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Large-scale boilover experiments using crude oil

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Abstract

In order to know the mechanisms of boilover in a large tank, large-scale experiments using a 5 m diameter pan filled with crude oil were conducted. The initial fuel layer thickness was 0.45 m. At about 70 min after ignition, boilover occurred. The maximum irradiance was observed at the boilover and was about 22 times greater than that at steady burning. The increasing rate of the isothermal layer (hot zone) thickness was evaluated on the basis of measured temperature profile changes in the fuel. The measured periods from ignition to boilover coincide fairly well with those measured in the previous studies.

Keywords: Boilover; Radiation; Hot zone (isothermal layer); Fuel temperature; Crude oil

1. Introduction

Many huge crude oil tank facilities have been built in Japan for storing crude oil as a national oil strategy after the oil crisis of 1973. It is indispensable to know the hazardous aspects of large-scale tank fires for loss prevention associated with fires involving huge oil tank facilities. Therefore, we have studied the burning characteristics of large-scale tank fires by conducting a series of large-scale oil fire experiments in 1998 [1], and boilover with emulsified water [2]. Boilover is one of the most hazardous aspects of oil storage facility fires [3–7], so that we have paid close attention to it.

The conditions under which boilover occurs have been studied by Hall [5], Burgoyne and Katan [6], Blinov and Khudyakov [7], and Hasegawa [8]. Recently we conducted similar study using Arabian light crude oil, Murban crude oil, Sarukawa crude oil and fuel oil A [2,9–11]. It was shown that a condition necessary for boilover was the formation of an isothermal layer in the burning liquid. The thickness of the isothermal layer increases with time after ignition, and it may grow to be several meters deep in a large tank before boilover. It is known that when the lower boundary of the isothermal layer reached a layer of water on the bottom of the tank a sudden vaporization of water might occur. However, the processes of the isothermal layer formation and its growth are still unknown. In order to elucidate those processes, large-scale boilover experiments were conducted jointly by JNOC, NRIFD, and the University of Tokyo.

2. Experiments

2.1. Experimental site and weather conditions

The experiments were conducted at the East-Tomakomai Seaport in Tomakomai, Hokkaido, Japan. We decided to conduct the experiments in January. Even though it was very cold, a steady north wind blew in January, and a north wind was preferable because south of the experimental site was the Pacific Ocean, where there were no houses. For all

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the experiments, the temperature was about −4 °C, and the wind speed was 3–8 m/s.

2.2. Fuel

Crude oil used in the experiments was supplied by Idemitsu Co. A crude oil mixture equivalent to Arabian light crude oil was used as fuel. Arabian light crude oil is one of the most popular crude oils in Japan, and Arabian light crude oil or oils of similar properties are stored in many of the oil tanks of JNOC and other oil companies. Table 1 shows properties of the fuel used in the experiments, and its specifications are similar to slightly lighter the crude oil that we used in 20 m pan fire experiments [1]. Fig. 1 shows distillation curve of the fuels, which was measured by the oil supplier.

2.3. Facilities of experiments

Table 2 summarizes details of the experimental conditions. The weather station, which measured ambient temperature, humidity, wind direction, and wind speed, was provided at about 60 m east of the pan center and about 2 m from the ground. Weather data were measured every 5 min.

Table 1
Properties of blended crude oil used in the present study

Density (kg/m^3)[a]	0.84
Flash point (°C)[a]	<0
Kinematic viscosity (mm/s^2 at 50 °C)[a]	5.14
Specific heat(kJ/kg K)[b]	2.0[c]
	2.2[d]
Sulfur content (wt.%)[a]	2.29
Nitrogen (wt.%)[a]	<1

[a]Measured by the oil supplier.
[b]Measure with DSC by the authors(average, 20–90 °C).
[c]Sample was fresh crude oil.
[d]Sample was 22% distillated residue from fresh oil.

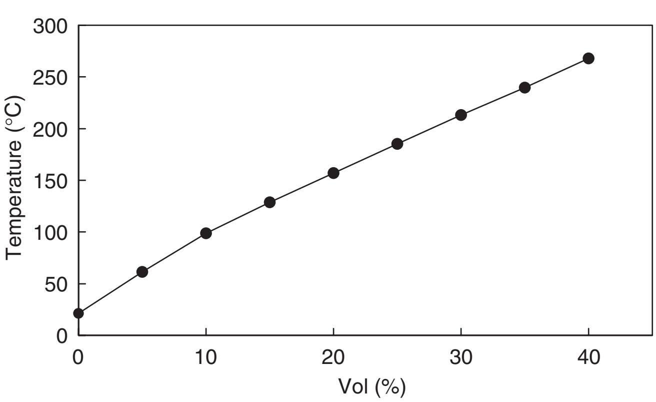

Fig. 1. Distillation curve of crude oil.

2.4. Apparatus

The steel pan used for crude oil burning was 5 m in diameter and 0.9 m high (Figs. 2 and 3). The initial free board (vertical distance between the initial fuel surface and the top edge of the pan wall) was 350(±50) mm. Experiments were conducted with fuel pools at 450 mm in depth, and the water layer thickness was 100 mm. In order to know the burning behavior without boilover, a preliminary test was conducted in a 4 m diameter pan [2]. In this test, boilover did not occur because water in the fuel was removed carefully before the test.

2.5. Measurements

2.5.1. Burning rate (fuel level regression rate)

A level meter connected by a pipe to the bottom of the pan wall was used to measure the burning rate (fuel level regression rate). Burning rate was also evaluated using data of the temperature profiles inside the fuel.

2.5.2. Radiation intensity (irradiance)

Twelve radiometers to measure radiation from the fires were placed around the burning pan at a height about 1.2 m from ground level. Each radiometer had a time constant of 0.3 s and covered a view angle of 118°. Radiometers were set at $L/D = 5$, 7 and 10, where D is the pan diameter and L is the horizontal distance from the center of pan. Two IR-cameras were set at $L/D = 7$ to measure radiation intensities from the flames to the windward and leeward sides. Detailed specifications of the IR-camera were presented in our previous papers [1,2]. For fire fighting, it is most important to know radiation intensities at these distances from the pan, as well as oil splashing phenomena at boilover. To obtain the maximum radiation intensities at each place, the radiometers faced the fire center. The radiometer outputs were calibrated by a black body source before the experiments. A data acquisition system was used to store the data in a computer every 5 s.

2.5.3. Temperature

Temperature profiles inside the liquid and the flame were measured using K-type sheathed thermocouples composed of 0.32 mm diameter wires. These were embedded along with the center pole, built at the pan center. Because there was little difference in measured temperatures at various points in the same depth [2,9], a side pole was not built for measuring radial temperature profiles. Temperatures at the surface of the pan wall were also measured by thermocouples.

3. Results and discussion

Table 3 summarizes the results of the experiments. The flames were extinguished automatically after boilover occurred.