THERMAL AND SMOKE MEASUREMENTS OF VEHICLE FIRES

Establishing practical large-scale experiment for vehicle fires

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ABSTRACT

Experiments were conducted to evaluate the hazard risks of vehicle fires. Sensors were strategically placed in passenger cars to determine the temperature, propagation rate and direction of flame. The life safety hazard evaluations such as smoke and gas analysis were included. An important ignition position was performed in the engine compartment. The effects of different ignition positions and the opening of door glasses were also reviewed.

The experimental results indicate that the maximum temperature when a vehicle burns varies commonly from 900℃~1000℃. The flame reaches in the face of a driver about 6~7 minutes and the windshield glass breaks about 10 minutes after the ignition in the engine compartment of vehicle. And the smoke and gas concentrations reached the limit of human inhalation after 13~14 minutes. Especially the concentrations of carbon monoxide exceeded the TWA(50 ppm) during short time after ignition in cases of all experiments.

INTRODUCTION

In overseas researches, the experiments for large-scale have been studied as the efforts to develop the construction method for buildings and criteria of extinguishing system capability.[1] Particularly various room fire experiments have been proceeded through the U.S. and Japan. Parker calculated heat release rate by oxygen consumption for various applications in 1982.[2] Harland and Anderson proved that carbon monoxide acted as the most important material of various death causes according to the results of several fire experiments.[3]

Nowadays large fires occur in not only common business buildings but also a number of merry-making places, and they result in fatal damage to an equipment or human.[4] However, due to cost restrictions and environmental concerns, numerous full-scale fire characterization tests are not generally feasible.[5] Fire death statistics in many cases show that the inhalation of toxic gases result in human deaths. The actual delivery of toxic gases to the victim can be separated into two effecting factors.[6] One is a toxic effect and the other is a mass loss rate. Regularly the toxic potency measurements are most approximately measured in bench scale and expressed as followed below.

$$(\text{toxic effect, per kg of material}) \times (\text{mass loss rate})$$

Vehicle fires mainly include the engine compartment fire and passenger compartment fire. In cases of engine compartment fires, their flame comes up to the passenger compartment breaking the windshield glass by an ignition source. Passenger compartment fires are caused by passengers' carelessness, cigarette fire for example, and they propagate rapidly through vehicle upholsteries. Especially the passenger compartment fires are easy to spread, once ignited, because vehicle upholsteries are comprised of combustible light-weight plastics. Also these plastics are very dangerous owing to their toxic gases when burn. And the inherent fire safety characteristics (i.e. ignitability, flame spread and decomposition products) of polymerics located within internal compartments play a major role in determining whether a newly started fire becomes a fizzle or a catastrophe.[7]

EXPERIMENTAL METHOD

In this research, the fire experiments for total five cars dealt with scrapped cars were performed. Ignition positions were selected at three positions of the engine compartment, passenger compartment and tire. Commonly vehicle structures can be divided into the engine compartment, passenger compartment and trunk but the ignition position for optimization in this research was installed in the engine compartment occupying most of vehicle fires.

On the other hand, the passenger compartment was selected as the other ignition position. Passenger compartment is the place occurring incidental fires by the arson of cigarette et al., which is comprised of various upholsteries: *Door Trim, Package Tray, Floor Carpet, Head Line, Instrument Panel.* The floor carpet of these upholsteries is very weak with heat because they are the lowest L.O.I. (Limited Oxygen Index).[8] Finally the trunk was selected as ignition position.

During experiments, thermocouples with K-type(chromel-alumel) were arranged at total eight positions containing ambient temperature because vehicles were very small when compared with the sizes of other buildings. Owing to this fact, it was proved to be unnecessary to set large numbers of thermocouples. Concretely the arrangement of thermocouples is one at the engine compartment, five at the passenger compartment and one at the trunk. The five thermocouples installed in the passenger compartment were set two in the height of each of 20cm, 70cm from the ceiling in the side of a driver, and two there in the rear side of an assistant and one in the center finally. The amount of combustible fuels was nearly the same as both sides of the front seats (a driver's side and an assistant's side) and rear seats. Therefore, it was unnecessary to install the sensor at both sides equally.

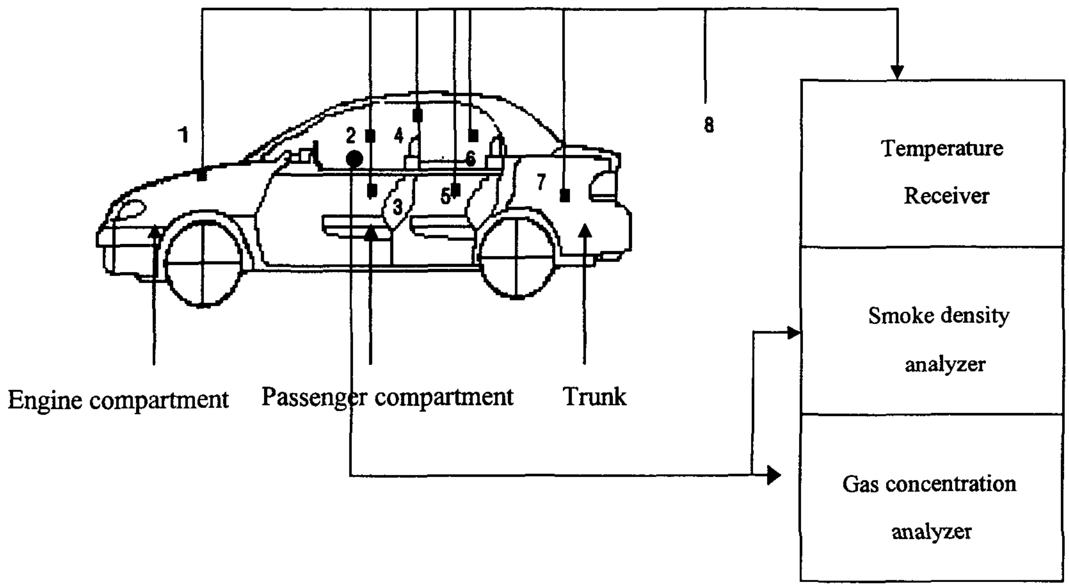
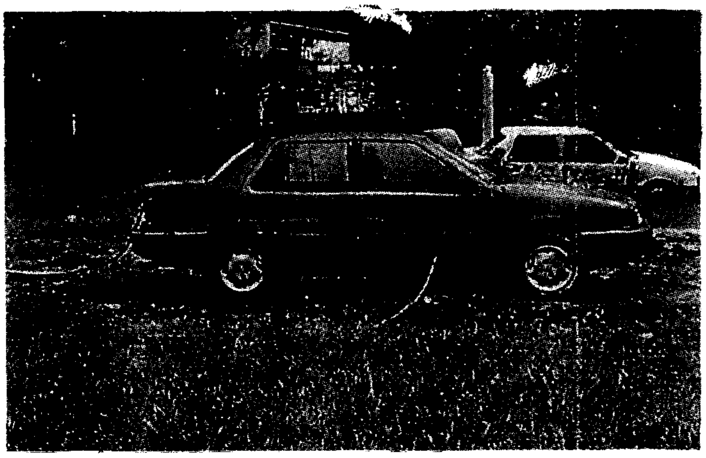


Fig. 1 Schematic drawing of the experimental apparatus for vehicle fires



(a) Appearance of the passenger car used in this experiment

(b) Photograph of thermocouples and smoke sensor installed in the passenger compartment

Fig. 2 Plan view of vehicle fire experiment

Table 1. The conditions of ambient velocity and pipe velocity*

Ignition position	Ambient velocity [m/s]	Pipe velocity [m/s]
Engine compartment	0.75	0.86
Passenger compartment	0.37	1.13
Tire	1.34	1.31

* *Pipe velocity is the inside velocity of SUS pipe*

The experimental method to measure smoke density can be divided into two types. One type is the ionization method by using α wave (radioisotope). The other type is the obscuration method by using floodlight and receiver (photocell). In this experiment, the obscuration method was selected because it has more reliability and has been standardized over the world. Concretely the method is used in determining the concentration of smoke and dust by using obscuration ratio of visible ray by *Lambert's Law*. Determination range is 10[mV] on full scale 100% when obscuration ratio is 0.5[m]. The main compositions are floodlight, light receiver, selenium photocell, light-source adjustment, rectifying filter adapter, and iris. A hole at the passenger compartment ceiling was drilled, in which SUS pipe was inserted. Once passing SUS pipe, the smoke is gathered in the apparatus. The hole diameter was about 20mm and the determination position for gathering smoke was fixed on the height of 22cm from the passenger compartment ceiling in the side of a driver to agree with the height of a driver's respiration.

Gas concentration was measured by Enerac model 2000 having used in analyzing the efficiency of combustion as well as excess air and carbon dioxide. The determination is important factor to evaluate the effect for human safety, and then the values as time passages were determined. Owing to apparatus damage, it is connected with smoke density analyzer.

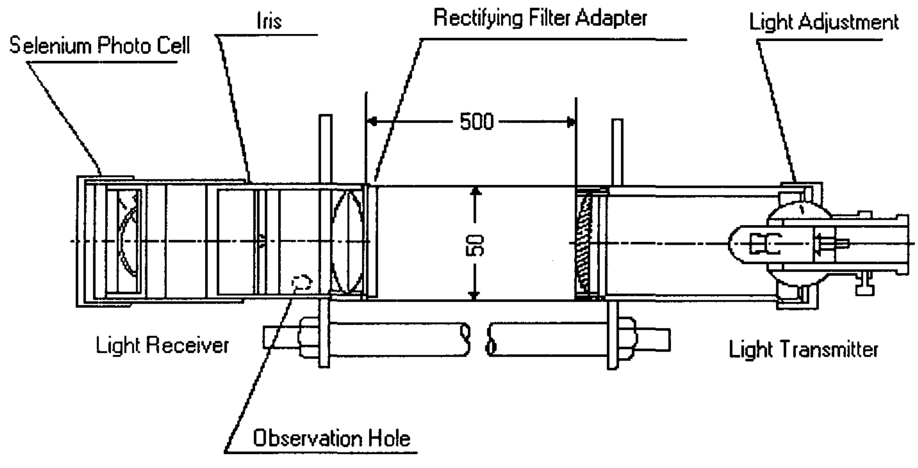


Fig. 3 Schematic diagram of smoke density apparatus

In addition, the variables used in this research were ignition positions (engine compartment, passenger compartment, and trunk), the number of open door glasses, the positions of thermocouples, and the kinds of ignition sources. Especially the amount of gasoline in a fuel tank was considered as the important variable, and then it is pulled out entirely from the fuel tank and injected there again. For making constant condition, the amount of gasoline in the fuel tank was fixed on 10 ℓ.

Table 2. The number and classification of ignition sources

Ignition position	Size [number]	Ignition source
Engine compartment	30cm × 30cm [5, 25, 40]	fabrics soaked in gasoline
Passenger compartment	-	gasoline
Tire	30cm × 30cm [10]	fabrics soaked in gasoline

RESULTS AND DISCUSSIONS

The temperature graphs show the different shapes as the ignition positions for temp.1 sensor (at the engine compartment center) - Fig. 4. The inside temperature of engine compartment, appeared high compared with the passenger compartment and tire in primary 10 minutes. Because the amounts of combustible materials in the engine compartment were small, the time from flash-over to decay phase was short. But the total combustion time appeared long at the passenger compartment and the continuity of high temperature also appeared there. The reason was that flame stayed long there despite of time passages. And the windshield glass broke slightly with the crack in 3 minutes from ignition and perfectly in 4 minutes 30 seconds. After this time, the wind speed strengthened, and then the propagation velocity of flame was accelerated. The temperature depended on irregular wind speed and fluctuated. The rupture of fuel tank is observed by small peak on graphs. The maximum temperature indicates in 23 minutes 30 seconds (853℃).

The flame propagation when a tire burns draws comparatively low temperature curve. The flame was affected by the wind speed (the peak speed: 1.37m/s) and its direction and so on. The temperature increased from ignition to the rupture of radiator via the windshield glass due to air inflow, and then dropped in 50 seconds after the rupture of radiator due to the consumption of combustible materials. After this time, the temperature increased again due to the rupture of battery and the breakage of door glass in the side of a driver. And the temperature was accelerated due to the rupture of engine oil and tire, and then dropped rapidly because the simultaneous breakage of door glasses brought about the excessive supply of oxygen. The temperature increased again from the breakage of an assistant's door glass to the rupture of fuel tank via the rear window. After the rupture of fuel tank, the temperature fluctuated to total destruction by fire.

On the other hand, Fig. 5 shows the temperature profiles in case of passenger compartment fire (ignition source: a little amount of gasoline, at rear-seat). In figure, it was shown that the temperature curve for only temp.1 sensor did seldom drop to low.

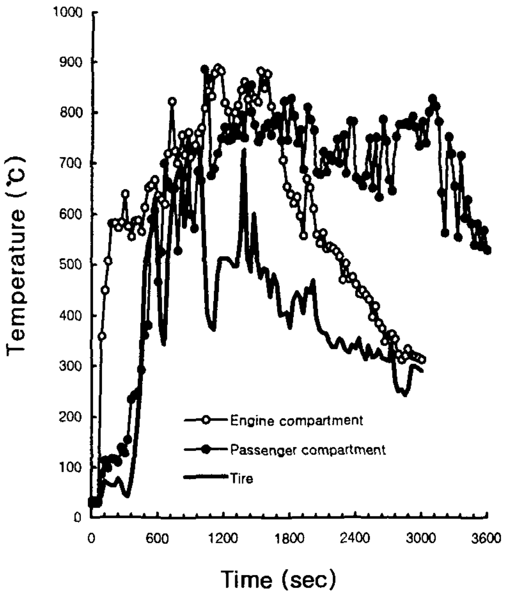


Fig. 4 Temperature profiles as different ignition positions in the vehicle fires

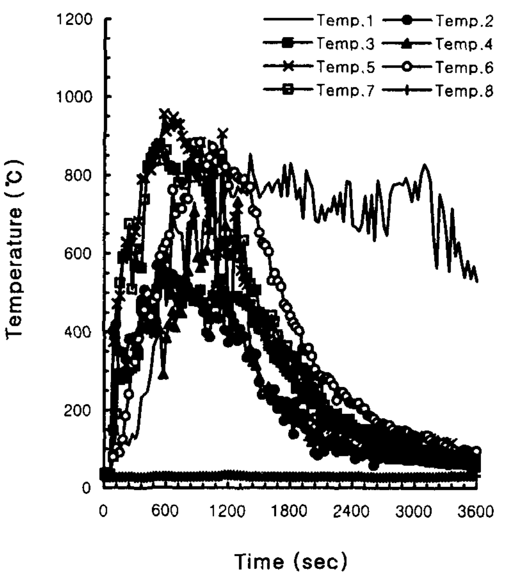
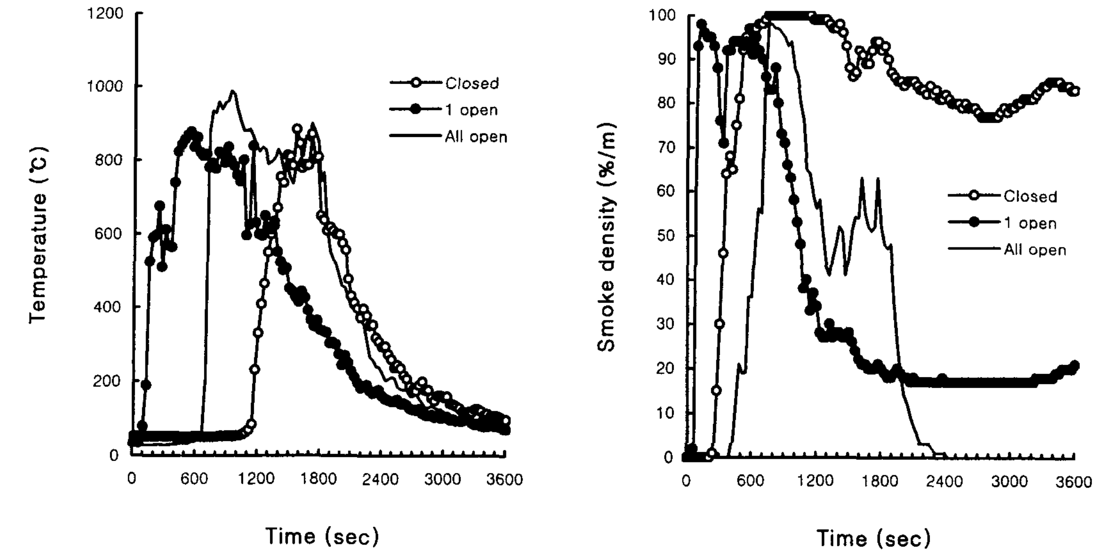


Fig. 5 Temperature profiles as different sensor positions in the vehicle fires

Fig. 6 shows the temperature profiles and smoke density changes as the number of open door glasses. Fire-growth point was observed clearly in regular sequence: one opened, all opened, and closed. And the temperature curve in case of all opened was observed by two peaks on graphs owing to the combustion restarting of combustible materials, and the decay phase agreed with that of closed. The maximum temperature was showed up in case of all opened and the others were similar. The smoke density increased greatly in case of one opened because the smoke density sensor was installed in the position related with open door glass but the breaking acceleration of door glasses decreased the amounts of smoke during short time. In case of closed, the smoke density did seldom drop during total destruction by fire owing to continuous stay of flame. In case of all opened, the fire-growth point was started lately and after passing about 13 minutes, dropped but increased again with drawing somewhat fluctuations by several effects. Also the value was almost dropped to zero degree owing to the flame extinction by rapid combustion.



(a) Temperature profiles (b) Smoke density changes

Fig. 6 Temperature profiles and smoke density changes as the opening of door glasses in the vehicle fires

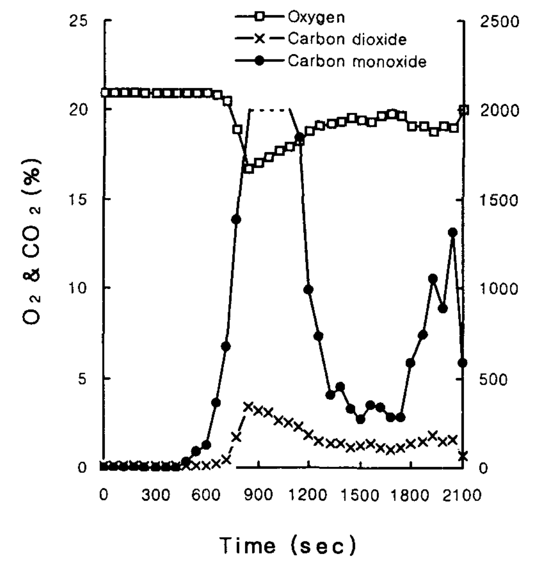


Fig. 7 Gas concentration changes during the vehicle fires

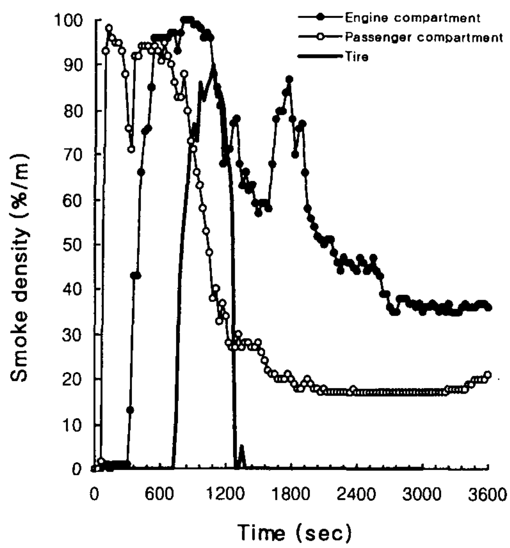


Fig. 8 Smoke density changes as different ignition positions in the vehicle fires

Chemical gas concentrations as time passages were also focused in this experiment. Fig. 7 shows the case of the bonnet ignition with fabrics[40]. After 14 minutes, carbon monoxide gas concentration increased on exceeding the limit of the apparatus's capability (2000ppm) and continued for 4 minutes, and dropped rapidly. After this time, the concentration increased again, and dropped in 34 minutes. The windshield glass of the car broke about 11 minutes and by the result, the concentration reached the maximum point. Also it could be shown easily that oxygen graphs and carbon dioxide graphs were almost symmetrized perfectly. On the other hand, the smoke densities as the ignition positions are shown by Fig. 8. The early proceeding sequence was the passenger compartment, engine compartment and tire but the smoke density in the passenger compartment fire decreased rapidly because the flame burned the materials in compartment and propagated towards the others' directions. And the smoke density in the engine compartment fire increased slowly owing to slow propagation towards room but did seldom drop as time passages. After it dropped about 20 minutes, it increased again due to the rupture of fuel tank. In case of tire fire, the windshield glass broke early compared with the others, and then after burned the combustible materials in the passenger compartment, the smoke density dropped to zero point. The smoke was observed only during 8 minutes 30 seconds and after the rupture of fuel tank, it increased a little.

CONCLUSIONS

In case of engine compartment fire, the flame reached in the face of a driver after passing about 6~7 minutes from ignition and the breakage of windshield glass appeared about 10 minutes. Fire-growth point appeared before 2 minutes and the temperature curve of flashover appeared about 900℃ before 20 minutes, after this time, the flame reached in the decay phase. When a vehicle burns, the inside temperature of the passenger compartment varies from 900℃ to 1100℃, which fluctuates because of wind speeds, and then it takes one hour and a half to become extinct completely. The effecting factors for fire-growth characteristics were the rupture of engine oil and fuel tank, irregular wind speed and its direction. And the fire scene when a vehicle burnt indicated that the paint on vehicle surface was melted at first and as the result, aluminum constituting vehicle's frame was melted lately. In case of open door glasses, the phenomenon melting the rear window was also observed. As reviewing the effects of open door glasses, the fire-growth point was observed clearly in regular sequence: one opened, all opened and closed. The maximum temperature was observed in case of all open glasses and in case of close glasses, the time from flashover to post-flashover was short compared with other cases and the tilt was also rapid. As reviewing the effects of ignition positions, the peak of temperature profiles appeared in regular sequence: engine compartment, passenger compartment and tire. In case of engine compartment fire, the temperatures varied high compared with the passenger compartment and tire fire in primary 10 minutes. Because the amounts of combustible materials in the engine compartment were small, the time from flash-over to decay was short. The propagating velocity was the fastest in case of passenger compartment fire. Meanwhile, the breakage of windshield glass was also the shortest in the passenger compartment. The breakage time as ignition positions appeared as 11 minutes in the engine compartment, 4 minutes 30 seconds in the passenger compartment and 17 minutes 25 seconds in the tire. The analysis for smoke and gas showed that the amounts of those reached the limit of human inhalation after 13~14 minutes. Especially the carbon monoxide gas concentrations exceeded the limit of a life-threat in all experiments and the values reached the TWA(50 ppm) during short time. Also oxygen and carbon dioxide gas concentration changed extremely. In addition, smoke was observed very long in the engine compartment and the smoke density in the passenger compartment was observed by primary time passages. Especially the smoke density when a tire burnt, increased on a rapid tilt during a short time (about 10 minutes).

ACKNOWLEDGMENTS

This research can be represented as vehicle fire modeling using computational simulations. And this experiment datum may help fire fighters to expand the services of prevention, suppression and fire-prevention management for various fires. Furthermore we can compare with the experimental research for building fires and review the relations for each other. This research was performed by Industrial Safety Research Center in Hoseo University.

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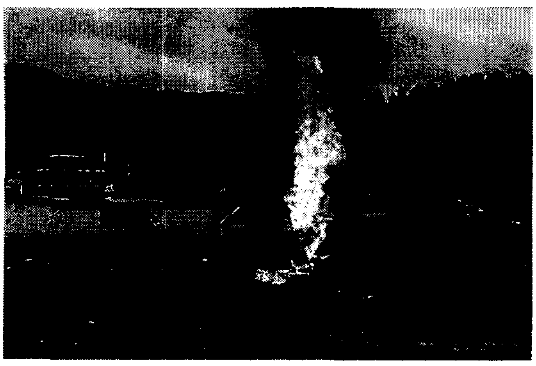
APPENDIX

(a) Primary

(b) The photograph of inflow and outflow



(c) The photograph at the time of the rupture of fuel tank

(d) The last period

Fig. 9 Plan view of the experiment for vehicle fire as sequence (Ignition in the engine compartment)