Journal of the Korean Society
for Marine Environmental Engineering
Vol. 6, No. 3. pp. 37~44, August 2003

Penetration Behavior of Spilled Fuel Oil C into Coastal Sandy Beach

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해양에서 유출된 C중유의 토양 침투 거동

by
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Abstract

To know the penetration behavior of spilled oil into sandy beach sediment is very important, because the penetration depth of the stranded oil into the sediments is one of the most significant information to know effect of spilled oil on biological communities and to set up cleaning method. The purpose of this study is to clarify the effects of wave and/or tidal action on penetration of spilled oil into the sediments and to clarify main factor in oil penetration using sandy beach model. Specific conclusions derived from this study are as follows. Spilled fuel oil C penetrated into the sediments only by falling tidal fluctuation and not by wave action on sandy beach environment, and the first tide is most important for the penetration of stranded oil. Over 80% of bulk fraction in penetrated fuel oil C was concentrated to the top 2 cm sediment-layer. Moreover, the penetration of stranded oil into the sandy beach sediments was strongly correlated with the oil viscosity affected by temperature.

요 약

해상에서 유출된 기름의 조간대 토양 침투에 관한 정보는 유출된 기름의 생태계 피해와 생태계 피해를 최소화하기 위한 처리대책의 수립에 있어서 중요한 단서가 된다. 본 연구에서는 사질지형의 조간대 모형을 이용하여 파도와 조석에 의한 유출된 기름의 토양 침투 거동을 파악하고, 침투에 미치는 주된 영향인자를 규명하는 것을 목적으로 하여 연구를 수행하였다. 해수와 유출된 C중유의 연안 해변 토양 침투는 전혀 다른 거동을 보이는 것을 알 수 있었다. 해수는 파도와 조석의 물리적 작용에 의해서 토양 중으로 침투를 하였으나, 유출된 C중유는 파도에 의해서는 침투되지 않고 조석작용에 의해서만 토양 중으로 침투하는 것을 알 수 있었다. 그리고 평방미터당 1 L의 유출유가 표착하였을 경우 약 80%이상의 유분이 토양 표층 2 cm의 부분에 집중되는 침투경향을 나타내었다. 그리고 유출된 기름의 토양침투에는 온도의 변화에 의존하는 기름의 점도가 강한 영향을 미치는 것을 알 수 있었다.

Keywords: Coastal pollution, Sandy beach model, Fuel oil C, Wave and tidal action, Oil viscosity.

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1. INTRODUCTION

It is estimated that 1.7~8.8106 tons of petroleum hydrocarbon are released into marine environment annually(Natural Research Council [1985]). There are many causes on these releases, that is, natural sources, municipal and industrial waste discharge, urban runoff, and accidental releases related to the handling and transportation of crude oil and petroleum products. Tanker accidents induce large scale of oil pollution and one of the largest oil spills was that of the Exxon Valdez, which discharged approximately 36,400 tons of Alaskan North Slope crude oil into Prince William Sound in March 1989. About 50% of the spilled oil stranded on shores and contaminated about 2,000 km of shorelines along Gulf of Alaska(Swannell et al.[1996]; Wolfe et al.[1994]).

When spilled oil penetrates into the shoreline sediments, the oil affects the ecosystem of sediments directly and indirectly through changing shore sediment into anaerobic (Jhonston[1970]), reducing grazing pressure of grazer(Carman et al.[2000]), and decreasing nutrients supply from seawater to benthic organism(Cheong et al.[2000]). In order to minimize biological injury in the ecosystem, it is necessary to remove the oil as quickly as possible. Cleaning techniques of penetrated oil include manual pick-up with absorbent pads, mechanical treatment using equipments such as grader and scraper, chemical treatment by use of dispersant, digging trenches and bioremediation(Cormack[1999]). To approach the cleaning techniques, knowledge on the penetration behavior of spilled oil into the sediments is very important to upgrade the efficiency of treatments attempted. And, penetration depth of stranded oil into the sediments is one of the most significant factors in biodegradation cleansing processes (Owens[1978]).

In previous studies(Vandermeulen et al.[1979] Hayeset al.[1993] Hayes et al.[1999]), oil penetration was investigated lately after from the penetration of spilled oil on intertidal sediments. However, to understand the initial penetration behavior is very important to remove the spilled oil before the oil penetrate into the sediments, and to minimize impact by penetrated oil on intertidal biological communities by earlier treatment of the oil using cleaning techniques. Unfortunately, the penetration behavior of spilled oil into the sediments has not been fully understood.

The purpose of this study is to clarify the effects of wave and/or tidal action on penetration of oil into the sediments and to clarify main factor in oil penetration using sandy beach model.

2. EXPERIMENTAL METHODS

2.1 Sandy beach model

The model is composed of a sandy beach(L 5.0 m × W 0.8 m × H 1.0 m), wave maker (breaking wave height: ~50 mm high), tide control device(tidal period: 1~7 hr), reservoir(4 m^3), temperature control system(3~30 ℃). This facility is automatically controlled by computer system shown in Fig. 1. The body of simulator is made of FRP and has two observation windows with 0.9 m wide and 0.6 m long. The simulator was filled with transparent glass beads(diameter = 1 mm, density = 2.5 g/cm^3) as model sediments to visualize the penetration of spilled oils into sandy beach sediments. The sediment was profiled with a slope approximately 1/10. Synthetic seawater was made to have a salinity of 32±2 psu using tap water and commercial salt for aquarium(MARINE- TEC. Co. Sealife). In this study, breaking wave height(Hb) and wave periods were set at 50 mm and 0.8 s, respectively, because low energy waves which had Hb of 50~100 mm

Fig. 1 Image of model sandy beach (1 sandy beach, 2 wave maker, 3 tide control device, 4: reservoir, 5 temperature control system, 6 computer control system).

and wave periods of $0.8\sim2.0$ s were often observed in enclosed Hiroshima Bay, Japan.

There is no wave reflection in the simulator, because wave absorber was set up in the opposite side and absorbs generated wave. Tide was controlled with semi-diurnal tidal cycle, and vertical fluctuation velocity of seawater by tide was determined as 0.009 cm/s based on the mean tidal range of 2 m in the Hiroshima Bay. The water level was fluctuated with the range of 45 cm, up 15 cm and down 30 cm from the sediment surface of observation window of right side(Fig. 2). Out of tidal range was set as lag time for next rising or falling tide to simulate the tidal fluctuation of field, because the oil penetration is correlated with tidal period.

2.2 Seawater tracer and test oil

Potassium permanganate was used as seawater tracer to compare the infiltration behaviors with and without oil on the sediment surface. Specific gravity of the potassium permanganate was 1.01. The potassium permanganate of 25 ml was applied.

Fuel oil C was used in the study and its physico-chemical properties is shown in Table 1. Different kinds of silicon oil in viscosity as 12, 125, 1,650 and 21,000 mm^2/s were prepared to clarify effects of viscosity on oil penetration. These silicon oils were colored in

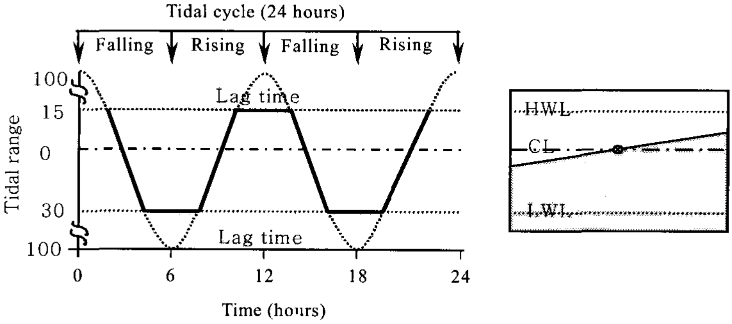

Fig. 2 Tidal fluctuation. Dashed line shows tidal range from the sediment surface of observation window on right side (HWL; high water level, CL; center line, LWL; low water level).

blue(Orient Chemical Industries, LTD., Oil Blue 2N) for visual observation of penetration depth.

Table 1 Physico-chemical properties of fuel oil C used in this study.

Items	values
Viscosity at 15℃ (mm^2/s)	3,750
Density at 15℃ (g/cm^3)	0.95
Pour point (℃)	-10
Sulfur content (% wt.)	2.15
Water content (vol.)	0.1

2.3 Oil penetration by wave and/or tidal actions

To clarify the effects of wave and/or tidal actions on infiltration of oil and seawater into sandy beach sediments, 1 L/m^2 of the fuel oil C was spilled over the water surface and 25 mL of the potassium permanganate solution (0.02 mol/L) was dropped by pipette on the saturated sediment surface (Cheong et al. [2000]). The volume of oil applied was determined by the previous studies on oil spills(Smith et al.[1981]; Delaune et al.[1984]; Little[1987]; Lin et al.[1996]; Oudot et al. [1998]).

Three experimental approaches were conducted; wave only(for 5 minutes), tide only (for 6 hours) and the combination of wave and tide(for 6 hours). In the case of the "wave only", waves were applied for 5 minutes without any tidal movement. In the case of "tide only", the water level was lowered from HWL to LWL(Fig. 2) by tidal fluctuation at tidal velocity of 0.009 cm/s without any wave. Both wave and tidal fluctuation were applied for a tidal cycle in case of "wave and tide combination".

The infiltration of the oil and seawater was measured by visual observation and image analysis taken by video camera(SONY Co., Digital Handy Camera DCR-VX1000).

2.4 Vertical movement of stranded oil for 15 tidal cycles

To estimate penetration of stranded oil into the sediments, the fuel oil C was spread over the water surface at HWL, and evenly stranded on the sediment surface by falling of water level. The vertical movement of stranded oil in the sediments was monitored under "wave and tide combination" for 15 tidal cycles.

At the end of experiment, oil-contaminated sediments was sampled with a cylindrical acryl core split lengthwise and taped together(diameter = 5 cm, length = 30 cm) to determine the vertical distribution of the oil contents. The sediments was sliced with 2 cm interval and mixed completely prior to extraction by dichloromethane. The oil concentration was determined by Thin-layer Chromatography(TLC) in combination with a flame-ionization detector(FID) employing Chromarod Ⅲ(Iatron Laboratories Inc., Tokyo).

2.5 Effects of viscosity on the oil penetration

The viscosity of oil as a function of temperature was determined by U-tube Reverse Flow Viscometer equipped with kinematic viscosity bath TV-5S(Thomas Kggaku Co., LTD).

To clarify the relationship between viscosity and penetration, the dyed silicon oils, the crude oil and the fuel oil C were applied to glass beads column with 5.5 cm in diameter and 50 cm in length at 15℃. The oils were applied by using syringe on the water surface at HWL which risen 5 cm from the surface of the filled glass beads, and then the water level was also fallen with 0.009 cm/s. After a falling tide, the penetration depths of the oils were recorded.

3. RESULTS AND DISCUSSION

3.1 Oil penetration by wave and/or tidal actions

Fig. 3 shows the penetration depths of the fuel oil C and seawater in the sediments by wave and/or tidal actions. Seawater infiltrated into the sediments to 21 cm from the sediment surface by just wave action for 5 min, whereas the fuel oil C did not penetrate into the sediments.

Seawater also infiltrated into the sediments by the tidal fluctuation. The fuel oil C, however, penetrated into the sediments with much slower velocity than seawater, and the depths were approximately 2.3 cm. A falling tide made the oil penetration into the sediment but a rising tide did not work.

Under the combination of wave and tidal actions, the oil showed almost the same penetration behavior as the tidal fluctuation without wave. That means that the tidal fluctuation acts main role for penetration of oil into the sandy beach sediments.

3.2 Vertical movement of stranded oil for 15 tidal cycles

Fig. 4 shows the vertical penetration of the stranded fuel oil C for 15 tidal cycles. The experiments were carried out in February 17~24 and August 9~16. Oil layer after tidal cycles could be separated into black and brown layers. The penetration depth of the fuel oil C by the first tidal cycle was about 2 cm both in February and August. However, the first tide was the most important for the penetration of the fuel oil C. The fuel oil C penetrated deeper in high temperature period (August 9~16) than low temperature-period (February 17~24). That means that the penetration depth is probably correlated with viscosity affected by temperature.

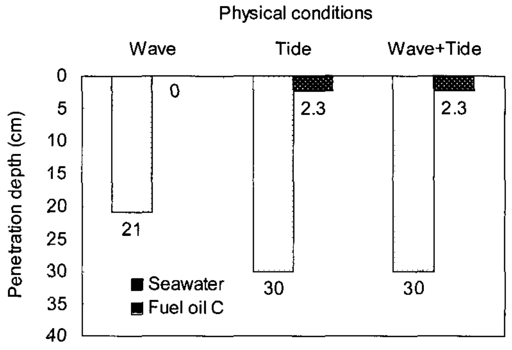

Fig. 3 Penetration of seawater and the fuel oil C by wave and/or tidal actions.

Fig. 5 shows temperature fluctuation over the experimental periods. The mean

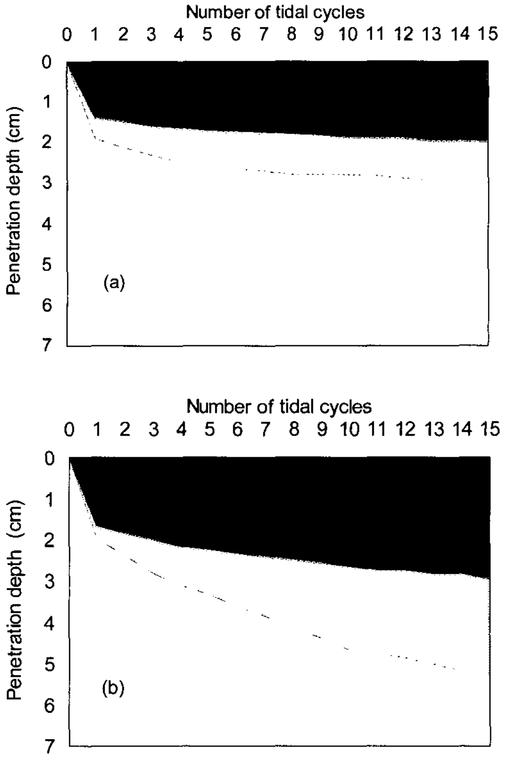

Fig. 4 Penetration behavior of the stranded fuel oil C into the sediments in February 17~24 (a) and August 9~16 (b).

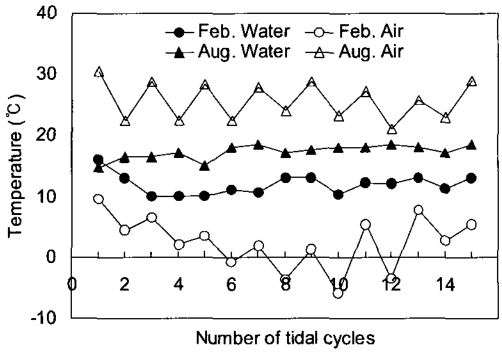

Fig. 5 Temperature fluctuation over the experimental period in February 17~24 (a) and August 9~16 (b).

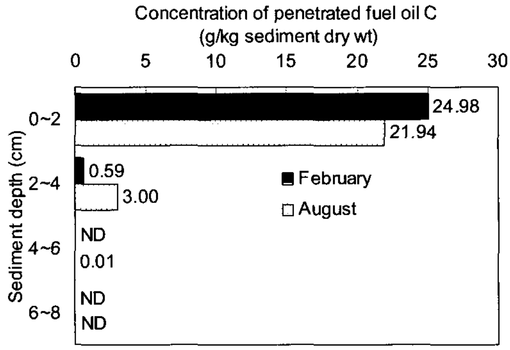

Fig. 6 Concentration of penetrated the fuel oil C after 15 tidal cycles in February and August(ND; not detected).

the experimental periods. The mean temperatures of air and water in February 17~24 were 2℃ and 12℃, and those of August 9~16 were 17℃ and 26℃, respectively. Both air and water temperatures in August were significantly higher than those of February.

Except for the air and water temperatures, there were not any kinds of other influence factors in oil penetration. So it could be guessed that the penetration of stranded oil into the sediments is strongly correlated with viscosity affected by temperature.

Fig. 6 shows the vertical distribution of hydrocarbon concentration in the sediments after 15th tidal cycle from stranding of the fuel oil C. The hydrocarbon was detected to 4 cm below from the sediment surface in February, whereas in August it was detected to 6 cm below.

However, the results indicate that over 80% of the penetration oil was confined to the top 2 cm sediment-layer in the both experimental periods. This result was coincided with the penetration depth of black and gray layers after 15th tidal cycles(see Fig. 4).

3.3 Effects of oil viscosity on penetration

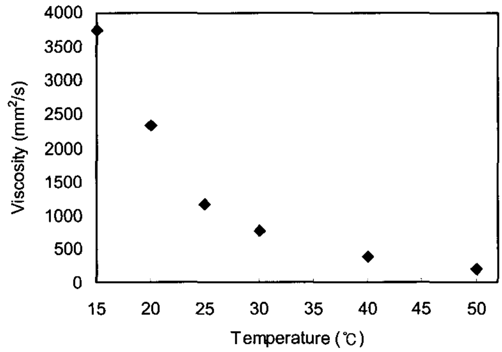

Fig. 7 Relationship between viscosity and temperature in the fuel oil C.

Since it is suggested that viscosity of oil affected by temperature is important for penetration of oil into the sediments, the relationship between viscosity and temperature was investigated and shown in Fig. 7. The viscosity of the fuel oil C was significantly declined from 3,750 mm^2/s to 202 mm^2/s according to the change of temperature at 15℃ and 50℃. The viscosity of the fuel oil C was significantly affected by temperature.

To clarify effects of viscosity on oil penetration, column experiment was conducted using silicon oils with different kinds of

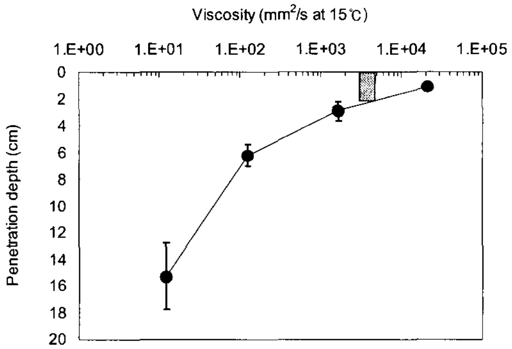

Fig. 8 Relationship between viscosity and penetration depth in the silicon oil and fuel oil C. The symbols show the penetration depth of the silicon oil(black circle and standard deviation) and the fuel oil C(black panel) with standard deviation(error bar).

viscosity. Fig. 8 shows the relationship between viscosity and penetration depth of silicon oil. The penetration depth of the fuel oil C was also fitted in Fig. 8. At the lowest viscosity of silicon oil (12 mm^2/s at 15℃), the penetration depth was 15.3 cm, whereas the depth was 1.1 cm at the highest one (21,000 mm^2/s at 15℃). The penetration depth of the fuel oil C was exactly fitted in the range of standard deviation of silicon oil at the same viscosity.

Reed et al.[1989] and Bear et al.[1991] reported that the penetration depth of spilled oil into the sandy beach sediments depended on the viscosity and specific gravity of the oil.

From these results, therefore, it is cleared that the penetration of fuel oil C into the sandy beach sediments is significantly affected by viscosity. However, it may be necessary to further study the effect of specific gravity on the penetration of spilled oil.

4. CONCLUSIONS

The purpose of this study is to clarify the effects of wave and/or tidal action on penetration of spilled oil into the sediments and to clarify mainfactor in oil penetration using sandy beach model.

Specific conclusions derived from this study are as follows. Spilled fuel oil C penetrated into the sediments only by falling tidal fluctuation and not by wave action on sandy beach environment, and the first tide is most important for the penetration of stranded oil. Over 80% of bulk fraction in penetrated fuel oil C was concentrated to the top 2 cm sediment-layer. Moreover, the penetration of stranded oil into the sandy beach sediments was strongly correlated with the oil viscosity affected by temperature.

Acknowledgement

This work was supported by the Japan Society for the Promotion of Science(JSPS). This project is a "Research for the Future Program for Evaluation and Restoration of the Effects of Oil Pollution on Coastal Ecosystem".

I wish to express my gratitude to KOA OIL Co. LTD for providing the fuel oil C.

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