Bench-Scale Studies of Poly(vinyl chloride) Fires with Water Mist

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ABSTRACT: Bench-scale tests to study the effect of water mist on burning solid poly(vinyl chloride) (PVC) were carried out with a cone calorimeter. Water mist was discharged from a small nozzle under two operating pressures, 0.4 and 0.7 MPa. The corresponding water flow rates were 103.5 and 134 mL/min, respectively. The cone angle of the discharged water spray was 90°, and the volume mean diameter of the mist was about 90 μm. The results were useful in understanding the effects of discharging water mist to suppress the diffusion flame from burning PVC. The reignition process also was studied. The testing method was appropriate for studying the interaction between water mist with smaller droplets and the diffusion flame in a confined space. There, the combined effects of oxygen displacement, gas phase, and fuel surface cooling were the key extinguishing mechanisms. The critical water mist application rate on burning PVC under different thermal radiative heat fluxes was able to be determined. © 2005 Wiley Periodicals, Inc. J Appl Polym Sci 99: 2520–2527, 2006

Key words: PVC; radiation; calorimetry

INTRODUCTION

The thermoplastic material poly(vinyl chloride) (PVC) is widely used in a range of consumer products and construction materials. Examples are packaging sheets, cling films, bottles, credit cards, audio records, imitation leather, car interiors, window frames, cables, pipes, flooring, wallpaper, and window blinds. There have been fire concerns that burning PVC would produce harmful dioxins and other compounds containing chlorine. A better understanding of how to extinguish PVC fires is essential for designing appropriate fire protection systems.

Water is widely used for fire control, suppression, and extinguishment. Water systems therefore are installed to protect buildings. For example, fire hydrant and hose reel systems are required in almost all high-rise buildings in the Far East. Automatic sprinkler systems are required in most nonresidential buildings because the system is believed to be efficient in controlling solid fires. In recent years fine water spray (water mist) has been used extensively for suppressing solid fires.[1] A main reason for using water mist is as a substitute for the total gas flooding system based on halon.[2] Many experiments have been conducted on extinguishing plastic fires with water spray.[3–5]

Fine water droplets discharged from a water mist system evaporate while traveling through flames. Some can reach the burning fuel surface. Although flame cooling and oxygen displacement by water mist are important in suppressing fire, cooling the fuel also should be considered.

Extensive studies of water mist fire suppression systems have been reported in the literature.[1,3–5] The interaction of water mist with a diffusion flame in a confined space has been investigated.[6–10] However, not many works have studied how water mist can enhance combustion in order to increase the heat release rate.

In the present study the effect of water mist on small-scale solid fuel PVC fires in a confined space was investigated. Bench-scale tests in a cone calorimeter were carried out. The heat release rates with and without discharging water mist on PVC samples were measured. The associated heat and smoke release rate curves of the interaction of water mist with such a diffusion flame in a confined space are reported.

Bench-scale tests

Bench-scale experiments were performed by burning solid PVC samples in a cone calorimeter. The pilot

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ignition source was not used for spontaneous ignition tests. The PVC sample was 100 mm square in size, as required for testing in a cone calorimeter. The sample was 3 mm thick and its mass was about 41 g. Three radiant heat fluxes—30, 50, and 70 kWm^{-2}—were tested.

A small nozzle was designed for discharging water mist. It was a single-pressure atomizer with a system operating pressure varying from 0.2 to 0.7 MPa. The corresponding volume flow rate ranged from from 68 to 134 mL/min. A laser Doppler velocimetry/adaptive-phase Doppler velocimetry (LDV/APV) system was used to measure the velocity and the droplet size distribution functions of the discharged water mist. The measuring techniques and the system configurations were described previously[11] and are not repeated in this article.

The operating pressures in this study were 0.4 and 0.7 MPa. The corresponding water flow rates were 103.5 and 134 mL/min, respectively. Water mist would be generated with characteristic curves measured at 10 cm below the nozzle and at 3 cm from the center, as shown in Figure 1. The mean volume diameters were between 50 and 120 μm, giving a mean of 90 μm. The mean velocity of the water mist in the axial direction along the sprayer axial varied from 0.4 to 0.8 m/s. The total amount of water mist applied in each test was controlled by varying the application time from 5 to 10 s. The actual water mist application rate also was checked in the burning tests.

The experimental procedure used has been described previously; only a summary is presented in this article.[12] The water mist nozzle was placed about 90 mm above the PVC sample, as shown in Figure 2. Water was stored in a pressurized tank using compressed air. The water spray discharged through the nozzle would cover the PVC sample. The PVC sample was put on a balance with a steel tray for collecting the water applied. The whole setup was integrated with a cone calorimeter to adjust the heat flux incident on the sample surface. Flue gas was collected by the exhaust hood for monitoring the oxygen consumption rate according to the ISO procedure for a cone calorimeter.

On ignition of the sample with a stable flame on the surface, sustained burning was enabled for some time. Water mist was then discharged to act on the flame until it was extinguished. Reignition might occur even though the flame appeared to be extinguished for the reignition tests.

RESULTS

For those tests under a heat flux of 50 kWm^{-2}, the PVC sample was allowed to burn for another 95 s after ignition before discharging the water mist. Starting at this time, the reignition time was recorded. At an operating pressure of 0.4 MPa, the specimen was exposed under external radiation for another 505 s until reignition by applying electric sparks. Reignition was judged by having a stable flame again appear at the sample surface. The discharge of the water mist was stopped when the flame was extinguished for the second time.

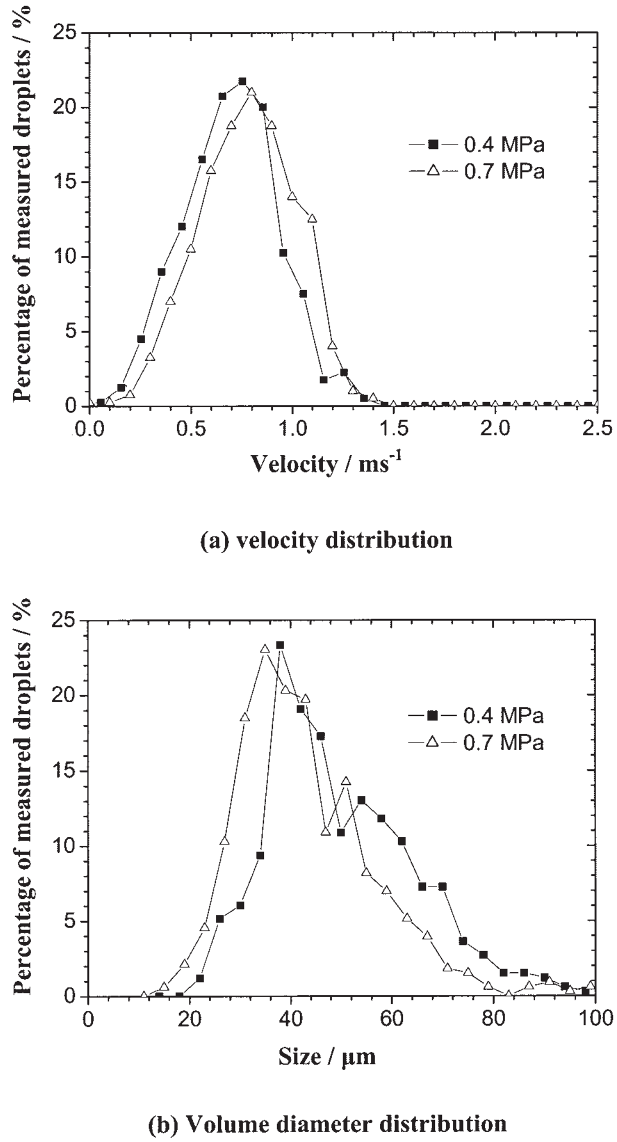


Figure 1 Measurements of water mist characteristics.

The curves of the heat release rate per unit area, oxygen (O_2) concentration, smoke production rate, carbon dioxide (CO_2), and carbon monoxide (CO) concentrations for the PVC fire under 50 kWm^{-2} without discharging water mist are shown in Figure 3. The results for the PVC fire with water mist discharged at a pressure of 0.4 MPa are shown in Figure 4, and those with water mist discharged at a pressure of 0.7 MPa in Figure 5.

For the tests under external radiation of 70 kWm^{-2}, the PVC sample was allowed to burn for

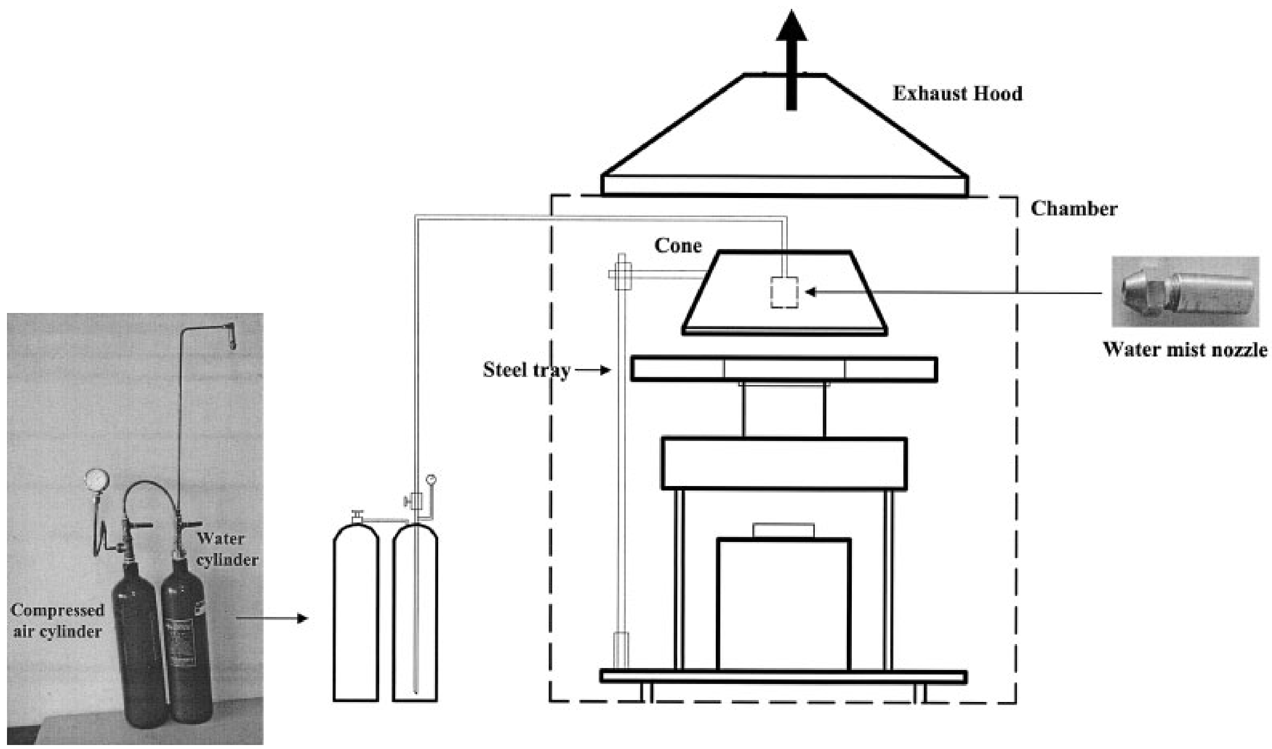


Figure 2 Experimental setup.

another 90 s after ignition with a stable flame on the surface. Water mist was then discharged until the flame was extinguished. The reignition time was recorded starting from that moment. Under this high heat flux, the samples were reignited 200 s after extinguishing the flame with water mist discharged at a pressure of 0.7 MPa and were reignited 240 s after extinguishing the flame with water mist dis-

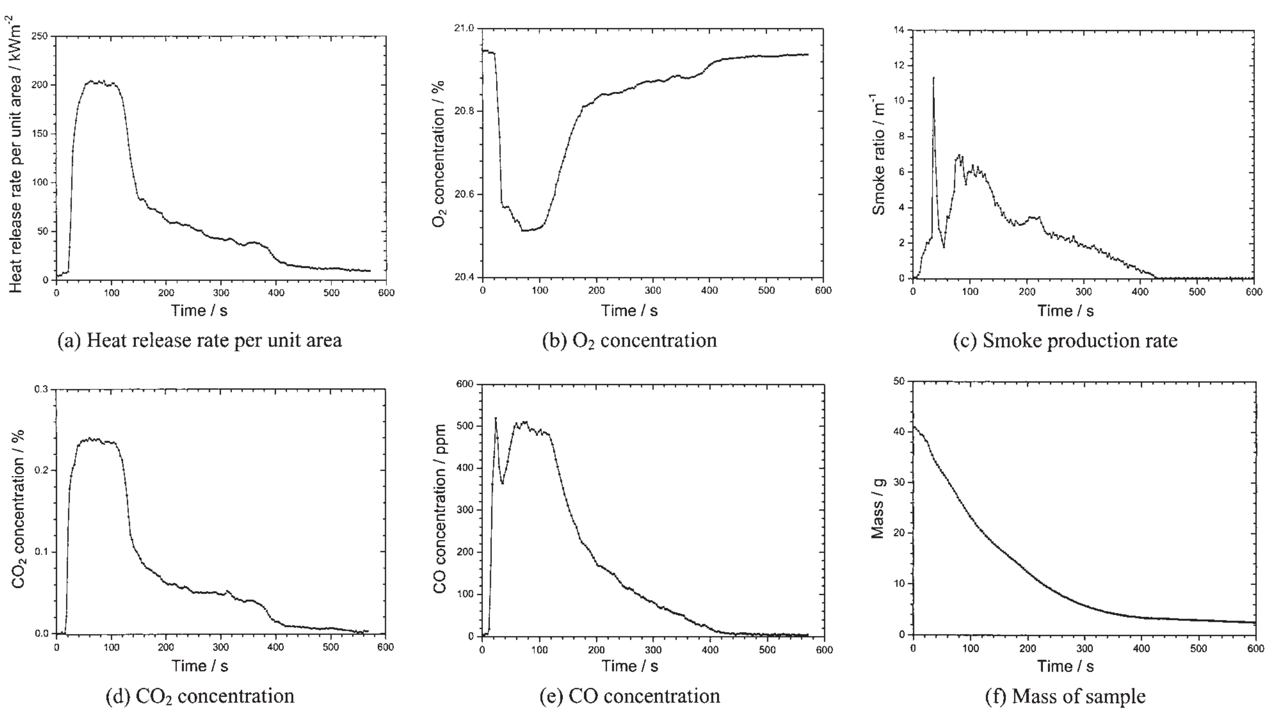
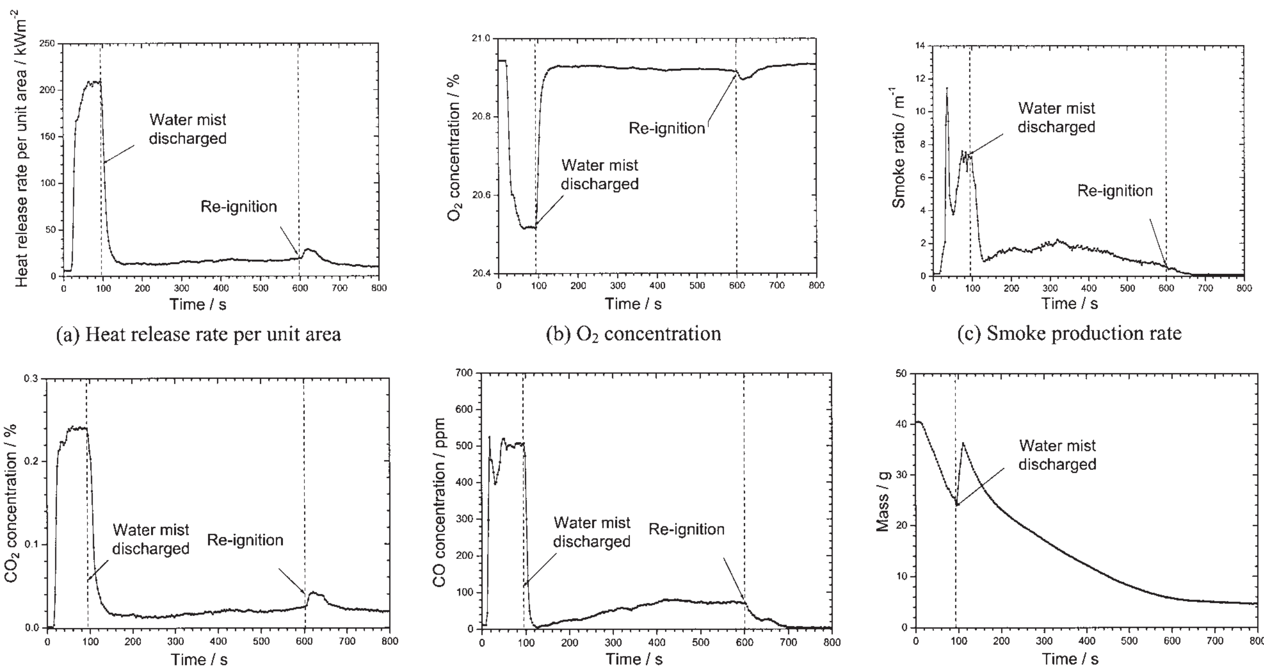


Figure 3 50 kWm^{-2} without water mist.



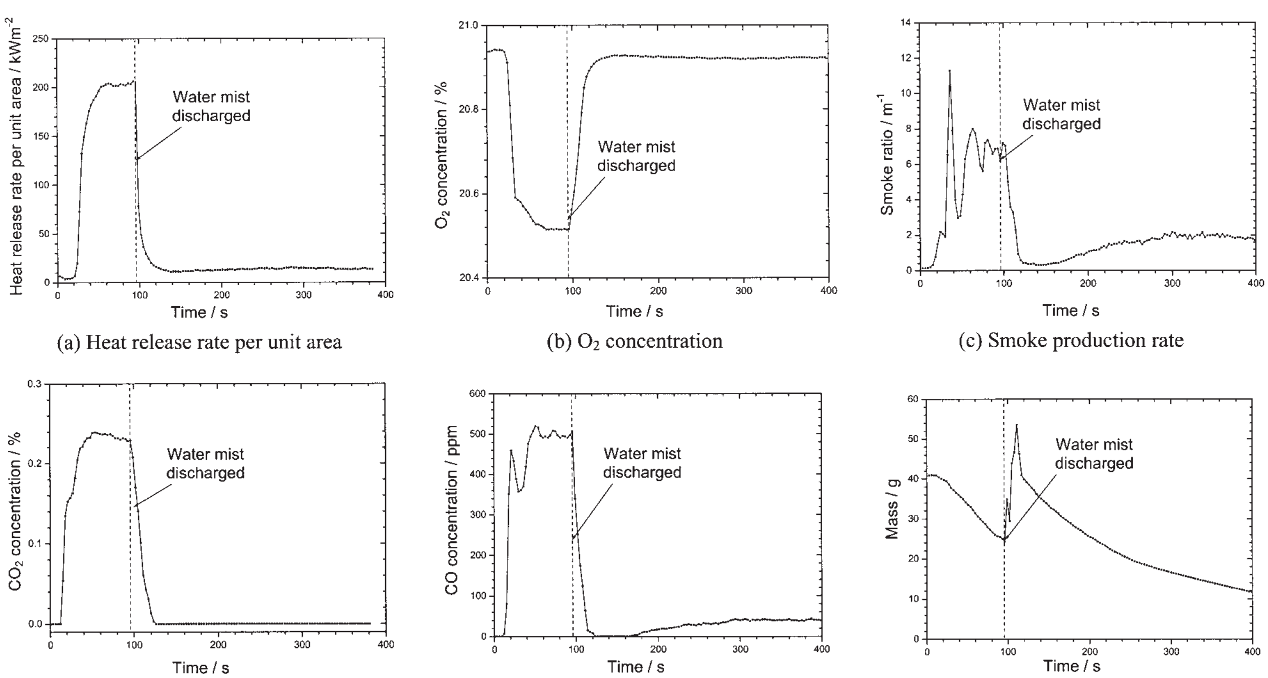
(a) Heat release rate per unit area (b) O_2 concentration (c) Smoke production rate

(d) CO_2 concentration (e) CO concentration (f) Mass of sample

Figure 4 50 kWm^{-2} at 0.4 MPa with reignition.

charged at a pressure of 0.4 MPa without using electric sparks.

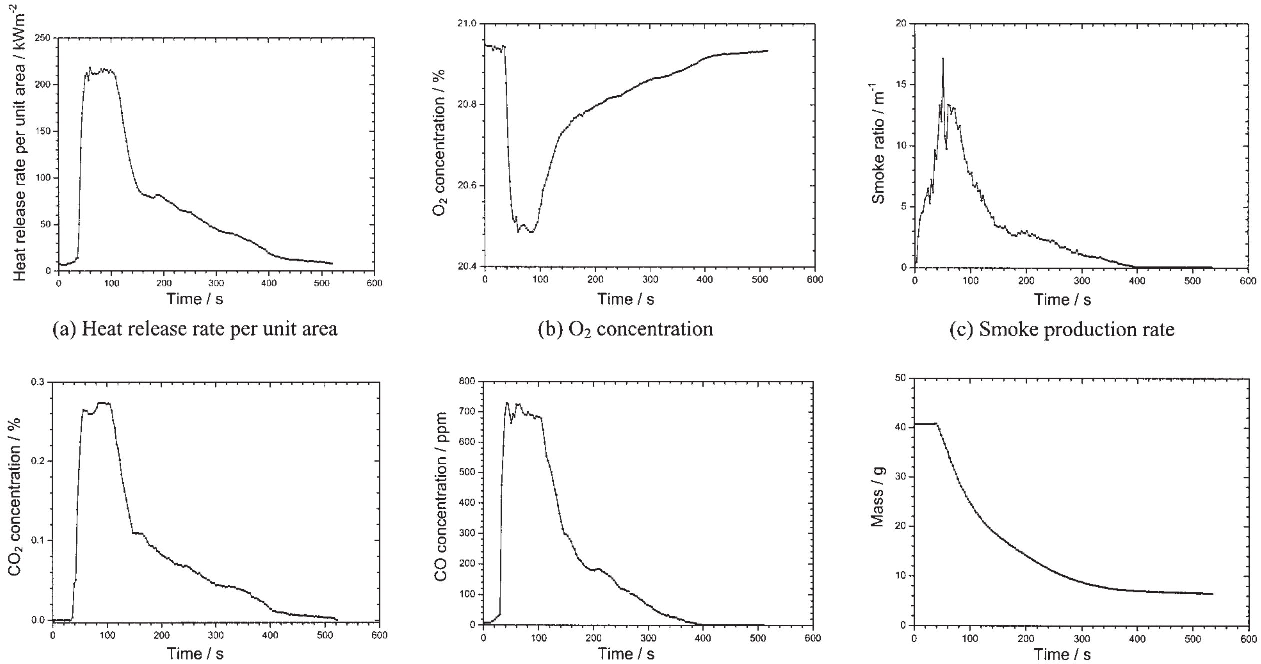
The results for heat release rate per unit area, O_2 concentration, smoke production rate, CO_2, and CO concentrations under 70 kWm^{-2} without discharging water mist are shown in Figure 6. The results for the PVC fire with water mist discharged at a 0.4 MPa pressure are shown in Figure 7, and those with water mist discharged at a 0.7 MPa pressure are shown in Figure 8.



(a) Heat release rate per unit area (b) O_2 concentration (c) Smoke production rate

(d) CO_2 concentration (e) CO concentration (f) Mass of sample

Figure 5 50 kWm^{-2} at 0.7 MPa without reignition.



(a) Heat release rate per unit area (b) O_2 concentration (c) Smoke production rate

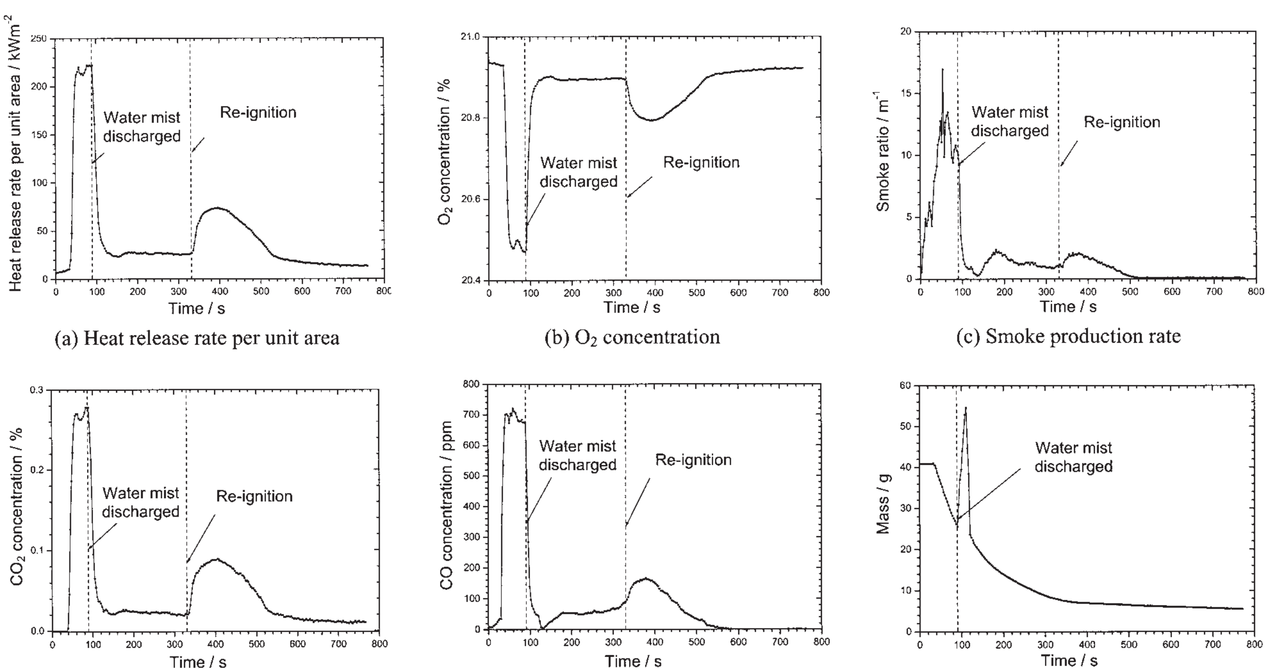
(d) CO_2 concentration (e) CO concentration (f) Mass of sample

Figure 6 70 kWm^{-2} without water mist.

Under a low heat flux of 30 kWm^{-2}, the PVC samples could only burn with a stable flame for about 40 s after ignition. The curves of the heat release rate per unit area, O_2 concentration, smoke production rate, CO_2, and CO concentrations of burning the PVC samples only are shown in Figure 9.

DISCUSSION

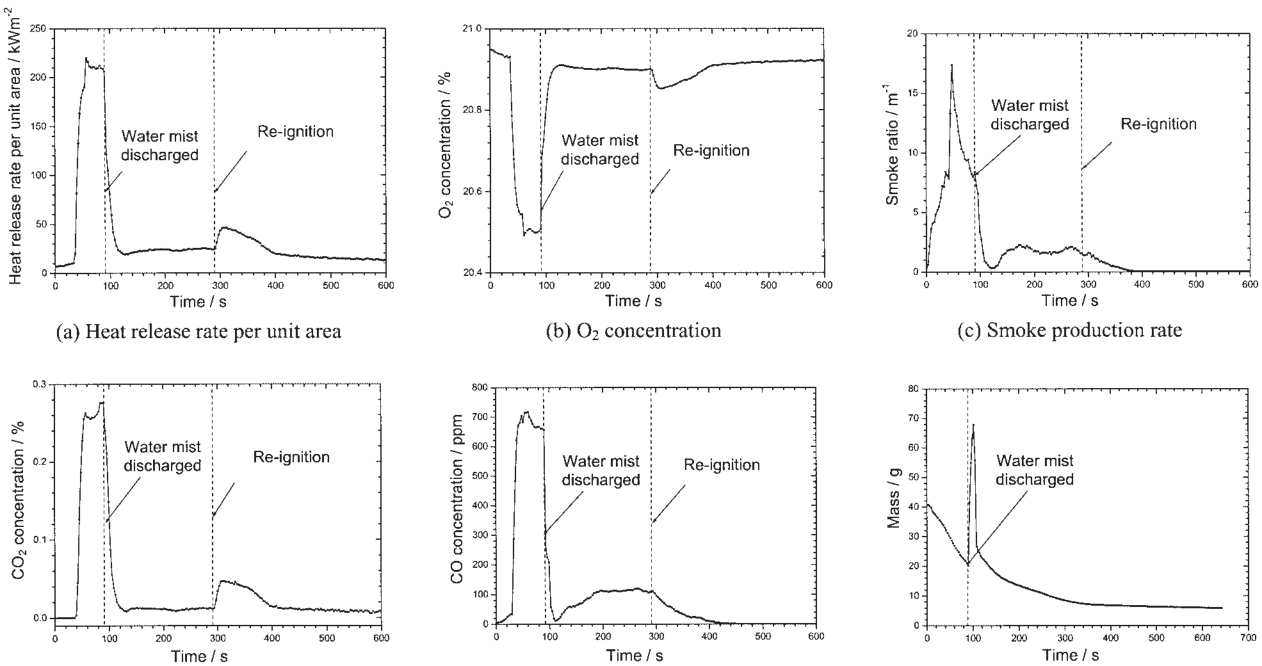
The PVC samples were observed to burn for about 90 s after discharging of the water mist, as shown by the measured results such as the heat release rate per unit area curves noted above. The heat release rate de-



(a) Heat release rate per unit area (b) O_2 concentration (c) Smoke production rate

(d) CO_2 concentration (e) CO concentration (f) Mass of sample

Figure 7 70 kWm^{-2} at 0.4 MPa with reignition.



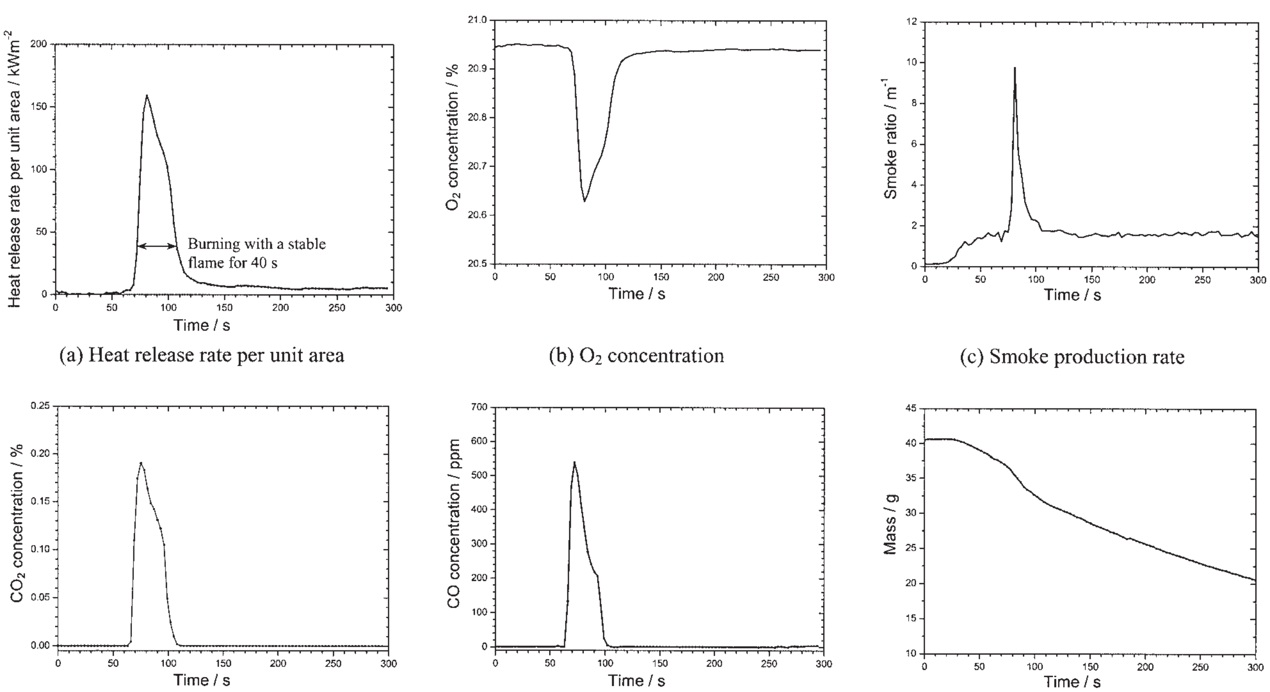
(a) Heat release rate per unit area (b) O_2 concentration (c) Smoke production rate

(d) CO_2 concentration (e) CO concentration (f) Mass of sample

Figure 8 70 kWm^{-2} at 0.7 MPa with reignition.

creased immediately to a roughly constant value after application of the water mist. The heat release rate decreased faster at 0.7 MPa, the higher operating pressure.

Carbon monoxide would be generated over 90 s without discharging water mist. In fact, the CO concentration increased immediately—within the first 6 s.



(a) Heat release rate per unit area (b) O_2 concentration (c) Smoke production rate

(d) CO_2 concentration (e) CO concentration (f) Mass of sample

Figure 9 30 kWm^{-2} without water mist.

TABLE I
Summary of Results

Heat flux	50 kWm^{-2}				70 kWm^{-2}					30 kWm^{-2}
		0.4 MPa				0.4 MPa		0.7 MPa		
Testing conditions	No water mist	Ignition	Reignition	0.7 MPa	No water mist	Ignition	Reignition	Ignition	Reignition	No water mist
Maximum heat release rate (kWm^{-2})	204	209	29	205	217	222	74	212	47	159
Maximum smoke production rate (m^{-1})	11.30	11.44	0.50	11.29	17.15	16.94	2.01	17.36	1.40	9.78
Maximum CO_2 concentration (%)	0.24	0.24	0.04	0.24	0.27	0.28	0.089	0.28	0.05	0.19
Maximum CO concentration (ppm)	520	525	71	519	729	721	166	717	110	539

The effects of the radiant heat flux and operating pressure of the water mist on the maximum heat release rate, maximum smoke production rate, maximum CO_2, and CO concentrations of burning PVC fire with and without reignition are summarized in Table I. It was observed that the maximum values for these quantities during reignition were less than the values after the first ignition.

Note that before ignition, a large amount of PVC was volatilized from the sample. The smoke release rate reached a peak value and then decreased after ignition. With the water mist discharged, both the CO concentration and the smoke release rate decreased. Further work should be conducted to investigate why.

Before reignition, the smoldering fires were less dependent on O_2 concentration. Water mist would not decrease the reaction rate easily unless injected directly into the fuel. But discharging water mist can prevent the transition from smoldering to flaming.

Water mist can be delivered to the flame by discharging the spray to the confined space with a suitable spraying angle and volume flux. Oxygen is then displaced to suppress the fire in a short time, even using very little water. It was observed that obstructions within the rig would affect fire suppression significantly. This was more obvious for small fires with weaker buoyancy for entraining sufficient mist into the flame. If the interaction of the flame with water mist was not stable, any physical disturbance would extinguish the fire. For example, changing the spraying angle or the flow rate could break the equilibrium to extinguish the fire.

CONCLUSIONS

Water mists are defined as sprays in which 99% of the volume is made up of water droplets less than 1000 μm in diameter.[2] The extinguishing capacity is determined by the drop size distribution, the spray location, the spray momentum, the enclosure geometry, the obstructions within the space, and the type of fuel.[13] Most fires that occurred in confined spaces would give diffusional flames with different fuels. It is very important to study the interaction between the water mist and the diffusional flame over the burning object for better design of the system.

The effect of water mist on small-scale PVC fires in a confined space has been studied experimentally as in above. The heat release rate was measured by the oxygen consumption method with a cone calorimeter. Preliminary results showed that such a low-pressure water mist system would be effective in controlling PVC fires. It is suggested that future studies focus on:

- different nozzle and fuel types;
- different radiant heat fluxes;
- smoke movement and control together with a water mist system.

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