Polarization: A Key to an Airborne Optical System for the Detection of Oil on Water

Abstract. *Skylight polarization, which varies with the position of the sun in the sky, influences the contrast of oil on water. Good contrast is most consistently obtained by viewing in azimuth directions toward or away from the sun. Contrast is enhanced by imaging selected polarization components and by taking the difference between orthogonal polarization components.*

Oil pollution on the sea amounts to about 2×10^6 metric tons per year (*1*). We have been concerned with the remote detection of this pollution and have found that on clear days thin films of oil are often difficult to see from the air and that contrast with the surrounding water depends upon solar elevation and direction of view. We wish to report that the detection of oil slicks can be improved by utilizing polarization techniques. We obtained good contrast by viewing a specific polarization component. Our experimental and analytical studies provide an explanation, and also indicate that most consistent detection can be achieved by viewing in azimuth directions toward or away from the sun, and that additional contrast should be attainable by imaging the differences between orthogonal components.

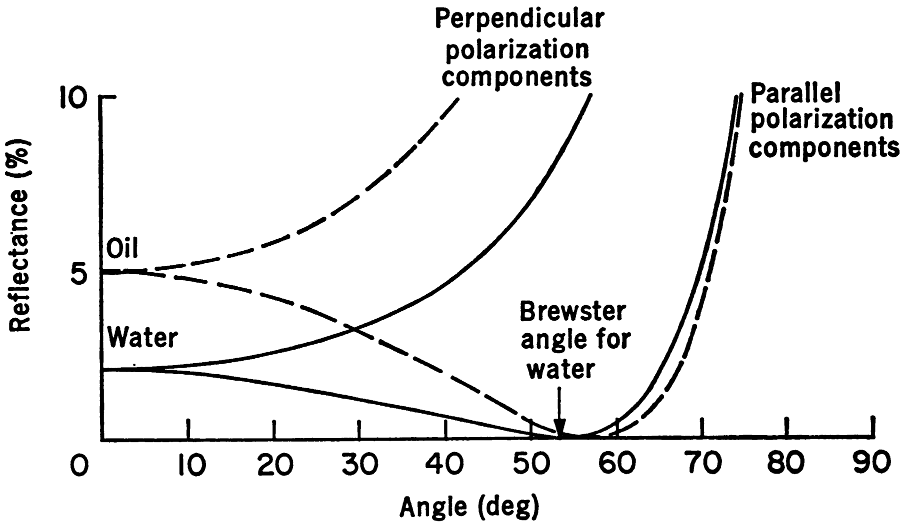

Fig. 1. Reflectance of polarization components as a function of the angle of incident light for oil and water; the index of refraction for water is 1.34, and the index for oil is 1.57.

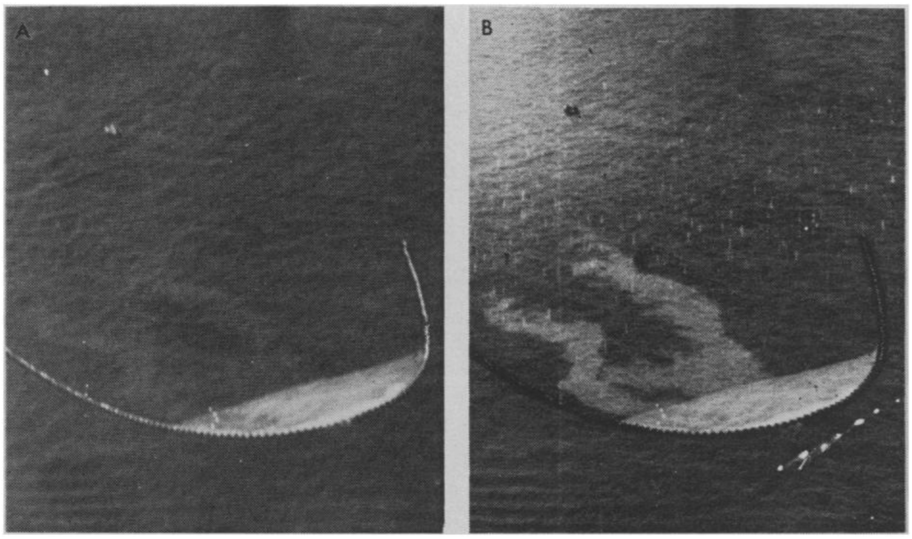

Fig. 2. Photographs of an oil spill: (A) parallel polarization component; (B) perpendicular polarization component.

An airborne sensor viewing oil on water "sees" light reflected at the surface plus light backscattered from beneath (*2*). The reflected light comes from that portion of sky in the specular direction. The backscattered light comes from direct sunlight and skylight which penetrates the water surface from all directions. Thin oil films, those less than about 0.2 μm, attenuate a negligible amount of backscattered light (*3*) and therefore are distinguishable from water solely on the basis of reflected light.

The reflectance of oils and water are described by the laws of Fresnel, as illustrated in Fig. 1. Figure 1 shows the reflectance for the parallel and the perpendicular polarization components of incident light, the parallel component being parallel to the vertical plane of incidence. These curves indicate that (i) the reflectance of the perpendicular component is large, especially at high angles of incidence; (ii) oil is always brighter than water if only the perpendicular component is viewed; (iii) the reflectance of the parallel component is comparatively low; and (iv) a crossover in contrast between oil and water occurs near the Brewster angle, approximately 53°, for the parallel component; that is, from nadir to about 53° oil is "brighter" than water, but beyond 53° water is "brighter" than oil. Thus oil on water can be best detected if an observer views in azimuth directions where the skylight, which is the source of the specularly reflected light, has a large perpendicular polarization component. The observer should also look at a nadir angle larger than about 40° so as to see a large amount of reflected light. The reason is that thin oil films can best be detected by reflected light, and therefore it is desirable to maximize the amount of reflected light detected relative to the amount backscattered from beneath the surface.

Our measurements of skylight polarization show that the largest perpendicular components are in the azimuths toward or away from the sun. Therefore, these are the best viewing angles from which to observe slicks. These measurements also showed the perpendicular component to be very small at 90° azimuth when the sun is low in the sky, that is, early morning or evening. This explains the reversal in contrast that we have observed from time to time. During low solar elevations, if one looks at 0° or 180° azimuth to the sun, an oil film will appear brighter than water, but at 90° azimuth most of the energy will be of the parallel polarization component and, as shown in Fig. 1, a crossover in contrast can occur near 53°, in the direction of downward view.

To illustrate the advantage of viewing one polarization component in preference to another, we took photographs (Fig. 2) of an oil spill with two cameras having polarizers rotated 90° with respect to each other. We used Kodak infrared aerographic film 2424 with a Wratten No. 25 red-transmitting filter. The scene is an oil spill contained by a barrier. In the center is a thin film of oil, exact thickness unknown, and toward the bottom, within the barrier, is a thicker pool of oil. Figure 2A was taken with a polarizer oriented to transmit the parallel component, and for Fig. 2B we used a polarizer which transmitted the perpendicular component. Although this particular day was partially overcast, the advantage of the perpendicular technique is readily seen. The thin slick stands out vividly, as shown in Fig. 2B.

On the basis of these photographs, it appears that enhancement in contrast can be obtained by a difference technique. Figure 2A contains information primarily from light backscattered from beneath the water surface (background information). Figure 2B contains information from both backscattered plus reflected light (background plus signal). By subtracting one image from the other, the thin oil slick should stand out vividly. This differencing of images forms the basis of an airborne oil-spill detection system presently under development.

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References and Notes

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2. J. P. Millard and J. C. Arvesen, *J. Appl. Opt.* **11**, 102 (1972).
3. A. A. Allen and R. S. Schlueter, *Gen. Res. Corp. Rep. TM 1230* (November 1969).
4. We thank B. G. Ponseggi for taking the photographs in Fig. 2. We thank Commander R N. Abrahams, Office of Research and Development, U.S. Coast Guard, for his cooperation in coordinating our overflight of the photographed oil-spill area.

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Horizontal Bands in the Belousov Reaction

Abstract. *The formation and propagation of spatial patterns in the presence of an initial gradient in temperature or the concentration of one or more of the reactants is explained kinematically. Experimental verification of this mechanism is given, showing that diffusion plays a very minor role in the formation of the bands.*

Belousov (*1*) reported that a solution containing bromate ions, malonic acid, sulfuric acid, and a small amount of cerous ion will undergo temporal oscillations. If the oxidation-reduction indicator tris(1,10-phenanthroline) ferrous complex (ferroin) is added, the stirred solution turns alternately from reddish purple to clear blue and back again. The chemical mechanism and kinetics of this reaction have been extensively investigated, particularly by Noyes *et al.* (*2*); see also (*3, 4*).

Various authors have reported the ability of this solution to form spatial patterns when the fluid is not stirred. Busse (*5*) noticed horizontal bands forming when the fluid was allowed to sit undisturbed in a vertical tube, and Zaikin and Zhabotinskii (*6*) reported that if the fluid is placed in a thin layer (about 2 mm), patterns of outwardly propagating concentric rings form. These spatial patterns are also discussed in (*7*). Some of the authors do not attempt an explanation of the origin of the patterns; those who do, appear to assume that the same mechanisms are at work in producing both kinds of spatial structure. In general it has been supposed that diffusion plays an important role, although only qualitative reasoning has been used to support this conjecture.

We believe that the bands noticed by Busse are formed for reasons qualitatively different from those responsible for the "target patterns" of Zaikin and Zaikin and Zhabotinskii (*6*) reported form in the presence of an externally imposed gradient of concentration (or temperature). The purpose of this report is to show that under such conditions bands form and propagate for strictly kinematic reasons; that is, the oscillations occurring at different places in the fluid are independent of one another and the macroscopic spatial pattern arises from spatial variations in the frequency of these independent oscillators. In particular, diffusion is of negligible importance. We shall cite some experimental evidence in support of this hypothesis. Details of these experiments and some mathematical arguments are presented more fully in (*8*). This kinematic mechanism does not work for the target patterns, which form without any externally imposed gradient. We discuss elsewhere (*9*) how diffusion can interact with the chemical kinetics to form the target patterns.

Concentration gradients can be formed by mixing together all but one component, and then adding the last one without thorough mixing. If H_2SO_4 is added last it tends to sink; if cerium is added last it tends to float. Thus, there is a density gradient associated with the concentration gradient. In each of these two situations bands form and propagate upward. As time goes on there appear to be more and more bands, and they move more and more slowly through the fluid (which is not itself in motion).

The frequency of oscillation of this reaction (in homogeneous circumstances) is quite sensitive to many

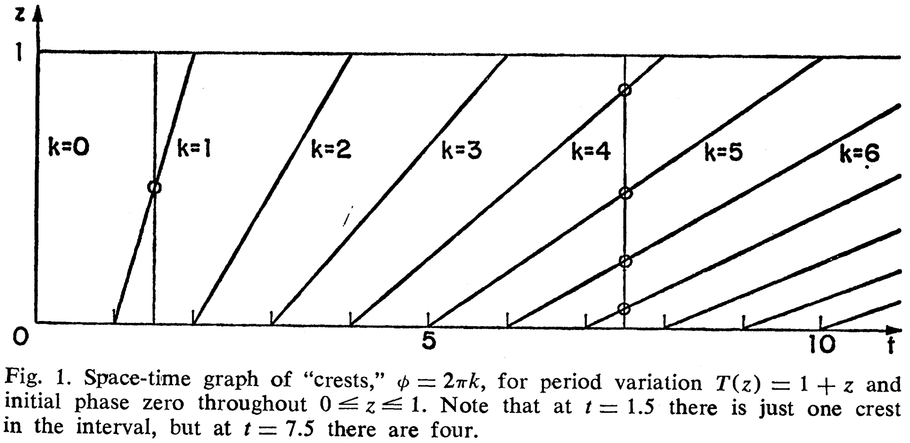

Fig. 1. Space-time graph of "crests," $\phi = 2\pi k$, for period variation $T(z) = 1 + z$ and initial phase zero throughout $0 \leq z \leq 1$. Note that at $t = 1.5$ there is just one crest in the interval, but at $t = 7.5$ there are four.