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On the Adhesion of Oil and Ice

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ABSTRACT

This paper describes a study on the adhesion between oil and ice and gives the main results. The experimental study consisted of contact angle and inclination angle measurements. Both measurements were taken both on ice in air and under ice in water. The test temperatures on ice in air were –1°C, –12°C and –18°C. Under ice the test temperature was the water temperature, i.e., 0°C. Three different oil types were included in the measuring program. North Sea Brent crude oil was tested as fresh and as artificially pre-altered. The third oil type was diesel fuel. On the basis of the contact angle measurements, the surface energies at interfaces between oil, air, water and ice were investigated. In addition, theoretical assessments of the oil spreading on ice, the work of adhesion between oil and ice and the influence of the liquid-like layer of ice on its adhesion to oil were performed. The inclination angle measurements yielded indications of the static and dynamic friction between oil and ice. Theoretical calculations were conducted on the motion resistance of oil drops sliding along the bottom of ice in water.

INTRODUCTION

General

As the unfortunate accidents of MT *Antonio Gramsci* in the Baltic Sea in 1987 and MT *Exxon Valdez* in Prince William Sound in Alaska in 1989 have shown, the risk of a marine oil spill in an ice-covered sea is real. In addition, those accidents, among others, have shown that our knowledge of oil spill combating in cold and icy conditions is inadequate. Therefore, there is an obvious need for research on the subject. To meet this need, VTT Manufacturing Technology, Espoo, Finland, the St. Petersburg State Technical University, St. Petersburg, Russia, and the Murmansk Marine Biological Institute, Murmansk, Russia, have established a joint research project entitled Marine Oil Spill Combating in Arctic and Sub-Arctic Conditions. In addition to the organizations above, the industry and oil spill combating authorities in both Finland and Russia also take part in the project, which has been scheduled for the years 1995-97.

As a part of the above research project VTT Manufacturing Technology and St. Petersburg State Technical University carried out an experimental laboratory study on the adhesion between oil and ice in November-December 1995 in the VTT laboratories in Espoo, Finland. The study measured the contact angles of drops of different oils on the top surface of ice in air and under the bottom surface of ice in water. In addition, special inclination angle tests were conducted. When the oil drop was lying on the ice piece, the ice was slowly inclined till the oil drop started to move on the ice surface. The angle initiating the oil movement was measured. In addition, the velocity of the oil drops was measured when the drops slid along the underside of the inclined ice piece in water.

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Adhesion Between Oil and Ice

Adhesion may be defined as the state in which two surfaces are held together by interfacial forces which may consist of valence forces, interlocking action, or both (Skeist, 1977). Additionally, the adhesion between a solid and a liquid is sometimes also interpreted as the ability of the liquid to wet the solid (Zisman, 1977).

When a sessile drop of a liquid lies on a solid surface, the Young-Dubré equation defines the form of the drop using the three surface energies and the contact angle shown in Fig. 1.

Using the notation of Fig. 1, the Young-Dubré equation is written (Zisman, 1977)

$$\gamma_{SV} - \gamma_{SL} = \gamma_{LV} \cos\theta \tag{1}$$

where γ_{SV}, γ_{SL} and γ_{LV} are the surface energies at the solid/vapor, solid/liquid and liquid/vapor interfaces, respectively, and θ is the contact angle. Some of the surface energies above are difficult to measure in practice, but the contact angle is an easily measurable quantity. Therefore, the contact angle is a commonly used indicator of the adhesion between a liquid and a solid. The small contact angle indicates strong adhesion. In other words, the smaller the contact angle, the better the liquid wets the solid.

The Young-Dubré equation holds strictly true only in a vacuum (Pocius, 1986). In practice, however, the contact angle measurements are carried out in air, disregarding the possible small errors this may result in (Pocius, 1986). Also, in this work the contact angle measurements on ice were conducted in air. For those tests the application of the Young-Dubré equation is in accordance

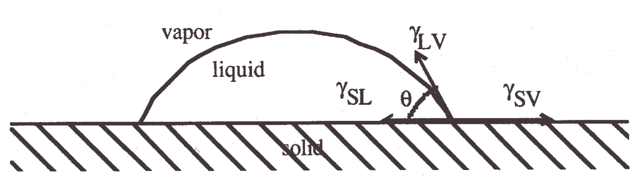

Fig. 1 Sessile drop of liquid on solid surface