Experimental Study on Fire Hazard of Residential Fires Before and After Sprinkler Activation

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ABSTRACT

Fire experiments were conducted in a real scale room which is assumed to be a residential living room under the various opening conditions and locations of wood crib fire source to study on fire hazard before and after sprinkler activation. Concentrations of oxygen and carbon monoxide, smoke density, and temperature were measured to look into environmental conditions in a room of fire origin. The response time of residential sprinklers was also examined in relation to distance between sprinkler heads and a fire source.
Keywords : *residential fire, residential sprinkler, fire hazard*

INTRODUCTION

Every year, many lives of disaster vulnerable people like elderly, infants, and physically handicapped are lost in residential fires in Japan[1]. For example, it is reported in the "White Book on Fire Service in Japan, 1995"[2] that 88% of structure fire deaths excluding incendiary suicides came from residential fires and 53% of that were elderly, infants, and physically handicapped persons. Besides this fact, Japan is facing the problem of rapidly aging of a society that is expected to continue to a stage where one fourth of total population are 65 or older around in 2020. Therefore, it is earnestly desired to develop measures for reducing fires and fire deaths in homes.

From this viewpoint, the Fire and Disaster management Agency issued a "Technical guideline on residential sprinkler system and residential detectors"[3], as of March 25, 1991. Reflecting this trend of the administration, fire protection equipment makers started the development of a quick response sprinkler head. Also, the Japan Fire Equipment Inspection Institute started experimental research[4] on test fires for establishment of approval procedures on residential sprinklers.

As the first step to study the feasibility of residential sprinklers to save persons in a room of fire origin, we carried out fire experiments using wood crib fire source in a real scale test room to look into fire hazard before and after sprinkler activation. We measured and examined the temperature near the ceiling, the vertical temperature distribution, smoke density, and the gas concentration as environmental conditions inside a fire room. Also, to consider performance of residential sprinklers, response time of sprinklers was measured in relation to distance between sprinkler heads and a fire source since a fire dose not always starts from the center of a room.

OUTLINE OF THE EXPERIMENTS

Fire Test Room

The area of a fire test room is 13.7 m^2 (3.8m x 3.6m), and the room height is 2.4 m. The walls and the ceilings are covered with rock wool cement board and the floor is covered with water-proof plywood. There is a slide door in the east side of a fire test room which is used to adjust the ventilation condition by changing the width of a door. Next to a fire test room, there is an observation room where measurement apparatuses are installed. The outline of the fire test room is shown in Fig. 1.

Fire Source and Ignition

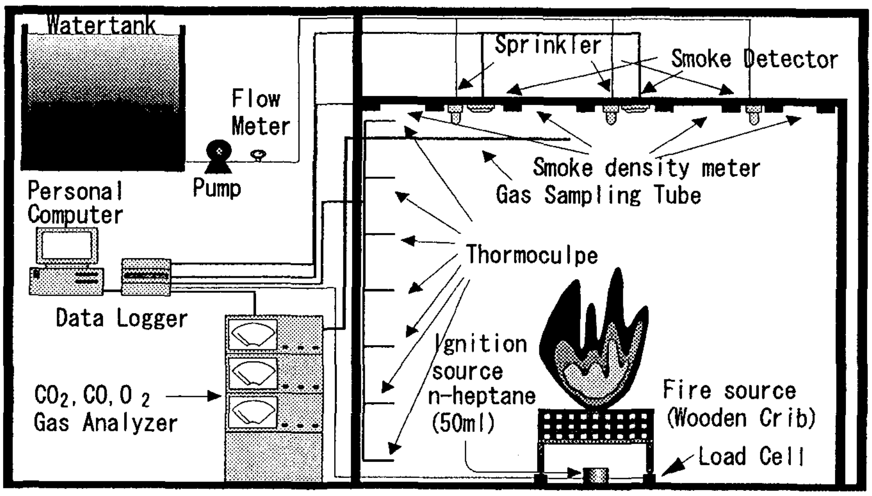
The fire source is wood crib whose configuration and ignition method are specified as a test fire in the "Technical guideline on residential sprinkler system and residential detectors"[3]. The wood crib is assembled with 6 layers of 58 pieces of cedar crib, 0.03m x 0.035m x 0.90 m for each piece, the total weight of that is about 20kg. The wood crib was ignited by combustion of 50ml n-heptane in a heat source pan on the floor beneath the wood crib's center.

Measurement of Temperature

The temperature was measured with 1mm ϕ K- type thermocouples. Thermocouples are installed near the ceiling surface for looking into horizontal distribution and also installed in the positions as the center of the fire room (A point), south of A point by 0.9m (B point), and near the south window (D point) for looking into vertical distribution as shown in Fig. 2(a).

Measurement of Smoke Density and Gas Concentration

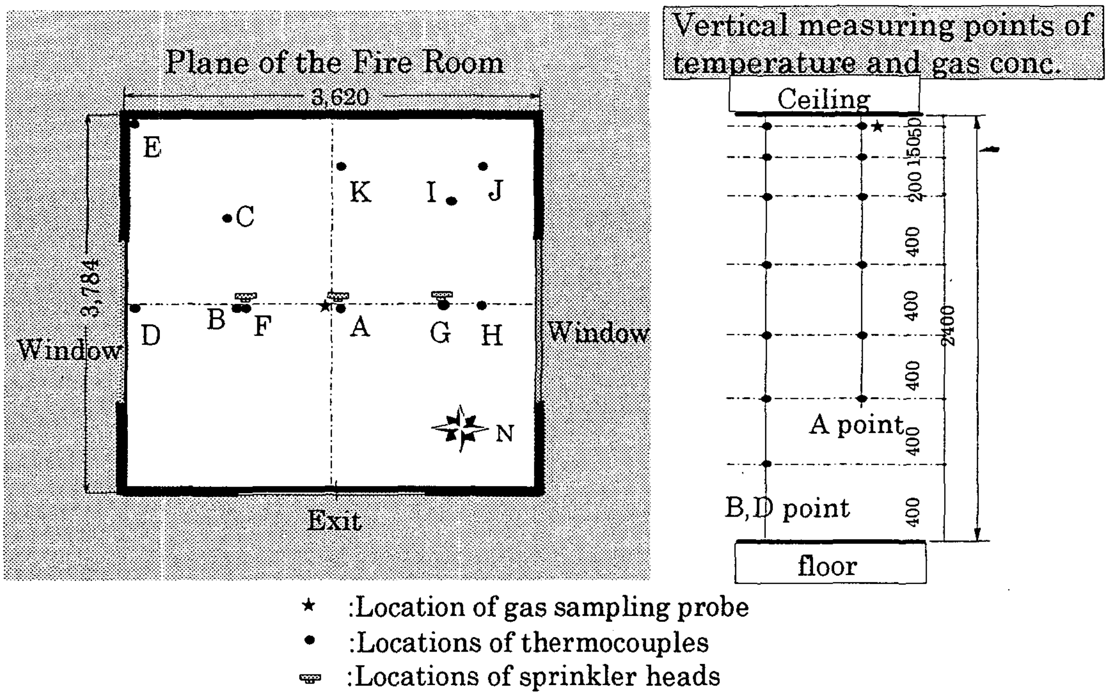
Smoke density was measured with smoke density meters of 1m light pass length. In order to see horizontal distribution of smoke density near the ceiling, six smoke density meters were placed. And, seven smoke density meters were placed along the south window in order to see the vertical distribution of smoke density. The gases concentration was measured at the center of the fire room,



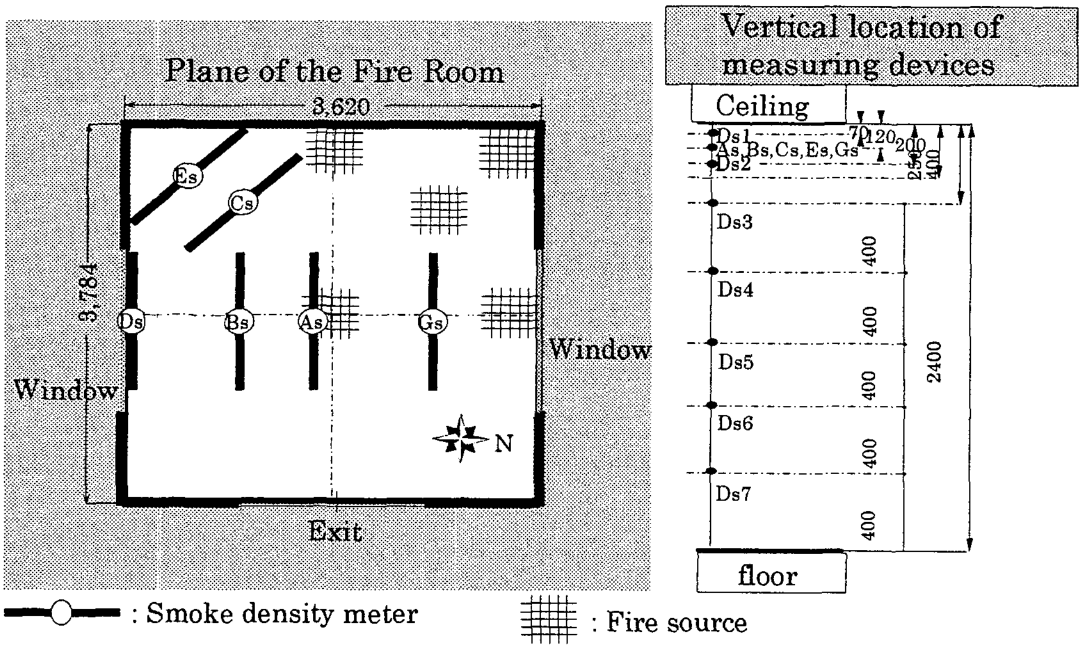
Observation Room   Fire Room

Fig. 1 Schematic diagram of a fire test room.

0.05m below the ceiling level. O_2 concentration was measured using O_2 gas analyzer with the range of 16% to 21% and CO gas concentration was measured using CO gas analyzer with the range of 0% to 2%. The gas sampling position is shown in Fig. 2(a) and positions of smoke density meters are shown in Fig. 2(b).



(a) Positions of thermocouples, gas sampling, and sprinkler heads.



(b) Positions of smoke density meters and a fire source.

Fig. 2 Positions of measurement devices, sprinkler heads, and a fire source.

Table 1 Experimental conditions.

Exp. No.	Locations of sprinkler heads	Location of fire source	Ventilation conditions	Wooden crib's moisture content (%)
1	A	A	1/2 opened	17.8
2	F、G	A	1/2 opened	16.4
3	F、G	A	1/4 opened	17.3
4	F、G	A	1/8 opened	14.2
5	F、G	A	1/16 opened	12.6
6	F、G	A	Closed	13.0
7	A	J	Closed	13.4
8	F	J	Closed	12.5
9	A	K	Closed	10.1
10	F、G	K	Closed	12.5
11	F	H	Closed	10.8
12	A	I	Closed	13.1
13	No Sprinkler	J	Closed	14.3
14	No Sprinkler	J	Closed	13.3
15	No Sprinkler	J	CLosed	13.4

Wooden crib's moisture percentage(%) represents the average of four measurements.

Sprinkler Installation and Water Discharge Condition

Sprinkler heads with the nominal release temperature of 72℃ were installed at the center of a fire room (A point), and at the two positions (F point and G point), 0.8m away south and north respectively from A point, as shown in Fig. 2(a). The conditions of water discharge of sprinkler heads were as follows.

(1) In case that only the sprinkler at A point is available.

Water discharge flow : 28 l/min. Water pressure : 1.08 ~ 1.17 kgf/cm^2.

(2) In case that the sprinklers at F point and G point are available.

Water discharge flow : 57 l/min. Water pressure : 1.19 ~ 1.24 kgf/cm^2.

The water discharge flow was 34 ~ 36 l/min when only one of F and G sprinkler activated.

The Conditions of Experiments

The experiment conditions of 15 fire tests are shown in Table 1. The experiment No. 1 to No. 6 in Table 1 are the cases that the fire source was placed in the center of a fire room with variety of ventilation conditions. The experiment No. 7 to No. 12 are the cases that the ventilation condition was fixed (the sliding door is closed) with variety of location of the fire source. The experiments No. 13 to No. 15 were done without sprinklers.

RESULTS AND DISCUSSIONS

The Temperature Profile and The Fire Behavior

The temperature near the ceiling level above the fire source. The temperature-time curve near the ceiling level for the cases that the fire source is at the center of the room (Exp. No. 1 to Exp. No. 6) traces three stages such as a preheating stage of the wood crib by the burning of n-heptane where the temperature flattens after slight increase, then a drastic temperature rising stage after the ignition of wooden crib, and a cooling stage where the temperature drops due to the sprinkler's water discharge As all of the cases followed the same pattern, the reproducibility of the crib fire is considered to be obtained, although temperature-time profiles shown in Fig. 3 were the data of different opening conditions. It is seen that there is a difference in the drastic temperature rising point, ranging from 10 seconds to about 1 minute among the curves. As the preheating time of wood crib differs by the wooden crib's moisture, the room's temperature, and humidity, so the preheating time must be disregarded when the comparison of temperature-time profile among experiments is discussed.

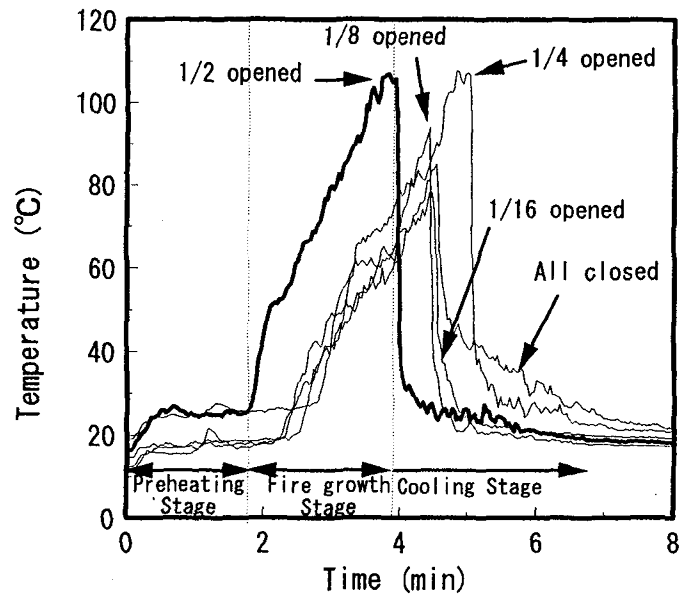


Fig. 3 Temperature-time profiles near the ceiling level above the fire source.

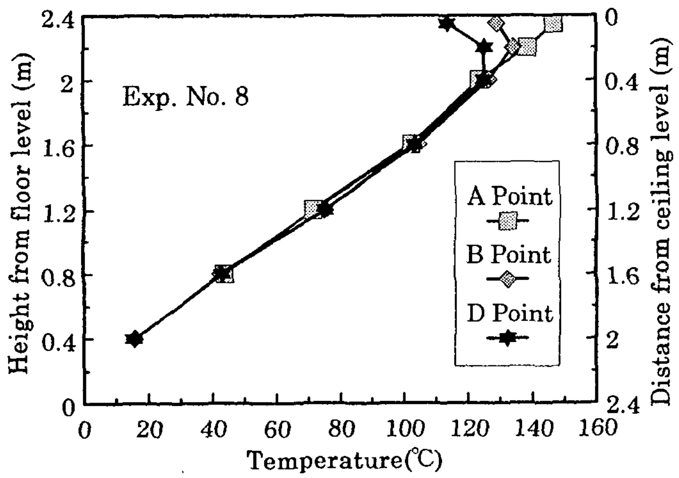


Fig. 4 Vertical distribution of temperature in the fire test room for the experiment No. 8.

Vertical temperature distribution. The vertical distribution of temperature before sprinkler activation at the A, B, and D points for the Exp. No. 8, where the fire source was set at the north west corner and the sliding door was closed, is shown in Fig. 4. Between 0.4m and 2m below the ceiling level, the temperature decreases linearly as a measuring point gets closer to the floor, and the vertical distribution of temperature is nearly the same for the points A, B, and D. This indicates that the smoke layer in the room was stratified until the sprinkler activation when the opening was all closed. The temperature near the ceiling decreased as a measuring point gets further from the fire source. This feature of the temperature near the ceiling was commonly seen in all of the experiments.

Smoke Density

The Fig. 5 and Fig. 6 show the change in smoke density at points Gs, As, Bs, and Ds near the ceiling level and also at points along the wall at Ds (excluding Ds2) for the experiment No. 8 respectively. The experiment No. 8 was done in a condition that was most unfavorable for activation of sprinklers, because the fire source and the sprinkler head were most separated among all of the experiments in Table 1.

From Fig. 5, before activation of sprinklers, the change of smoke density was similar among the data for the points on the ceiling except for Ds1. Four and a half minutes after the ignition, the smoke density reached 60%/m to 70%/m and then flattened. On the other hand, after activation of sprinklers, the density at all of the points became uniform with time lapse due to the stirring effect of the air by water discharge. And the smoke density rose up to nearly 100%/m about two minutes after the sprinkler activation.

From Fig. 6 for measuring points on the Ds vertical line, before the activation of sprinklers, the smoke density rose with lapse of time in the order of higher position of points since the smoke layer was falling at the same period. Although the smoke density, except for the point Ds7, was in the stable state after the increasing state before the sprinkler activation, the smoke density at Ds7 was still in the increasing state. Thus, the smoke boundary layer at the sprinkler activation can be estimated to be in between Ds6 and Ds7. After the sprinkler activation, the smoke density at all of the points, regardless of the height, became uniform as time elapsed due to the stirring effect of the room's air by discharged water, and then it became almost 100%/m two minutes after the sprinkler activation.

Gas Concentration (O_2, CO)

The response time of sprinklers was longer as the distance between a sprinkler head and a fire source was larger as seen Fig. 7.

For the cases, Exp. No. 1 to No. 6, that the fire source was placed in the center of the room, the response of sprinklers were quick and the fire was extinguished in the fairly early stage, so the O_2 concentration was 19% to 20% and CO gas concentration was 200ppm at most before the sprinkler activation and was about 500ppm after sprinkler activation which was not a so large value. Therefore, we introduce the data of the Exp. No. 8 which was done in a condition that was the most unfavorable for the activation of sprinklers in Fig. 8, because the fire source and the sprinkler head were most separated among all of the experiments in Table 1.

In this experiment, the sprinkler was activated 7 minutes after the ignition, and the water discharge up to 13 minutes after the ignition controlled the fire. However, when the sliding door was opened 15 minutes after the ignition, the fire started to grow again. This indicates that the imperfect combustion state was thought to continue even after the sprinkler activation. CO gas concentration rose drastically 7 minutes after the ignition when the sprinkler was activated, and it became 2000ppm just before the stop of water discharge by a sprinkler (13 minutes after ignition), and reached 3500ppm at the end of the experiment (15 minutes after the ignition).

These values of CO gas concentration were close to the level as the lethal concentration for 30

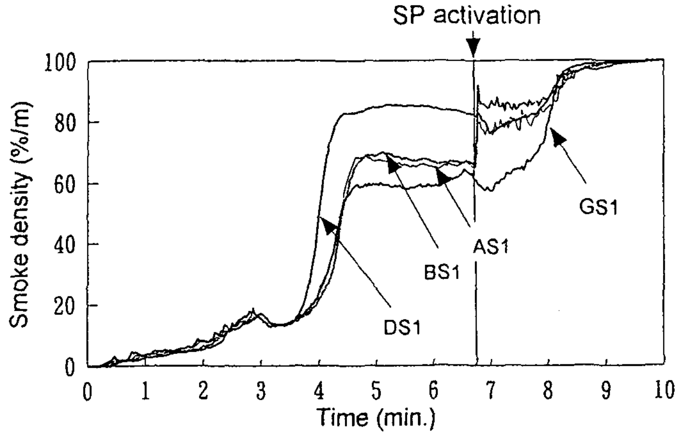


Fig. 5 Smoke density at different points near the ceiling in lapse of time for the experiment No. 8.

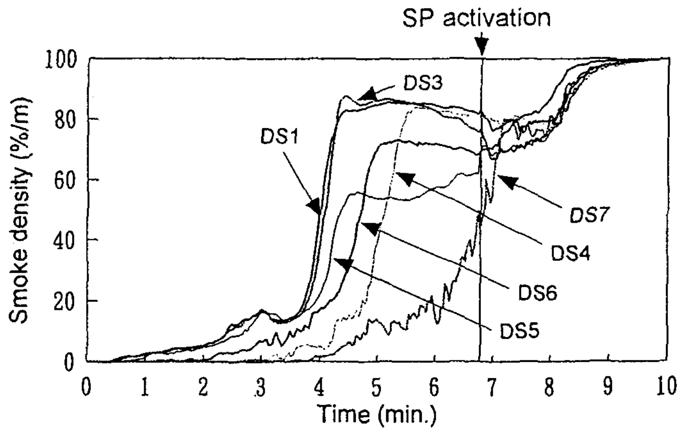


Fig. 6 Smoke density at different points along the wall at Ds point in lapse of time for the experiment No. 8.

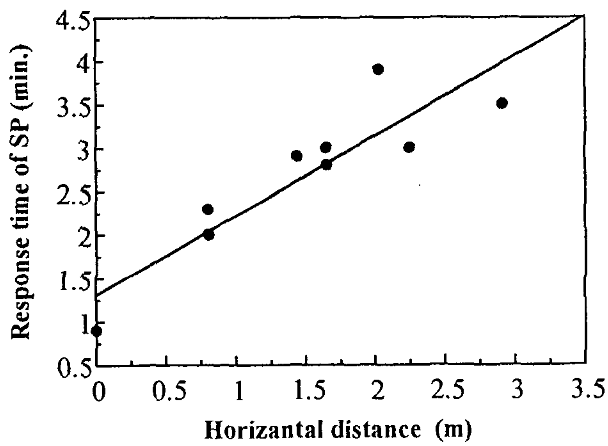


Fig. 7 Relation between response time of sprinklers and distance between a sprinkler head and a fire source.

**Note: The response time in this figure is adjusted by subtracting preheating time from the time after ignition.*

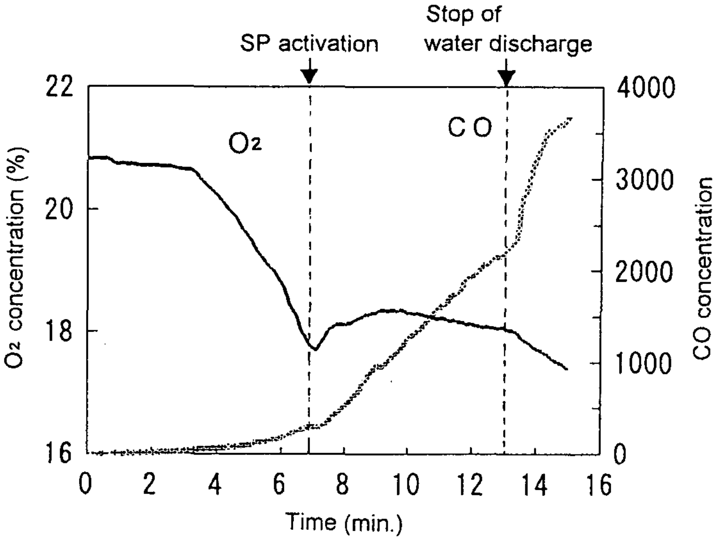


Fig. 8 O_2 and CO concentrations in lapse of time for the experiment No. 8.

minutes exposure, 4000ppm. Although this result is for the case most unfavorable in terms of sprinkler activation among all the experiments in Table 1, we should note that persons, specially the disabled, left in a room of fire origin could be involved in a critical condition for survival even after activation of sprinklers when a fire starts in a location not close to sprinkler heads.

CONCLUDING REMARKS

We conducted fire experiments in a real scale room using a wood crib fire source, and measured temperature, smoke density, and gas concentration before and after activation of sprinklers to look into environmental conditions in a room of fire origin. The result were as follows.

(1) In this condition, it was confirmed that the residential sprinkler systems can control the wood crib fire.

(2) The CO gas concentration increased to be a critical level for survival in a room of fire origin even after activation of sprinklers when the condition was the most unfavorable for the activation of sprinklers. Also, the high smoke density after sprinklers activation should be remarked as one of environmental conditions of a fire room along with the unification of smoke by the stirring effect of the air by sprinkler's water discharge.

(3) The response time of sprinklers was longer as distance between sprinkler heads and a fire source is was larger.

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