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Effect of the Opening Area of Compartment on the Backdraft Time

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Abstract: When a fire occurs in a ventilation confined compartment, the fire gradually weakened and finally self-extinguishes due to the oxygen concentration in the compartment will decrease and eventually below the flammable limit. Meanwhile, a large amount of high-temperature combustible substance is generated in the compartment during this period by pyrolysis or evaporation of fuel. When the compartment ventilation is improved, such as the window is broken, fresh air flows into the compartment and mix with high-temperature combustible substances and lead to the fire occurs again. This special phenomenon during the development of a compartment fire is called backdraft. In addition, a large amount of high-temperature combustible substances is accumulated in the compartment before the backdraft occurs. Therefore, once a backdraft occurs, it always leads to a flashover, which means a fire has reached fully development stage and is out of control. Hence, a backdraft will lead to substantial finical loss and heavy casualties. To investigate the influence of compartment opening area on backdraft time, we conducted fire experiments of solid fuel in a reduced-scale compartment. The temperature and the gas concentration in the compartment were measured by thermocouples and gas analyzer, respectively. Results show that the backdraft time of solid fuel would become shorter as the opening area of the compartment increases. The results of this research could improve the understanding of the backdraft mechanism of solid fuel and provide a strategy to delay or even restrain the backdraft occurrence for firefighters.

Keywords: Backdraft, Small-Scale Experiment, Solid Fuel

1. Introduction

Backdraft is a special phenomenon during the development of a compartment fire. Many backdraft fires have demonstrated that a backdraft can lead to substantial finical loss and heavy casualties [1-4]. Hence, the researchers concluded that backdraft is a dangerous special fire behavior and called it a firefighter's killer [5, 6].

The backdraft phenomenon was first studied by Fleischmann and his collaborators [7-12]. Then, many scholars have done lots of researches on backdraft. Gottuk et al. used diesel as fuel, carried out real-scale backdraft experiments on the board of a test ship [13]. To study the backdraft phenomenon, Weng and Fan and Weng et al. carried out model-scale fire experiments of gas fuel [14, 15]. According to backdraft experiments of liquid fuel, a dynamic model which can be used to describe the smoker layer temperature was deduced by Gong et al. [16]. Besides, Wu et al. conducted small-scale fire experiments of gas fuel to investigate the backdraft phenomenon [17]. Chen et al. and Wu et al. carried out model-scale experiments to study some aspects of backdraft, such as, temperature profile in the compartment and critical factors that determining the occurrence of backdraft [18, 19]. Tsai and Chiu carried out three full-scale backdraft experiments that selected solid materials as fuel [20].

In recent years, with the rapid development of computer technology, many scholars also have investigated the backdraft through simulation software. By using Fire Dynamic Simulator (FDS) code, Ha et al and Myilsamy et al. investigated the influence of the compartment opening geometry on backdraft, Ashok et al. studied the relationship between the gravity constant and backdraft phenomenon [21-24]. Besides, Kro´l et al. studied the backdraft phenomenon by Ansys Fluent [25].

However, the ignition position or extra heat source was artificially set or used during experiments at previous studies. Besides, some studies also changed the ventilation condition when there still have a flame in the compartment. All above experimental operations are different from a real-world backdraft fire. To diminish the influence of these operations, the experiment's progress in this study only depended on the burning or smoldering of the solid fuel in the compartment. Neither extra heat source nor ignition source was used during experiments. Besides, when the ventilation condition of compartment changed, flame on the fuel surface had distinguished. The results of this research could help people understand backdraft phenomenon of solid fuel.

2. Experimental Set-up

The schematic reduce-scaled compartment that had served in our previous study and used in this study was shown in Figure 1 [17]. The compartment was made by welding stainless steel that thickness was 2.5 mm. The length, width and height of compartment was 1.1 m, 0.75 m, and 0.4 m, respectively. Bolt systems was constructed and face-plates can be replaced by pulling out bolt. Then, three compartments opening area (S_1), 0.075m^2, 0.15m^2, and 0.225m^2, respectively, can be obtained. In this study, the solid fuel was woodblock and its upper surface area (S_2) was approximately 0.0294 m^2. Numbers 1-7 in figure 1 represent the location of the thermocouples.

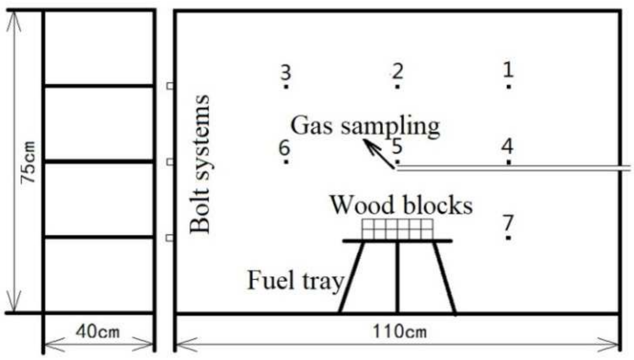

Figure 1. *Model of experimental compartment.*

At the beginning of the experiments, the opening area of the compartment was 0.15 m^2. Because it is difficult to ignite wood blocks directly, the blocks were ignited by the heat from the burning of alcohol. Since the alcohol was ignited, the window of the compartment was closed after 360 seconds (t_1) later. When the window of the compartment was closed, the flame gradually extinguished due to oxygen-starved and blocks turned to smolder. A period time (t_2) after the flame extinguished, the compartment window was opened again. Then, the fresh air flowed into compartment in the form of gravity flow and lead oxygen concentration in the compartment increases. With the increasing of oxygen concentration, woodblocks smoldering intense and eventually backdraft occurred. The time from compartment window opened to flame appeared was defined as the backdraft time (t). Table 1 shows the experimental settings:

Table 1. *Experiment settings.*

Test No.	S_1 (m^2)	S_2 (m^2)	t_1 (s)	t_2 (s)	t (s)
1	0.075	0.0294	360	120	502
2	0.15	0.0294	360	120	342
3	0.225	0.0294	360	120	44
4	0.075	0.0294	360	60	725
5	0.15	0.0294	360	60	470
6	0.225	0.0294	360	60	202

3. Result and Discussion

Taking test No. 2 as an example, the temperature and gas components concentrations various progress during the experiment are descripted as follows.

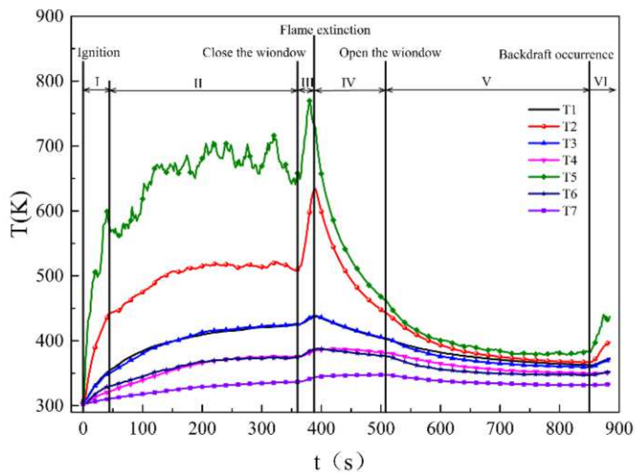

Figure 2. *Temperature curves of the test No. 2.*

At the beginning of the experiment, alcohol sprayed on the upper woodblocks burned and released heat, so the temperature curves first rising rapidly (stage I of Figure 2). It is well known that burning usually consumes O_2 and meanwhile produces CO_2. Therefore, the O_2 concentration decreases, and meanwhile the CO_2 concentration increases (stage I of Figure 3). With the alcohol burning, the woodblocks were heated to the ignition temperature and began burning steadily. Hence, the temperature curves gradually transmit stability (stage II of Figure 2), and the concentration of O_2 and the CO_2 fluctuates around a certain value (stage II of Figure 3). During above period, the compartment window was opened, the ventilation condition of the compartment as well, the burning of alcohol and woodblocks were relatively complete and only less products of incomplete burning were produced. Therefore, at above period, the concentrations of CO and C_XH_Y, which both are incomplete burning production, were very lower (stage II of Figure 3).

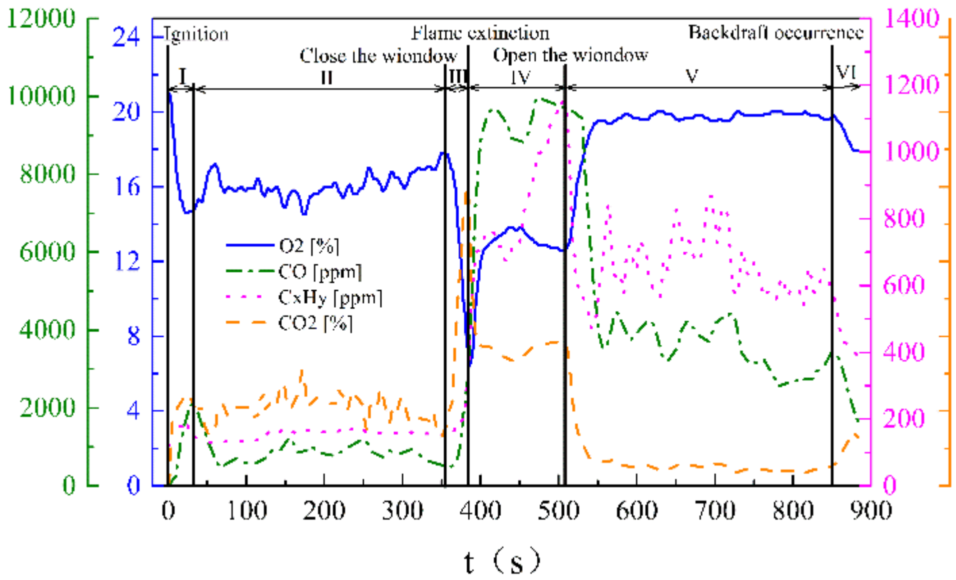

Figure 3. *Gas components concentration curves of the test No. 2.*

After the compartment window was closed, although fresh air cannot flow into the compartment, the existing O_2 in the compartment can still maintain woodblock burning for a short period of time. Therefore, with the woodblocks burning, the O_2 concentration decreases and meanwhile the CO_2 concentration increases (stage III of Figure 3). During this period, little heat can be released to ambit from the compartment wall by conduction, meanwhile, woodblocks burning still released heat. That means the heat accumulated in the compartment is more than that dissipated. Therefore, temperature curves are shown an upward trend (stage III of Figure 2). During the above period, woodblocks burning gradually transmitted from complete to incomplete, so the concentration of CO and C_XH_Y slightly increases (stage III of Figure 3).

When the O_2 concentration in the compartment below the flammable limit, flames on the surface of woodblocks were extinguished, then woodblocks transited to smoldering, and temperature decreased rapidly (stage IV of Figure 2). At this period, the concentration of O_2 and CO_2 gradually decreased and increased, respectively. However, the concentration of CO and C_XH_Y rapidly rise (stage IV of Figure 3) due to large amount of incomplete burning production produced during smoldering,

After the compartment window was opened again, the fresh air flowed into the compartment and lead to the concentration of O_2 and CO_2 rapidly rise and decreased, respectively, and finally fluctuated near a certain value (stage V of Figure 3). Meanwhile, the temperature curves kept a downward trend because convective between hot gas in the compartment and ambit environment out the compartment lead to heat dissipation increased. However, with the O_2 concentration in the compartment increased, the heat released increased due to the woodblocks smoldering gradually intense, so the temperature curves finally remained stable (stage V of Figure 2). Meanwhile, the concentration of CO and C_XH_Y remained a high value (stage VI of Figure 3) after the compartment window opened because woodblock still smoldering and produced incomplete burning productions. However, when backdraft occurred, a flame appeared and temperature curves began to rise (stage VI of Figure 2), the concentration of CO and C_XH_Y rapidly decreased (stage VI of Figure 3).

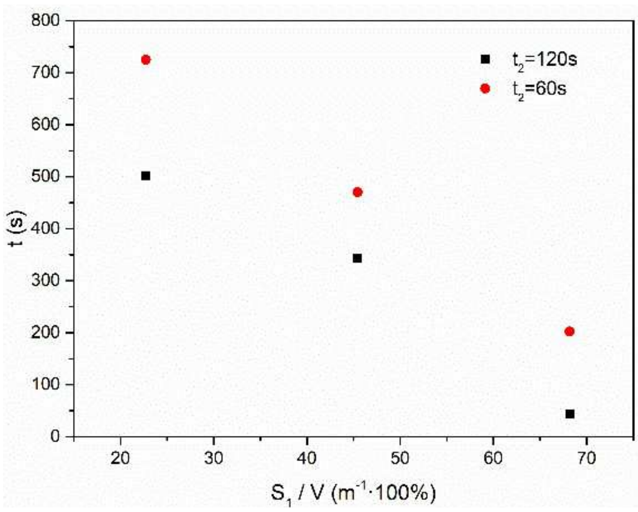

Figure 4. *Effect of the compartment opening area on the backdraft time.*

From Figure 4, it can refer to the opening area increase would induce the backdraft time decrease. Because the opening area increase will lead to more fresh air flow into the compartment and more smoke and flammable substances flow out the compartment. Thus, the concentration of combustible mixture in the compartment rapidly changes, and flammable limit can achieve in a shorter time and then backdraft occurs.

4. Conclusion

This study conducted backdraft fire experiments of solid fuel in a reduced-scale compartment and investigated the influence of the compartment opening area on the backdraft time. Following are the main conclusions:

1. The main operations of experiments are ignition, closing, and opening the compartment window. The experimental phenomena are alcohol burning, woodblock burning, woodblock smoldering, fresh air flowed into the compartment, smoldering intense, backdraft occurrence, and woodblock burning again.
2. During the experiments, the temperature curves present one descent period, two stable periods, and three ascending periods. The concentrations of O_2 and CO_2 have opposite trends, and the concentration of CO and C_XH_Y have the same trends.
3. With the compartment opening area increasing, backdraft time decreases. It indicates that when fighting a backdraft fire, the upper part of the compartment should be opened to discharge the high-temperature gas in the compartment. In this way, the backdraft can be avoided or delayed.

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