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조간대에 표착한 기름이 해수의 침투에 미치는 영향

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Effects of Stranded Oil on Seawater Infiltration in a Tidal Flat Environment

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요 약 문

해수 중에는 연안 조간대의 저서생물의 생존에 필수적인 용존산소와 영양염이 풍부하게 내포되어 있기 때문에 해수의 토양침투는 저서생물의 생존과 밀접한 관련을 맺고 있다. 그러나 유출된 기름이 조간대에 표착하게 되면 해수의 침투가 차단되어 생물에게 많은 피해를 유발시킬 것이다. 또한 유출된 기름의 토양 침투에 관한 정보는 생태계 영향을 최소화 하고 처리를 위한 대책수립의 단서로서 매우 중요하다. 본 연구에서는 유출된 기름의 침투 거동을 파악하고 침투된 기름의 해수 침투 차단을 검토하는 것을 목적으로 하여 연구를 수행하였다. 점도가 낮은 원유가 C중유보다 침투 깊이가 약 2배 깊었으며, 유출된 기름의 침투 깊이는 조간대에 표착된 기름의 양에 따라 영향을 받는 것을 알 수 있었다. 그리고 표착된 기름은 첫번째 조석에서 가장 급격한 침투거동을 보였으나, 두번째 조석변동부터는 급격한 침투 변화는 나타나지 않았다. 그리고 침투한 유분의 수직적 분포로부터 기름은 토양 표층 2 cm에 집중적으로 분포하는 것을 알 수 있었다. 한편 해수의 침투량은 표착유의 양에 비례적으로 감소하였으며, C중유가 원유보다 약 1.7배 정도의 해수의 토양 침투량을 감소시키는 것을 알 수 있었다. 따라서, 침투한 기름의 처리는 가능한 빠른 시간 내에 수행되어야 해수의 침투를 회복시켜 연안 조간대 생태계의 피해를 최소화 시킬 수 있다고 판단된다.

주제어 : 기름유출, 조간대 생태계, 기름의 토양침투, 해수의 침투차단

ABSTRACT

Understanding the seawater infiltration into tidal flat sediments is very important, because it is significantly correlated with the supply of dissolved oxygen, nutrients and organic matter to benthic organisms for survival. However, oil blocks interstitial spaces of sediments, reduces seawater infiltration and results in the decrease in oxygen, nutrients and other food supply to benthic communities. The penetration depth of the stranded oil into the sediments is one of the most significant information to know the effect of spilled oil on biological communities and to set up a cleaning method. So, we initiated this study to quantify the penetration behavior of spilled oil and to evaluate the influence of the penetrated oil on seawater infiltration in tidal flat environment and its ecological implications. The penetration depth of the crude oil into the tidal flat sediments was two times deeper than that of the fuel oil C, and the depth was significantly affected by stranded oil volume. However, the penetration depth of stranded oil was abruptly dropped at first falling tide, but not significantly fluctuated after that. Moreover, hydrocarbon concentration showed the highest within the upper 2 cm. Seawater infiltration was decreased in proportion to the stranded oil volume. The seawater infiltration was more affected by the penetrated fuel oil C about 1.7 times than the crude oil, because the interstitial spaces of the top of sediments were more clogged by the fuel oil C. Therefore, quick cleaning actions for penetrated oil will be necessary for recovery of seawater infiltration, because the seawater contains oxygen and nutrients necessary for the survival of benthic organisms in tidal flat.

Key words : Spilled oil, Tidal flat ecosystem, Penetration of spilled oil, Blockage of seawater infiltration

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1. Introduction

Tidal flat plays an important role in environmental preservation, visual aesthetics and bio-productivity. Tidal flat is a habitat for various species of benthic organisms. These benthic organisms obtain dissolved and particulate matters necessary for their survival from the infiltrated seawater supplied by wave and tidal actions[1,2].

In these days, however, tidal zone is often threatened by various anthropogenic pollutants. One of significant anthropogenic pollutants is oil. Oil enters marine environment in many ways like natural seepage, refinery emission, ship cleaning operations and accidental spills. In particular, tanker accidents which may result in the release of relatively large amount of oil near sensitive coastal environments are of great concern. For example, the *Amoco Cadiz* discharged 0.2 megatons of Kuwait crude oil into the waters along the Brittany coast in March 1978; the *Exxon Valdez* released 0.04 megatons of Alaskan North Slope crude oil into Prince William Sound in March 1989. About 30% of the *Amoco Cadiz* spilled oil contaminating 320 km of coastline and about 50% of the *Exxon Valdez* oil spill covered 2,000 km of shorelines along the Gulf of Alaska[3-5].

In the previous studies, Hayes *et al.*[6] investigated the behaviour of shoreline oil one year after the Gulf War oil spill.

Hayes *et al.*[7] investigated the long-term persistence of *Exxon Valdez* oil in gravel beaches.

However, it should be understood penetration behaviour of spilled oil at the very beginning to minimize the impact of penetrated oil on biological communities and to know the fate of penetrated oil by physical dispersion.

Huge oil spills seriously damage ocean and shoreline environment[3]. When spilled oil stranded and penetrated into coastal sediments, oil deteriorates benthic ecosystem directly and indirectly through making the sediment anaerobic[8] or reducing of grazing pressure of grazer[9]. In addition, penetrated oil may reduce the supply of oxygen and nutrients necessary for benthic organisms by the reduction of seawater infiltration.

Up to the present, Cheong *et al.*[1] have studied the earlier penetration behaviour of spilled oil and its effects on the infiltration of seawater in sandy beach environment, however, it is not cleared in tidal flat environment.

The purpose of this study is to quantify the penetration behavior of spilled oil and to evaluate the influence of the penetrated oil on seawater infiltration in tidal flat environment.

2. Experimental set-up and methods

2.1. Simulator

A simulator composed of a tank, tide control device, temperature control system and computer control system was used for this oiling study (Fig. 1). A 1 m long, 0.5 m wide and 1 m high simulator has a window to observe oil penetration. Sediments was collected from coastal area of Fukuyama in Japan and the grain size distribution is shown in Fig. 2. And, the physicochemical properties of the sediments are shown in Table 1. Acrylic columns (inner diameter = 5.5 cm, length = 50 cm) packed with the sediment from tidal flat were installed vertically in the tank. The packed sediment was contact with artificial seawater flowing upward through 75 μm mesh fixed in bottom of the column. For stabilization of the packed sediment the seawater level was fluctuated for 3 days (12 tidal excursions)

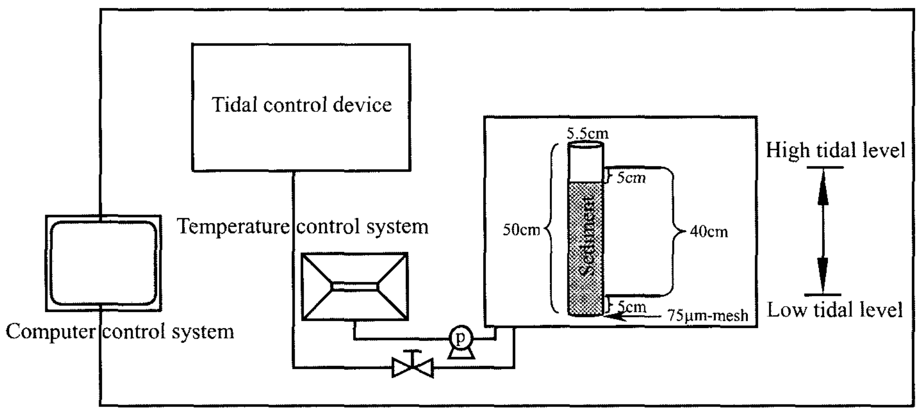

Fig. 1. Schematic diagram of experimental set-up for oiling studies.

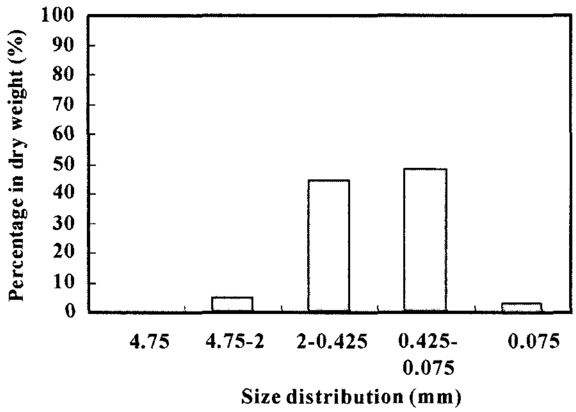

Fig. 2. Grain size-distribution of sediments.

Table 1. Physicochemical properties of sediments used in this study

Items	Values
Silt content (%)	2.8
Organic content (%)	0.93
Porosity (%)	43
Mean grain-size (mm)	0.65

before oil application. Synthetic seawater was made to have a salinity of 32±2 psu using tap water and commercial salt for aquarium (MARINE-TEC. Co. Sealife). Tidal fluctuation was made by gravimetrical flow resulting from rising and falling of the tidal control tank. Tide was controlled with semi-diurnal (12-h) tidal cycle, and vertical fluctuation velocity of seawater by tide was determined as 0.009 cm/s in consideration of the mean tidal range of 2 m in the Hiroshima Bay. Only tidal fluctuation was permitted in these oiling studies. The tidal level was fluctuated with the range of 40 cm shown in Figs. 1 and 3. Outside of the tidal range shown in Fig 3 was set as lag time for next rising or

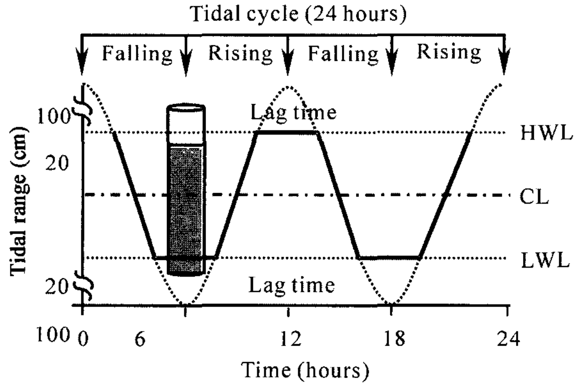

Fig. 3. Tidal fluctuation. The dash line shows tidal range from the sediment surface of observation window of right side. HWL; high water level, CL; center line, LWL; low water level.

falling tide to simulate the tidal fluctuation in field.

2.2. Test oil

Upper Zakum crude oil and fuel oil C were used in the present study. The viscosity, density and pour point of the crude oil were 28 mm^2/s at 15°C, 0.87 g/cm^3 at 15°C and −15°C, respectively. On the other hand, the fuel oil C had 3,750 mm^2/s at 15°C of viscosity, 0.95 g/cm^3 at 15°C of density and −10°C of pour point. Oil was applied on the surface of water over sediment columns at high tide, and a typical test duration consisted of a further 16 tidal excursions, twice daily. Added oil volume was 1, 2, 4 and 8 L/m^2 based on the previous studies on oil spills[10-14].

2.3. Oil penetration

The penetration depths of applied oils were recorded for 16 tidal cycles. At the end of experiment, to determine the vertical distribution of the oil content, oil-contaminated sediments was sliced at 2 cm interval and mixed completely prior to extraction by dichloromethane. Oil concentration was determined using Thin-layer Chromatography (TLC) in combination with a flame-ionization detector (FID) employing Chromarod III (Iatron Laboratories Inc., Tokyo).

2.4. Effects of penetrated oil on seawater infiltration

Penetrated oil will interrupt the flow of water through sediment in tidal zone. So, to simulate the effects of penetrated oil on seawater infiltration, the oil penetrated sediment columns were taken out of the tank at high tide and installed on the funnel attached mesh cylinder. Dropped water volume through the interstitial spaces of the oil penetrated sediment for 3 min was recorded and expressed as volumetric flow rate.

3. Results and Discussion

3.1. Oil penetration

Fig. 4 shows changes of the penetration depth of the crude and fuel oil C according to applied oil volume and elapsed time. As shown in Fig. 4(a), penetration depths of the two oils increase in proportion to the applied oil volume. The depth of the crude oil, however, was two times deeper than that of the fuel oil C. The difference in penetration depth between the crude oil and fuel oil C may be caused by difference in viscosity (crude oil : 28 mm^2/s, fuel oil C : 3,750 mm^2/s at 15°C).

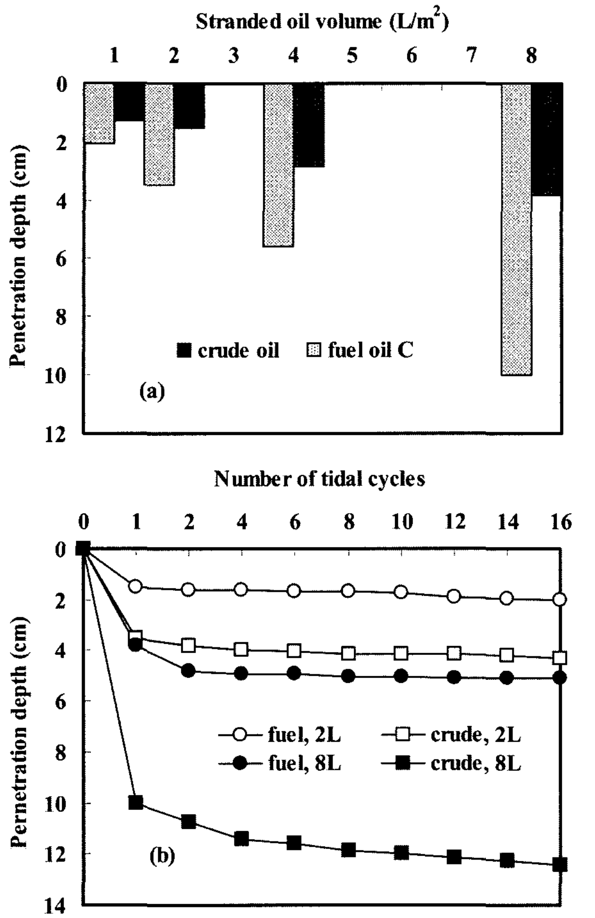

Fig. 4. Comparison of penetration depths of applied oils into tidal flat sediments by changes of applied oil volume (a) and elapsed time (b).

Fig. 4(b) shows the changes in the penetration depth of the two applied oils by tidal action. The depths of the oils abruptly declined after the first tidal cycle and were slightly decreased from the first tidal cycle to 16th tidal cycle. However, the depth was not significantly changed after 1st tidal cycle.

It must be pointed out that the stranded oil volume and viscosity significantly affect the penetration depth and the first tide is the most important for the penetration of stranded oil.

Fig. 5 shows the vertical distribution of hydrocarbon concentration determined by TLC-FID after 16th tidal cycle from applying oils. Highest concentrations of penetrated oils were founded at 0-2 cm of sediment layer. The concentration of the fuel oil C at that layer in each volume was two times higher than that of the crude oil.

From these results, it is clear that the fuel oil C with higher viscosity was concentrated at top sediment surface.

3.2. Effects of penetrated oil on seawater infiltration

Fig. 6 shows the change in the seawater infiltration according to applied oil volume and elapsed time. The volumetric flow rate of seawater in unoiled condition was 0.35 cm^3/s, however the flow rates in oiled conditions gradually decreased in proportion to the applied oil volume. When applied oil volume was increased from 2 L/m^2 to 8 L/m^2, the flow rate of seavater was decreased from 11% to 49% by the crude oil, and decreased from

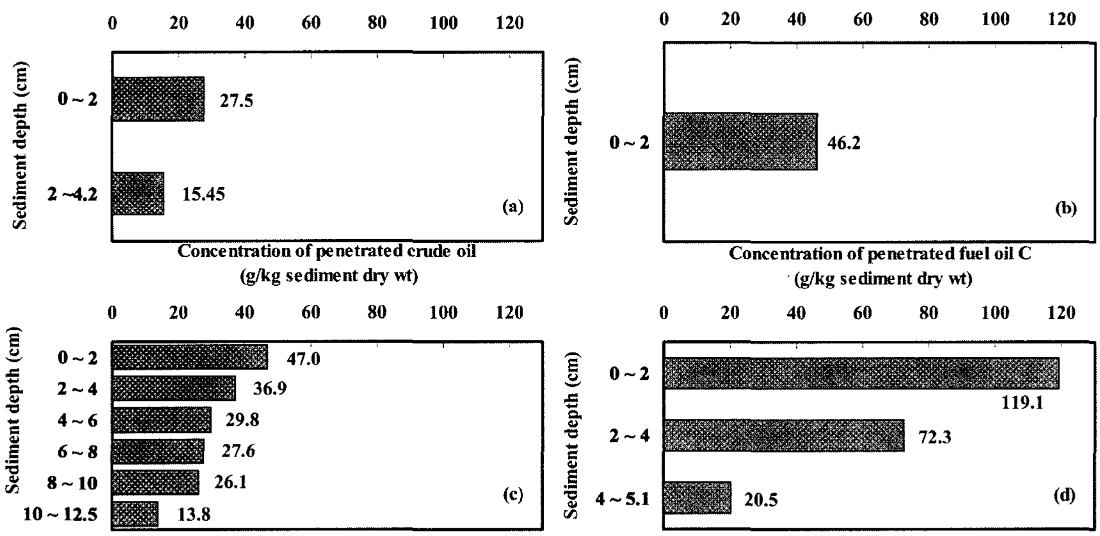

Fig. 5. Comparison of vertical distribution of penetrated crude oil (a, c) and fuel oil C (b, d) after 16th tidal cycle. Applied oil volumes were 2 L/m^2 (a, b) and 8 L/m^2 (c, d).

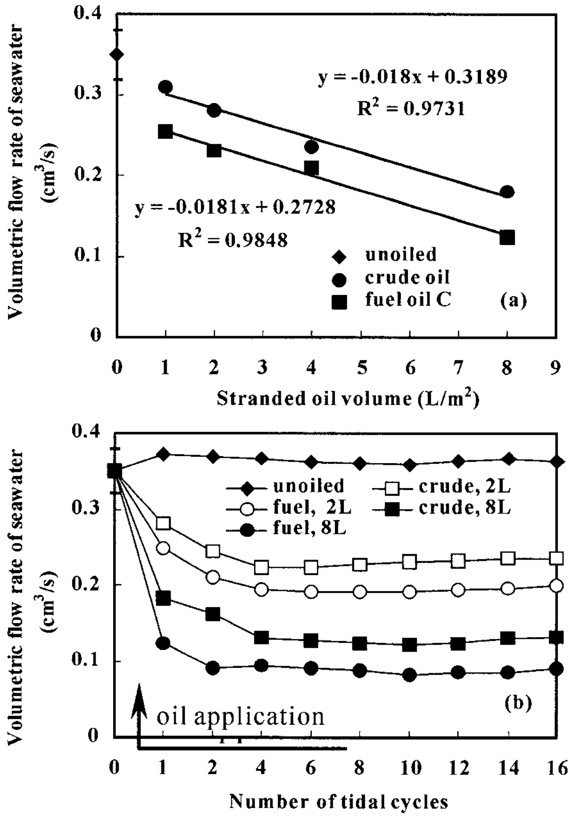

Fig. 6. Comparison of seawater infiltration through the oil penetrated sediments by changes of applied oil penetrated sediments by changes of applied oil volume (a) and time lapse (b).

26% to 63% by the fuel oil C. The penetrated fuel oil C obstructed seawater infiltration about 1.7 times more than the crude oil.

In Fig. 6(b), the volumetric flow rates kept decreasing to 4th tidal cycle from the oil application, but were not significantly changed from 4th tidal cycle to 16th tidal cycle.

It is clear that the seawater infiltration is affected by stranded oil volume and the penetrated fuel oil C more obstructs seawater infiltration into the sediments than the crude oil.

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In order to calculate the relationship between the clogging of interstitial spaces of sediments by penetrated oil and seawater infiltration, oil concentration at 0-2 cm sediment layer (see in Fig. 5) and seawater infiltration after 16th tidal cycle (see in Fig. 6(b)) were used, because we guess that the oil concentration at the top of sediments is the most

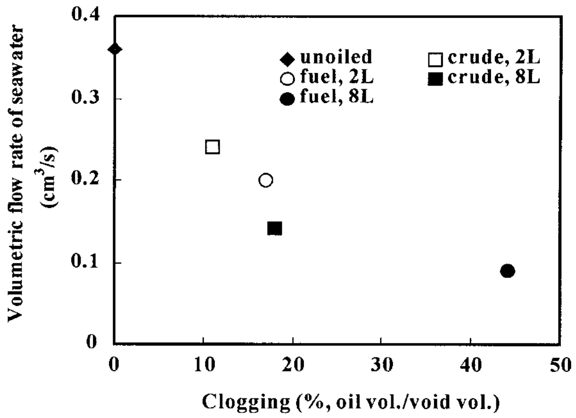

Fig. 7. Relationship between clogging of interstitial spaces and seawater infiltration.

important for the seawater infiltration.

As shown in Fig. 7, the interstitial spaces was clogged by the crude oil about 11% and 18% at 2 L/m^2 and 8 L/m^2 in applied volume, and was clogged by fuel oil about 17% and 44% at each volume, respectively. Therefore, the seawater infiltration is more blocked by the penetrated fuel oil C than crude oil by clogging of interstitial spaces.

This result indicates that the fuel oil C will be more dangerous than the crude oil because of reduction in oxygen, nutrients and other food supply to benthic communities in tidal zone.

4. Conclusions

The purpose of this study is to quantify the penetration behavior of spilled oil and to evaluate the influence of the penetrated oil on seawater infiltration in tidal flat environment and its ecological implications.

Specific conclusions derived from this study are as follows. The penetration depth of the crude oil into the tidal flat sediments was two times deeper than that of the fuel oil C, and the depth was significantly affected by stranded oil volume. However, the penetration depth of stranded oil were abruptly dropped at first falling tide, but were not significantly fluctuated after that. Moreover, hydrocarbon concentration was higher within the upper 2 cm.

Seawater infiltration decreased in proportion to the stranded oil volume. The seawater infiltration was more affected by the penetrated fuel oil C about 1.7 times than the crude oil. because the interstitial spaces of the top of sediments were more clogged by the fuel oil C.

Therefore, quick cleaning actions for penetrated oil will be necessary for recovery of seawater infiltration, because the seawater contains oxygen and nutrients necessary for the survival of benthic organisms in tidal flat.

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