Fire extinction by water spray

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This paper aims to make clear the effects of water spray characteristics - such as drop size, mass flux of spray, and entrained air velocity-and burner center and burner rim temperature on fire extinction. The test was done under the constant mass flux of spray and under the constant drop mean size. As a result, extinction patterns are classified into three types, - the blow out, the blow off and the fade out. The blow out is affected mainly by an air flow. The blow off is affected mainly by the evaporation of spray on the burner surface. The fade out appears when the burner surface temperature is not high enough for spray to evaporate and spray covers the burner surface gradually. In case of the blow out, the extinction time is very short. In case of the blow off, the flame intensity decreases gradually because the fuel concentration and oxygen decrease when spray particles reach the burner surface and evaporates. In case of the fade out, the extinction time is rather long because spray covers the burner and combustion area decreases gradually.

1. Introduction

Nowadays fire extinction by water spray is remarked as the substitute of halogenide because of less environmental burden, high ability of extinction and easy acquisition of water [1]-[4]. The effective extinction by water spray is expected to lessen the damages by water jet. Cooling and suffocation are expected in fire extinction by water spray because it evaporates easily and provides much vapor when drop size is small. Also air flow entrained by water spray makes the density of combustible gas thin, which promotes extinction. For the effective fire extinction, it is necessary to investigate how spray characteristics affect fire extinction, and extinction pattern.

Fire intensity, burner surface temperature, drop size, drop velocity, spray volume flux and air velocity in spray are considered to involve in fire extinction. In this paper we tried to control each parameter independently as much as possible so that we can make clear how spray characteristics and burner surface temperature influence extinction time and extinction pattern. We examined effects of spray characteristics on extinction time and pattern in case entrained air velocity was varied with constant drop mean size and volume flux, in case drop mean size was varied with constant volume flux and entrained air velocity, and in case volume flux was varied with constant entrained air velocity and drop mean size.

Afterwards, we examined the effect of burner surface temperature on extinction time and pattern, when burner surface temperature was varied with constant spray characteristics.

2. Experimental setup and conditions

2.1 Experimental Setup

Figure.1 illustrates the experimental setup used in this research. The experimental setup is consisted of two parts, the fire source and the extinguisher. The fire source is diffusion flame of the city gas, which is formed over the sintered metal with radius 45mm installed on top of the copper pipe. To keep the burner surface temperature constant, it was monitored with a K-type thermocouple fixed at the burner center and the burner edge. The spray nozzle is installed in the center of the atomization tower with 250mm in diameter. Drop mean velocity and spray volume flux can be adjusted by moving the atomization tower up and down. Air velocity was controlled through the use of the axial fan installed on top of the atomization tower. We use full corn nozzles and hollow corn nozzles with various capacities and measure drop mean size, spatial distribution of drop mean size, volume flux, and drop mean velocity about each nozzle at the time of varying injection pressure, in advance. Drop mean size and volume flux are adjusted to setting values by changing nozzles and varying distance from the flame source to spray nozzle. Drop mean size and velocity were measured through the use of Phase Doppler Particle Analyzer (PDPA), and spray volume flux was measured by capturing method.

A K-type thermocouple was installed in the burner rim not only the burner center. Oil was made to circulate around the burner as shown in Figure.1 and a flexible heater was installed inside the copper pipe. Thus burner center temperature and rim temperature were made to be controlled independently so as to investigate influences of burner surface temperature. Extinction time and pattern were examined by varying burner center temperature and rim temperature under constant flame intensity and spray characteristics.

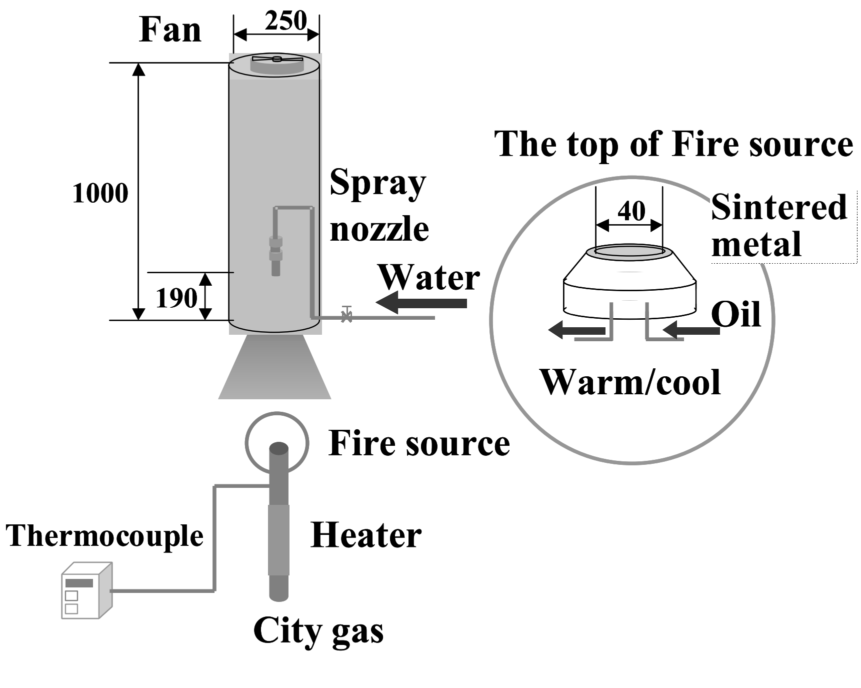


Fig.1 Experimental Setup

2.2 Experimental Conditions

Table 1 displays the experimental conditions in this research.

Table.1

ITEM	VALUE	ITEM	VALUE
Spray		Flame	
Volume flux [m^3/m^2s]	0.012, 0.035, 0.055×10^{-3}	City gas	CH_4
Drop mean size D_{30} [μm]	80, 100, 170, 260, 280,320	Flow rate [m^3/s]	1.57×10^{-5}
Mean drop velocity [m/s]	1.0-1.6	Burner rim temperature [K]	363,368,373,380,388
Air velocity [m/s]	0.4, 0.6, 0.7, 0.8	Burner center temperature [K]	393,408,423,443

3. Results and discussions

3.1 Extinction pattern

The extinction states are classified into three patterns according to the relation between spray characteristics and flame conditions when water spray is conflicted to the stable diffusion flame on the sintered metal. Figure 2 shows the three extinction patterns.

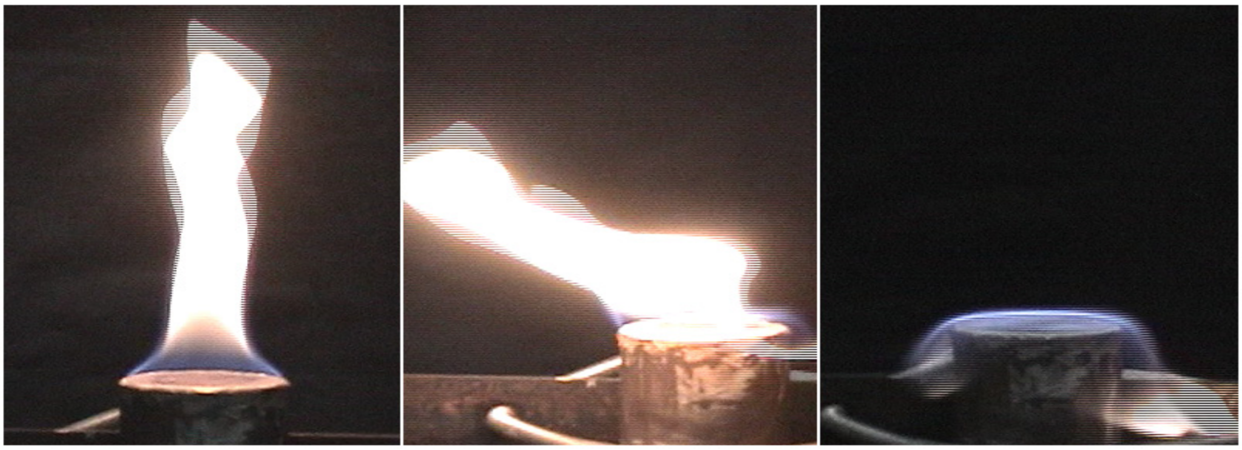
(a) Blow out (b) Blow off (c) Fade out

Fig.2 Extinction patterns

The blow out (Fig.2. a): stable flame turns unstable by airflow, thus suddenly blows out. In this case, extinction time is rather short. It seems that the air velocity in water spray mainly involves in this pattern because when just airflow is conflicted to the flame source without water spray, only the blow out appears. Figure3 shows the flame pattern by varying air velocity without water spray. The fire flame turns unstable guradually as air velocity increases and go down below the burner surface. Thus the fire flame results in blowing out suddenlly.

The blow off (Fig.2 b): the base of the flame moves up to the top of the flame from the burner surface. Thus the fire results in being extinguished. It seems that this is due to the increased density of vapor around the burner surface; the flame front is cooled down and the density of the fuel and oxygen decrease. In this case extinction time is also rather short.

The fade out(Fig.2 c): the spout area of the fuel decreases as water pools on the burner surface gradually; the fire flame lessens and goes out. This pattern appears as burner surface temperature and volume flux are low. It is considered that drops cool off the burner surface gradually and pool on it when reaching the surface, as a result water spray doesn't evaporate. In this case extinction time is rather long.



(a) Air Velocity:0 m/s (b) Air Velocity:0.8 m/s (c) Air Vlocity:1.4 m/s

Fig.3 Flame pattern

3.2 Effect of spray characteristics on mean extinction time and pattern

3.2.1 Effect of Drop mean size

Extinction time by varying drop mean size and entrained air velocity is examined under the constant spray volume flux. The result is shown in Figure.4. Mean extinction time decreases with the increase of drop mean size at any air velocity. This is because the blow off, which shows a short extinction time, appears so frequently since drops immediately evaporate on the burner surface and on the fire flame in case drop mean size is so large that many drops reach the burner surface. On the other hand in case drop mean size is small, the burner surface is cooled slowly because the number of drops that reach the burner surface decreases, thus the fade out, which shows a long extinction time, appears so frequently. In case air velocity is 0.6m/s and the drop mean size is 100μm, only the fade out appears and mean extinction time is 147 seconds. The same pattern appears in case air velocity is 0.4m/s and drop mean size is 170μm.

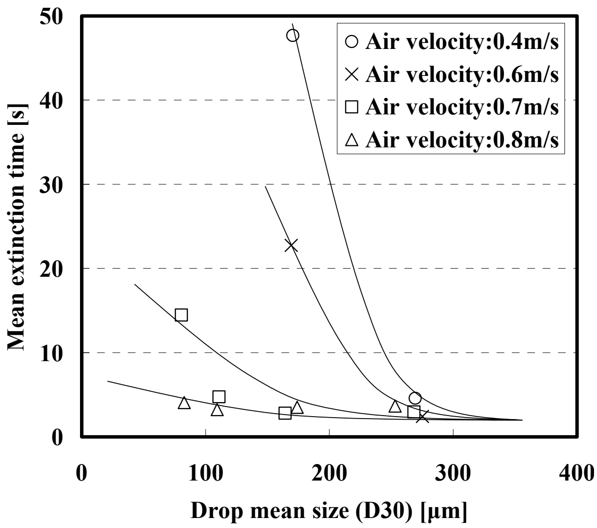


Fig.4 Effect of drop mean size on extinction time

3.2.2 Effect of Air velocity in the water spray

Most of the extinction patterns shown in Figure.5 are the blow off. This pattern tends to transfer to the blow out with the increase of air velocity, i.e. mean extinction time decreases. It can be thought that airflow mainly causes the blow out. Fire blows out over 1.4 m/s in air velocity with this fire condition when only air is jet to the fire without water spray. Also Figure.5 obviously shows that the extinction state similar to the blow out is observed under much lower air velocity than 1.4m/s when water spray is added. In case drops are added to airflow, the limit of the blow out seems to be lower because they make the fire cool and make the density of the fuel and the oxygen thin by drop evaporation.

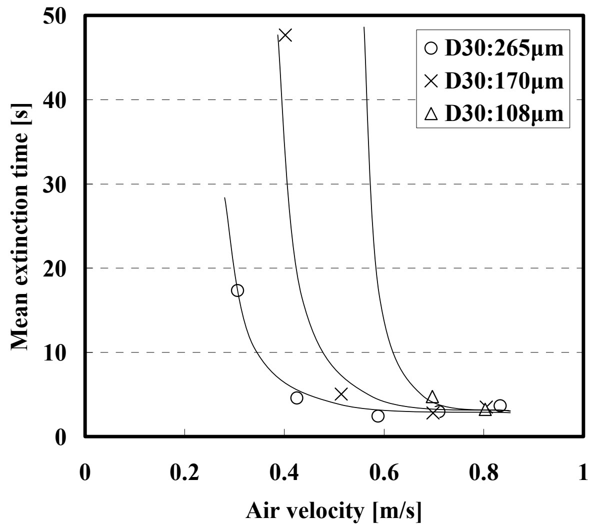


Fig.5 Effect of air velocity on extinction time

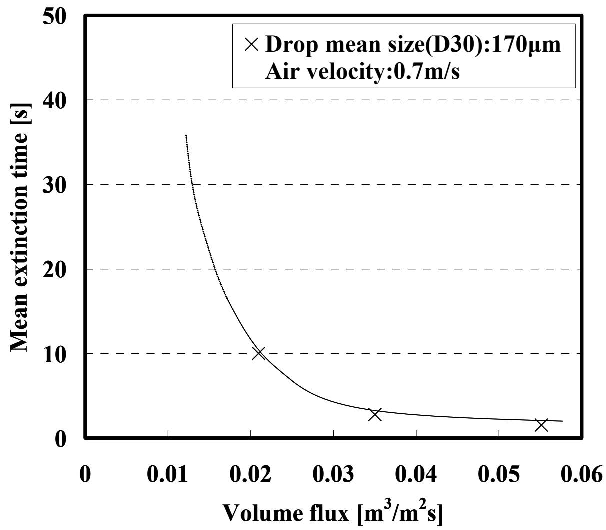


Fig.6 Effect of spray volume flux on extinction time

3.2.3 Effect of Volume flux

Mean extinction time is shown in Figure.6 by varying spray volume flux under the constant drop mean size and entrained air velocity. Mean extinction time suddenly decreases with the increase of spray volume flux because the vapor made around the burner surface or in the fire increases and makes the fire front cool. On the contrary the fire isn't extinguished less than the spray volume flux being 0.012 $10^{-3}m^3/m^2$□s.

3.3 Effect of Burner surface temperature

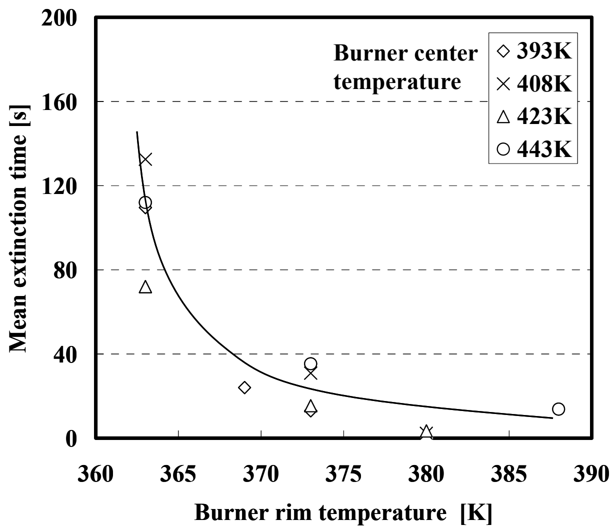


Fig.7 Effect of burner rim temperature on extinction time

Figure.7 shows the relation between burner rim temperature and mean extinction time under constant burner center temperature. Being hardly influenced by burner center temperature, mean extinction time suddenly decreases when burner rim temperature increase under constant burner center temperature.

3.3.1 Mean extinction time of each extinction pattern

Figure.8 and 9 show mean extinction time of blow off and fade out by varying each burner center temperature and rim temperature. Mean extinction time of blow off is consistently about 3-8 seconds nearly regardless of burner center and rim temperature as shown in Figure.8. On the contrary, burner rim temperature falling below 365K, mean extinction time of the fade out suddenly increases. Burner rim temperature exceeding 365K, mean extinction time of fade out is about 50-100 seconds, comparatively long time, nearly regardless of burner center and rim temperature.

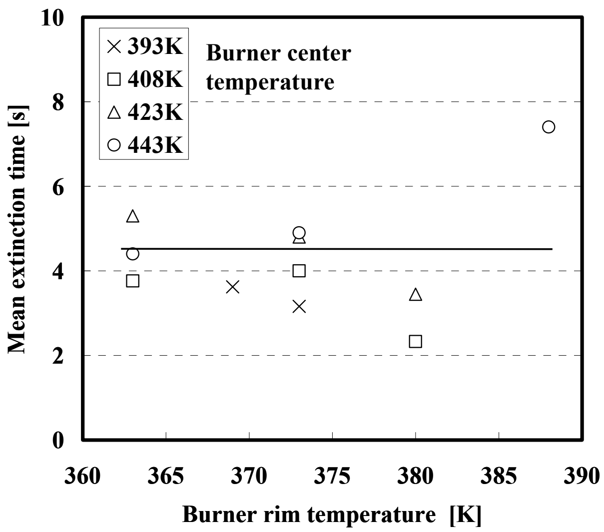


Fig.8 Mean extinction time of the blow off

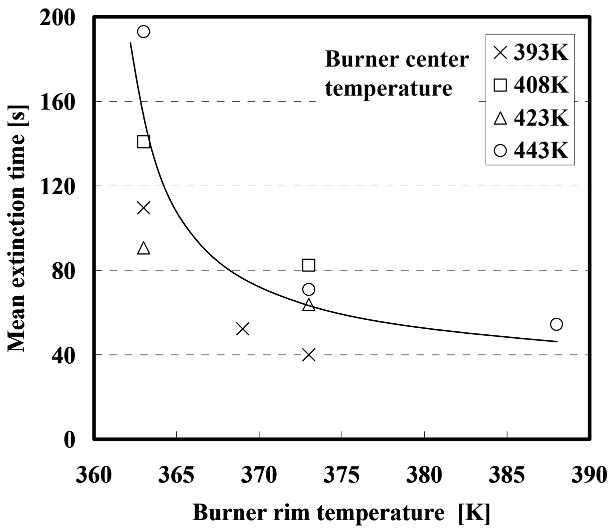


Fig.9 Mean extinction time of the fade out

3.3.2 Effect of Burner rim temperature

Figure.10 shows the blow off ratio, i.e. the blow off to total, by varying burner rim temperature under constant burner center temperature. In this condition the blow out was not observed. Therefore vertical axis in Figure.10 shows the number of the blow off to all number of extinction experiment under constant condition. The blow off ratio increases with burner rim temperature increasing as shown in Figure.10. This is considered to be caused by instability around the base of the fire, for amount of vapor increase that arises per a unit of time. Drops immediately evaporate around the

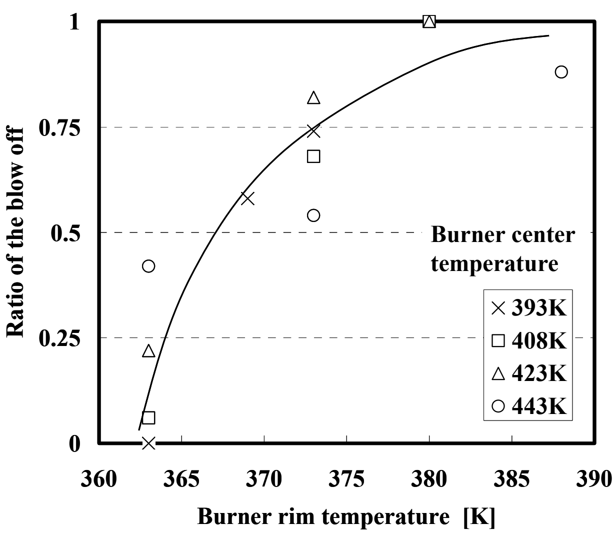


Fig.10 Ratio of the blow off

burner rim with the increase of burner rim temperature since the evaporation rate increases.

Mean extinction time decreases according to increase of burner rim temperature that can be seen in Figure.7 since the blow off, showing a short extinction time, appears rather frequently with increase of burner rim temperature shown in Figure.10.

4. Conclusions and future work

The effect of spray characteristics and burner surface temperature on extinction time is examined in this study and the results are summarized as follows.

(1) The extinction states are classified into the three patterns, the blow out, the blow off, and the fade out.
(2) The blow out is mainly involved in entrained airflow by water spray and this extinction time shows rather short.
(3) The blow off is mainly caused by the vapor generated around the burner rim that makes the flame front cool down and makes the densities of the fuel and oxygen around the burner rim. This extinction time is rather short.
(4) The fade out is mainly caused by that the spout area of the fuel decreases and this prevents combustion as drops cover the burner surface gradually without evaporating. Especially in case volume flux and drop mean size is small, the fade out tends to be shown more.
(5) The blow off ratio increases with the increase of the burner rim temperature.
(6) Extinction time of the blow off is hardly influenced by burner center and rim temperature, but one of the fade out decreases sharp with the increase of burner rim temperature.
(7) Mean extinction time increases with the decrease of drop mean size, volume flux and air velocity under other conditions being constant.
(8) Mean extinction time decreases sharp as burner rim temperature increases.

These conclusions suggest that the blow off essentially involve in vapor generated in the neighborhood of the burner rim and vapor flow. Henceforth flow around the burner rim should be observed and quantified.

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