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Experimental investigation of the fire extinguishing capability of ferrocene-containing water mist

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ABSTRACT

This study focuses on the fire-suppression capabilities and corrosive properties of ferrocene dispersions. The motivation behind the present study was to develop a high-performance, phosphorus-free fire suppressant. Aqueous dispersions containing micron-sized ferrocene particles and surfactants were prepared using sonication techniques. In this study, Triton X-100 (TX), Noigen TDS-80 (NT), Tween 60 (T60), and Tween 80 (T80) were used as surfactants. Suppression experiments involving pool fires clearly indicated that aqueous ferrocene dispersions containing TX and micron-sized ferrocene with a $d_{50} = 16.9\ \mu m$ exhibit shorter extinguishing times than a conventional wet chemical. Corrosion trials using steel plates immersed in ferrocene dispersions containing TX confirmed that there was no pitting corrosion, implying that ferrocene dispersions containing TX do not present a corrosion risk.

1. Introduction

As shown in Fig. 1, the fire statistics of Japan indicate that the number of deaths and the economic losses due to fires were 1678 and approximately 85.3 billion yen, respectively, in 2014 [1]. Developing a more effective fire suppressant can make a large contribution to containing fires and reducing casualties and economic losses caused by such fires. Ammonium dihydrogen phosphate ($NH_4H_2PO_4$) is an active substance in ABC powder, which is widely used as a multipurpose fire-extinguishing agent. Serious concerns, however, exist about the risk of depletion and the increasing cost of phosphate rock [2]; hence, new fire-extinguishing agents should be phosphorus-free materials. Needless to say, unlike halogenated hydrocarbon fire suppressants such as Halon 1301 (bromotrifluoromethane) and Halon 2402 (dibromotetrafluoroethane), new agents are required to have zero ozone depletion potential [3,4]. Fine water mist with or without additive(s) is a prime candidate for a new fire-extinguishing agent because of its environmentally friendly, inexpensive, and high-performance characteristics [5]. Additives are used to further enhance the fire suppression efficiency and typically include a surfactant [6,7], alkali metal salts [8], and transition metal salts [9]. A performance-enhancing agent reduces the amount of suppressant required to extinguish a flame, perhaps resulting in preventing damages due to water.

Transition metal compounds generally have a high ability to extinguish a flame. For instance, iron pentacarbonyl is up to two orders of magnitude more effective than Halon 1301 [10]. However, iron pentacarbonyl is highly toxic, and the use of this material as a fire-extinguishing agent is therefore very limited. In general, fire suppression applications require the suppressants to have low toxicity and cost and be noncorrosive to fire-extinguishing equipment. Of all the transition-metal compounds, ferrocene (illustrated in Fig. 2a) has drawn attention because of its high suppression capability and low toxicity; several researchers in related fields experimentally demonstrated that ferrocene and its derivatives are good flame inhibitors [11] and flame retardants [12]. For instance, Linteris et al. numerically and experimentally demonstrated the high flame inhibition efficiency of ferrocene vapor [13], and Mehdipour-Ataei and co-workers reported a good flame retardancy for poly(amide ether amide)s having ferrocene moieties [14]. In addition to the good inhibition efficiency of ferrocene, an advantage of using ferrocene is that iron is an abundant

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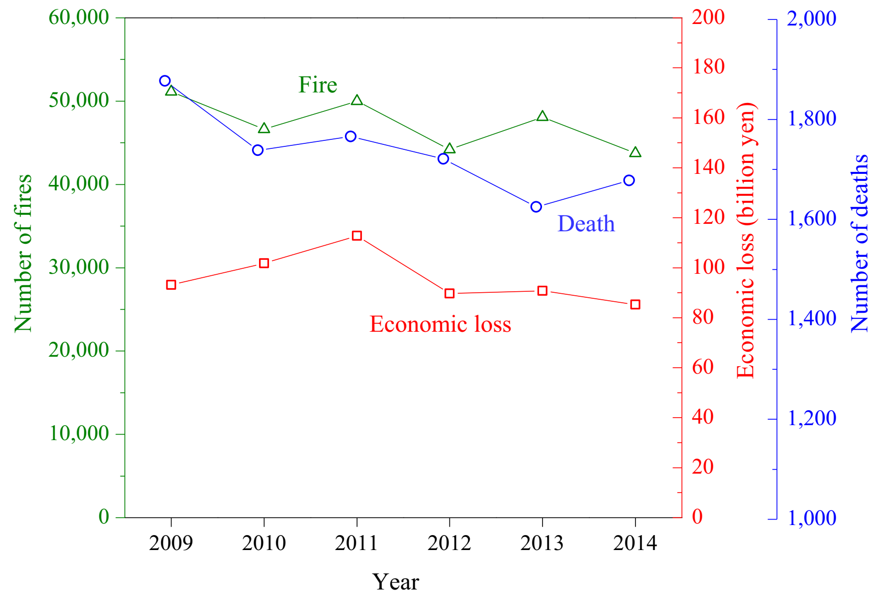

Fig. 1. Trends in fires, deaths, and economic losses from 2009 to 2014 in Japan (adapted from [1]).

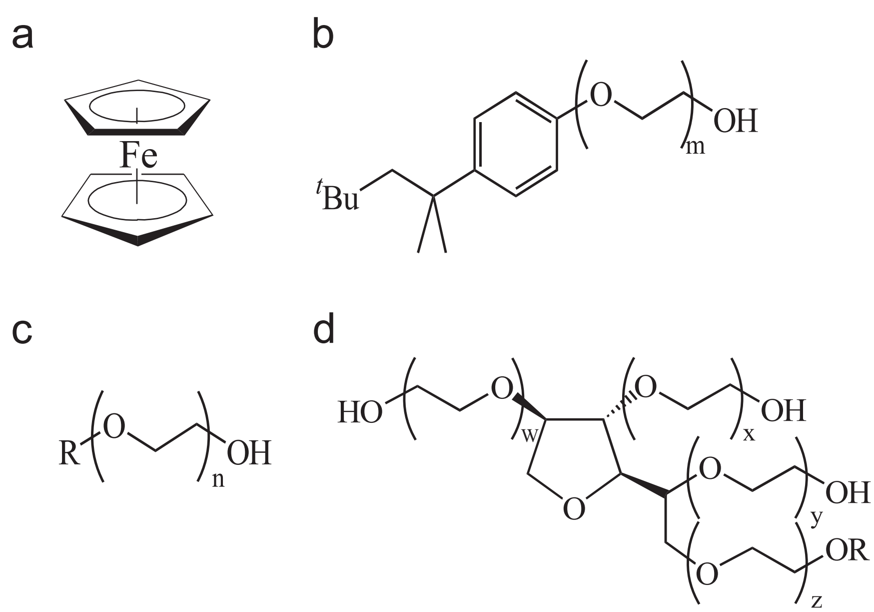

Fig. 2. Chemical structures of (a) ferrocene and the nonionic surfactants: (b) Triton X-100 (TX, m=10), (c) Noigen TDS-80 (NT, n=8, R=n-$C_{13}H_{27}$), and (d) Tween 60 (T60, $w+x+y+z=20$, R=$CO(CH_2)_{16}CH_3$) and Tween 80 (T80, $w+x+y+z=20$, R=cis-$CO(CH_2)_7CH=CH(CH_2)_7CH_3$).

element. However, when ferrocene is employed as an additive in water, it has two distinct disadvantages: water insolubility and a decrease in the extinguishing efficiency at higher ferrocene fractions. The former means that it is difficult to use lipophilic ferrocene (as is) as an additive in water. The latter shows that the fire suppression ability of a ferrocene dispersion depends on its concentration [13,15], implying that the amount of ferrocene added to a flame must be carefully controlled when using ferrocene as an additive. To solve these issues, Koshiba and co-workers [16] recently proposed a novel water-based suppressant containing ferrocene: an aqueous dispersion of ferrocene powder. Such an approach would offer the advantage of easy preparation of dispersions containing an optimum ferrocene concentration. The earlier studies mainly demonstrated that (i) the extinguishing efficiencies of aqueous ferrocene dispersions are maximized at a ferrocene concentration of approximately 100 ppm (i.e., the fire-extinguishing capability of ferrocene dispersions is also fraction dependent) and that (ii) the extinguishing capability is positively correlated with the dispersibility of ferrocene dispersions. Unfortunately, however, only a few expensive gemini surfactants have been employed. In addition, the corrosive properties of ferrocene dispersions were not investigated. The suppression ability of ferrocene dispersions containing general-purpose and commercially available surfactants and the corrosive properties of such ferrocene dispersions must be investigated.

The present paper describes the fire-extinguishing properties of aqueous ferrocene dispersions containing commercially available and inexpensive nonionic surfactants: Triton X-100 (hereafter referred to as TX), Noigen TDS-80 (NT), Tween 60 (T60, also known as Polysorbate 60), and Tween 80 (T80, also known as Polysorbate 80). The influences of the ferrocene particle size and the surfactant used on the ability of the dispersions to extinguish fires are addressed. Furthermore, the corrosive properties of ferrocene dispersions were studied.