ATTENUATION OF WIND WAVES BY ARTIFICIAL SURFACE FILMS OF DIFFERENT CHEMICAL STRUCTURE

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Abstract. Experiments in a wind wave tunnel have shown that spectra of wind generated waves are modified by monomolecular surface films. Apart from the well known decrease of energy density two additional effects have been observed: a shift of the energy peak maximum and a dip in the short wavelength region of the gravity wave spectrum. Two mechanisms which would cause the shift of the peak maximum and one mechanism possibly contributing to the spectrum dip in the short gravity wave range are discussed.

Introduction

The widespread occurrence of natural and man-made surface films ("slicks") has been known for many years, but attention has been drawn to surface film investigations after it could be shown that wave-wave interaction and wind-wave interaction processes are modified by slicks. As a consequence, care has to be taken when using radar backscattering data from the ocean surface for infering wind speed in the presence of such slicks. On the other hand new possibilities of investigating some mechanisms of air-sea interaction processes and of detecting pollutants arise from these effects (for reviews see Hühnerfuss and Garrett, 1981). Slicks normally occurring on the sea surface are formed by a mixture of different chemical compounds. In order to find a correlation between the chemical structure of the film forming substances and their influences on the above mentioned air-sea interaction processes, systematic experiments have been performed in our wind-wave tunnel. Direct wave damping effects (viscous damping) have been investigated using mechanically generated waves in the frequency range 1 - 2.5 Hz, and are reported elsewhere (Hühnerfuss, Lange, and Walter, 1981a, 1981b). In this paper we present the results of experiments with wind generated waves producing indirect wave damping effects (modification of wind coupling to the wave field and of wave-wave interaction).

Experimental

The experiments have been performed in our wind-wave tank (see Hühnerfuss et al., 1976) using wind speeds between 4 - 14 ms^{-1} over a clean water surface and a wind speed (U = 8 ms^{-1}) in the presence of 6 different surface films. Since the surface film material is blown to the beach end of the wind-wave tunnel a 75 mMol solution of the substance in ethanol was continuously dropped onto the water surface, the dropping frequency was adjusted to the wind speed action of moving the film. A collapse of the monomolecular surface film

by compression at the beach end was avoided by allowing a thin surface layer of oil and water to slip over the top of the beach behind a barrier. Prior to each experiment the water surface was thoroughly cleaned by blowing all the experiment disturbing surface active pollutants to the downwind end of the tank, where it was removed by a perforated tube connected to a vacuum pump. The amplitudes of the waves were measured by a single thin wire (40 μm diameter tungsten) resistance probe (Hühnerfuss et al., 1976) after a fetch of about 16 m. Degrees of freedom used for the spectral analysis were 66.

Results and Discussion

The spectra obtained by spreading consecutively 9-octadecenoic acid methyl ester, Z-isomer, (trivial name: methyl oleate (OLME)), hexadecanoic acid methyl ester (palmitic acid methyl ester (PME)), 9-octadecen-1-ol, Z-isomer (oleyl alcohol (OLA)), and hexadecan-1-ol (cetyl alcohol (CEA)) on clean water (H_2O) are depicted in Fig. 1 for a wind speed of 8 ms^{-1}. The spectrum of hexadecyl-trimethyl-ammonium-bromide (CEM3AB) looks similar to that of PME and the spectrum of 9,12,15-octadecatrienoic acid methyl ester (linolenic acid methyl ester (L3ME)) is nearly identical with the OLME spectrum. Therefore, the CEM3AB and L3ME spectra were not plotted in Fig. 1. In addition to the wave damping characteristics observed on mechanically generated waves in the presence of surface films (Hühnerfuss et al., 1981a, 1981b), two unexpected results are obtained in the case of wind generated waves:
1) the peak frequencies of the wind wave spectra with surface films present are shifted to higher frequencies in reference to the peak frequency of clean water, and
2) the typical form of f^{-5} frequency dependence (Phillips, 1977) measured for clean water is in some cases strongly modified, i. e. the spectrum shows a dip in the frequency range f = 4 - 6 Hz. In the presence of two of the six surface active substances investigated in this paper, PME and CEM3AB, this effect is so pronounced that even the smaller spectral peak of the harmonic wave is suppressed. In the presence of OLA the dip in the spectrum is still discernable, but wave attenuation by this surface film is less intensive in this frequency range and the peak of the harmonic wave is not completely eliminated.

1) Shift of the Peak Frequency

The shift of the peak frequency of the wind wave spectrum could be due to two effects:
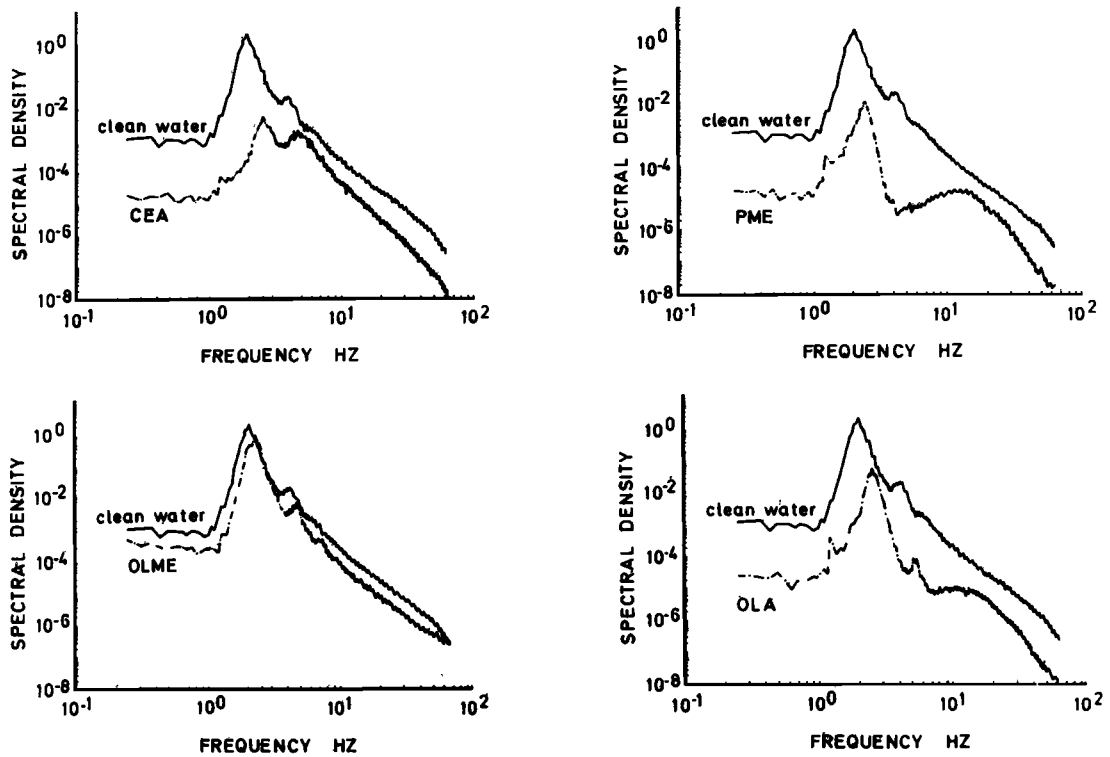a) monomolecular surface films are known to lower the surface tension, thus an indirect influence

Fig. 1. Wind wave spectra (wind speed U = 8 ms^{-1}, fetch about 16 m, degrees of freedom 66) of a clean water surface (solid lines), and in the presence of a hexadecanol (CEA), hexadecanoic acid methyl ester (PME), 9-octadecenoic acid methyl ester, Z-isomer (OLME), and 9-octadecen-1-ol, Z-isomer (OLA) surface film.

can be assumed taking into account the results of Wu et al., (1979). According to their theory the energy transfer by nonlinear wave-wave interaction takes place via 5 - 9 Hz waves to longer and shorter waves in wind-tunnel experiments. In this frequency range the surface tension term of the Kelvin equation

$$v^2 = \frac{gl}{2\pi} + \frac{2\pi\gamma}{\rho L} \qquad (1)$$

starts to become significant, where γ is the surface tension, v is the velocity of a wave of length L on a deep liquid, g the gravitational
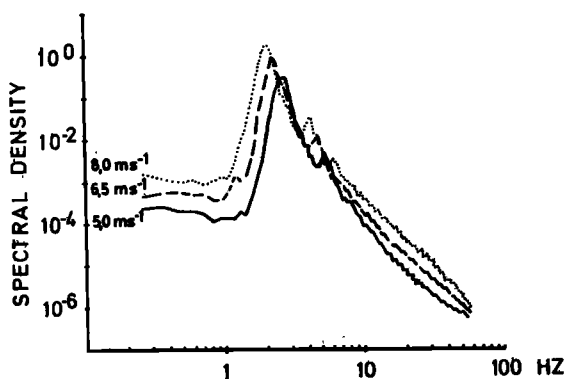
constant and ρ the density of the liquid. In the frequency range 5 - 9 Hz, which is relevant for the energy transfer by nonlinear wave-wave interactions (Wu et al., 1979), the contribution of the surface tension term varies between about 10 - 40%. Therefore, substances strongly lowering surface tension are expected to modify v^2 such that significant modifications of wind moment transfer occurs, which in turn alters the amount of energy transfered to longer waves by nonlinear interactions. In accordance with these assumptions, spectra obtained in the presence of CEA (lowering the surface tension under the dynamic conditions of a wind-generated wave by about 75 %) show a significant frequency shift, whereas in the presence of L3ME (surface tension lowering by about 20 %) only a slight frequency shift can be observed.

b) a second mechanism for explaining the shift of

Fig. 2. Wind wave spectra (fetch 16 m, degrees of freedom 66) of a clean water surface at a wind speed U = 8 ms^{-1} (dotted line), 6.5 ms^{-1} (dashed line), and 5 ms^{-1} (solid line).
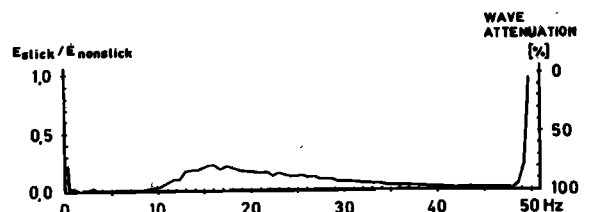

Fig. 3. Ratio of the wave energy of a slick area, hexadecyl-trimethyl-ammonium-bromide slick, and non-slick area plotted vs. frequency, obtained at a wind speed U = 8 ms^{-1} (fetch about 16 m, degrees of freedom 66). The scale on the right hand side shows the corresponding values for wave attenuation in per cent.

the peak frequency of the wave spectrum can be derived from the observation that the roughness of the water surface is decreased by surface films. This implies that the momentum transfer from the wind to the wave field is lowered. It is well known that a decrease in the wind speed leads to an increase in the peak frequency (Hasselmann et al., 1973). For example, in the presence of an OLME film the peak frequency is 2.2 Hz for a 8 ms^{-1} wind. The same peak frequency is measured for a 6.5 ms^{-1} wind over a thoroughly cleaned water surface (Fig. 2). And the frequency of the peak maximum in the presence of a CEA film (f = 2.7 Hz) corresponds with that obtained at a wind speed of U = 5 ms^{-1} over a clean water surface (Fig. 2). As a consequence of this effect, the wind speed required to produce a wave spectrum with a given peak frequency is lower over clean water than over slick-covered water surfaces.

From the results it can be concluded that depending on the wave damping intensity of the different surface films a spectrum of an "effective wind speed" is obtained which is lower than the actual wind speed.

2) Dip in the Energy Spectrum

As a second remarkable effect which was observed is a dip in the energy spectrum in the short gravity wave range in the presence of those surface films which give rise to strong wave damping as was the case of PME (Fig. 1) and CEM3AB. This dip corresponds with a maximum in wave damping in the short gravity wave range (Fig. 3).

Since the dip occurs in a frequency range in which nonlinear energy transfer is expected in a wind-wave tunnel at a wind speed U = 8 ms^{-1} (Wu et al., 1979), it is assumed that the action of both wave damping and nonlinear energy detraction in this frequency range cannot be balanced by redistribution of energy. This assumption is supported by calculations of Valenzuela and Laing (1972) who conjectured that for light winds U ≤ 6 - 7 ms^{-1} a dip might occur in the wave spectrum in the short gravity wave range as a result of the nonlinear wave-wave resonant interactions. This would also be consistent with the above mentioned hypothesis that an "effective wind speed" instead of an actual wind speed has to be used, in order to relate wind speed and wave spectra obtained in the presence of a surface film: due to the action of a surface film exhibiting strong wave damping, e. g. PME, a "light wind wave spectrum" according to Valenzuela and Laing (1972) is obtained instead of the wave spectrum usually measured at a wind speed of 8 ms^{-1} over clean water surfaces.

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