Abstract of 2020 Master's Thesis

(Department of Ocean Technology, Policy, and Environment,
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氷海流出油の風化過程モデルの開発とその応用に関する研究

Study on modelling of weathering process for oil spill in ice covered sea and its application

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1. Introduction

1.1 Background

In recent years, rich natural resources, seasonal decline of summer sea ice and increasing global demand in energy have pushed industrial activities up in the Arctic Ocean area. The Northern Sea Route (hereinafter called 'NSR') lying in the Arctic Ocean is considered as one of the most commercial international shipping routes through the ocean and has potential positive economic effects in terms of distance and time. And there has been a keen rise of the transit cargo shipping along the NSR in the past decade. Meanwhile, increasing shipping activities have magnified the potential for an oil spill in the area. An oil spill accident would cause a devastating blow to not only fragile marine ecology but also local tourism and fisheries.

Numerical simulation by oil spill model is regarded as an efficient tool for risk assessment and response technology of potential oil spill accident. However, current oil spill model development cannot meet the need of predicting spilled oil behavior in the ice covered sea since the presence of sea ice, especially for the Arctic Ocean where sea ice condition is highly complex.

Spilled oil behavior is depending on two main processes, transport process and weathering process. A reliable oil spill model is supposed to describe both processes. Transport process models developed in the past have obtained good agreement with actual experiment results in reliability test. But the absence of weathering process in the model raises a potential worry to accuracy of prediction since oil physical properties and volume are influenced by weathering. For weathering process model, most of current models are developed on the open water scenario and ignore the influence of ice on oil. But many experiments have observed the influence with different ice conditions. So developing an ice-specific weathering process model for oil spill in ice covered sea is necessary. The model may help improve prediction accuracy and provide with information about changed physical parameters of oil.

1.2 Purpose

(1) Develop an ice-specific weathering process model for oil spill in ice covered sea. Couple the weathering process model with transport process model and check prediction performance. (2) Show practical application of oil spill model in oil spill accident response technology of the Arctic Ocean region.

2. Model in this study

Fig. 1 shows the aimed structure of oil spill model in this study. The ice-POM model (ice-Princeton Ocean Model) provides with necessary high-resolution ocean environment data input and the model developed by Terashima (2003) and Rheem and Yamaguchi (2004) is applied for transport process calculation. The transport process model segments sea ice and oil slick in Eulerian mesh and predicts oil motion by solving momentum equation in every grid. The involved forces include pressure force, friction force, added mass force and surface tension [1].

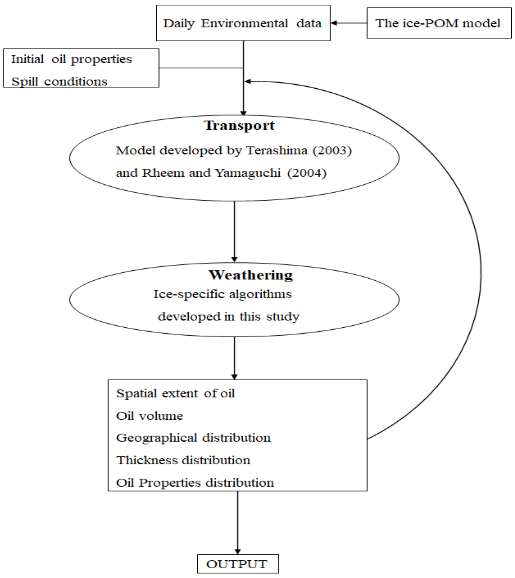

Fig. 1 Overall Structure of oil spill model in this study

2.1 Weathering modelling

In weathering model of this study, only evaporation, emulsification and accompanying viscosity increase are considered because they are most important weathering processes in a short term after an oil spill happens in water with ice. Data from a series of meso-scale oil weathering experiments by Brandvik et al. (2010) was used for modelling in this study. The experiments were performed with five different crude oil types spanning a large variation with respect to oil properties and weathering behavior, and with different ice concentration from 0% to 90%.

Evaporation

In our model, we assume that oil under bottom of ice has little contribution to total evaporation and main evaporation is from oil at gaps among ice floes. We introduced local oil thickness, which is based on four stages of oil spill in water with ice defined in the transport model (shown in Fig. 2), to replace average oil thickness in evaporative loss calculation. Additionally, we developed a calculation method to estimate exposure parameters of weathering oil based on its current density, which is also significant for a more accurate evaporative loss estimation.

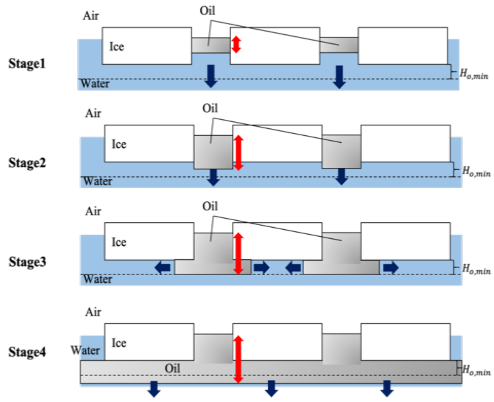

Fig. 2 Four stages of oil spill in water with ice. Red arrow means local oil thickness for evaporative loss calculation.

Emulsification

Water content in oil represents the degree of oil emulsification in this model. We modified old equation for oil in open water and described influence of ice on emulsification by introducing a new coefficient C_Y instead of the constant in the equation. C_Y is calculated by a function of ice concentration. The function was obtained by a polynomial regression of the meso-scale experiments data. Specific regression result is shown in Fig. 3. Because this regression used data of all five types oil, the algorithm is considered as general for a wide variety of crude oil types.

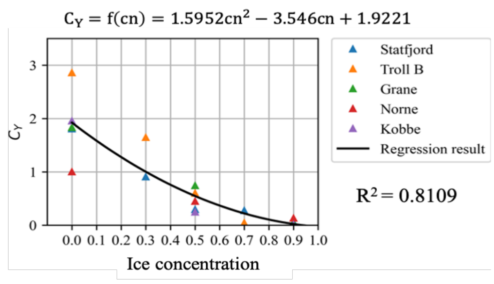

Fig. 3 Polynomial regression of C_Y.

Viscosity

Evaporation and emulsification both cause viscosity increase. In our model, current oil viscosity is calculated by adding up respective viscosity increase caused by the two processes. And we assume the presence of ice mainly influences the viscosity increase by emulsification and introduced a new coefficient C_μ that describes specific influence of ice concentration to viscosity increase by emulsification in our model. Algorithm calculating C_μ is only developed for special oil types at current stage. In this study, we only gave calculation of C_μ for the Statfjord and Troll B crude oil, because the two have experiment data covering the widest range of ice concentration.

2.2 Model validation

Oil spill experiment in no-ice sea

Two oil spill experiments were used for validating the reliability of developed weathering model. First experiment involved an oil release of 100 tons of Statfjord crude oil in open water by Audunson (1984). Environment condition and crude oil property for simulation referred to study by Sebastiao and Soares (1995) [2]. Besides comparison with experiment data, we also compared prediction by our model with result by Sebastiao et al. (1995) [2]. Fig. 4 shows the comparisons of evaporative loss, water content, viscosity and density. The result indicates our model had a better performance, especially in evaporative loss.

Oil spill experiment in the Barents Sea of high ice concentration

The second experiment for validation is the one performed by Brandvik et al. in May 2009. The experiment was conducted in the Barents Sea of a high ice concentration of 0.8~0.9. Total 7 m^3 Troll B crude oil was released into the ocean. Environment conditions and crude oil property for simulation followed technical reports of the experiment. Fig. 5 shows the comparison of model prediction and actual experiment data. Although deviation happened, prediction of evaporative loss, water content and viscosity achieved a good agreement with experiment. Predicted density was not good and had a large deviation from experiment result. The inaccuracy of density prediction suggests an overall understanding of emulsification process is still absent in our model at current stage.

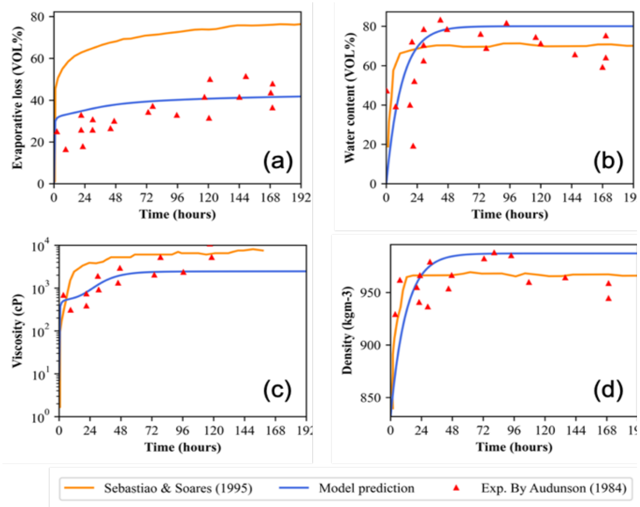

Fig. 4 Comparison of first experiment validation. (a) evaporative loss (b) water content (c) viscosity (d)density

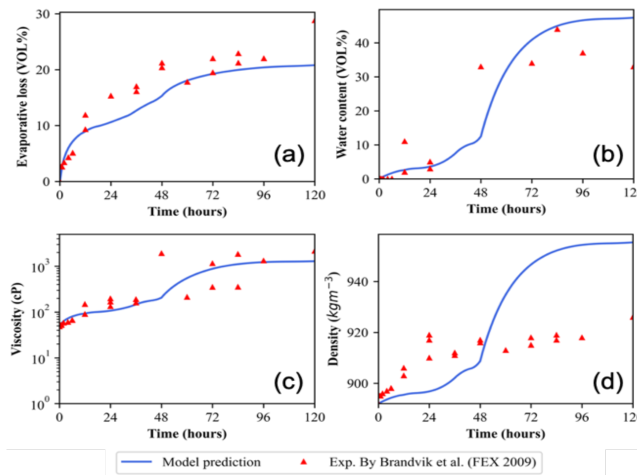

Fig. 5 Comparison of second experiment validation. (a) evaporative loss (b) water content (c) viscosity (d)density

3. Model application

3.1 Oil spill accident simulation

Two individual oil spill accident simulations were performed. The two accidents happened at same location around the Dmitry Strait in the Arctic ocean, while spill periods were different. Besides oil thickness distribution and oil location, since we developed the weathering process model in this study, we got the spatial viscosity distribution prediction after an oil spill. Fig. 6 shows oil viscosity distribution prediction of 10 days and 15 days after oil accident happened in one simulation. Prediction of specific spatial oil viscosity distribution is of significance to the oil pollution clean-up methods decision-making for the Arctic Ocean.

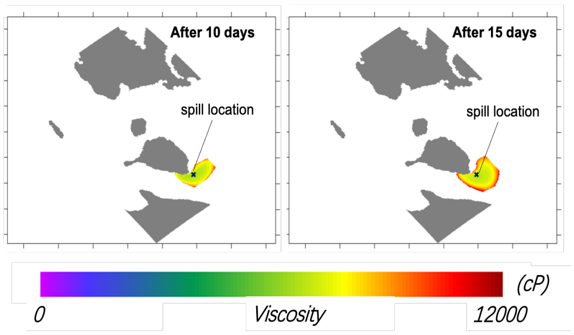

Fig. 6 Prediction of spilled oil viscosity distribution of 10 days and 15 days after accident happened. Grey part is land (close to the Dmitry Strait), and blue cross is the spill location.

Additionally, we simulated the same oil spill accident but without weathering for studying influence of weathering process calculation on oil behavior prediction. We compared oil film shape, area and location between simulations with weathering and without. Difference was observed but not significant. And when oil spill happened in ocean without sea ice the difference was smaller. We infer that environment condition such as ocean current dominates spilled oil behavior for oil spill accident in actual ocean. And when sea ice is present in the ocean, weathering process has a more apparent influence on spilled oil behavior because sea ice weakens influence from current and wind.

3.2 Hazard map application

Hazard map is an important practical application of oil spill model in oil spill response technology for visualizing the risk of a potential oil spill accident in a region. In this study, we developed two kinds of hazard map. One is called "traditional hazard map", displaying probability of oil reaching specific spilled oil location after an accident; the other is "time window hazard map", displaying the time percentage of being exposed to oil of specific location in the total time after accident happened. Total Six series of above hazard maps were created for the regions around four most important straits and one important port on the NSR. Fig.7 gives an example of them.

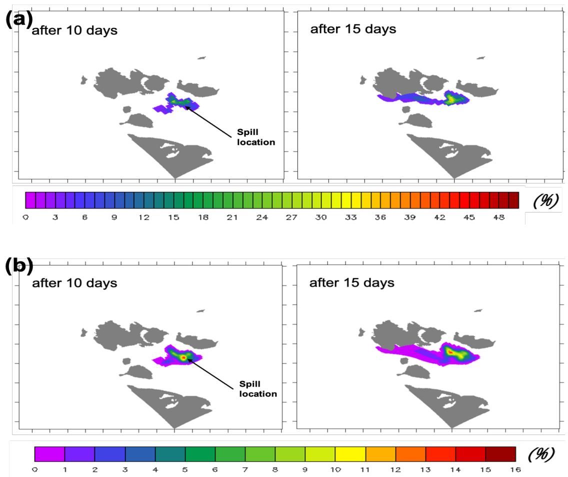

Fig. 7 Hazard maps for oil spill accident happening close to the Sannikov Strait. (a) traditional map (b) time window map. After 15 days oil has probability of spreading through the strait and reaching the Laptev Sea. And area at south of the Novaya Sibir has the longest time of being exposed to oil pollution, about 2.5 days.

4. Summary

In this study, we developed an ice-specific oil weathering process model, coupled it with a reliable transport process model developed in the past and obtained an oil spill model for oil spill accident in ice-covered sea. The model showed a good performance in reliability test. We introduced practical application of the model, including (1) predict viscosity distribution of spilled oil for oil clean-up methods decision (2) create hazard maps for important regions on the NSR, helping us to estimate risk of being polluted for specific ocean area or shores.

References

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[2] Sebastiao, P., and C. Guedes Soares. "Modeling the fate of oil spills at sea", *Spill Science & Technology Bulletin* 2.2-3: 121-131, 1995.