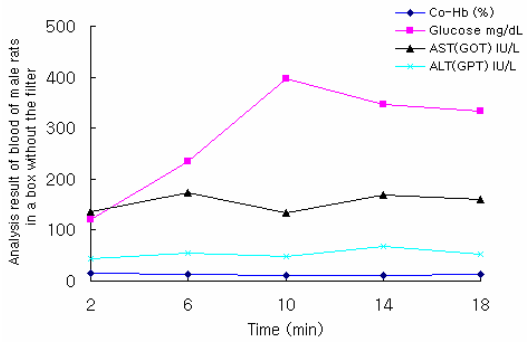

Figure 10. Results of blood test (male rats) in the box without filter protection.

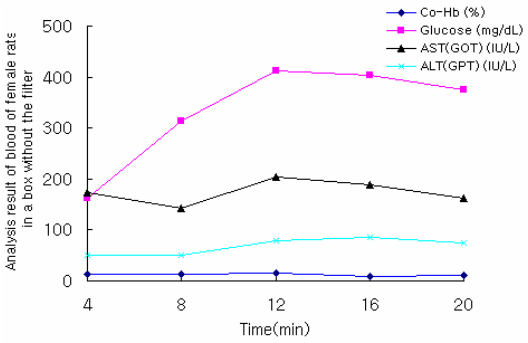

Figure 11. Results of blood test (female rats) in the box without filter protection.

Figure 12, 13 shows the results of blood test in the box with filter protection. The Co-Hb concentration in blood is always below 10%, and the glucose concentration is recorded to a peak value of 154mg/dL within the 20 minutes of sampling time. Both two indexes are within the range of normal level. ASL(GOT) and ALT(GPT) are respectively recorded to a concentration within 128~202IU/L, and a concentration within 49~70IU/L. It can be observed from these results that the concentration of active enzyme in the blood samples extracted from the rats not protected by the filter is comparatively higher. It also can be observed from the results that the concentrations of AST(GOT) and ALT(GPT) keep rising regardless if the rats were protected by filter or not. The reason for this phenomenon is that stem cells and other organ cells are destructed and flow into the blood, which evidently indicates the toxicity of combustion gases. The concentration of enzyme in the blood samples extracted from the rats not protected by filter shows a steady value after 12 minutes elapse since ignition, which indicates that all the rats have been dead. While inside the box protected by the filter, all the rats stayed alive through the experiment. In the blood samples extracted from the rats not protected by filter, the Co-Hb concentration is about two times higher than the one in the samples extracted from the rats protected by filter. It is concluded from this fact that the filter can significantly reduce the inflow of CO gas. By comparing blood test results in terms of sex, it can be seen that the male rats show a much larger enzyme concentration, than female rats do. This phenomenon is estimated to be owing to the fact that the male rats act and breathe more vigorously than female rats do.

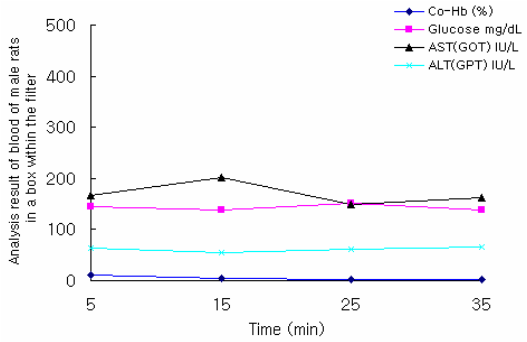

Figure 12. Results of blood test (male rats) in the box with filter protection.

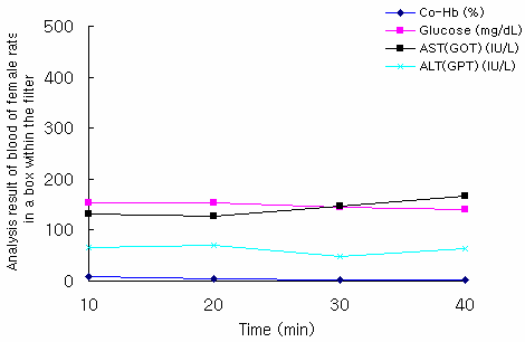

Figure 13. Results of blood test (female rats) in the box with filter protection.

4. Conclusion

In this study, the toxicity of combustion gases released from residential container fires was analyzed, and the performance of the filter mounted in gas mask was evaluated.

1) The peak concentrations of combustion gases are respectively measured as follows:
a) O_2(3.45%), CO_2(9.7%), CO(5395ppm), NO_x(223ppm), SO_x(467ppm), HCl(62.3ppm), HCN(117.8ppm) for the box without filter protections; and
b) O_2(above 19.5%), CO_2(below 1.9%), CO(331ppm), NO_x(10ppm), SO_x(4ppm), HCl(62.3ppm), HCN(117.8ppm) for the box with filter protection.
2) The results of blood test indicate that the Co-Hb concentration will decline regardless if the box is protected by filter or not. For the rats not protected by the filter, the concentration of glucose in their blood keeps rising for 12 minutes; while for the rats protected by the filter, the concentration of glucose shows no significant change. AST(GOT) and ALT(GPT) also show a minor increase, which is caused by the destruction of stem cells and organ cells after exposure to toxic combustion gases.
3) When it was 2 minutes 45 seconds after ignition, one rat inside the box without filter protection firstly lost ability to move. Within the next 3 minutes, all the 10 rats became unable to move. According to the results of blood test, the rats maintained breathing for 12 minutes after ignition, and turned dead shortly afterwards. On the contrary, the rats in the box with filter protection always kept alive.

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