Burning Rate in a Small Compartment Fire

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ABSTRACT

This paper describes results of preliminary measurement of burning rate (mass loss rate) change in a 0.85 m high, 0.82 m wide, 1.05 m long compartment, a roughly one third scale residential room. Interior wall surfaces including the ceiling were partially covered with 12 mm thick wood to simulate a room fire. These woods were the fuel for the fire. The mass loss rate of wood in the compartment was measured by electrobalances. Wood inside the compartment detached from the outer walls of the compartment and stood independently on the special tray. Thus the mass loss rate was precisely measured by electrobalances. Each outer surface of the compartment was covered with two layers of insulation board to obtain a highly insulated condition. The compartment had a small opening in the middle of the front wall to realize a low-ventilation condition.

A rapid increase of burning rate was observed. Two distinct behaviors were observed. One was related to so-called pre-backdraft and the other was to backdraft. It was found that both phenomena needed high mass loss rate before they happened. As there were no big differences in the mass loss rate changes for both phenomena, it seems that both phenomena strongly depended on wood pyrolysis characteristics.

Another special experiment was carried out by replacing the opaque insulated side wall with a refractory glass window. Fire ball growth or flame propagation during backdraft was observed visually and recorded by a video. It was found that a small flame appeared near the ceiling at first. Then the backdraft flame propagated through the compartment consuming oxygen and the

accumulated excess pyrolyzate in the compartment.

INTRODUCTION

Backdraft and flashover are unique fire phenomena occurred in a compartment. Once either phenomena happens, firefighters have chances to be injured or to lose their lives. Damage due to fires with backdraft or flashover will be bigger. Fire reports and studies related to backdraft and flashover emphasizing various aspects have revealed characteristics of both phenomena. [1] - [10]

Backdraft is defined as a rapid deflagration following the introduction of oxygen into a compartment filled with accumulated excess pyrolyzates. [1] Flashover is distinguished from backdraft by the existence of deflagration and a more controlled introduction of oxygen.

Backdraft, or rapid deflagration, tends to release a flame from the opening and make big exterior fireballs. [2] - [4] Backdrafts may occur several times under specified conditions. [6] , [7] , [10]

On the contrary, flashover occurs when certain thermal conditions in the compartment are satisfied. In flashover, the whole compartment is filled with flame and rapid temperature rise is observed. In some case, flame also erupts from the opening. If there is no big difference between the erupted flame of flashover and exterior fireball of backdraft, it may be a little bit difficult to distinguish between the phenomena.

Fortunately, flashover may not occur under low-ventilation conditions because oxygen concentration is too low. Instead of flashover, various phenomena such as ghosting flame, self-extinguishment of the fire and smoldering will occur. We may call these pre-backdraft phenomena.

The dangerous consequences of a backdraft are well recognized in Sapporo, Hokkaido, Japan. In the northern part of Japan, especially in Hokkaido, highly insulated houses are built to keep out of the cold. It is necessary to establish the fire fighting methods which protect against backdrafts. Unfortunately there has been only a small amount of research on backdrafts. [1] - [7]

In the previous paper [10] , preliminary experimental results on backdrafts were reported. It presented backdraft scenarios in a one third scale compartment with a small opening in the middle of the front wall.

Recently, the authors have made a new special compartment. A newly developed refractory glass have been used as one side wall to observe the inside of the compartment. We also have measured mass loss rate of actual wood in the compartment and made more precise temperature distribution maps in the compartment. Gas analysis of upper and lower layer in the compartment have been carried out by measuring O_2, CO_2 and CO. From these experimental results, a more sophisticated and comprehensive understanding pre-backdraft and backdraft phenomena have been obtained.

EXPERIMENTS

Figure 1 shows a schematic view of the experimental apparatus giving the internal dimensions of the compartment. The inside dimension are 1.05 m (D) x 0.82 m (W) x 0.85 m (H) . The compartment volume is 0.732 m^3. The floor area is 0.861 m^2. The compartment is about a one third scale residential room. A big observation window made of refractory glass was installed on the right side wall shown in Figure 1.

A calcium silicate board (t=12 mm) and a fireproof insulation board (Mitsubishi Chemical Maftec board : t=25 mm) were chosen for the walls of the compartment. All walls were fundamentally made by two pieces of fireproof insulation board. The outside of all walls was covered with calcium silicate board. Gaps between the walls were tightly filled with heat - proof sealing material and covered with heat - proof tape.

Three-dimensional coordinates are introduced to clarify the location of various objects shown in Figure 1. The location of the coordinate origin is in the corner of the compartment and is indicated by closed circle shown in Figure 1.

Lauan wood was used as the fuel for the fire. Interior wall surfaces of the rear (x=0 mm or 0.0D) , the side (y=820 mm or 1.0W) and the ceiling (z=850 mm or 1.0H) were partially or fully covered with 18 mm thick and 150 mm width lauan wood to simulate a room fire as shown in Figure 1. The length of lauan wood for the ceiling was 0.9m and others were 0.62m. These woods were perforated with 13 mm diameter holes staggered with a 50 mm pitch. The lauan wood was dried for 24 hours at 60 ℃ before each experiment.

Two pine wood cribs each weighing 2.0 kg were used as igniters. Cribs were set in the right rear corner of the compartment as shown in Figure 1. The cribs were ignited by an LPG torch burner.

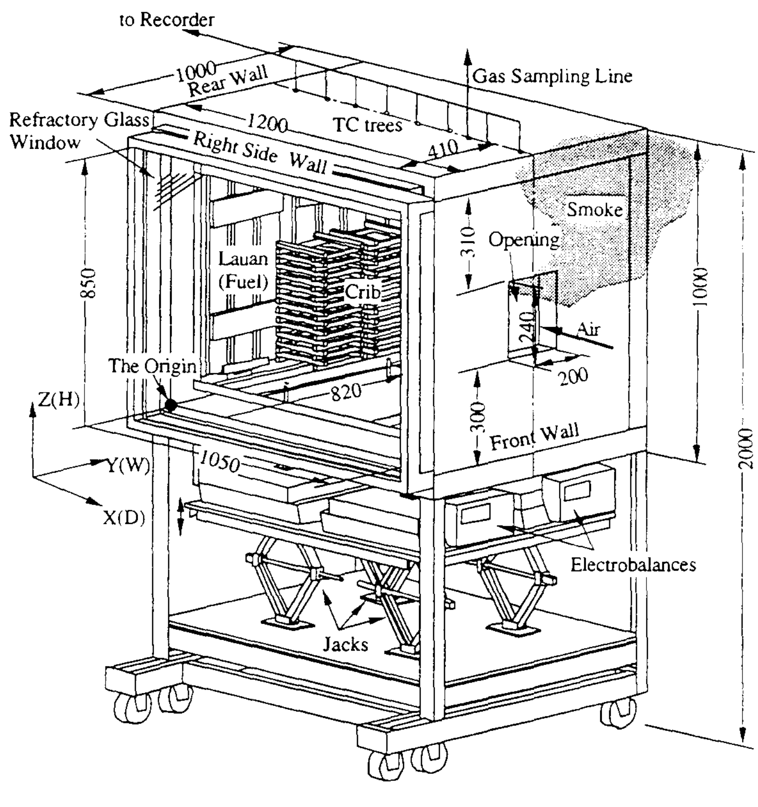

Figure 1. Schematic View of Experimental Compartment

The special frame made of

1.6mm thickness steel angle was used to measure mass loss of lauan and pine wood precisely. The frame was apart from the compartment and stood, independently, on electrobalances as shown in Figure 1. Fireproof insulation blanket (Mitsubishi Chemical Maftec blanket : t=25 mm) was used to keep the compartment airtight.

An opening in the center of the front wall, shown in Figure 1, permitted fresh air to enter the compartment. The size of the opening was empirically determined by preliminary experiments. The ventilation parameter $AH^{1/2}$ was $0.024m^{5/2}$. This opening was kept open during a fire test to promote fire in the wood cribs.

Eight vertical thermocouple trees were hanged from the ceiling as shown in Figure 2. Thermocouple trees were placed on the vertical center line of the front wall (y=410 mm or 0.50W), that with the opening. The thermocouples were 1.6 mm Type K thermocouple wire with a stainless steel overbraid. Each thermocouple tree had seven thermocouples on it. Totally fifty six measuring points were placed at equal intervals of 130 mm vertically and horizontally. The highest thermocouples were placed 20 mm below the ceiling. Every measured point was identified its dimensionless location like (0.44D, 0.50W, 0.67H) as shown in Figure 2. The temperatures reported here are uncorrected values.

Gas concentrations in the upper and lower layers in the compartment were measured with two copper probes (I.D. 6mm, O.D. 8mm) on a front gas tree (0.75D, 0.50W) shown in Figure 2. One probe (GT) was placed at 0.89H or 90 mm below the ceiling. Another probe (GB) was placed at 0.06H or 60 mm above the floor.

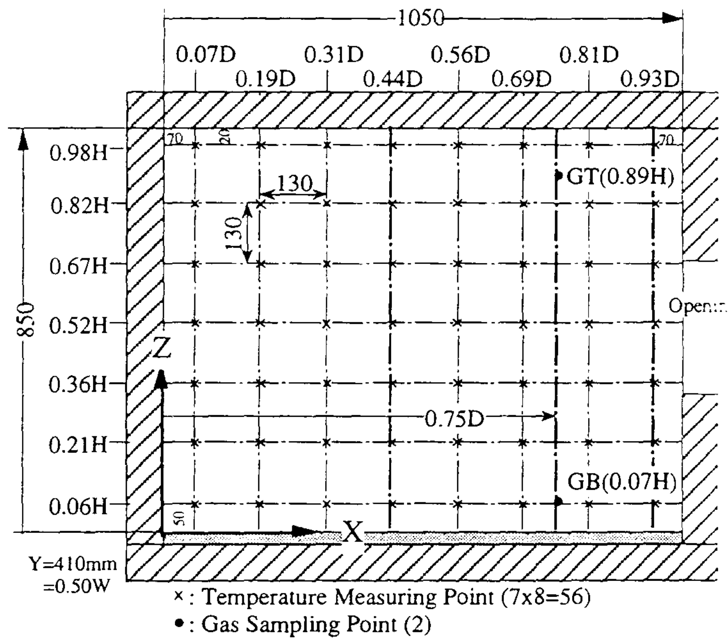

Figure 2. Temperature and Gas Measuring Point

The gas analyzing system is shown in Figure 3. A drain filter of cotton wool and silica gel was used before gas analyzing. Carbon monoxide and carbon dioxide was detected by IR-scattering meter (Riken Keiki RI-550A) . Oxygen was measured by Galvanic cell (Riken Keiki : GD-F4A) . The response time of the gas analyzing

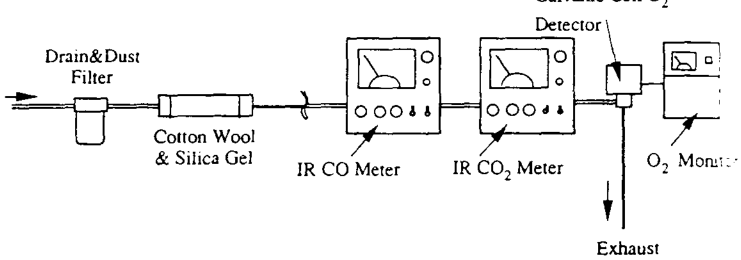

Figure 3. Gas Analyzing System

/stem was about 60 seconds including delay time due to the sampling line and the detector :sponse time.

The temperature and gas data was recorded every one second by a hybrid recorder (NEC anei RD3500) and was stored on a 1 mega-byte SRAM memory card.

Two video cameras were set in the front of the observation window and in front of the side 'all to record backdraft development, exterior fireball, and smoke color and movement.

:ESULTS AND DISCUSSION

lass loss rate and fuel (wood) mass loss histories were shown in Figure 4. Mass loss rate was btained by processing the mass loss data. Here total projected areas (1.23m^2) of the side and :ar wall and the ceiling was used for the mass loss rate. In Figures 5 and 6, temperature histories ear the compartment center <=460mm or 0.44D) and near the pening (x=980mm or 0.93D) are hown. Oxygen, CO and CO_2 oncentration histories are shown in 'igures 7 and 8. Figure 7 shows gas oncentration histories near the eiling (GT=0.75D, 0.50W, 0.89H) Figure 8 shows gas concentration iistories near the floor (GB=0.75D,).50W, 0.06H) .

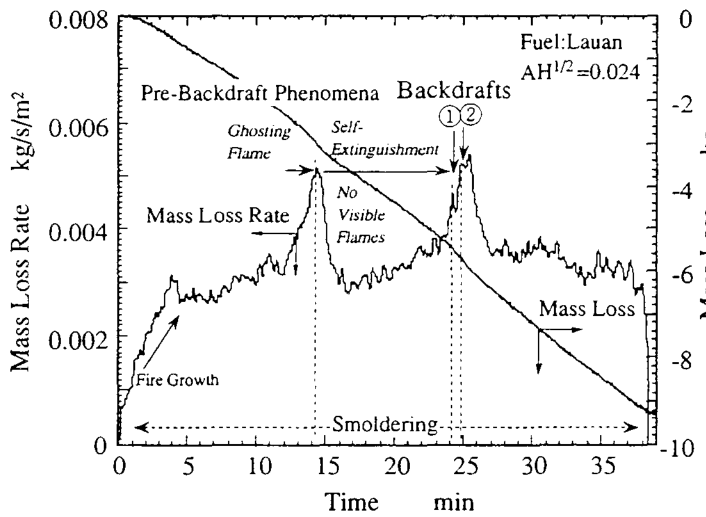

Figure 4. Mass Loss Rate and Fuel Mass Loss Histories

ꟷire Growth

\fter ignition, the cribs started to burn ınd fire spread to the rear wall, the ide wall and the ceiling . Until five ninutes after ignition, the crib fire nainly increased the mass loss rate hown in Figure 4. At around five ninutes, the crib fire almost died and he mass loss rate remained almost :onstant with the value of 2.8 g/s/m^2. Oxygen concentration near the :eiling also became nearly constant vith the value of 3 % shown in Figure

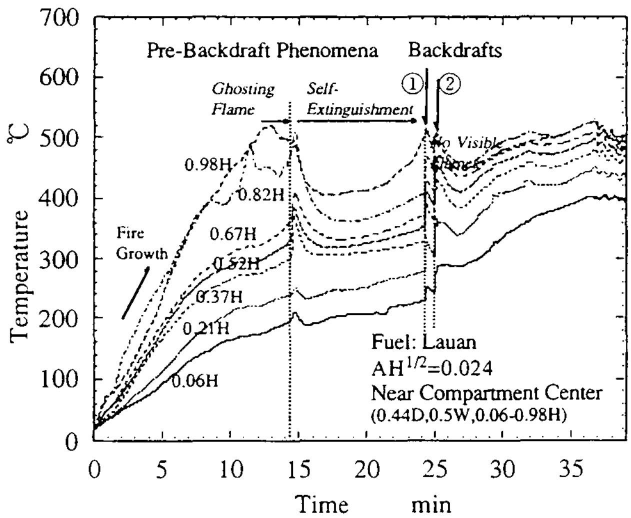

Figure 5. Temperature Histories
Near Compartment Center

7. This means that fire was in a ventilation-limited condition after the crib fire. Figure 8 supports this idea because the CO_2 concentration has a peak at five minutes. Two distinct layers, namely upper and lower layers were forming from this point.

On the other hand, temperatures at all measured points rose until around fifteen minutes after ignition, as shown in Figures 5 and 6. This means that fire gradually spread to the walls and ceiling. At around eight minutes, the mass loss rate started to increase again. At twelve minutes after ignition, fire reached flashover conditions.

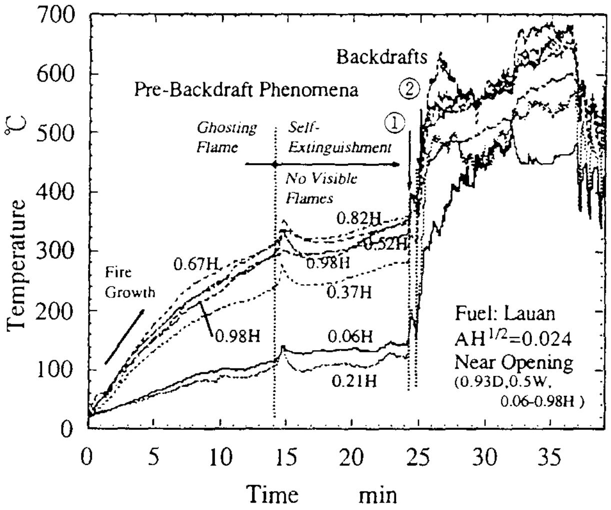

Figure 6. Temperature Histories Near Opening

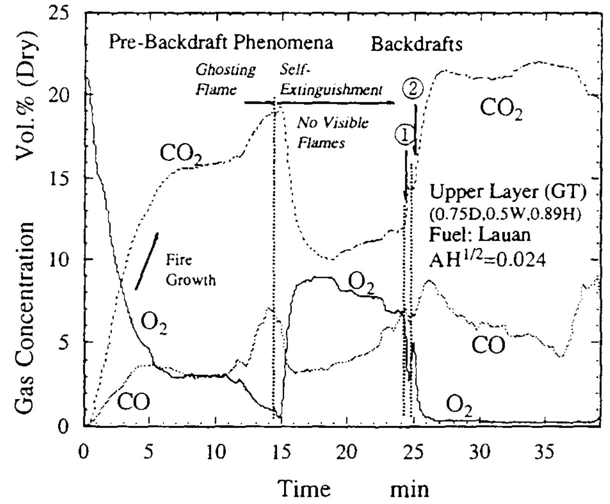

Figure 7. Gas Concentration Histories Near Ceiling

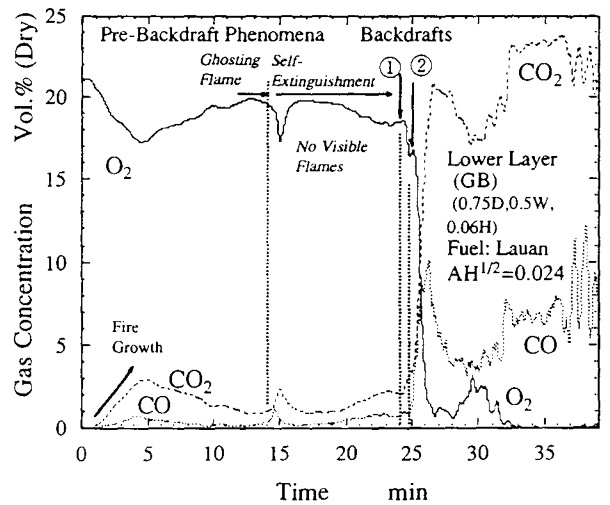

Figure 8. Gas Concentration Histories Near Floor

Pre-backdraft Phenomena (Ghosting Flame, Self-extinguishment of the Fire and Smoldering)

At twelve minutes after ignition, the mass loss rate started to rise rapidly again. This rapid increase of mass loss rate must be the onset of ghosting flame. The maximum mass loss rate was 5.1 g/s/m^2 at around fourteen minutes. Before the mass loss rate peak, temperatures show in Figures 5 and 6 except near the ceiling (at 0.98H and 0.82H in Figure 5) continued to rise. This is because the fire under poor ventilation could not spread flame on the surface of the combustible material freely due to the lack of oxygen and heat. Heat sources near the ceiling might be blocked by the dense smoke due to incomplete combustion. The increased CO concentration seen in Figures 7 and decreased temperatures at 0.98H and 0.82H in Figure 5 support this idea.

The pre-backdraft phenomena observed in this experiment showed very unique characteristics. After the mass loss rate peak, at around fourteen minutes and thirty seconds, temperatures as shown in Figures 5 and 6, except temperature at 0.98H in Figure 5, rose rapidly and made peaks. On the other hand, oxygen concentration near the ceiling became almost zero just before fifteen minutes after ignition. These experimental results show that ghosting flame may occur near the maximum mass loss rate peak, but ghosting flame was soon self-extinguished due to the depletion of oxygen in the upper layer. The rapid increase of oxygen concentration at fifteen minutes, shown in Figure 7, clearly showed the self-extinguishment of the fire or the ghosting flame.

Thus, the ghosting flame was self-extinguished and the mass loss rate started to decrease rapidly to around 2.8 $g/s/m^2$ at sixteen minutes, see Figure 4.

Just after the self-extinguishment of the fire, there were no visible flames in the compartment but a constant mass loss rate was observed. Smoldering of the wood became main reaction and started again from sixteen minutes in Figure 4. The mass loss rate gradually became bigger, from 2.8 $g/s/m^2$ to 3.6 $g/s/m^2$ at twenty three minutes, per Figure 4. At around twenty three minutes, the mass loss rate started to increase rapidly again and the fire might reach backdraft conditions. A relatively long, about ten minutes, smoldering period was observed before a first backdraft occurred.

During Backdraft

At twenty three minutes after ignition, the mass loss rate started to rise rapidly again as shown in Figure 4. The first backdraft was observed at around twenty four minutes. Just after the backdraft, the rapid temperature and oxygen concentration drop were observed as shown in Figures 5 and 7. The second backdraft occurred at around twenty five minutes. Just after the second backdraft, fire in the compartment gradually shifted to an ordinary room fire from the opening side. This trend was found from the temperature rise in Figure 6 and oxygen concentration drop near the floor in Figure 8.

Fireball Growth During Backdraft

In the previous experiment, fireball growth outside the compartment was observed. [10] In this experiment, a refractory glass window (1.0m x 0.8m) was set into the side wall to see the inside of the compartment. Thus fireball growth inside the compartment could be viewed and was recorded by the video camera. The typical fireball growth process is showed in Figure 9 a-h, a sequence photographs taken over a total 1.5 seconds.

A small flame appeared at around the center of the compartment (0.4D) and near the ceiling (0.6H), as shown in Figure 9-b. (The ventilation opening is in the center of the wall seen to the right of the picture.) This small flame rapidly spread to the floor and in the direction of the

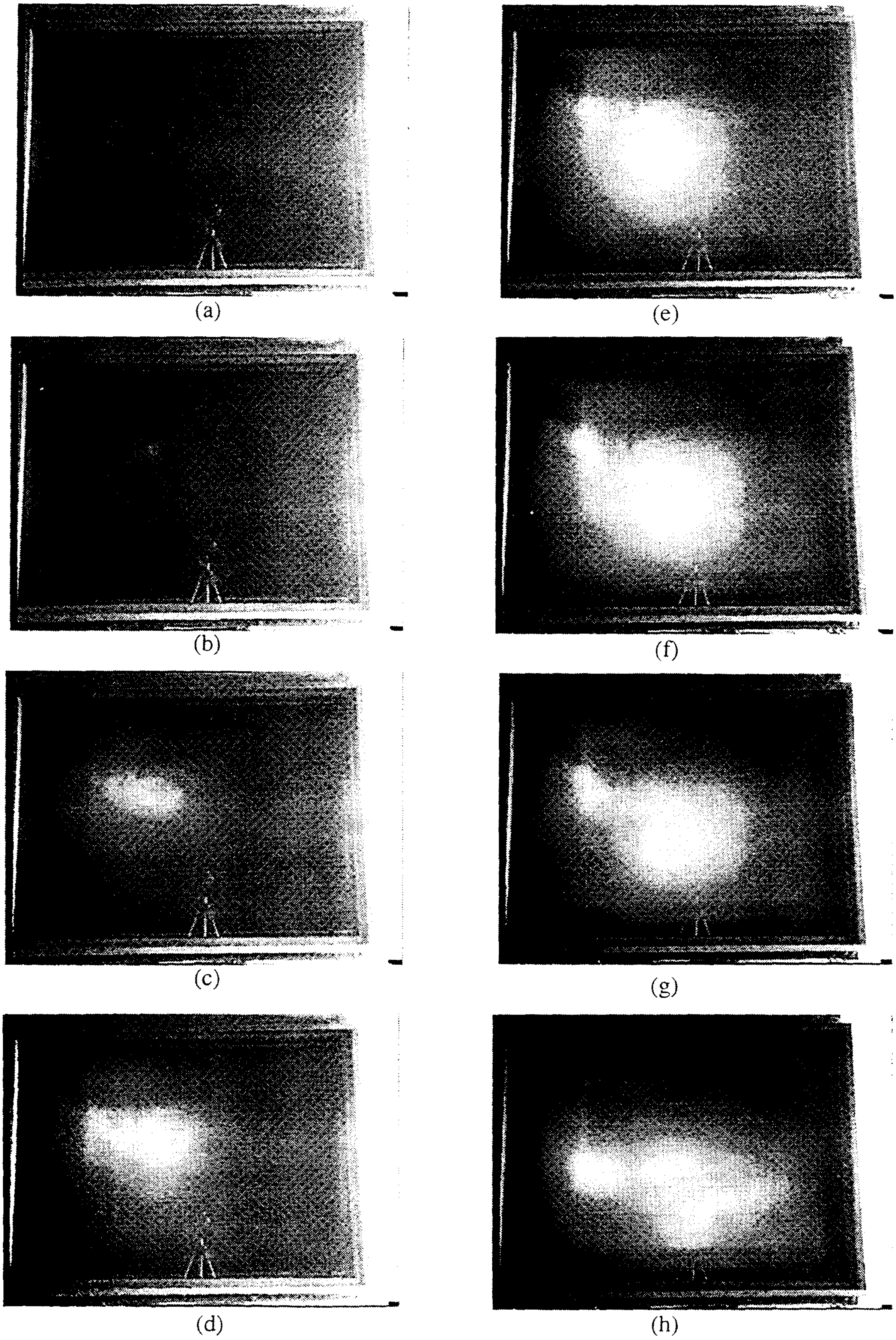

Figure 9 A Backdraft Fireball Growth in the Compartment

opening, as shown in Figure 9-c to g. The lower layer was fully occupied by the developed flame as shown in Figure 9-h. Then the flame moved toward the opening. Thus backdraft fireball consumed all oxygen in the compartment.

CONCLUSION

Preliminary backdraft experiment were carried out by using actual wood. The mass loss rate of actual wood, and O_2, CO_2 and CO in the upper and lower layer in the compartment were measured. Precise temperature distribution maps were made. Backdraft and pre-backdraft phenomena caused by actual pyrolyzates from wood were observed through the side wall made of a newly developed refractory glass. The results obtained from experiments in a one third scale compartment under highly insulated and low-ventilation conditions may allow the following conclusions :

1. Before pre-backdraft and backdraft occurred, a rapid increase of mass loss rate was observed.
2. A ghosting flame occurred under a low-ventilation condition tends to the self-extinguishment of the fire due to the depletion of oxygen in the upper layer.
3. Backdrafts happened at relatively high mass loss rate conditions. This is because backdrafts always need accumulated excess pyrolyzates.
4. After backdraft or he self-extinguishment of the fire occurred, a rapid decrease of mass loss rate was observed.
5. Fireball growth in the compartment during backdraft was observed by a sequence photographs taken by video. The data tells us that the backdraft fireball consumed all the oxygen in the compartment.

ACKNOWLEDGMENTS

This research is being assisted by a Grant in Aid for Scientific Research from the Ministry of Education, Science and Culture, Japan (No.09650643) . The authors wish to thank to the Japanese Ministry of Education and Dr. John A. Rockett for editorial assistance.

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