FLAME SPREAD OVER PAPER SOAKED WITH A COMBUSTIBLE LIQUID

Takeshi SUZUKI and Toshisuke HIRANO
(The University of Tokyo, Tokyo 113, Japan)

ABSTRACT

This paper describes the results of an experimental study of free-convective flame spread over the surface of a paper sheet soaked with a combustible liquid. Effects of volatility on the flame spread processes over the surface of a combustible were examined.

It was shown that aspects of flame spread depended on the characteristic of the paper sheet. When the flash point was below the ambient temperature, a flame spread so fast that the leading flame edge reached the end before pyrolysis of paper began. To the contrary when the flash point was above the ambient temperature a leading flame edge extended ahead of the brown zone indicating pyrolysis of paper. In both cases the flame was seen to spread at a steady rate.

The flame spread rate over a paper sheet soaked with combustible liquid is larger than that over a dry one. However, the flame spread rate across the free surface of a liquid fuel was larger than that over a paper sheet soaked with the same liquid. The difference in the flame spread rate is attributable to the effect of volatility.

KEYWORDS : Fire physics, Fire development, Flame spread
Heterogeneous combustion, Liquid-soaked solid burning

INTRODUCTION

The flame spread over the surface of a combustible is a complex process. It is known that a number of factors influence flame spread.[1-5] Volatility is the most important one of them. However previous studies on it are very few. By making a combustible liquid soak in a porous solid combustible, its volatility can be controlled. When the liquid is more volatile than the solid combustible, the solid combustible becomes more volatile. By the use of this characteristic the effects of volatility on flame spread over the surface of a paper sheet were examined.

The knowledge obtained through the present study on novel aspects of flame spread phenomena seems to be useful for understanding the flame spread mechanisms over combustibles with wide range of characteristics.

EXPERIMENTAL

The experimental arrangement is illustrated in Fig.1. A paper sheet of 3cm x 14 cm in the surface area is clamped between pairs of metal straps, leaving 2 cm exposed to burn.

Paper sheets of six different thicknesses were used. Their properties are listed in Table 1. The combustible liquid used is methanol or decane. Their properties are listed in Table 2. The flash point of methanol is 285 K while that of decane is 317 K. The flash point of methanol is below the ambient temperature (289 K - 294 K). It is considered that a flammable mixture is established before ignition near the surface of a paper sheet soaked with methanol. The flash point of decane is above the ambient temperature. Vapours near the surface of a paper sheet soaked with decane are

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below its lean flammability limit. Since the flash point of dry paper is 533-573 K, the flash point of paper soaked with methanol or decane is less than that of dry paper by more than 200 K.

Rates of vertically downward and horizontal flame spread were measured. The rates of flame spread over a dry paper sheet and that of downward flame spread over a liquid-soaked paper sheet are determined by dividing the distance between points marked on the paper surface by the elapsed time for flame spread between the points. Also the rate of horizontal flame spread over a liquid-soaked paper sheet is determined by dividing the distance between the junctions of two chromel-alumel thermocouples (diameter = 0.1 mm) by the time interval between the signals of the thermocouples.

EXPERIMENTAL RESULTS

1. Aspects of flame spread

Aspects of a vertically downward spreading flame over a dry paper sheet of 0.24 mm thick are shown in Fig.2. A flame was seen to spread at a constant rate over the paper surface. The luminous yellow flame follows the blue leading flame edge. The leading flame edge extends ahead of the brown zone where pyrolysis of paper starts to take place.

Aspects of a vertically downward spreading flame over a paper sheet of 0.24 mm thick soaked with decane are shown in Fig.3. A flame was seen to spread over the paper surface at a uniform rate. The luminous yellow flame follows the blue leading flame edge. The leading edge of the brown region indicating pyrolysis of paper begins behind the leading flame edge.

Aspects of a vertically downward spreading flame over a paper sheet of 0.24 mm thick soaked with methanol are shown in Fig.4. A blue flame flashes over the paper surface at a steady rate. The paper started to turn brown from both ends of the paper sheet after the leading flame edge reached the bottom end.

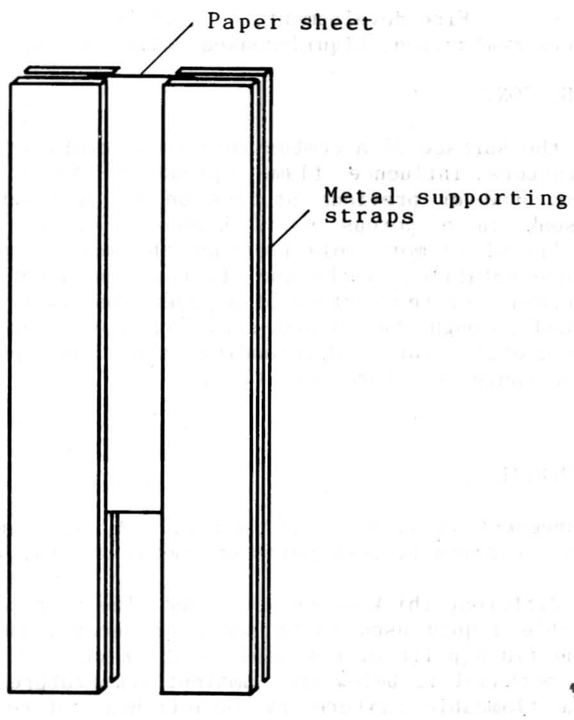

Fig.1 Experimental arrangement used in this study.

2. Flame spread rate

Rates of vertically downward flame spread are shown in Fig.5. For dry or decane-soaked paper the flame spread rate is seen to depend on the thickness of the paper sheet while for methanol-soaked paper it is almost independent of the the thickness of the paper sheet.

Rates of horizontal flame spread are shown in Fig.6. For dry or decane-soaked paper the flame spread rate is seen to depend on the thickness of the paper sheet while for methanol-soaked paper it is independent of the thickness of the paper sheet. Table 3 shows rates of flame spread across the free surface of a liquid fuel. The flame spread rate across the free surface of decane is as large as that over horizontal paper sheets soaked with decane. The flame spread rate across the free surface of methanol is much larger than that over the horizontal paper sheets soaked with methanol.

Table 1 Paper properties

thickness of paper sheet	mass of paper sheet per unit area	density of paper sheet	mass of soaked decane per unit area	mass of soaked methanol per unit area	density of paper sheet soaked with decane	density of paper sheet soaked with methanol
cm	g/cm2	g/cm3	g/cm2	g/cm2	g/cm3	g/cm3
0.018	0.008	0.5	0.01	0.01	1	1
0.021	0.009	0.4	0.01	0.01	1	1
0.024	0.011	0.5	0.01	0.01	1	1
0.027	0.012	0.5	0.01	0.01	1	0.9
0.040	0.017	0.4	0.02	0.02	0.9	0.9
0.070	0.035	0.5	0.03	0.04	1	1

Table 2 Properties of liquid[6]

		Methanol	Decane
Chemical formula		CH_3OH	$C_{10}H_{22}$
Molecular weight		32	142
Boiling point (K)		337	447
Enthalpy of vaporization (kJ/kg)		1101	360
Enthalpy of combustion (MJ/kg)		20.8	44.7
Closed cup flash point in air at 1 atm (K)		285	317
Flammability limit (vol%)	lean	6.7	0.6
	rich	36.5	5.4
The least autoignition temperature (K)		658	474

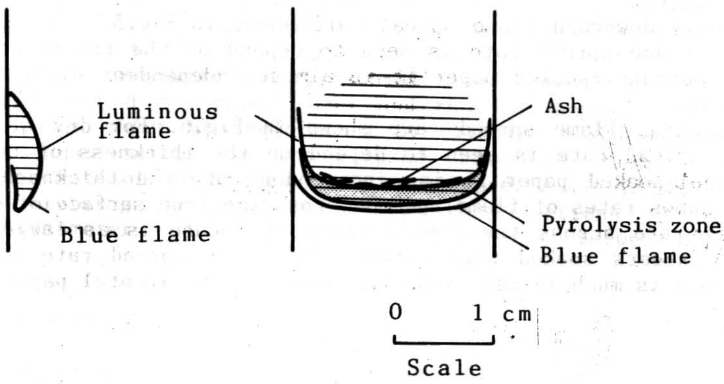

Fig.2 Aspects of a spreading flame over a dry paper sheet.

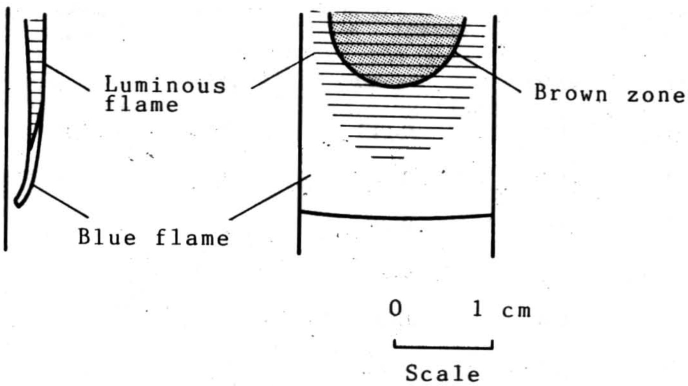

Fig.3 Aspects of a spreading flame over a paper sheet soaked with decane.

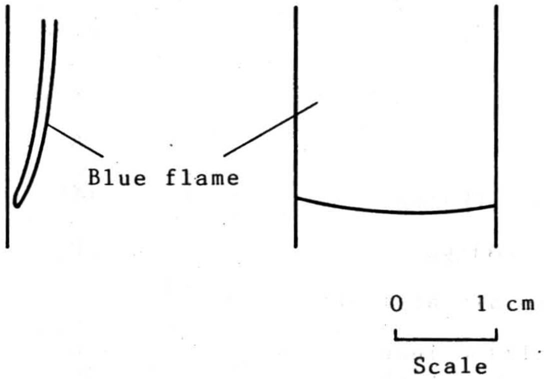

Fig.4 Aspects of a spreading flame over a paper sheet soaked with methanol.

Table 3 Flame spread rate over liquid surface (liquid temperature = 293 K)

	(cm/s)
Methanol[7]	100 to 200
Decane[8]	2

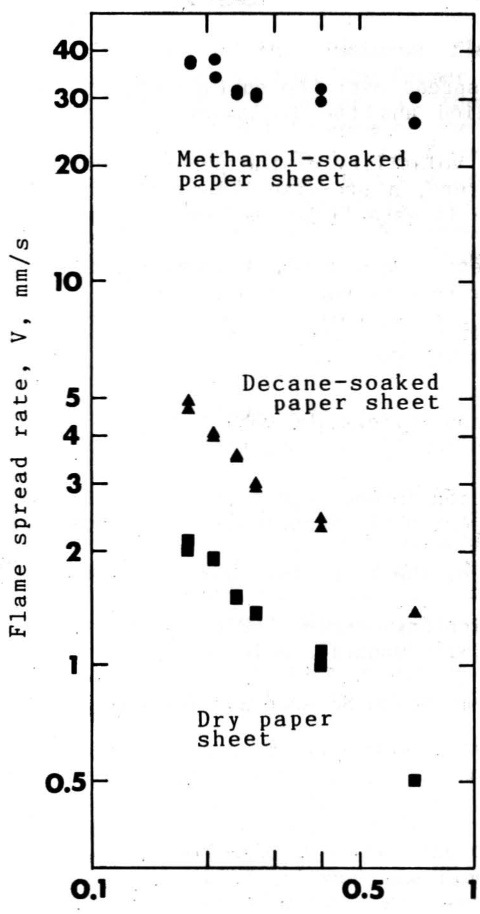

Fig.5 Variation of vertically downward flame spread rate with thickness.

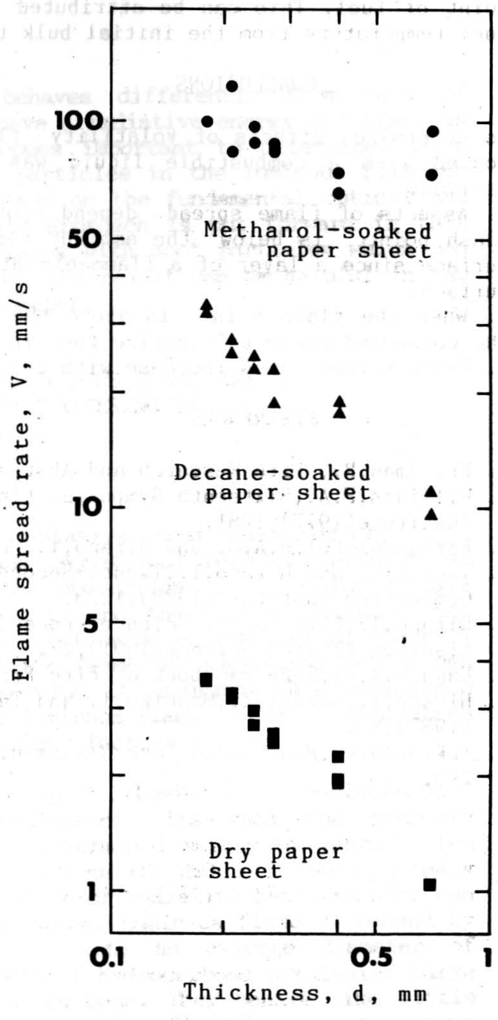

Fig.6 Variation of horizontal flame spread rate with thickness.

DISCUSSION

The flash point of methanol is 285 K which is below the ambient temperature. It is considered that a layer of a flammable mixture is established before ignition near the surface of a paper sheet soaked with methanol and that a pre-mixed flame flashes over the surface. Paper starts pyrolysis after all methanol vaporizes. Thus as observed in the present study there must be weak or no effect of thickness on flame spread rates.

The flash point of decane is 337 K which is above the ambient temperature. Vapours near the surface of a paper sheet soaked with decane are below its lean flammability limit. In order for a flame to spread a flame must heat the condensed phase and vaporize fuel. It is considered that paper starts pyrolysis after all decane vaporizes. Since thickness increases with heat capacity of the condensed phase, there is strong effect of thickness on flame spread rates.

When thickness is the same, flame spread rate increases with decreasing the flash point of fuel. This can be attributed to the decrease of heat capacity for raisihg fuel temperature from the initial bulk temperature to its flash point.

CONCLUSIONS

To determine effects of volatility flame spread over the surface of a paper sheet soaked with a combustible liquid was studied and the following conclusions were derived.

1. Aspects of flame spread depend upon the volatility of the paper sheet. When the flash point is below the ambient temperature, a pre-mixed flame flashes over the surface since a layer of a flammable mixture is established before ignition near the surface.
2. When the flash point is above the ambient temperature, a spreading flame heats the condensed phase to vaporize fuel in order to continue spreading.
3. Flame spread rates increase with decreasing flash point.

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