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Prediction of Oil-ice Sandwich Formation

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ABSTRACT

A study was undertaken regarding the formation of the so-called oil-ice sandwich, a phenomenon in which oil placed underneath an ice cover is entrapped in ice under freezing conditions. The study was a part of a larger research project on the behaviour and recovery method of oil in ice-covered waters. Laboratory tests were performed to study the ice growth under the oil layer. A numerical calculation that takes into account convective heat transfer through the oil layer agreed well with the experimental results. This was an attempt to predict the formation of an oil-ice sandwich in field conditions.

INTRODUCTION

The commercial production of oil has started in one of the oilfields off Sakhalin, the Russian island just north of Japan. Production from another oilfield will come in a few years. Production is planned on a year-round basis in the near future, including winter. In this season, the Sea of Okhotsk, where Sakhalin is located, is covered by ice; the existence of ice means harsh conditions for the production and transportation of oil as well as higher risks of accidental oil spills. Because the fate and behaviour of oil spills in ice-covered waters will completely differ from those in open waters, recovery techniques of new mechanisms are required. However, knowledge about oil spilling in ice is very limited, especially in Japan.

In view of the situation, a research project was initiated in 2000 to study the behavior and recovery methods of spilled oil in ice-covered waters. Five research organizations in Japan—Hokkaido University, Iwate University, the National Maritime Research Institute, the Civil Engineering Research Institute of Hokkaido and North Japan Port Consultants Co., Ltd.—are participating in the project. One of the objectives of the project is to study the processes of oil-ice interaction in which oil is entrapped in ice. While recovery of oil entrapped in ice is practically impossible, understanding the oil-ice interaction is important from a viewpoint of pollution prevention. The entrapped oil can be transported by the ice motion and may cause pollution in areas away from the original spill site. Such entrapment of oil in ice can take place when air temperature is low and ice is growing. Under such conditions, oil spilled underneath the ice may be surrounded by growing ice and eventually be sealed up in the ice. This phenomenon may be termed the oil-ice sandwich. This paper presents the results of a study on the formation of an oil-ice sandwich.

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KEY WORDS: Oil spill in ice, oil-ice sandwich, Sakhalin, heat transfer in oil.

LABORATORY TESTS

Laboratory tests were undertaken to study oil-ice sandwich formation in a cold chamber at Japan's National Maritime Research Institute. Two types of tests were performed. In the first series, a rectangular tank 1.0 m by 1.0 m in surface area and 0.6 m in depth, was placed in the chamber. One of the tank sidewalls was made of acrylic resin to allow observation. The sidewalls and tank bottom were insulated with Styrofoam boards. The tank was filled with artificial seawater of 3.3 psu and frozen under $-20°C$ air temperature. After an ice sheet was grown in the tank, oil was injected underneath the ice. A machine lubrication oil and bunker-A oil were used for the test. Ice thickness ranged from 20 to 70 mm. The oil formed a slick under the ice. After the oil was injected, freezing was continued to allow further ice growth. When the oil was completely entrapped in the ice, the ice was cut out and stored in a freezer at $-20°C$. Detailed observations and measurements were made later on the cross-section of the oil-ice sandwich.

The second test series used small containers 0.1 m by 0.1 m in surface area and 0.3 m in depth. The sidewalls and container bottoms were also insulated. Containers were filled with artificial sea water of 3.3 psu and topped with oil. Oil thickness varied from 10 to 80 mm, and the oil and water temperature was $-1.8°C$. Containers were placed in the cold chamber to let ice grow under the oil. After a given freezing period, the ice thickness under the oil was measured.

PROCESS OF OIL-ICE SANDWICH FORMATION

Fig. 1 is an example of a cross-section of an oil-ice sandwich from the first series of laboratory tests. Oil was entrapped in the narrow opening near the bottom of the ice. The oil was injected under the ice away from the tank sidewall so as to avoid heat transfer through the wall. It is seen that the ice grown under the oil was thinner than that grown outside the oil layer after the oil injection.

There are 2 possible ways to explain the process of oil-ice sandwich formation (Fig. 2).

1. Ice first grows around the perimeter of the oil, and then along the bottom of the oil slick, eventually sealing the slick.