Technical notes on Fundamental Experiments of Firefighting using Bubble Curtain and Underwater Dispersion for Oil Burning on Water Surface

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Abstract

The Great East Japan Earthquake caused many industrial facilities to release oil into the ocean, with some of the spills igniting and resulting in substantial fire damage. Responding to these tsunami fires requires developing techniques for extinguishing fires and preventing the spread of offshore oil spill fires. In light of these challenges, we conducted research into response methods, specifically examining the efficacy of bubble curtains for fire containment. Furthermore, we investigated the use of underwater dispersion extinguishing as a firefighting technique for extinguishing burning oil on the surface of water by dispersing it into the water below. We conducted small-scale experiments for fundamental validation, and confirmed that both methods show promise as effective approaches for responding to burning oil on the water surface.

Key words

Tsunami fires, Oil spill fires, Bubble curtains, Underwater dispersion extinguishing, Firefighting techniques,

1. Introduction

The Great East Japan Earthquake in 2011 led to numerous fires caused by the tsunami. For combating fires on burning oil at the water's surface, essential technologies include both technology to prevent the spread of fire and technology to extinguish fire.

As a device to prevent the spread of burning oil at sea, fire-resistant oil booms are known to be used in the in-situ burning method (M.Fingas,2013), whereby spilled oil is intentionally set on fire and incinerated. Nevertheless, these methods and devices are quite expensive and necessitate a high degree of expertise, rendering them unsuited for prompt responses to tsunami fire emergencies.

In this study, we focused on using a bubble curtain as a preventive tool for burning oil on the surface of water. Numerous studies on bubble curtains and barriers have investigated and documented their effectiveness in containing spilled oil (e.g.T. McClimans,2012). Similarly, we also have previously investigated the effectiveness of bubble curtains in controlling conventional oil spills. They conducted experiments and Computational Fluid Dynamics (CFD) calculations to quantitatively evaluate the oil exclusion characteristics of bubble curtains(S.Hara,1985,I.Fujita,2016) The studies revealed the effectiveness of bubble curtains in preventing oil movement and containment. However, there have been no instances of bubble curtains being used for burning oil.

If the bubble curtains are proven effective in containing floating oil fires, they could serve as an excellent alternative to conventional fire-resistant oil booms. For instance, as demonstrated in Fig.1, they can be employed to safeguard vital coastal facilities from fires caused by tsunami. Bubble curtains, in particular, are likely to be more efficient compared to fire-resistant oil booms since they can contain fires at a greater distance from the installation line.

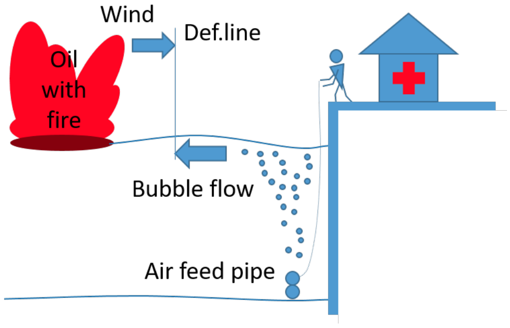


Figure 1 Image of bubble barrier applied to burning oil on the sea surface

On the other hand, foam fire extinguishers are often used for oil fire suppression in land-based facilities. However, these methods are susceptible to wind and have limited effectiveness in sea scenarios, which leads to a shortage of viable response methods. The primary difference between offshore oil spill fires and land-based fires is the abundance of seawater below the surface of the oil spill. By using this feature, objective fire suppression techniques that are tailored to offshore fires can be implemented. The substantial water volume present can be used as both a coolant and a smothering agent. Thus, we researched a new approach for extinguishing such fires—an underwater dispersion extinguishing method that involves spreading the blazing oil into a vast amount of water below it, as shown in Fig.2.

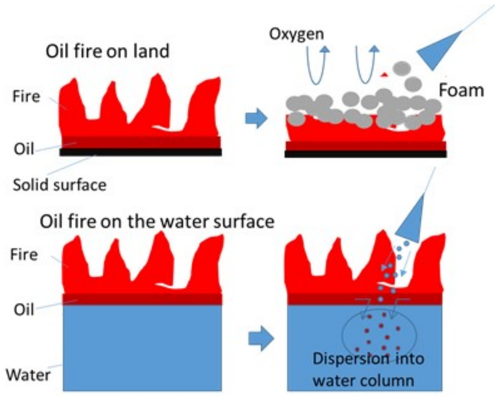


Figure 2 Image of underwater dispersion extinguishing method

In this study, to contribute to the development of new methods for addressing burning oil on the water's surface, we conducted fundamental principle verification experiments using a small-scale one-dimensional water channel to explore spreding prevention and firefighting techniques for burning oil.

2. Experimental

2.1. Experimental apparatus

The experimental tank utilized to conduct burning oil tests on the water surface is depicted in Fig.3. Its primary specifications are enumerated in Table 1. For safety purposes, the tank was positioned within a fireproof booth (L1,524×W1,524×H2,600) outfitted with 8mm thick calcium silicate board lining.

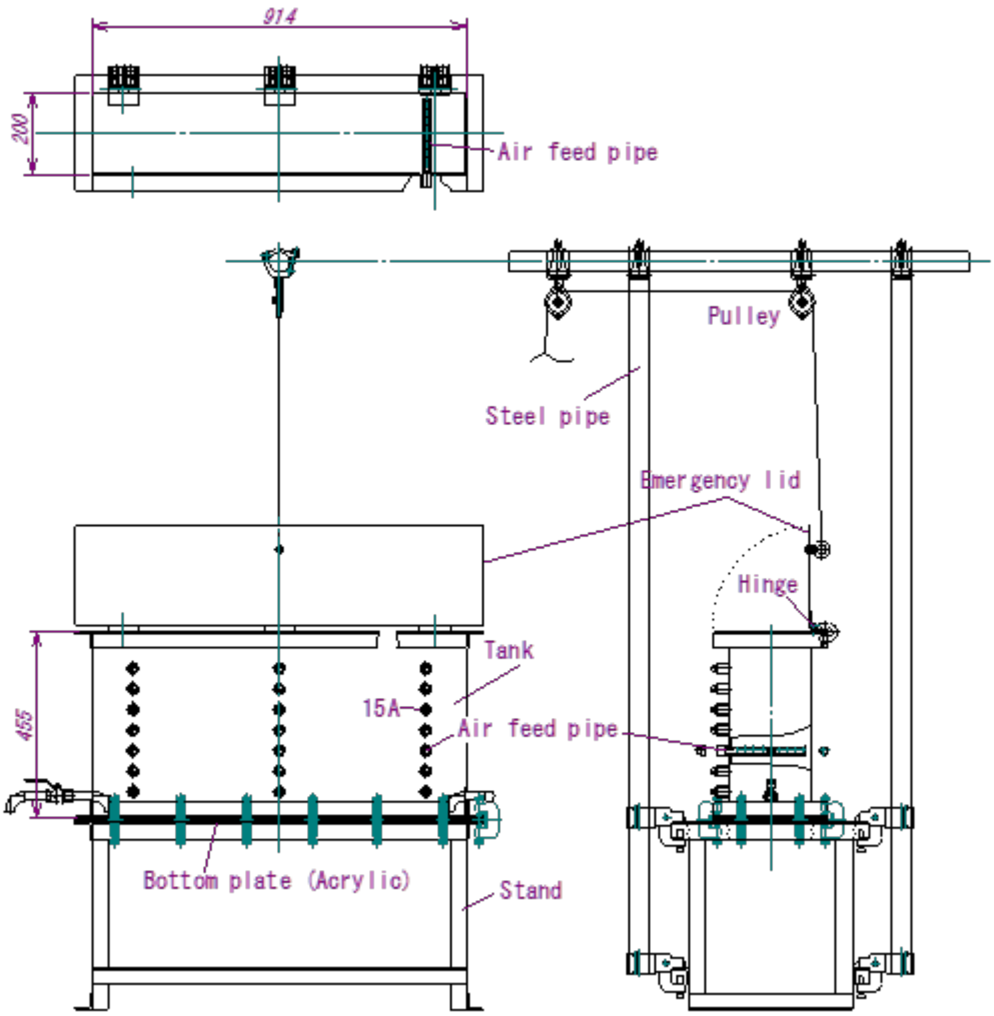


Figure 3 Experimental apparatus

Table 1 Major specification of experimental apparatus

Item	Description
Dimensions	L914×W200×H455
Materials	• Main body: steel • Lower surface of tank: Transparent acrylic resin (t8)
Air injection sockets	15A, 7 locations
Firefighting cover	Hinged opening and closing on the top of the tank (steel)

The tank was filled with water up to a specific level, and the test oil (kerosene) was poured onto the water surface and ignited with a fire starter. The experiment was observed by recording videos using cameras positioned above the inclined side of the tank and beneath the tank's bottom panel (transparent acrylic board). The combustion process during the experiment is depicted in Fig.4.

Figure 4 Example of burning oil in the test tank

2.2. Bubble curtain to control burning oil on the water surface

The air diffusion pipes were positioned on the right side of the tank at a water depth of 35cm, as shown by the orange hoses in Fig.4, and were configured to traverse the tank in the short direction. The pipes had 9 holes each with a diameter of φ1.5, spaced 20mm apart, from which bubbles were released. Airflow rates were varied from 10 to 160 liters per minute, and the behavior of the burning oil on the water surface was observed.

2.3. Dispersion extinguishing

The methodology for the firefighting experiments involving extinguishing agent spraying was as follows:

- A bubble curtain was applied from the right side of the tank towards the burning oil.
- Subsequently, the flame was directed towards the left side of the tank.
- High pressure fire extinguishing agents were sprayed on the accumulated flames.
- The duration between the initiation of extinguishing agent spray and the complete extinguishment of the fire was recorded.

For the experiments, a flat spray nozzle was used, as depicted in Fig.5, with its flow rate characteristics detailed in Fig.6. The extinguishing agents used for the experiment are listed in Table 2. The spraying flow rate was controlled by a metering pump.

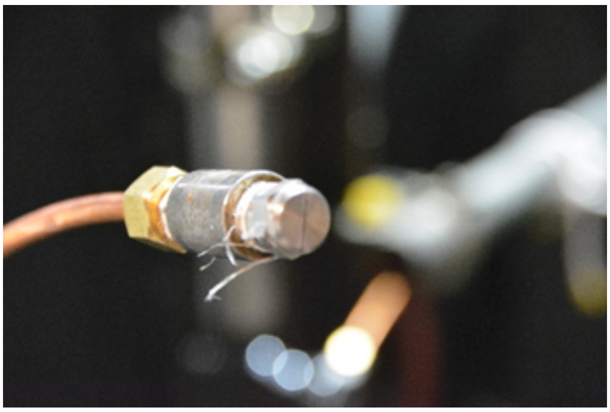


Figure 5 Spray nozzle used for extinguishing experiment

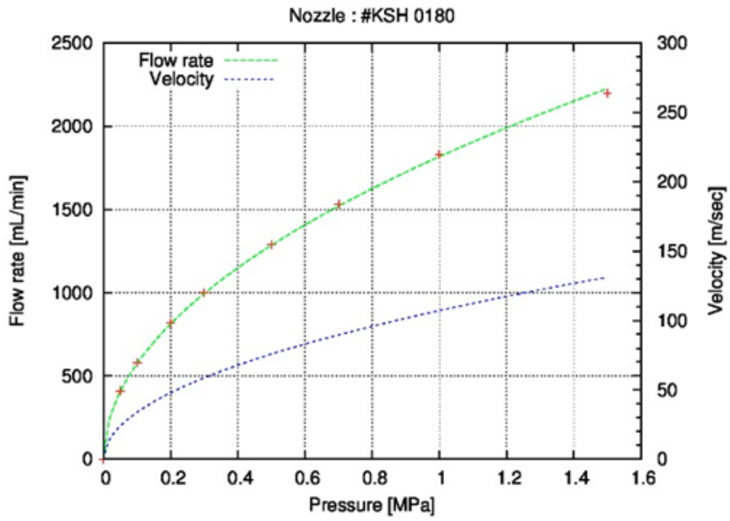


Figure 6 Performance curve of the spray nozzle used in the experiment

Table 2 Extinguishing agents used in the study

#	Ingredient
1	Sodium dioctyl sulfosuccinate (OTP-75®) aqueous solution
2	Monolaurin polyethylene glycol (MYL-10®) aqueous solution
3	Sodium hydrogen carbonate (baking soda) aqueous solution
4	Commercial oil dispersant (NEOS AB3000®) diluted solution

3. Results and Discussions

3.1. Drift control of buring oil by bubble curtain

Here we offer a brief summary of the experimental findings evaluating the effectiveness of bubble curtains for burning oil on the water's surface. Two sets of data, labeled Case 1 and Case 2, corresponding to low air supply (Qa = 10 l/min) and high air supply (Qa = 60 l/min) scenarios, respectively, are shown in Fig.7. The pictures on the left have been taken from beneath the tank, while the ones on the right have been captured from an elevated position above the tank. Sequential photos were taken every two seconds after air discharge initiation, revealing burning oil directed toward the left side due to bubble generation. This observation demonstrates the potential to control drift through bubbles regardless of oil burning, emphasizing the effectiveness of bubble-induced drift control.

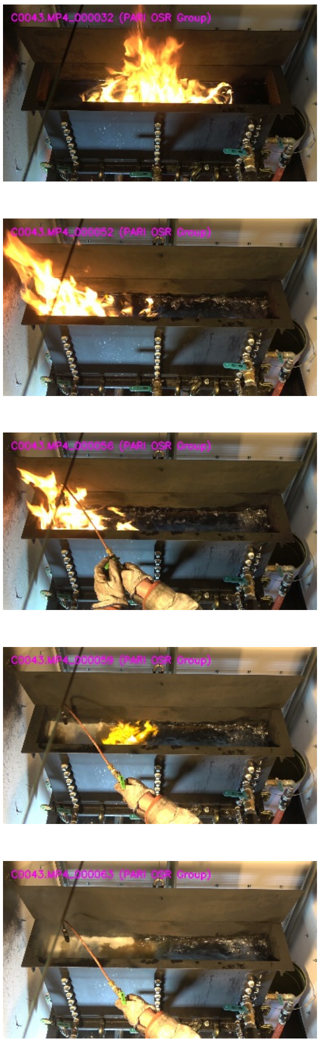
Case 1 | Case 2

$Q_a = 10l/min$ | $Q_a = 60l/min$

Figure 7 Burning oil exclusion by bubble curtain

3.2. Dispersion Extinguishing

An example of firefighting using the underwater dispersion method is shown in Fig.8. The figure represents the application of a dispersant, created by mixing sodium dioctyl sulfosuccinate (OTP-75) with industrial alcohol and water in a 1:1:3 ratio, at a flow rate of 2000 ml/min. The dispersant was applied to 400 ml of burning kerosene. The extinguishing time was 8.47 seconds. According to visual observation, although some bubbles were generated on the water's surface due to the agent's application, the quantity was not substantial. Unlike conventional foam fire extinguishants that rely on suffocation, it seemed that the mechanism of removal and cooling by the dispersion of oil within water dominated in this case.



Oil burning on the water surface

Flame moves to the left by bubble curtain.

Initiation of spray of extinguishing agent

Spray continue and its duration measured

Fire extinguished

Figure 8 Time-lapse photos of underwater dispersion extinguishing (Sodium dioctyl sulfosuccinate aqueous solution)

Table 3 Duration required for extinguishing fire

#	Spray agent	Oil	Duration[s]
1	Water		82.6
2	Sodium hydrogen carbonate aq.		37.2
3	Monolaurin polyethylene glycol (MYL-10) aq.	Kerosene	7.4
4	Sodium dioctyl sulfosuccinate (OTP-75) aq.		8.5
5	Commercial oil dispersant aq. diluted		16.6
6	Water	Kerosene/ oil dispersant	10.5

*Click hyperlinks to see movies.

A comparison of extinguishing times for different dispersants is displayed in Table 3. All tests were conducted with 400 ml of burning kerosene on the water's surface. In Case 1, the extinguishing agent was water alone at a rate of 2000 ml/min, yielding an extinguishing time of 82.6 seconds. In Case 2, a sodium hydrogen carbonate solution with a pH of 8.5 was used. Case 3 involved a solution of monolaurin polyethylene glycol at the same dilution ratio as OTP-75. Case 4 was as previously described. Case 5 is a commercially available oil treatment agent that is generally diluted with water in a 1:2 ratio. Conventional oil treatment agents are typically composed of solvents with surfactants dissolved in organic solvents. Although it is generally not recommended to dilute such agents when dispersing oil, for this experiment, the undiluted solution was avoided due to increased risk of fire. Therefore, the oil treatment agent was diluted with water to reduce flammability and employed. Case 6 differs from cases 1 to 5. In this instance, a 20% concentration oil treatment agent was gently sprayed on the oil on the water's surface before the fire ignited, without agitation. After ignition, water was sprayed onto the fire, following the method used in case 1.

Comparing these results, it's evident that the extinguishing times, which required a very long time for simple water-based firefighting without surfactant components, have been dramatically reduced for extinguishing agents containing surfactants. The reason for this difference can be explained as follows. In the case of using water alone as an extinguishing agent, the generated oil droplets are larger and the dispersed oil droplets in water have a tendency to coalesce and reignite when they return to the water's surface. On the other hand, extinguishing agents that contain surfactants reduce interfacial energy at the oil-water interface, resulting in finer oil droplets that are more stably retained within the water, leading to the observed differences. Additionally, Case 6 demonstrates that treating spilled oil with oil treatment agents allows for potential extinguishing at sea using water, even in the event of a fire. Case 2 involves using alkali for cleaning oil-based stains due to its known effectiveness. When comparing its extinguishing time, it displayed better results than water-based firefighting. However, its effect was not as pronounced as that of surfactants.

Summarizing the above experiments, for offshore oil spill fires, the presence of abundant seawater beneath the fire site offers the potential for efficient firefighting through dispersion, which contrasts with the suffocation firefighting method primarily used on land-based oil fires.

4. Conclusions

This technical note investigates response methods for offshore oil spills involving fires using a small-scale one-dimensional experimental tank model. We examined the application of bubble curtains, confirming their effectiveness even for burning oil. Furthermore, as a potential novel firefighting approach for offshore oil spill fires, we conducted experiments on underwater dispersion firefighting. Through high-pressure spraying of solutions containing surfactant components, we demonstrated the capability of achieving rapid extinguishing.

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