SPREADING OF OIL SPILLED UNDER FLOATING BROKEN ICE

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ABSTRACT: A numerical model is developed to simulate the spreading of oil under, through, and over a broken ice cover floating on calm water. The oil spreading under the broken ice cover is modeled by modifying the spreading equations for oil under solid ice. Oil seepage through the broken ice is modeled as simple porous media flow. The oil spreading at the water surface near the top ice surface is modeled by considering the interfacial tension and viscous forces. The transport processes are interconnected through mass conservation during numerical computations. The results are compared with data from new experiments conducted in this study as well as experimental data from a previous study. Both axisymmetrical and unidirectional spreading are considered. The simplified model presented here agrees reasonably well with the observed data. The study provides new insight into how to model the problem of spreading when oil is released under a broken ice cover.

INTRODUCTION

Oil spills in icy waters are a potential environmental problem in northern latitudes where oil-related activities take place. When oil is spilled in ice, it is more difficult to detect and clean up than in open water conditions. The damages to the ecosystem last longer in the colder weather than in a temperate climate (Malins 1977; Hoult et al. 1975).

A major task of contingency planning and cleanup is the detection and prediction of oil area of spread under various ice conditions. Oil spreading under solid ice has been studied by Hoult et al. (1975), Chen et al. (1976), Yapa and Chowdhury (1990), and Weerasuriya and Yapa (1993). The work by Weerasuriya and Yapa (1993) was on unidirectional spreading under solid ice, whereas the other three studies were on axisymmetrical oil spreading under solid ice. Goodman et al. (1987) developed a technique to measure the under-ice roughness to determine oil storage volumes. By knowing the oil storage volume, they could predict the areal spread of oil under the ice cover. There have been some studies on the spreading of oil in the presence of broken ice covers (e.g., Buist and Bjerkelund 1986; Venkatesh et al. 1990; Sayed and Ng 1993; Yapa and Belaskas 1993). Buist and Bjerkelund presented results from three field experiments. Venkatesh et al. (1990) modeled the movement and spreading of oil in ice of high to medium concentrations. Sayed and Ng (1993) experimentally studied oil spreading when spilled from the top of ice covers floating on water in the presence of a current. Yapa and Belaskas conducted a number of laboratory experiments for axisymmetrical spreading of oil when spilled under broken ice covers of high concentrations floating on calm waters. None of these studies has modeled numerically the complete process of oil spreading under ice, its transportation through broken ice, and its eventual spreading at the top of ice. The report by Dickins (1992) summarizes most of the oil-ice–related work.

In this paper a simplified numerical model is developed to simulate the behavior of oil when spilled under a broken ice cover floating on calm water. Both unidirectional and axisymmetrical cases are modeled. The numerical simulations are compared with laboratory data from new experiments conducted during this study as well as previously conducted experiments.

DESCRIPTION OF PROCESS

Fig. 1 schematically shows the general behavior that oil undergoes as an oil spill develops under a broken ice cover of moderate permeability. This schematic, although qualitative, was prepared based on measured experimental data (Yapa and Belaskas 1993). Oil spreads under the ice cover, and some of this oil seeps to and through the broken ice cover when conditions permit. As the oil slick advances under ice, some portion of the oil that seeped through broken ice reaches and spreads at the water surface near the top of the ice cover. As depicted by Fig. 1, the slick radius on the top side can eventually exceed that on the bottom. However, not all ice covers allow complete penetration of oil (Yapa and Belaskas 1993). Fig. 2 shows a photograph of an oil slick taken during the laboratory experiments. The photograph was taken from above the ice cover when oil was spilled below a broken ice cover. At the time the picture was taken a major portion of the oil had seeped through the cover to the top. This kind of slick was typical for most axisymmetrical cases discussed in this paper.

For numerical model formulation, our experimental obser-

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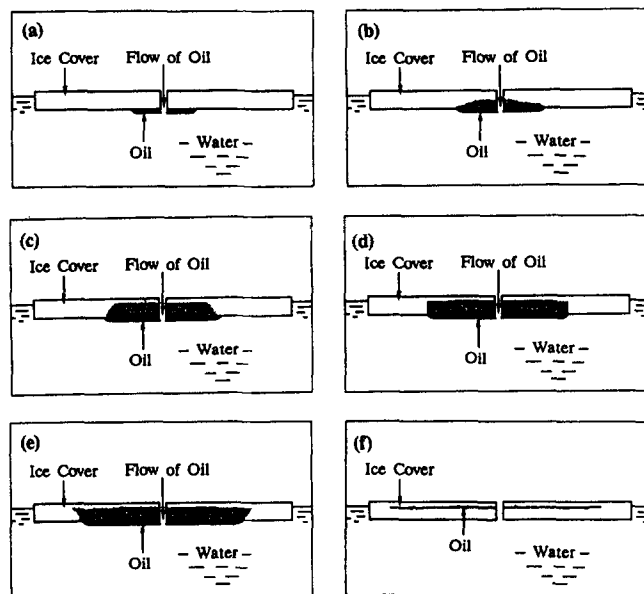
FIG. 1. Schematic Presentation of Oil Spreading in Type I Ice Cover: (a) Just after Oil Release; (b) after Seepage Has Started; (c) after Some Oil Has Surfaced; (d) Same Slick Size; (e) after Oil Supply Has Stopped; (f) Final Configuration of Oil Slick