FACILITY FORM 602

N69-21068
(ACCESSION NUMBER)

(THRU)

67
(PAGES)

1
(CODE)

CR# 100466
(NASA CR OR TMX OR AD NUMBER)

14
(CATEGORY)

BARRINGER RESEARCH LIMITED
TORONTO, CANADA

FINAL REPORT
THE FEASIBILITY OF DETECTION AND CLASSIFICATION OF FISH OIL SLICKS BY REMOTE SENSING

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C.
U. S. A.

PREPARED BY

BARRINGER RESEARCH LIMITED
304 Carlingview Drive
Rexdale, Ontario, Canada

TR-68-54

FEBRUARY - 1968

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Section 1

INTRODUCTION

1.1 PURPOSE OF STUDY

This final report is concerned with the feasibility of detection and classification of fish and mineral oil slicks on the surface of the ocean. The study was done for the National Aeronautics and Space Administration (NASW-1642) as an investigation into ultraviolet optical properties of the oils and oil films in an effort to determine the feasibility of remote sensing of the oils from a spacecraft platform. The ultimate aim of the study was to determine if the ultraviolet properties of the oils could be used as a means of detecting and monitoring the areas of high fish oil slick activity which in turn would indicate the location of the large fish schools.

The study was confined to the ultraviolet region of the spectrum because of the interesting ultraviolet absorption properties of the fish and mineral oils. Since the object of the work was to determine the feasibility of remote sensing, the approach was largely experimental in order to measure the ability of optical instruments to detect and differentiate different types of oil films. The primary problem of interest was the question of detection and then secondarily the question of differentiation between mineral oil and fish oil slicks. The problem of differentiating between the various fish oils was also considered.

1.2 TECHNICAL APPROACH

The basis for the experimental work was theoretically investigated by computing the polarization reflection effects of the air-oil-water interface with the effects of absorption in the oil taken into account. The effects of the seas surface was investigated in order to determine what angular effects were caused by the waves with respect to the polarization effects and the reflection qualities of the surface. It was found in the process of initial experimentation that the way in which the oils spread radically influences their optical properties. In an effort to clarify this, laboratory tests were done on the spreading characteristics of the fish and mineral oils in relation to surface agitation and impurities.

The absorption properties of the oils in the ultraviolet were of primary interest due to the possibility of selective reflection effects. A Bausch and Lomb Spectronic 505 scanning spectrometer was used to measure the absorption spectra of thin films of both fish and mineral oils. These measurements were used to determine the absorption index for the oils as a function of wavelength. The changes in refractive index as a function of wavelength also influences the selective reflection of the oil films. In order to measure this property, an experimental device was made up to measure the Brewster angle of the oils and the oil films in the ultraviolet.

The reflective properties of the bulk oils and the oil films on sea water were measured on the Spectronic 505 with a specially designed optical attachment. The apparatus was constructed to allow dual beam operation on a horizontal fluid surface so that the actual reflection spectra could be measured across the wavelength range of 2800 Å to 4300 Å. The measurements were made at two different angles of incidence and for different conditions of surface agitation. The optical properties of the vapor phase for the oils were investigated both for the ultraviolet and the infrared to test for possible absorption spectra which could be used for identification of the oil slicks.

In an effort to obtain more detailed information on the actual properties of the oil slicks on the ocean's surface field study was done on the west coast of Florida which was coordinated with the Bureau of Commercial Fisheries. During the trip photographs were taken of the various types of surface slicks which were sighted on the surface and correlated with the presence of fish schools in the area.

1.3 SUMMARY

The results of the study show that the fish oils can be readily classified by a multiband photometric system based on the absorption spectra when the oil sample is viewed in transmission. However, in reflection the oils are not readily detected or classified in the ultraviolet region of the spectru. The differentiation between fish oils and mineral oils can be done quite easily in the visible wavelength region. This means that mineral oil slicks are readily detected and identified by their increased reflectivity whereas the fish oil slicks which do not have a large increase in reflectivity over that of sea water, are not as detectable.

The ultraviolet reflection properties of the fish oils do not lend themselves to remote sensing systems. The lack of selective reflection in the ultraviolet and the surface spreading properties of the fish oils make detection and identification very difficult. The most promising area for remote sensing appears to be the thermal IR due to the expected temperature differences in the region of fish oil slicks. Further work should investigate the energy exchange mechanisms at the fish oil ocean interface and make experimental measurements with IR thermal sensors over the ocean.

It is believed that there is a good possibility for developing an infrared scanner incorporating spatial filtering which will be able to discriminate fish oil slicks on the surface of the ocean from orbital altitudes.

Section 2

THEORETICAL ANALYSIS

2.1 REFLECTION AT THE BOUNDARY BETWEEN TWO DIELECTRICS

Maxwell's equations when solved for the simple case of a plane parallel monochromatic wave incident on the boundary between two transparent media yield the following expressions for the reflected and refracted amplitudes:

Reflected Components

$$A_e = \frac{1 - \frac{m_2}{m_1}\frac{\cos\theta_1}{\cos\theta_2}}{1 + \frac{m_2}{m_1}\frac{\cos\theta_1}{\cos\theta_2}} \qquad (2\text{-}1) \qquad A_r = \frac{\frac{\cos\theta_1}{\cos\theta_2} - \frac{m_2}{m_1}}{\frac{\cos\theta_1}{\cos\theta_2} + \frac{m_2}{m_1}} \qquad (2\text{-}2)$$

Refracted Components

$$A'_e = \frac{2}{\frac{\cos\theta_2}{\cos\theta_1} + \frac{m_2}{m_1}} \qquad (2\text{-}3) \qquad A'_r = \frac{2}{1 + \frac{m_2}{m_1}\frac{\cos\theta_2}{\cos\theta_1}} \qquad (2\text{-}4)$$

Where θ_1 and θ_2 are the angles of incidence and refraction in media of refractive indices m_1 and m_2 respectively. The subscripts e and r refer to the components polarized parallel to and perpendicular to the plane of reflection respectively.

It can be seen that the reflected and refracted amplitudes depend on the angle of incidence and the refractive indices of the two media, since the angle of refraction θ_2 is related to the angle of incidence θ_1 by Snell's Law, $m_1\sin\theta_1 = m_2\sin\theta_2$. The reflected light is in general partially plane polarized, the amount of polarization depending on the angle of incidence and the refractive indices. At a particular angle of incidence where $1 - \frac{m_2}{m_1}\frac{\cos\theta_1}{\cos\theta_2} = 0$, a condition which is satisfied when $\tan\theta_1 = \frac{m_2}{m_1}$, equations (2-1) and (2-2) show that the reflected light is completely plane polarized perpendicular to the plane of reflection. The angle of incidence at which this occurs is usually called the Brewster angle or the polarizing angle.

Since it is the intensity of light which is actually measured and not the amplitude, the intensity can be obtained from the above expressions by

$$I = mA^2 \qquad (2\text{-}5)$$

The intensities of the reflected components have been computed for an air/water interface ($m_1 = 1$, $m_2 = 1.33$) and also an air/oil interface ($m_1 = 1$, $m_2 = 1.5$). They are shown in figure 2.1-1. It can be seen that the reflectivity of water at normal incidence ($\theta = 0°$) is 2%, and oil 4%. The Brewster angles for oil and water are about 53° and 56° respectively. It would appear therefore that there is a better possibility of detecting oil on water by virtue of the different reflectivities of oil and water, rather than by their effects on the state of polarization of the reflected light.

At normal incidence the expressions (2-1) and (2-2) reduce, to give for the reflected intensity of each component

$$I_n = \frac{m_1^2 \, (m_2 - m_1)^2}{(m_2 + m_1)^2} \qquad (2\text{-}6)$$

So far only a transparent, i.e. non-absorbing, medium has been considered. However it can be shown that the expressions representing a disturbance in an absorbing medium are formally the same as for a transparent medium if the refractive index is written as

$$m^* = m - ik$$

Where $i = \sqrt{-1}$ (2-7)

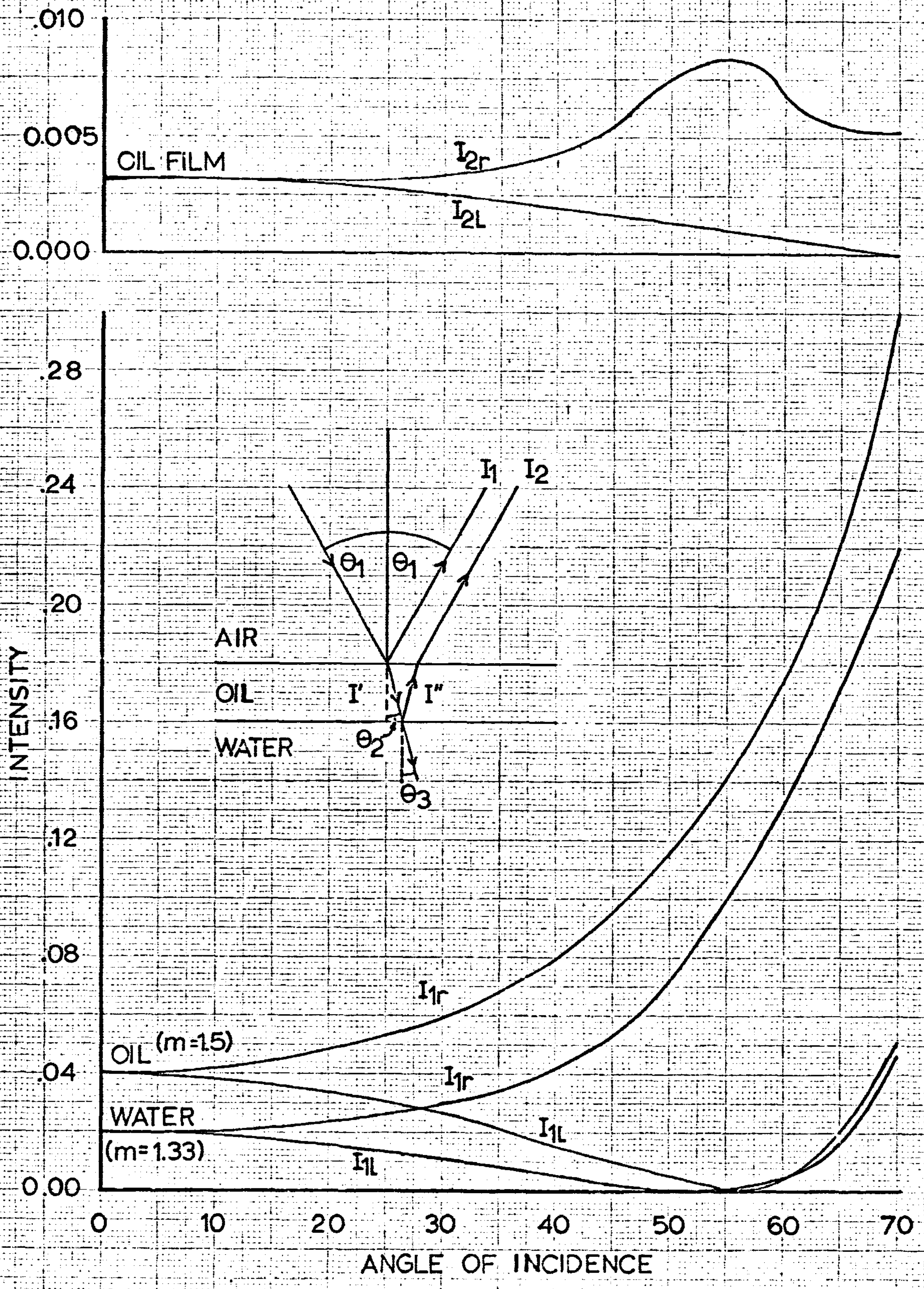
k = absorption index

m^* = complex refractive index

The absorption of light on passing through an absorbing medium is governed by the Lambert Law which can be written

$$I = I_o e^{-Kx}$$

Where x = the distance travelled (2-8)



REFLECTIVITIES OF WATER, OIL, AND OIL FILMS.

FIGURE 2.1-1

I and Io = the final and initial intensities

K = absorption coefficient

It is often convenient to specify the absorption by means of the absorption index k, as in

$$I = Ioe^{-\frac{2\pi}{\lambda_m}kx} \qquad (2\text{-}9)$$

Where λ_m is the wavelength in the medium

Comparing (2-8) and (2-9) it can be seen that

$$k = K\frac{\lambda_m}{2\pi} \qquad (2\text{-}10)$$

For oblique incidence on an absorbing medium, the expressions for the reflected components can be deduced, but the calculations are rather tedious. However at normal incidence the transition is simpler and by putting (2-7) into (2-6) and assuming the first medium is air ($m_1 = 1$), equation (2-6) becomes

$$I = \frac{(m-1)^2 + m^2k^2}{(m+1)^2 + m^2k^2} \qquad (2\text{-}11)$$

It follows that the reflectivity of an absorbing medium at normal incidence depends on the refractive index and on the absorption index. The variation of reflectivity with wavelength will therefore depend on how the two indices vary with wavelength. It might be hoped that one or the other would vary with wavelength characteristically for each oil, enabling them to be identified using a two colour measuring system.

2.2 REFLECTION FROM A THIN FILM OF OIL ON WATER

If oil is present on a smooth water surface in the form of a thin film then the reflection from the surface is modified by the addition of a component reflected at the oil/water interface and transmitted through the oil/air interface (I_2). Although the intensity of this component may be expected to be small at most angles of incidence compared to the intensity reflected from the upper interface (I_1) it may be important at angles near the Brewster angle where I_{1e} falls to zero.

By successive application of equations (2-1) through (2-4), the components of I_2 are found to be

$$I_{2e} = \left[\frac{1 - \frac{m_3 \cos\theta_2}{m_2 \cos\theta_3}}{1 + \frac{m_3 \cos\theta_2}{m_2 \cos\theta_3}}\right]^2 \left[\frac{4}{\frac{m_2\cos\theta_1}{m_1\cos\theta_2} + \frac{m_1\cos\theta_2}{m_2\cos\theta_1} + 2}\right]^2 e - \frac{8\pi ks}{\lambda_m \cos\theta_2} \quad (2\text{-}12)$$

$$I_{2r} = \left[\frac{\frac{\cos\theta_2}{\cos\theta_3} - \frac{m_3}{m_2}}{\frac{\cos\theta_2}{\cos\theta_3} + \frac{m_3}{m_2}}\right]^2 \left[\frac{4}{\frac{m_2\cos\theta_2}{m_1\cos\theta_1} + \frac{m_1\cos\theta_1}{m_2\cos\theta_2} + 2}\right]^2 e - \frac{8\pi ks}{\lambda_m \cos\theta_2} \quad (2\text{-}13)$$

Where θ_3 = angle of refraction at oil/water interface
m_3 = refractive index of water
s = film thickness

These components were computed at different angles for $m_1 = 1$, $m_2 = 1.5$ and $m_3 = 1.33$, i.e. an oil film on water, assuming $k = 0$ and are plotted in figure 2.1-1. I_{2r} is seen to be more than an order of magnitude less than I_{1r} at all angles of incidence, while I_{2e} is only greater than I_{1e} at angles close to the Brewster angle, where it is very small, about 0.001 of the incident intensity. The effect of I_2 on the reflectivity of an oil film is therefore negligible and has little influence on the state of polarization of the reflected light.

2.3 THE SURFACE CONDITION OF THE SEA

The previous analyses assumed a flat sea surface so that an observer at a particular point above the sea would receive light reflected at only one angle of incidence (more correctly over a small range of angles depending on the aperture and height of the observing instrument). In most sea conditions surface waves are present, so that when diffuse sunlight is incident on the sea surface, light from a wide range of angles of incidence can be received by the observer. When direct sunlight is incident on the surface light is received mainly from one angle of incidence, but from only a fraction of the surface in the field of view.

If we assume a sinusoidal surface waveform given by

$$y = a\sin px \tag{2-14}$$

Where $p = \frac{2\pi}{\lambda}$, λ = wavelength
a = amplitude

then it is obvious that some parts of the wave are more effective in reflecting light to an observer because of the varying curvature along the waveform. The relationship between the change in x required to give a change $\delta\theta$ in the angle of incidence (see figure 2.3-1) is as follows:

$$\delta\theta = \frac{p^2 A\sin px}{1+p^2A^2\cos^2 px}\,\delta x \tag{2-15}$$

It can be seen that $\delta\theta$ is a maximum when $x = \frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}$ etc., i.e. at the peaks and troughs of the waves.

At these points the curvature is greatest and the wave is least effective in reflecting light to an observing instrument of limited aperture. For example the ratio of the effective areas at px = 10° and px = 90° is in fact 20 when $\frac{a}{\lambda} = \frac{1}{4}$.

The mean gradient of the waveform can be shown to be $\frac{4a}{\lambda}$. When $\frac{a}{\lambda} = \frac{1}{4}$, this corresponds to a mean angle of incidence of 32° 36' when the observer is looking vertically downwards (see figure 2.3-2). When the observer is viewing at 60° to the normal, the mean angle of incidence is 27°24'. There is some evidence (see below) that the effect of oil on the sea surface is to produce an area which is relatively smooth. The visibility of the slick will therefore depend on the relative reflectivities of a smooth oil surface and a rough

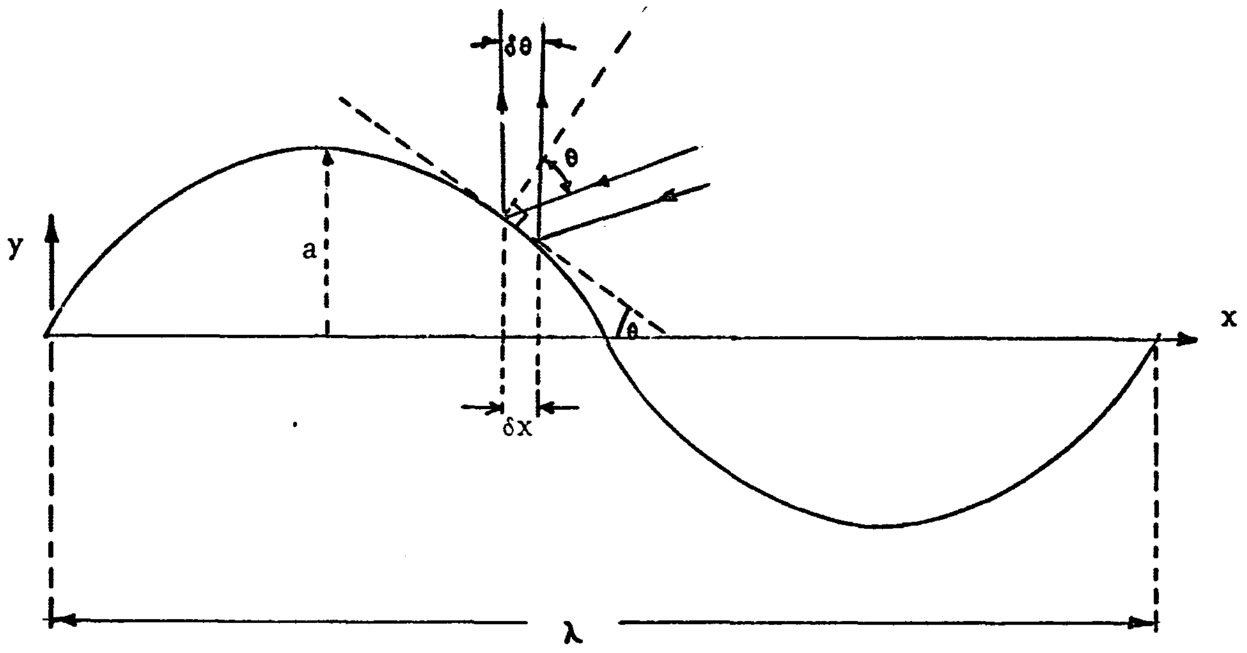
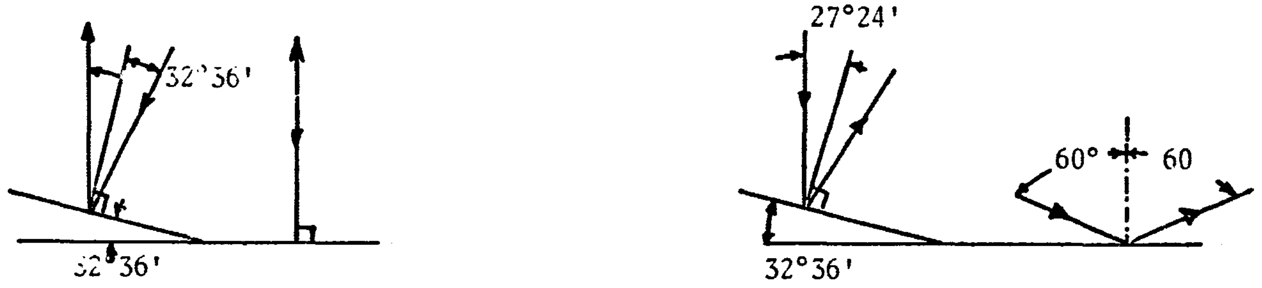


FIGURE 2.3-1 - WAVE STRUCTURE GEOMETRY



(a)

(b)

FIGURE 2.3-2 - WAVE STRUCTURE GEOMETRY

water surface. For the case $\frac{a}{\lambda} = \frac{1}{4}$, the relative reflectivity of the surfaces has been calculated at three angles of observation, directly above, and at 60° and 70° to the vertical. These values are shown in the table below.

TABLE 2.3-1 RELATIVE REFLECTIVITIES OF SMOOTH AND ROUGH WATER

	0°	60°	70°
$\frac{\text{OIL}}{\text{ROUGH SEA}}$	2.1	4.5	8.7
$\frac{\text{SMOOTH SEA}}{\text{ROUGH SEA}}$	1.1	3.1	6.8

It follows that when sea waves are present, patches of smooth water are more visible at oblique angles of incidence. If the patches are caused by oil on the sea surface, the relative visibility is increased at all angles of observation. Further from figure 2.1-1, the polarization ratio of light reflected at vertical incidence is 1.0 whereas at an angle of incidence of 32°36' which is the average angle of incidence on a surface wave with $\frac{a}{\lambda} = \frac{1}{4}$ and when viewed from directly above, the polarization ratio is approximately 3.0.

2.4 ABSORPTION BY OIL VAPOUR

In section 2.2 it was shown that the light reflected at the oil/sea interface was small compared to the light reflected at the air/oil surface so that differential absorption by the oil at different wavelengths was unlikely to be measurable. However the light reflected at the air/oil surface is in the range 4-100% of the incident intensity and the vaporization of oil on the surface may produce a sufficient concentration of vapour to give measurable absorption of radiation over a long pathlength. This would locate the oil on the sea surface and also if different oils had different absorption spectra, identification of the oils would be possible. Previous studies of the infrared absorption spectra of thin films of oil showed general differences between fish and mineral oils.(1)

If the concentrration of vapour is C and the total pathlength is ℓ, the amount of absorption is given by the Lambert Law

$$I = Ioe^{-KC\ell} \qquad \text{Where K is the absorption coefficient}$$

The effective thickness of the oil vapour layer, $C\ell$, depends on the vapour pressure of the oil vapour and the wind conditions.

2.5 REFLECTION FROM THE SEA BED

It was shown in Section 2.1 that only 2% of the light incident normally on an air/sea interface was reflected while 98% was refracted. In shallow seas the amount of light reflected from the sea bed may be considerable making details of the bed visible. This source of light from beneath the sea surface could reveal oil on the surface by absorption in the ultraviolet, provided that the transmission of ultraviolet light by sea water is sufficient.

REFERENCES

1. A. R. BARRINGER — Detecting the Ocean's Food (and Pollutants) From Space, Ocean Industry, May, 1967

Section 3
OIL FILM CHARACTERISTICS

3.1 OIL ON THE SEA SURFACE

The state of the oil on the sea surface i.e. whether it predominantly forms a film or a multitude of small lenses, or both, is important in determining the reflecting properties of the surface. It is to be expected that fish oils are liberated from the fish in small drops which then rise to the surface, but little is known of their subsequent behaviour. A laboratory study was undertaken to increase our knowledge of their behaviour.

3.2 LABORATORY EXPERIMENTS ON SPREADING CHARACTERISTICS

Single drops of each oil tested were placed on the surface of water contained in a 5" diameter dish. The effects were observed with the naked eye, with the aid of a microscope and also with a closed circuit T.V. system set to high contrast. The change in the reflectivity of the surface was observed near normal incidence using the apparatus described in Section 4.2. These observations were continued for several minutes after addition of the drop. In other tests the surface was agitated to simulate the effect of sea waves on the oil film. Both distilled water and sea water (Artificial-Tropic Marine) were used. The oils tested were Cod Liver, Herring, Menhaden, Hake, Tuna, Shark Liver, a Chevron Mineral oil and SAE 30 Lubricating Oil.

Single drops of the oils added to a distilled water surface immediately spread to give a thin film. The reflectivity of the film near normal incidence was between 2 and 3 times that of water. Contamination of the water by small quantities of oil, e.g. by using the same dish for two experiments even after vigorous washing, resulted in the drops showing high surface tension behaviour and remaining as drops on the surface. When oil drops were added to a film of the same oil on water, they showed similar behaviour and remained as droplets on the film.

When sea water was used, it was observed that the fish oils spread more slowly to form a film which spontaneously broke up to produce small islands of oil. Agitation of the surface had the effect of producing small globules or lenses on the surface. In this state the reflectivity of the surface near normal incidence was similar to that of water. In contrast, the mineral oils again produce a film which was stable even on agitating the surface. The reflectivity of the films did not change with time.

The results showed that the oil drops spread more readily on a distilled water surface than on a sea water surface. Fish oil films on sea water are unstable and on agitation of the water, break up to form small lenses on the surface. On the other hand mineral oil films showed more tendency to form and were more stable on agitation.

A drop of liquid placed on the surface of a second liquid will spread only if the total surface energy is reduced by the spreading process. This condition implies that there is a greater attraction between the unlike molecules than between the like molecules. The spreading coefficient of a drop of liquid B on the surface of a liquid A is given by

$$\begin{aligned}\text{Spreading Coefficient } (\phi) &= \text{Work of adhesion between surfaces of A and B} \\ &\quad - \text{Work of cohesion of liquid B} \\ &= T_A - T_B - T_{AB}\end{aligned}$$

Where T_A and T_B are the surface tensions of liquids A and B and T_{AB} is the interfacial tension between surfaces A and B.

If ϕ is the positive liquid B will spread on liquid A.
It follows from the equation above that if liquid B spreads on liquid A, liquid A will not necessarily spread on liquid B. As the surface tension of water is 73 dynes/cm. at 20°C. and oils have surface tensions in the region of 30 dynes/cm., the tendency of oil to spread on water, rather than the reverse, follows.

The better spreading property of oils on a distilled water surface can be explained by a greater adhesion between their surfaces because of the largely unsaturated nature of a distilled water surface. Mineral oils seem to have a greater adhesion to a water surface than fish oils.

Section 4

LABORATORY INVESTIGATIONS OF THE OPTICAL PROPERTIES OF OIL AND OIL VAPOUR

4.1 ABSORPTION PROPERTIES OF THIN FILMS

The apparatus used in the measurement of the oil absorption consisted of a recording spectrophotometer and specially constructed sample cells. The cells were made of two quartz plates separated by copper separating pieces with the plates held together by clamps. The quartz plates fitted vertically in the sample holder in the sample compartment of the Bausch and Lomb Spectronic 505, so that the sample beam was in line with the oil sample. The oil to be tested was placed on one of the quartz plates before the separating piece was put in place, the second quartz plate was then clamped up to it. The separations had escape outlets so that the excess oils could escape leaving only a thickness of oil equal to that of the separator. To determine the absorption of the more absorbent oils they were diluted 24:1 with XYLENE. This gave an effective oil thickness of 1μ.

As part of the experimental procedure the Spectronic 505 was zeroed with the unloaded quartz plates in position. The cell would then be filled with oil and the absorption measurement run. Several of the oils were tested at film thicknesses of .001" and .003", however the .003" film thickness tests were soon discontinued due to excessive absorption and only the .001" tests were continued. The tests were made from 2800 Å to 4300 Å since all the highly differential absorptions seemed to occur in this waveband.

Because the crude mineral oils were very absorbent it was decided to carry out the diluted oil absorption tests. Several solvents were tested that did not absorb ultraviolet light and XYLENE was found to be the best solvent although not having a limiting wavelength as low as several of the other solvents. XYLENE was found to exhibit a very sharp cut off at 2900 Å and so the dilute oil tests were run from 2900 Å to 4400 Å. Due to the resultant mixture having far less viscosity than the fish oil, it was found possible to load the sample holder with the diluted oil by capillary action. This method of loading was found to be far more efficient than the two step assembly of the quartz plates.

The results are given in tables 4.1-1 and 4.1-2 and are plotted in figures 4.1-1 and 4.1-2. Table 4.1-3 gives the absorption coefficient and the absorption index of the oils at wavelengths 3000, 3300 and 3600 Å calculated using equation (2-9).

It can be seen from figures 4.1-1 and 2 that some of the oils show marked variation of absorption with wavelength in the 2800-3600 Å region. To find the effect of changes in the absorption with wavelength on the reflectivity, the absorption index must be inserted into equation (2-11). From table 4.1-3 the highest value of the absorption index found is about 0.05. Putting this value in equation (2-11) we see that even using the highest value of k, $m^2k^2 << (m-1)^2$ and therefore the reflectivity should depend only on the refractive index in this spectral region.

4.2 REFRACTIVE INDEX OF OILS BY BREWSTER ANGLE (See Figure 4.2-1)

Because most of the oils tested were opaque none of the simple methods of determining the refractive index could be used. For this reason the Brewster angle method was employed. It was shown in Section 2.1 that at the Brewster angle the relationship $\tan\theta_1 = \frac{m_2}{m_1}$ held, so that the refractive index of a liquid may be obtained by the determination of the angle at which the component of the reflected light polarized in the plane of incidence, falls to a minimum. An apparatus (Figure 4.2-1) was constructed which had two arms which could be raised and lowered simultaneously by means of a winch.

On one arm was positioned a quartz iodine bulb, a collimating lens and a polarizing filter;on the other arm was positioned a photomultiplier, a

OIL UNDER TEST	WAVELENGTH A^{o}						
	2800	3000	3300	3600	4000	4300	
COD LIVER OIL	11 89	13 87	25 75	13 87	2 98	2 98	% Absorption % Transmission
HERRING OIL (ALASKAN)	36 64	18 82	10 90	5 95	4 96	7 93	% Absorption % Transmission
HERRING OIL COMMERCIAL	36 64	27 73	25 75	22 78	23 77	25 75	% Absorption % Transmission
TUNA OIL ALBACORE	92 8	85 15	74 26	41 59	21 79	16 84	% Absorption % Transmission
HAKE OIL (PACIFIC)	69 31	69 31	80 20	52 48	13 87	11 89	% Absorption % Transmission
SHARK LIVER OIL	99 1	98 2	92 8	61 39	23 77	18 82	% Absorption % Transmission
MENHADEN OIL (CRUDE)	72 28	56 44	43 57	31 69	27 73	27 73	% Absorption % Transmission
CHEVRON CRC 28536	97 3	97 3	94 6	56 44	23 77	13 87	% Absorption % Transmission
CHEVRON CRC 28537	99 1	99 1	69 31	6 94	1 99	2 98	% Absorption % Transmission

Table 4.1-1 % Absorption by oil films of thickness 25μ

OIL UNDER TEST	WAVELENGTH A°						
	2900	3000	3300	3600	4000	4300	
CHEVRON CRC 28533	96	93	77	56	38	27	% Absorption
	4	7	23	44	62	73	% Transmission
CHEVRON CRC 28534	91	87	72	54	37	28	% Absorption
	9	13	18	46	63	72	% Transmission
CHEVRON CRC 28535	99	96	82	63	40	30	% Absorption
	1	4	18	37	60	70	% Transmission

Table 4.1-2 % Absorption by oil films of thickness 1μ

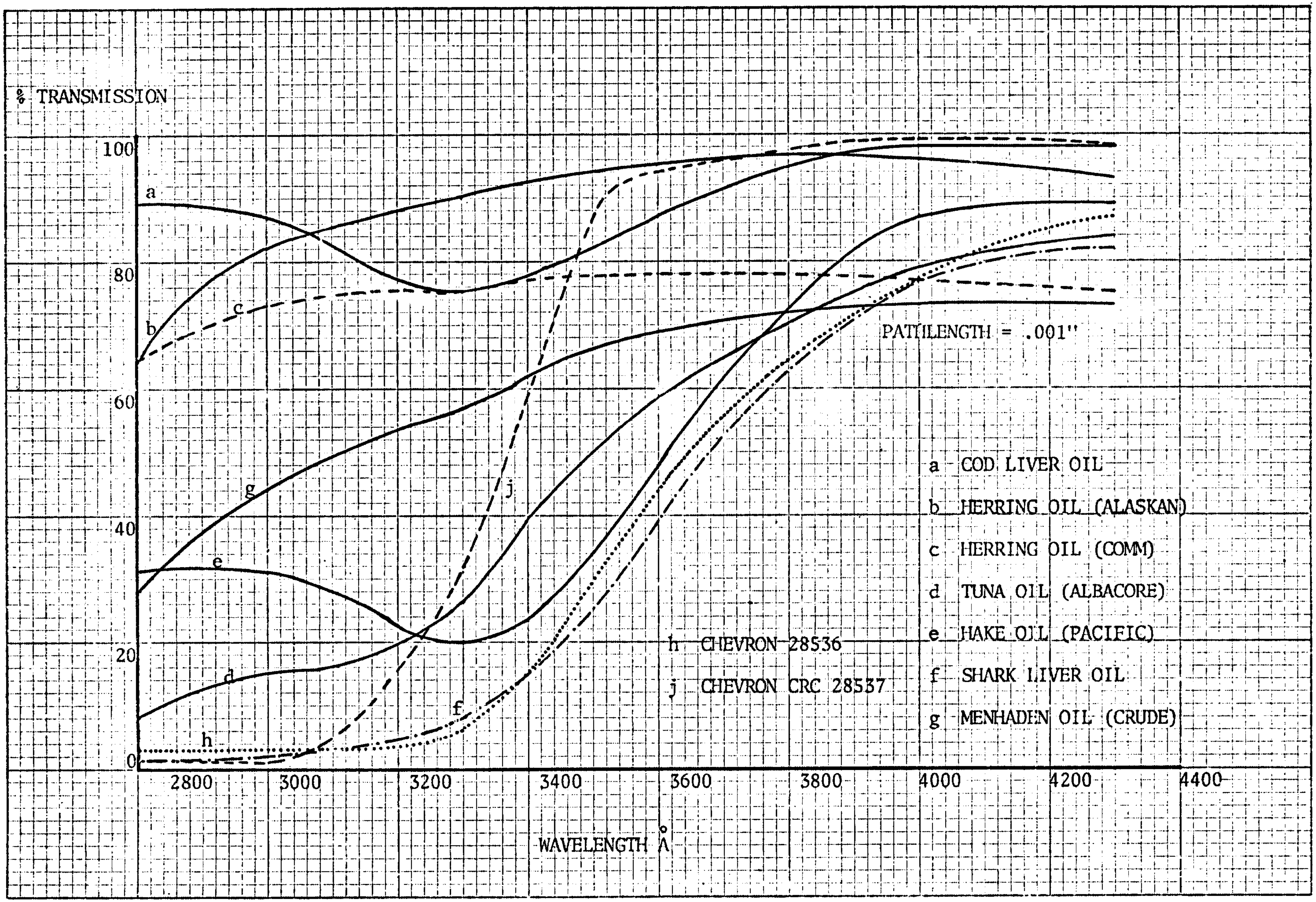
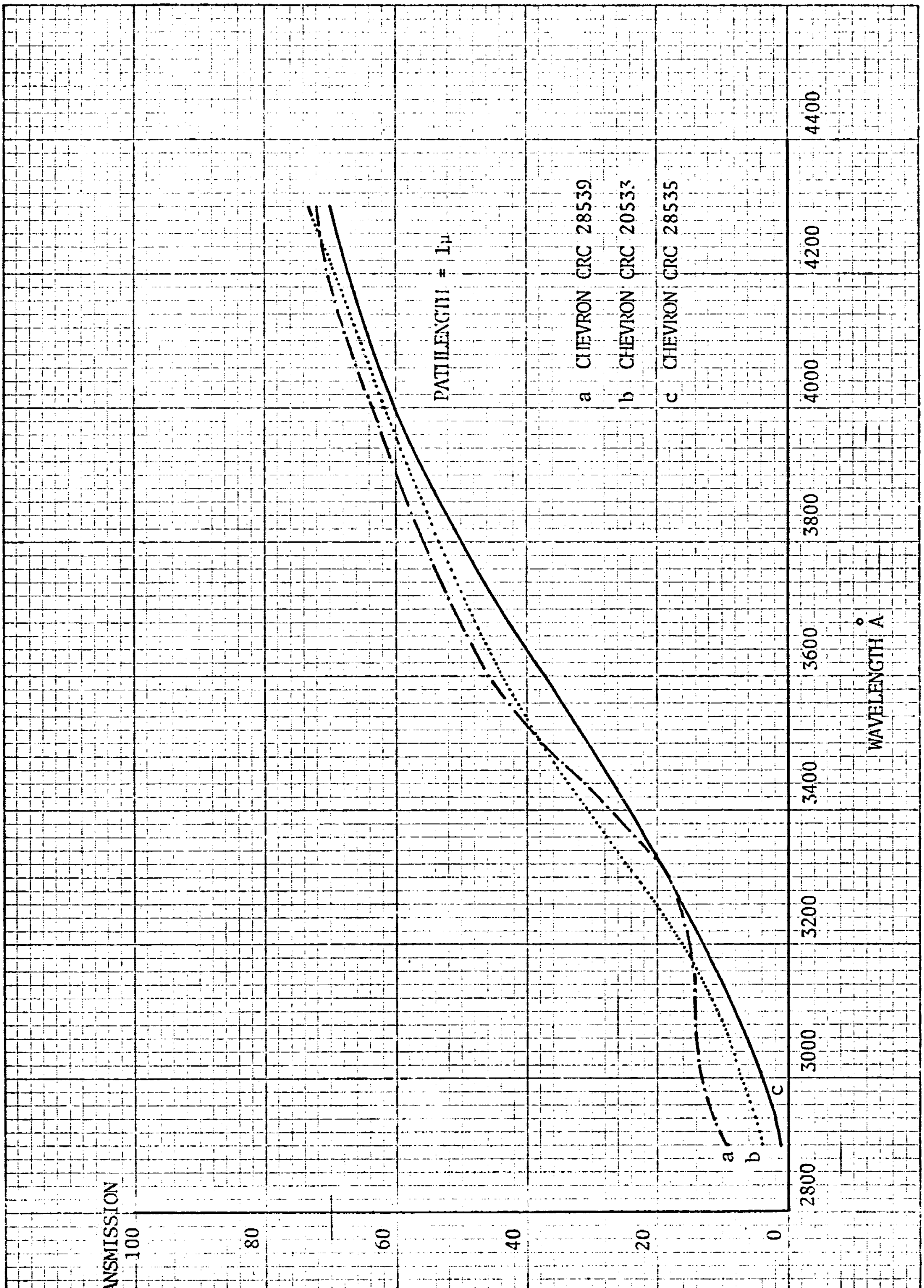


FIGURE 4.1-1 - OIL ABSORPTION SPECTRA



% TRANSMISSION
100
80
60
40
20
0
2800
3000
3200
3400
3600
3800
4000
4200
4400
WAVELENGTH Å
PATHLENGTH = 1μ
a CHEVRON CRC 28539
b CHEVRON CRC 20533
c CHEVRON CRC 28535
a
b
c

(iii)

OIL	WAVELENGTH Å	K ABSORPTION COEFFICIENT CM^{-1}	k ABSORPTION INDEX
MENHADEN (CRUDE)	3000	323.5	.000506
	3300	214	.000371
	3600	146	.000255
TUNA (ALBACORE)	3000	747	.001185
	3300	545	.000952
	3600	207.5	.000398
HAKE (PACIFIC)	3000	462	.000732
	3300	633	.00111
	3600	289	.000552
COD LIVER	3000	54.9	.0000875
	3300	113	.0001986
	3600	54.9	.000106
SHARK LIVER	3000	1540	.00246
	3300	995	.00175
	3600	370	.000715
HERRING (ALASKAN)	3000	78.1	.0001125
	3300	41.5	.0000727
	3600	16.1	.0000308
HERRING (COMMERCIAL PRODUCTION)	3000	124	.000196
	3300	113	.000198
	3600	98	.000187
CHEVRON CRC 28537	3000	1,813	.00275
	3300	462	.000781
	3600	244	.0000453
CHEVRON CRC 28536	3000	1,380	.00208
	3300	1,108	.001862
	3600	324	.000605
CHEVRON CRC 28533	3000	26,593	.0403
	3300	14,697	.0253
	3600	8,210	.0157
CHEVRON CRC 28534	3000	20,795	.0314
	3300	12,730	.022
	3600	7,766	.0148
CHEVRON CRC 28535	3000	33,525	.0508
	3300	12,729	.022
	3600	9,943	.019

Table 4.1-3 Absorption coefficient and index of the oils

SINGLE BEAM APPARATUS

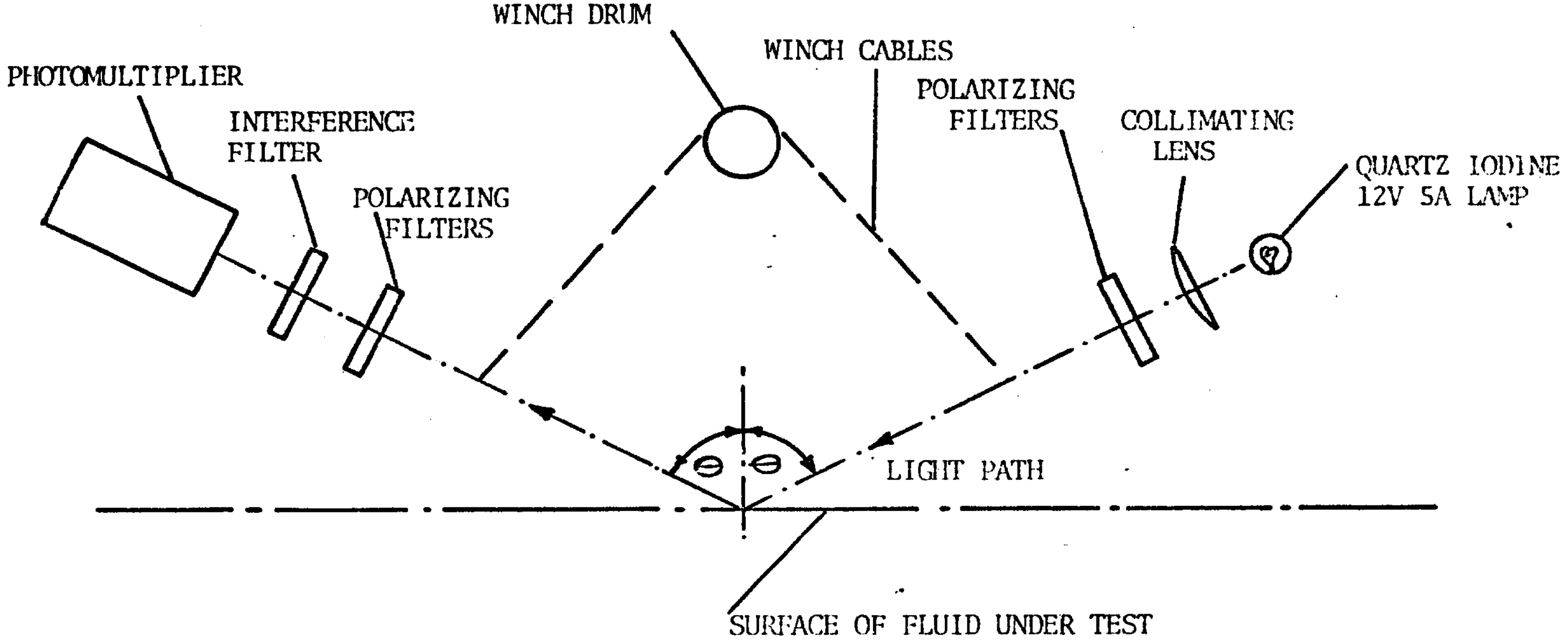


FIGURE 4.2-1

polarizing filter and a narrow band filter. The polarizing filters were set so that they polarized the light in the plane of incidence. With the fluid under test having its surface level with the common axis of the arms it is possible to have the collimated beam reflected onto the photomultiplier for any angle of incidence. The supply from the spectronic 505 was used for the photomultiplier but the output from the photomultiplier was fed into a separate chart recorder. The narrow band filter could be changed and tests were run with 3070 Å and 4500 Å filters.

The two arms had measuring pins set in them so that the distance between them could be measured at any time and the angle of incidence calculated. The tests were carried out in a darkened room and a large dark room cloth was draped over the apparatus to make certain that the stray light was not striking the photomultiplier. Disposable dishes were used throughout since it was virtually impossible to decontaminate the dishes once they had contained even minute amounts of oil.

The fluid under test was poured into a dish until its surface was level with the common axis of the arms of the single beam apparatus. The machine was set level so that the reflection from the liquid hit the center of the photomultiplier acceptance area. By winching up the arms slowly it was possible to detect the angle of incidence for minimum reflection, i.e. the Brewster Angle, to an accuracy of 0.2 degrees. When this angle was found the arms were locked and the distance between the measuring pins was determined and the angle of incidence and refractive index were calculated. All the oils, distilled water and sea water were tested in this way.

To determine the effect on refractive index of oil films on the surface of sea water, the dish was filled with sea water and the refractive index was measured as before, immediately after putting an oil drop on the surface.

TABLE 4.2-1 THE REFRACTIVE INDEX OF OILS, OIL FILMS AND WATER

		REFRACTIVE INDEX 3070 Å	 4500 Å
OIL	COD LIVER	1.50	1.50
	HERRING	1.51	1.51
	MENHADEN	1.53	1.53
	LUB OIL SAE 30	1.50	1.50
	CRUDE MINERAL	1.58	1.58
OIL FILM ON WATER	COD LIVER	1.25	
	CRUDE MINERAL	1.33	
	LUB OIL SAE 30	1.43	
WATER	DISTILLED	1.35	1.34
	SEA WATER	1.35	1.34

Table 4.2-1 shows that there is no significant difference in the refractive indices in any of the oils tested at the wavelengths 3070 and 4500 Å. There is therefore not likely to be any difference in reflectivity of the oils between these two wavelengths The fish oils, herring, cod liver and menhaden and the lubricating oil have similar refractive indices with values between 1.50 and 1.53. The mineral oil has an appreciably higher refractive index of 1.58.

Values of the refractive indices obtained for thin films of oil on water are lower than the bulk oil values. Films of around 1 micron thickness can however have different optical properties from those of the bulk material.

In Section 2.1 it was shown that the reflectivity at normal incidence is given by equation 6. If we take typical refractive indices of 1.50 for fish oil and 1.58 for mineral oil, the relative reflectivities to water are 1.9 and 2.4 respectively. If the oil spreads to a thin film of about 1μ thickness or less, these relative reflectivities may be much less.

4.3 DETERMINATION OF THE REFLECTIVITIES OF OIL AND OIL FILMS

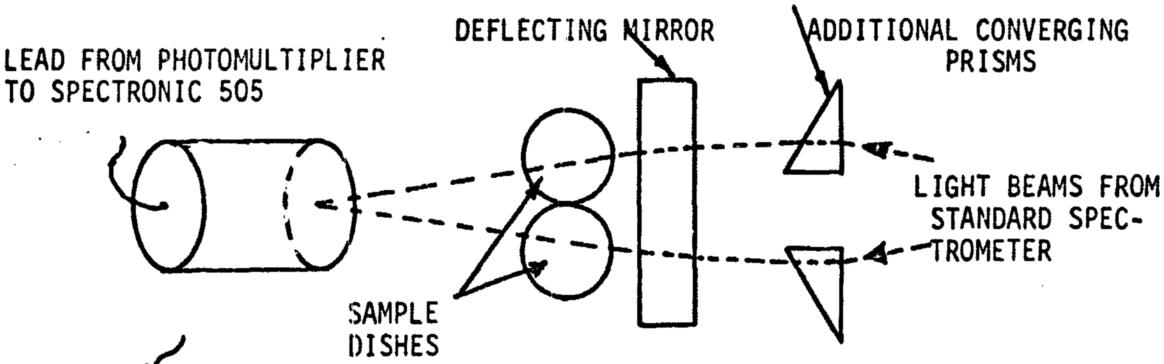
By placing a prism in each of the beams from the spectronic 505 it was possible to converge the two beams after a pathlength of approximately 11" as shown in figure 4.3-1. Immediately after passing through the prisms the light was deflected by a first surface mirror whose angle would be adjusted to give different angles of incidence onto a horizontal fluid surface. To pick up these reflections from the fluid surface a photomultiplier was placed in a housing and connected to the spectronic 505. The whole of the additional equipment that had been built onto the standard spectronic 505 was surrounded in a light tight box (figure 4.3-2) so that all the experiments could be conducted without any trouble through light leakage and dispensing with the need for a dark room. As before disposable dishes were used throughout for holding the fluid under test and the reference fluid. The dishes were put on an incline so that the reflection from the bottom of the dish did not strike the photomultiplier.

Because the photomultiplier acceptance area was only 1/2" diameter a quartz converging lens was placed before the photomultiplier. This lens converged the 1 1/4" beam onto the photomultiplier acceptance area. For the 60° incidence polarization tests, a mount was made to hold a polarizing filter in front of the lens. The screw mount enabled any angle of polarization to be easily and quickly available.

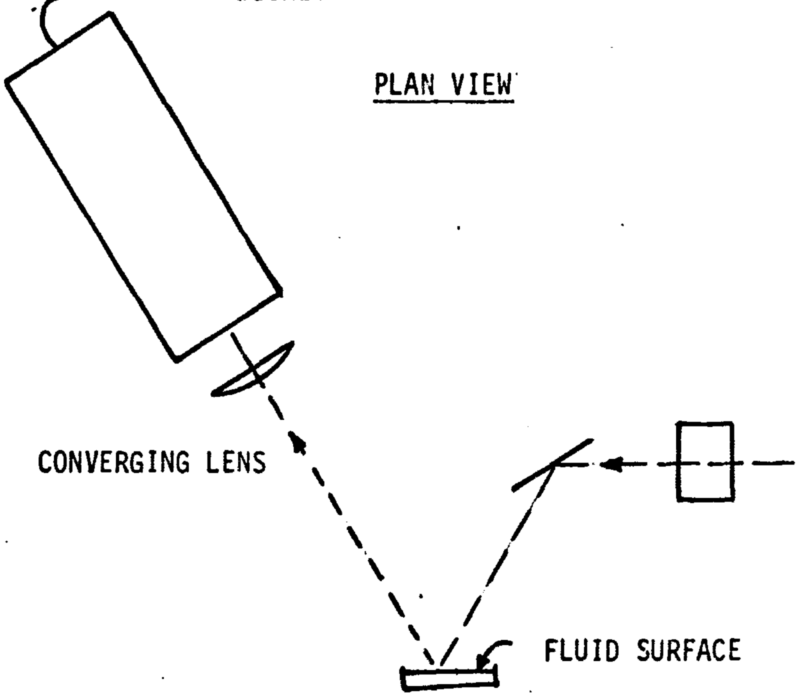
For the 30° reflectance tests the mirror was set at 30° to the horizontal. This then made the angle of incidence and reflection 30°. The tungsten light source was then placed in position and the wavelength dial of the Spectronic 505 set to 000. This gave a strong visible beam which made the positioning of the dishes and photomultiplier considerably easier.

It was found convenient to use SAE 30 Lube oil for the reference beam since this is stable and has a higher reflectance than sea water. This reduced the

DUAL BEAM REFLECTANCE APPARATUS

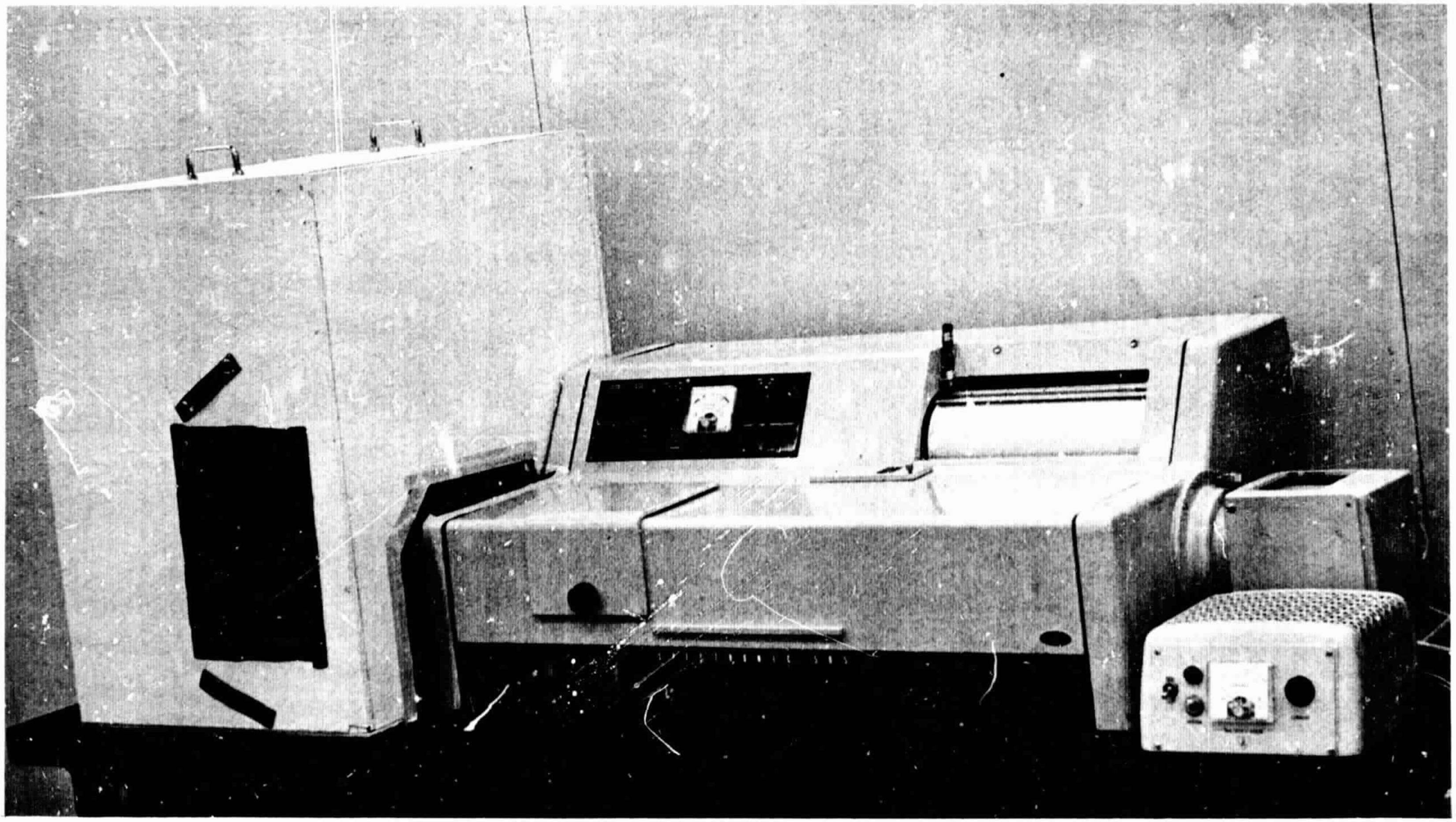


PLAN VIEW



SIDE VIEW

FIGURE 4.3-1



DUAL BEAM REFLECTANCE APPARATUS

FIGURE 4.3-2

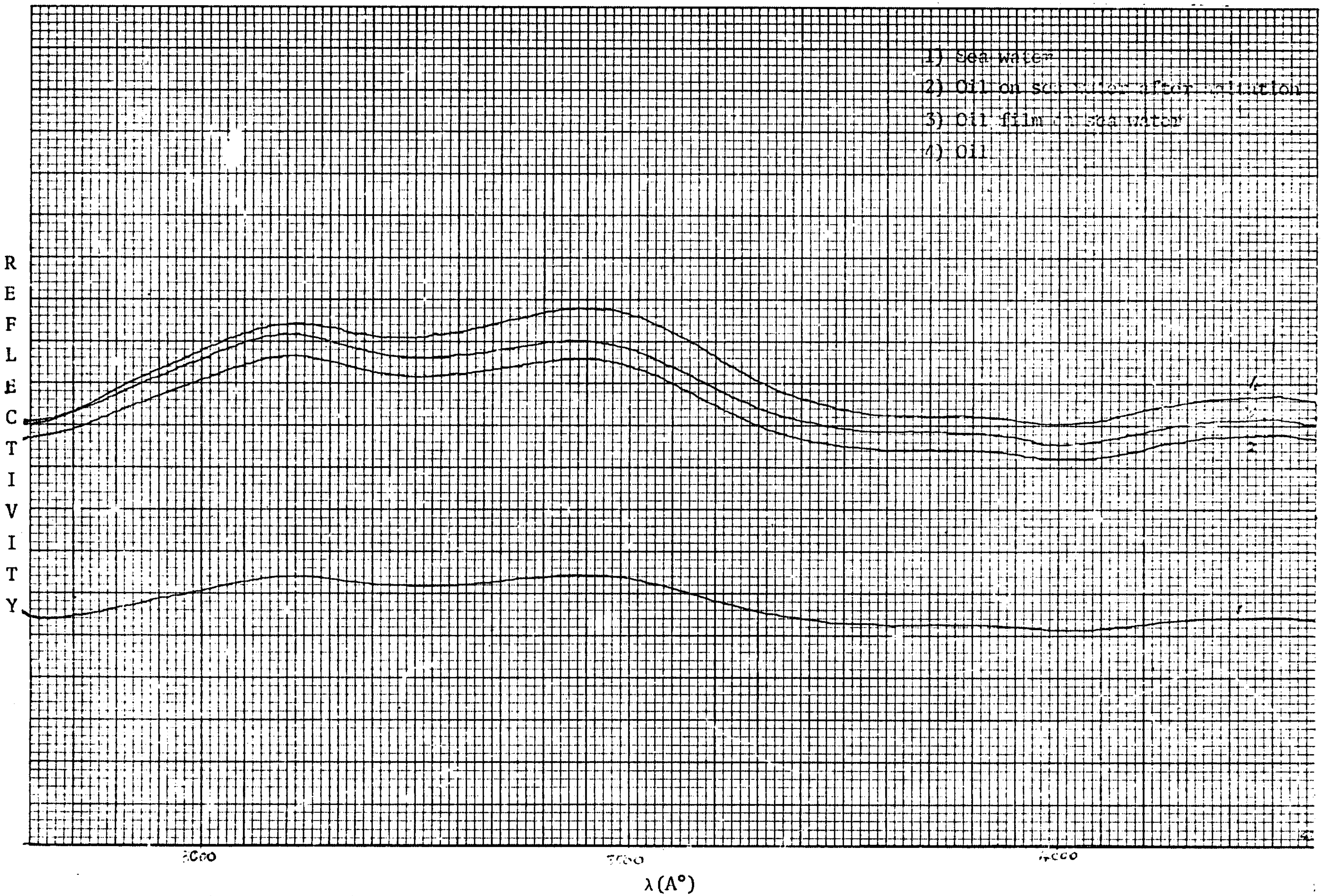
ratio of sample to reference, which was desirable since if the ratio is too high, permanent damage is done to the spectronic 505. In each of the tests the zero reflectance line was traced, followed by a trace of reflectivity against wavelength for a) sea water b) and oil film on sea water before and after agitation, c) the bulk oil. The wavelength range was from 2800 Å to 4300 Å.

For the 60° incidence reflectance tests the deflecting mirror was set at 15° from the horizontal. This gave an angle of incidence and reflection of 60°. The dishes and photomultiplier were repositioned to accept the new beam angle. The experiments were then carried out as had been the 30° incidence reflection tests, with the same traces being made.

The 60° incidence reflectance tests with polarization were carried out with the mirror dishes and photomultiplier in the 60° incidence position and a polarizing lens was mounted onto the end of the photomultiplier. Tests were carried out as before but with the light polarized in the plane of incidence.

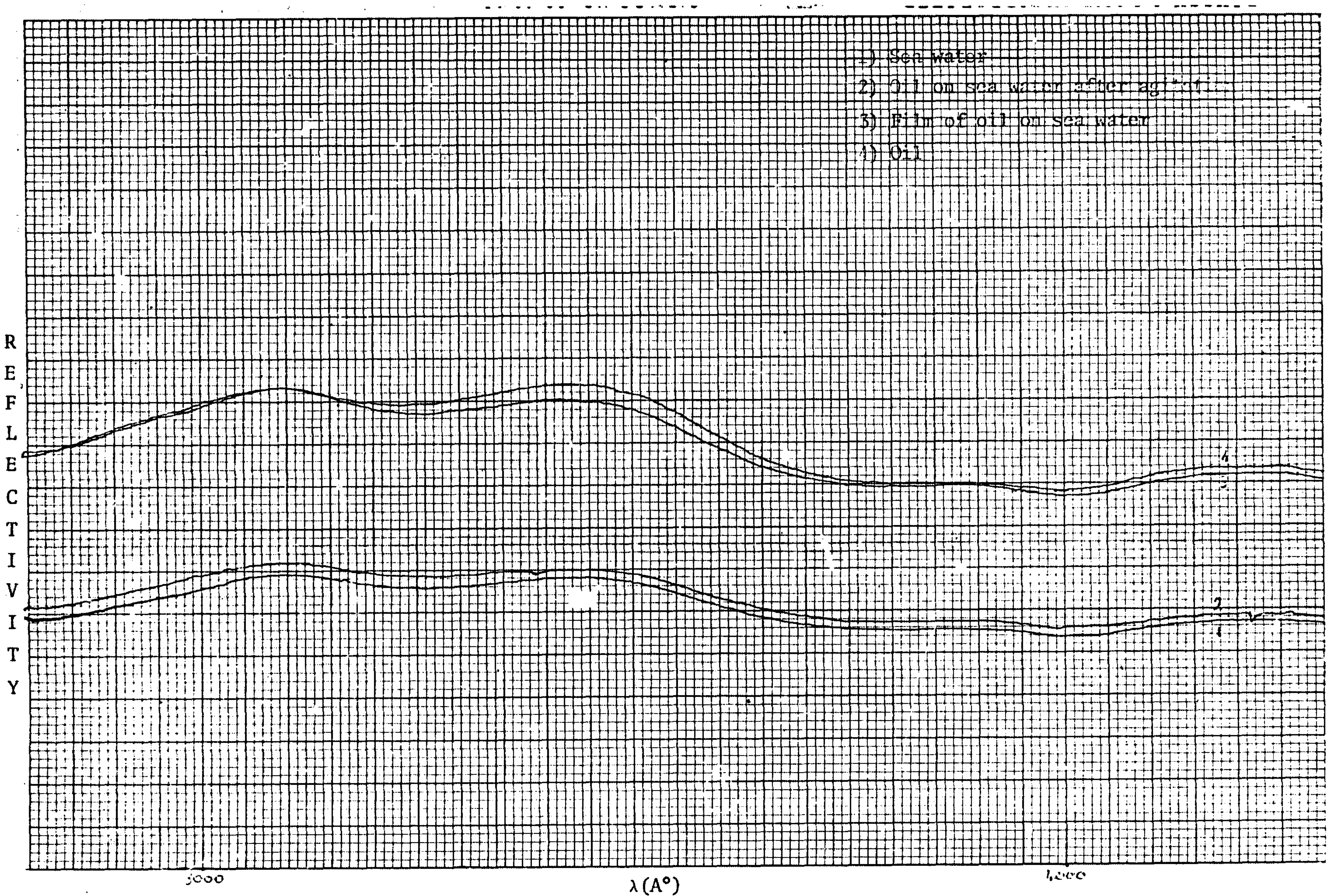
Typical experimental records are shown in figure 4.3-3 and 4 for a mineral oil and a fish oil, while all of the results on the reflectivities of the bulk oil and the undisturbed oil films are given in figures 4.3-5 and 6. Without exception, for all the fish oils, the effect of agitation of the water on the oil film was to break it up and reduce the reflectivity to a value close to that (Fig.4.3-7 for water. This can be seen in figure 4.3-4 which is typical of the fish oils. The mineral oils were stable on agitation (see figure 4.3-3), they showed the same reflectivity before and after agitation.

The reflectivities of the oils at 30° are approximately in accordance with the previously determined refractive indices. Cod liver oil, herring oil and lubricating oil have similar refractive indices and give similar reflectivities while menhaden and Chevron 28535 showing greater reflection also have higher



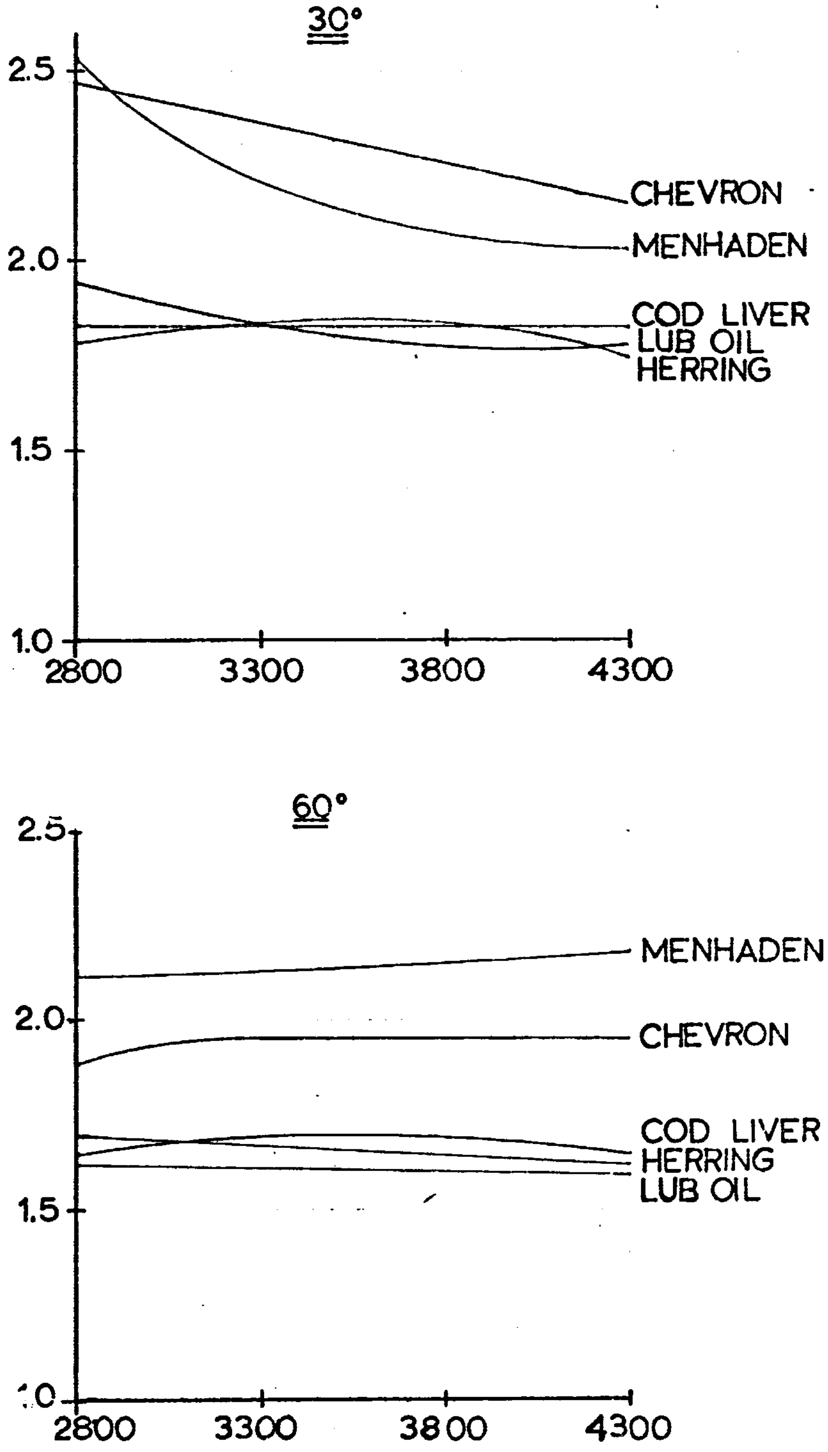
Experimental Record of reflectivity against wavelength for crude mineral oil

FIGURE 4.3-3



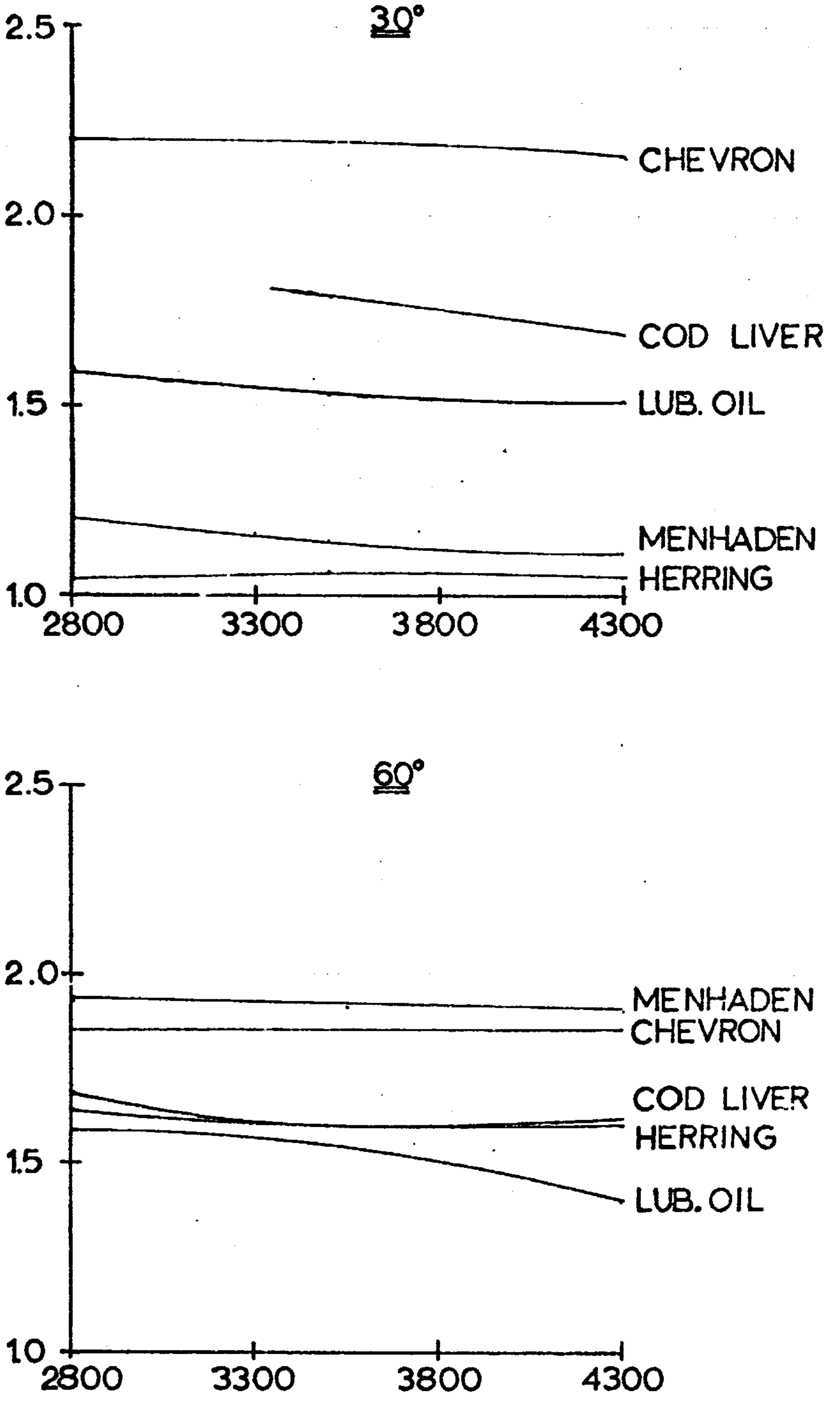
Experimental record of reflectivity against wavelength for cod liver oil

FIGURE 4.3-4



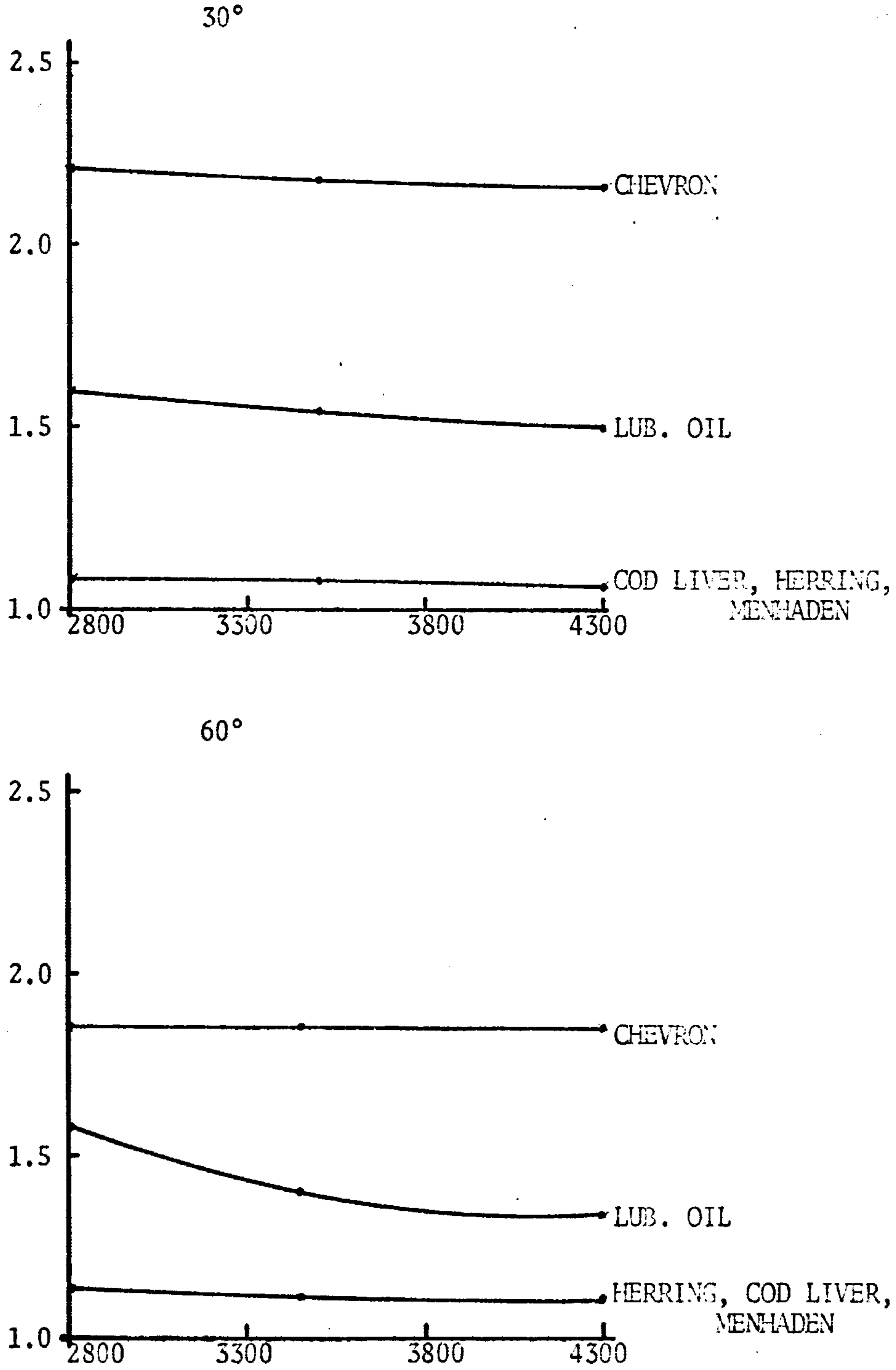
THE RELATIVE REFLECTIVITY OF OIL (REFLECTIVITY OF WATER = 1) AT 30° AND 60° ANGLE OF INCIDENCE.

Figure 4.3-5



THE RELATIVE REFLECTIVITY OF OIL FILMS (REFLECTIVITY OF WATER=1) AT 30° AND 60° ANGLE OF INCIDENCE.

FIGURE 4.3-6



THE RELATIVE REFLECTIVITY OF OIL FILMS AFTER AGITATION (REFLECTIVITY OF WATER = 1) AT ANGLES OF INCIDENCE OF 30° AND 60°

FIGURE 4.3-7

refractive indices. According to calculation (figure 2.1-1) the relative reflectivity of oil of refractive index 1.5 to water is 1.9 at 30°, which agrees fairly well with the measured values.

There is little variation of reflectivity with wavelength in the range 2800-4300 Å for the herring, cod liver and lubricating oils which agrees with the refractive index determinations. The Chevron and Menhaden oils gave a decreasing reflectivity with increasing wavelength amounting to about a 14% decrease from 3070 to 4500 Å, which would correspond to a change of only 3% in the refractive index.

At an angle of incidence of 60° the relative reflectivities are reduced as expected (figure 2.1-1). Again the cod liver, herring and lubricating oil have similar reflectivities and there is little variation with wavelength. It can be seen from figure 4.3-6 that the reflectivities of the films on water at 30° were spread over a wider range. This may be due to the physical state of the oil films which, in the case of the fish oils, have a tendency to break up spontaneously.

The crude mineral and cod liver oil films have a smaller reflectivity than that of the bulk material, an effect which was predicted by the refractive index measurements.

The polarization measurements made at 60° showed that the contrast between oil and water could be increased by excluding the component polarized perpendicular to the plane of incidence as predicted by figure 2.1-1. This is achieved at the price of a reduction in absolute intensity and a consequent reduction in signal to noise ratio.

4.4 VAPOUR ABSORPTION

4.4.1 Ultraviolet and Visible

The absorption properties of oil vapours were investigated in the wavelength range 2800 - 6800 Å using a 10 cm pathlength absorption cell in a Spectronic 505 spectrophotometer in double beam operation.

Gases from the bottles in which the oils had been stored were drawn into the cell. No absorption peaks were detected throughout the wavelength scan. Small amounts of oil were left inside the cell for periods up to 24 hours, but again no absorption lines were detected.

4.4.2 Infrared

The infrared absorption spectra of eight oil vapours were determined using a Beckman IR 10 Spectrophotometer. A 10 cm pathlength absorption cell was used with potassium bromide windows to provide adequate transmission in the wavelength range of interest, 2.5 - 14.0μ.

The oil vapours were drawn into the cell from the oil storage bottles and the spectra determined. Only Chevron mineral oils and cod liver oil gave an absorption peak. To increase the concentration of vapour in the cell, air was bubbled slowly through the oil in a test tube which could be heated to a controlled temperature. The cell was evacuated and drew air through the oil until atmospheric pressure was reached in the cell. It was hoped that by using this technique, the saturated vapour pressure of the oil would be attained in the air stream.

When the oil was at room temperature (25°C.), only the mineral oils and the cod liver oil showed strong absorption lines, although weak lines appeared in the spectra of all the other oils. Figures 4.4-1 to 4 show the spectra of crude

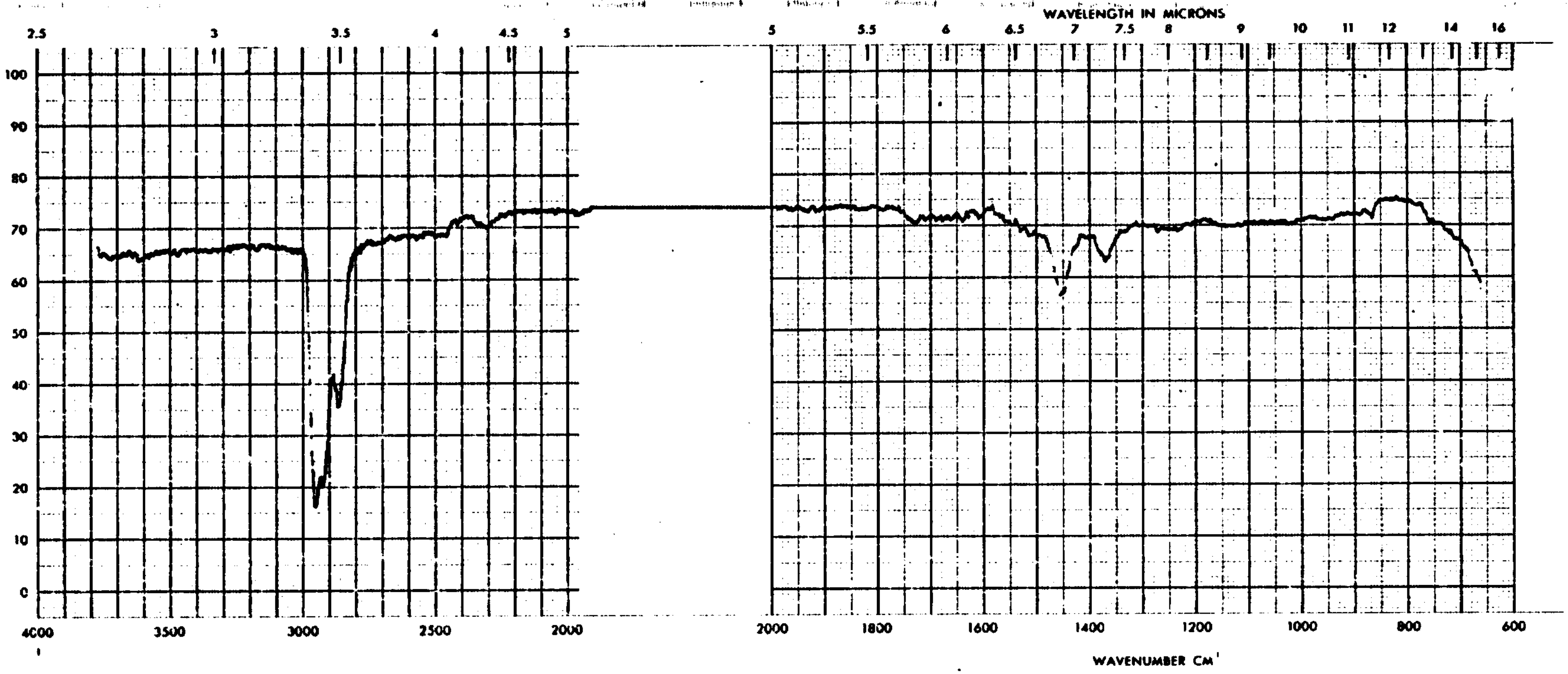
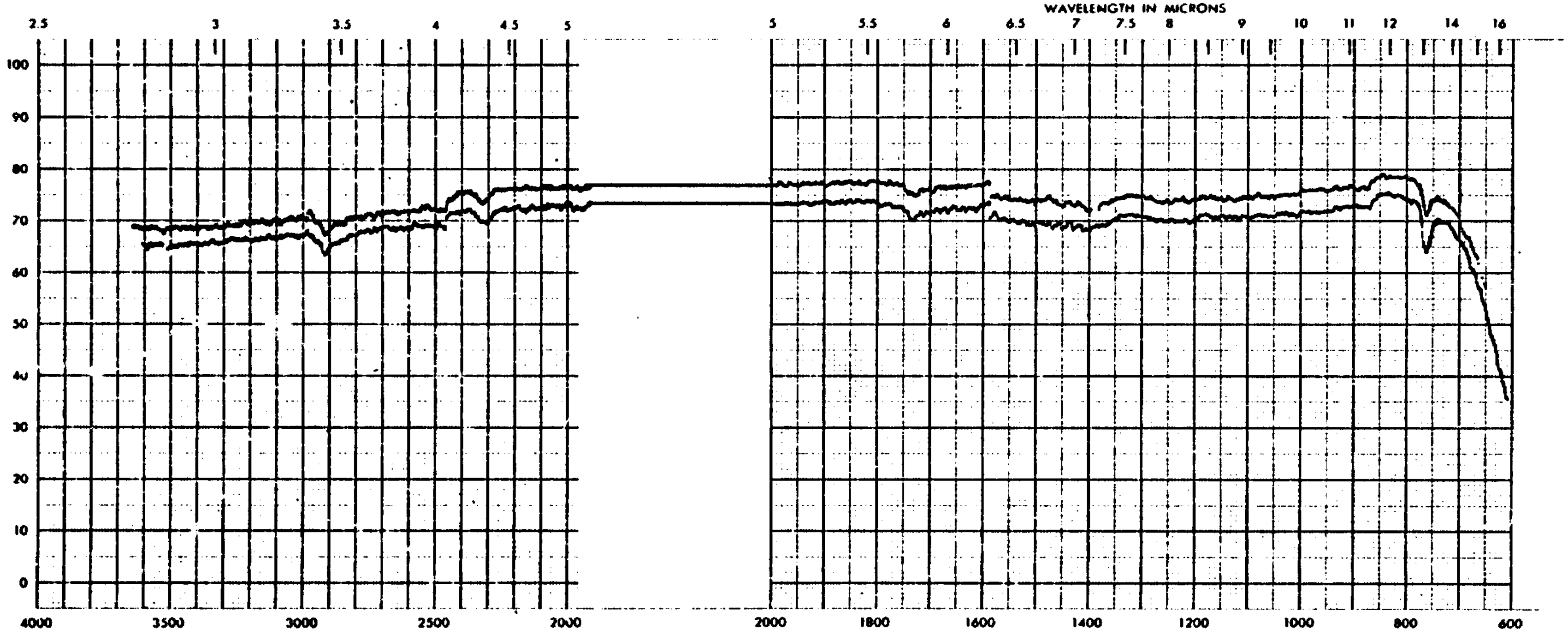


FIGURE 4.4-1 CRUDE MINERAL OIL VAPOUR



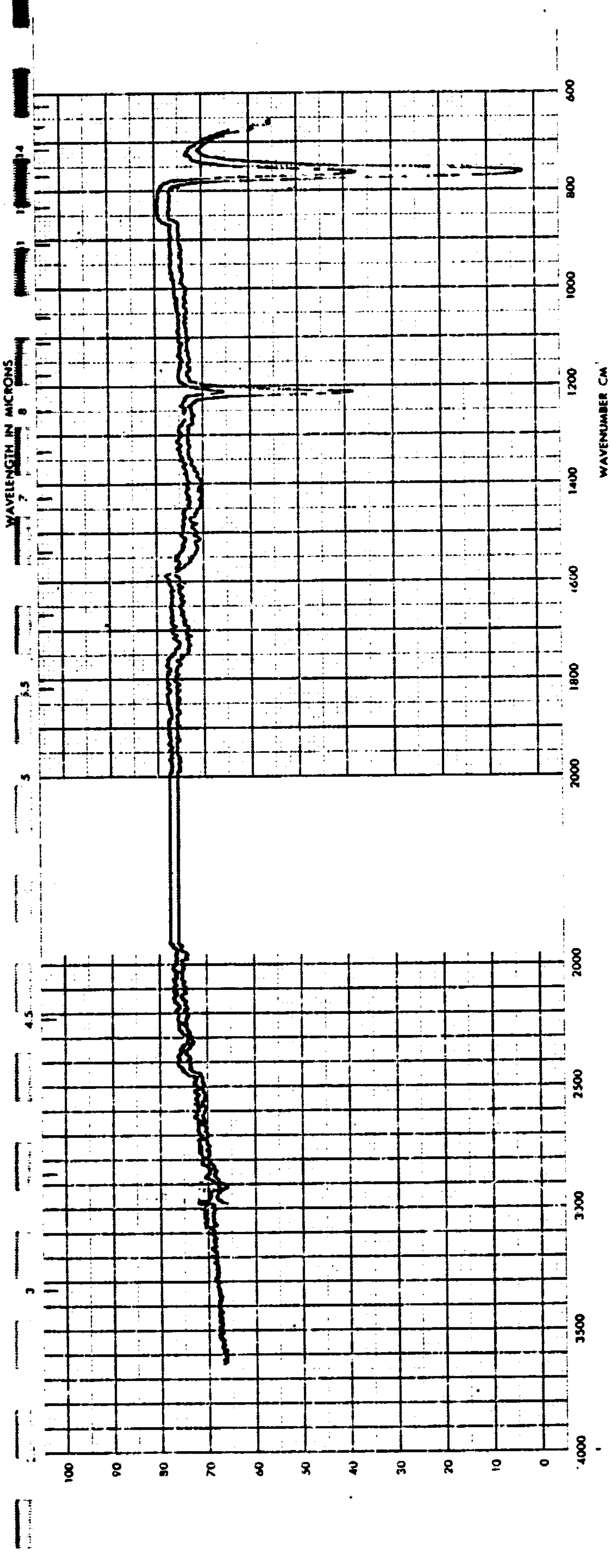
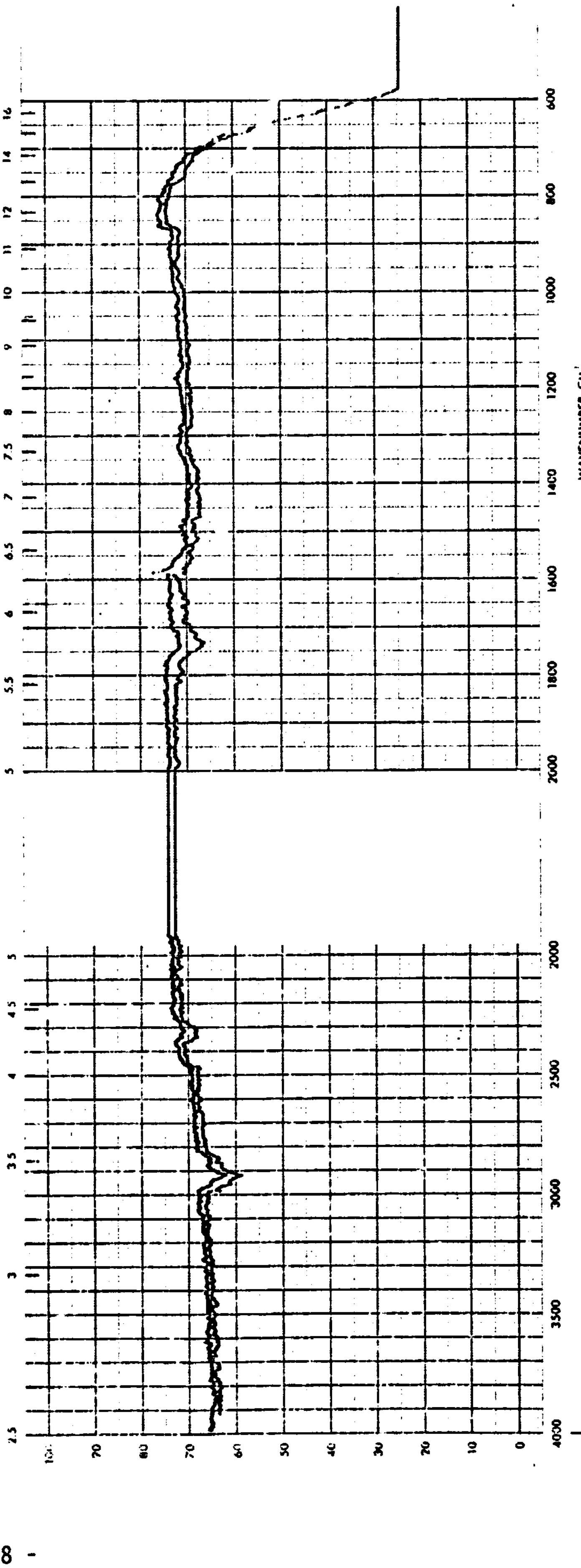


FIGURE 4.4-3 COD LIVER OIL VAPOUR



mineral oil at 25°C., cod liver, menhaden and herring oils at 25° and 50°C.

All of the oils gave an absorption line at 3.4μ - a characteristic carbon-hydrogen vibration line. The cod liver oil vapour had strong lines at 8.1μ and 12.8μ. These lines also appeared in the absorption spectra of herring, hake and tuna oil vapour although they were much weaker. The menhaden and shark liver oils gave a weak line at 5.7μ. The Chevron mineral oil gave a strong absorption at 3.4μ and weaker lines at 6.8 and 7.8μ, all characteristic carbon-hydrogen vibration lines.

4.5 DETERMINATION OF THE ABSORPTION OF ULTRAVIOLET LIGHT BY SEA WATER

Two 10 cm pathlength cells were filled with distilled water and placed in the reference and sample beams of the Spectronic 505. The zero absorbance line was thus recorded.

The sample cell was then filled with sea water and the absorption compared to that of distilled water in the wavelength range 2800 to 5800 Å. The results are given in table 4.5-1.

TABLE 4.5-1 ABSORPTION OF LIGHT BY SEA WATER
(ASSUMING DISTILLED WATER DOES NOT ABSORB)

WAVELENGTH Å	2800	3800	4800	5800
% ABSORPTION	12.5	9.4	9.9	9.7
ABSORPTION COEFFICIENT (cm^{-1})	0.013	0.009	0.010	0.010

Putting the above values of the absorption coefficient into equation 8, it can be shown that the transmission through one fathom of sea water is about 17% and through two fathoms, about 3%, assuming 100% transmission through distilled water. These figures represent maximum values of the transmission and it therefore seems that there is little possibility of detecting the ultraviolet light which is reflected from the sea bed when the sea depth exceeds a few fathoms.

Section 5

FIELD TRIP INVESTIGATION

5.1 STUDY LOCATION

The field trip portion of the fish oil study under NASA contract NASW-1642 was done on the west coast of Florida. The Aero Commander 500A, which had been outfitted with special quartz window veiwing pods and tracking mechanism, was used as the camera platform for the photographic work. The trip was coordinated with the United States Bureau of Commercial Fisheries from the Biological Laboratory in Pascagoula Mississippi, and also through the courtesy of the Bureau, with a commercial fishing fleet from Louisiana. The Bureau had their own boat, the Oregon II, in the area to obtain gorund truth in the areas of particular interest. This boat has been outfitted to carry scientific personnel and specialized sonar equipment to aid in the study of fish schooling activities.

The Barringer Research team worked closely with the Bureau of Commercial Fisheries (BCF) personnel to the point of exchanging personnel in each aircraft to facilitate training in fish school identification. Both aircraft were in air to air communication which aided in finding and photographing areas where large numbers of fish schools were found. The BCF aircraft was also in communication with the Oregon II to obtain simultaneous ground truth information concerning the type of fish. The actual size of the schools was determined by the Oregon II by both sonar sounding techniques and direct communication with the fishing vessels that were catching the schools.

The majority of the flights were done in the Fort Myer area of the Florida coast, working as far down as the Harnley River and Northwest Cape on the south end of Florida. After 3 days in the Fort Myer area the base of operations was moved up to the Clearwater-St. Petersburg region due to bad weather and rough seas. From this point flights were done up and down the coast from the Cedar Key and Crystal Bay area in the north to Tampa Bay area in the south. The flights lasted from 1 to 3 hours each and went as far as 30 miles offshore into the ADIZ.

5.2 RELATED SLICKS

The western coast of Florida is noted for its Thread Herring, and Menhaden fish schools which are used as bait and basic protein meal fish. There are also large quantities of Spanish Mackerel, Red Snapper, and Tuna which are considered game and food fish. The commercial fisheries are interested at the moment in the Menhaden and Thread Herring for their basic protein and oil content. During the BRL team's flights in the area the main fish of interest was Thread Herring.

The Thread Herring form very large schools in comparison with the size of the fish. The BCF has photographed schools up to a few hundred feet long with a rather irregular free form shape (figure 5.2-1) ranging from nearly circular to highly elongated. During the flights in the Fort Myer area many of these schools were sighted and photographed by the BRL team in colour and black and white. The schools form in the shallow areas near the shore ranging from 30 fathoms and shallower. From the air they appear as a very slowly moving grey-bluish shape in the water which may range from grey-blue in deep water to bright green in areas near the shore. If the water is slightly turbid and there is no growth on the bottom the problem of distinguishing the fish schools is very simple. With very little training one can rapidly spot a school at a low angle viewing (figure 5.2-2) to the horizon. However, in the shallow areas where the bottom does become visible, the problem is complicated considerably. The patches of growth from sea grass in the sand can have very similar shapes to the smaller schools and the dark colour is quite similar (figure 5.2-3). This means that a sufficient observation time must be available to pick up the

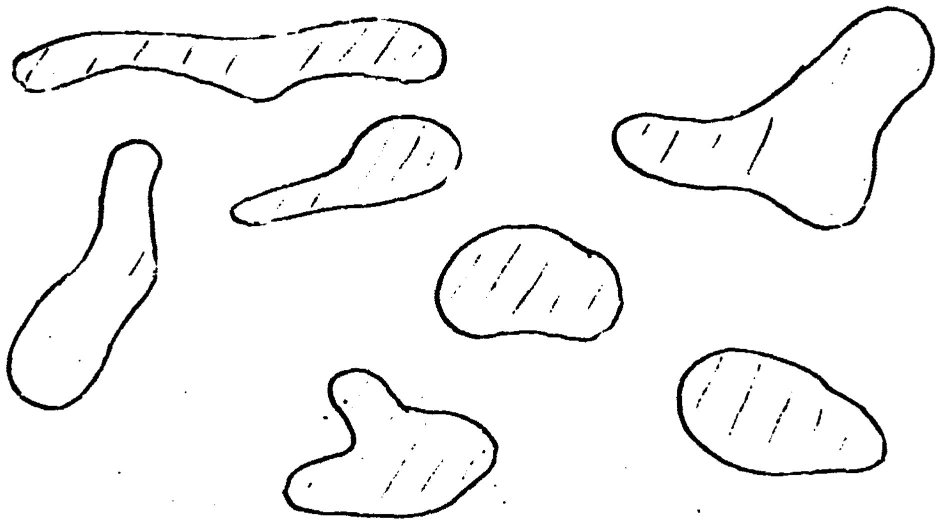


FIGURE 5.2-1 - FISH SCHOOL OUTLINE SHAPES

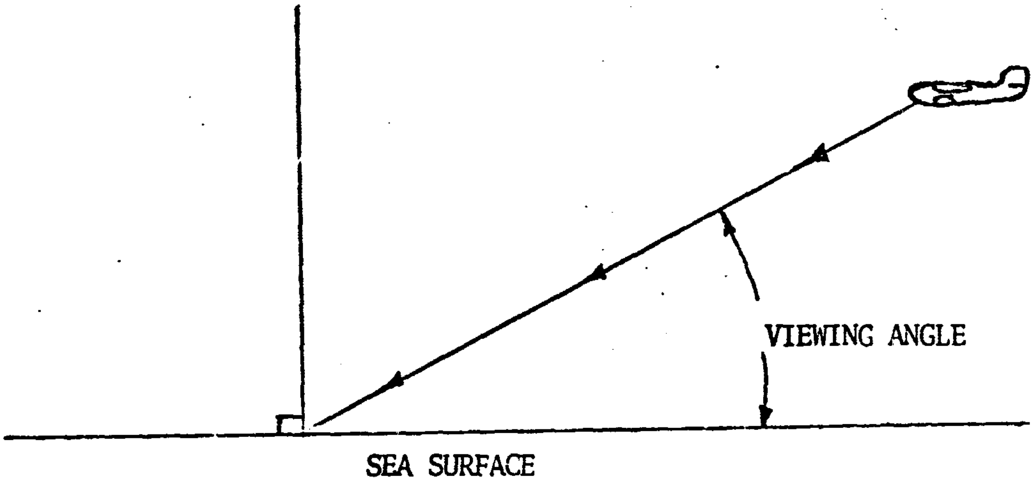
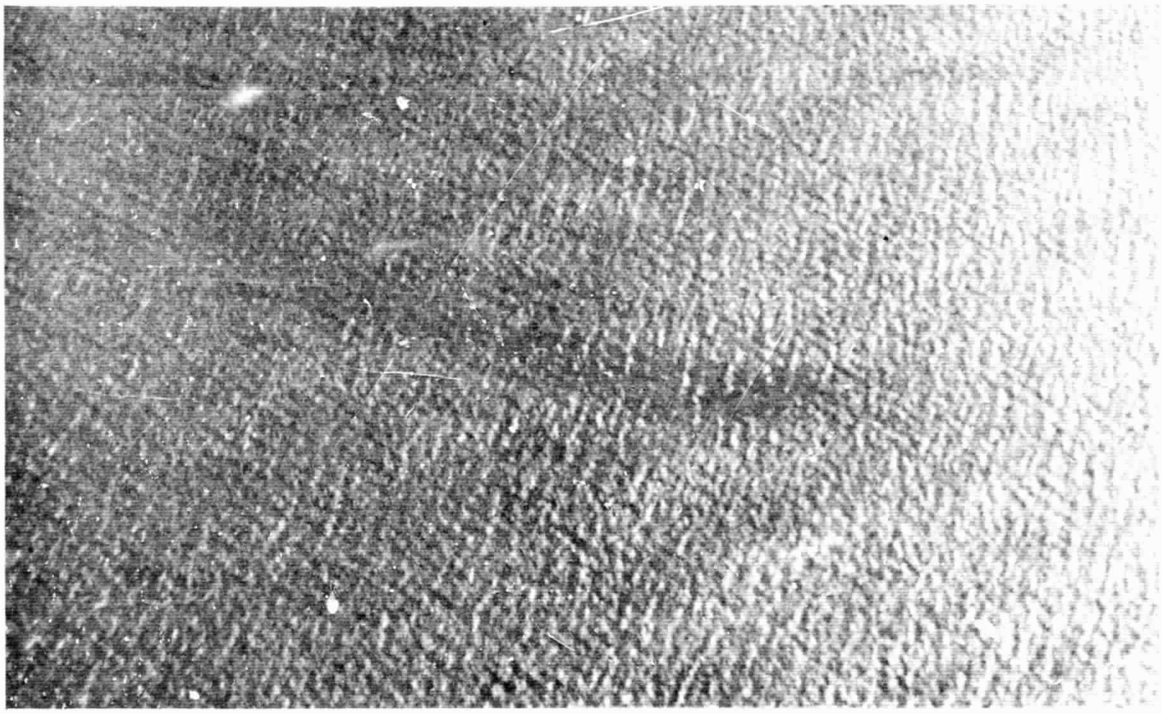


FIGURE 5.2-2 - VIEW ANGLE GEOMETRY

SHALLOW WATER BOTTOM APPEARANCE
FIGURE 5.2-3



SLICK NEAR FISH SCHOOLS
FIGURE 5.2-4

movement of the school with respect to its background. The illustration in figure 5.2-1 points out the fact that the schools do not necessarily appear as circular patches, but may appear quite elongated and irregular.

In the areas of high concentration of Thread Herring schools, there were many slicks on the surface which could be seen as smooth patches of water at small viewing angles. The patches were primarily ovoid (figure 5.2-4) and although some slicks were definitely associated with the presence of fish in general there did not appear to be a one to one correspondence between the slicks and the fish schools. Many photographs were taken of this type of slick from varying angles of view with respect to the sun as illustrated in figures 5.2-5 and 5.2-6. Naturally the slicks were most obvious when looking into the sun at low angles. As the slicks were approached in the aircraft from 3000 feet they rapidly became invisible as the viewing angle approached 90°. When directly over a slick there was no obvious discolouration of the water's surface, and in most cases the position of the slick was not directly over a school of Thread Herring. In all cases of slicks sighted in the vicinity of Thread Herring there was no visible patch when viewed from a 90° angle to the horizontal. These slicks were photographed in colour, in visual black and white and a sequence of runs with the 3090 Å and 3350 Å filter U.V. cameras was made.

The photographic runs made with the U.V. cameras were made during a period of high schooling activity with the whole surface of the sea in the Fort Myer area dotted with slicks. When making a run over the slick areas the procedure was to track on the visible schools of fish beneath the surface where a high correspondence between slick position and school position had been noted. The area of interest was colour photographed and then a run of U.V. exposures were taken directly over the school. In one instance, a very large slick with a circular head and long tail streaming away from it was in direct positional correspondence with the school below it. This was an exceptionally large

DOWN SUN SLICK APPEARANCE
FIGURE 5.2-5

CROSS SUN SLICK APPEARANCE
FIGURE 5.2-6

school, running better than 300 feet long and of irregular shape. The slick was one of the most pronounced and easily visible slicks observed. However, even in this case the slick was not observable from directly overhead. No discolouration of the water's surface nor change in texture was noticed and no direct correlation between the shape of the school and the shape of the slick was observed.

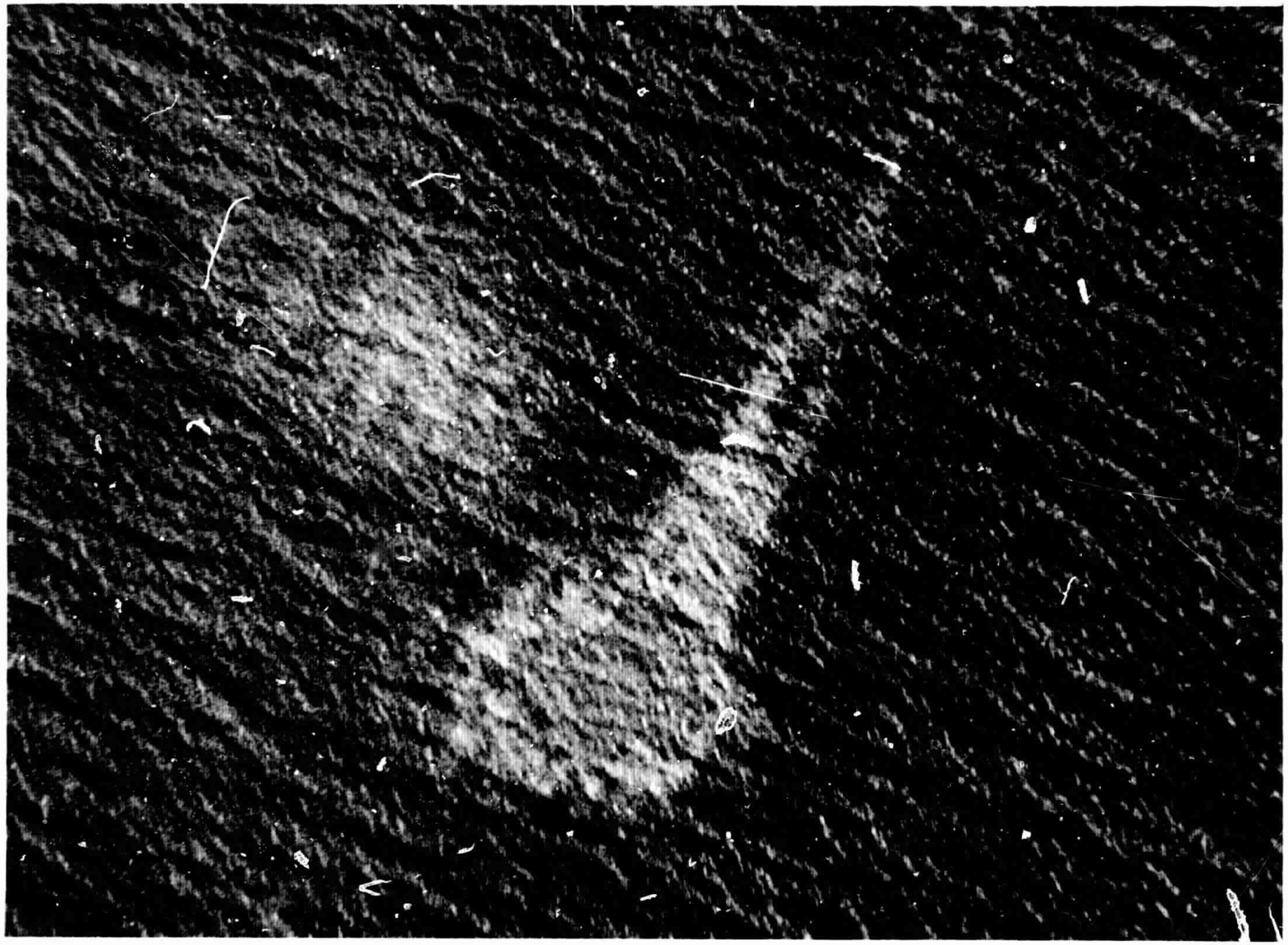
All of the slicks observed, which were associated with the heavily populated fish school areas, appeared to be primarily a surface calmness phenomena, rather than a definite increase in the reflectivity of the surface of the sea. This is the visual impression an observer recieves when looking at them from low angles. The observed characteristics of the slicks do not contradict the laboratory results which have been obtained with the Spectronic 505 spectrophotometer. The fish oils do not appear to cause any substantial increase in normal reflection as a function of wavelength over that of sea water. This means that when directly over a fish oil slick one would not expect to see it stand out in the visible due to increased reflection. However, the lack of small ripples on the sea surface could well be due to the lubricating properties of the fish oil film.

In many of the shallow areas of less than 30 fathoms, the visibility of the bottom is quite high. In vertical observations it appears that most of the light recieved by an observer is light being reflected from the bottom from sand or silt, which has been scattered by the sea water and hence appears quite green. The possibility of utilizing the U.V. absorption properties of the fish oils in transmission lies in the intensity ratio between reflected U.V. from the sea bottom to the intensity reflected from the surface. However, one can easily see that due to the optical properties of the ocean's surface, which acts as a disturbed mirror of approximately 1.7% reflection for raidation coming from the sun and sky half sphere, the surface component will be quite small. This is due to the fact that for an observer looking down normal to the sea's surface the only source of radiation will be the small cone of sky immediately above, which is limited by twice the maximum angle of deflection of the water's surface. Of this small amount of radiation only 2% average will be reflected back to the observer. On the other hand, of the order of 90% of the radiation from the sun and whole half sky sphere will be transmitted into the water, where it will be scattered and attenuated and eventually reflected from the bottom. From this relatively higher intensity source, the radiation of which will pass through the oil slick causing it to appear as a dark patch in the appropriate U.V. wavelength. This could be done while looking down on the sea's surface at normal incidence.

5.3 OTHER SURFACE SLICKS

The surface of the sea may have other types of slicks on it in the same area as fish schools. However, these types of slicks have no correlation with the presence of fish. These slicks can be due to mineral oils in bilge that is pumped overboard from boats or wind slicks which are caused by local areas of low wind velocity. Different zones of water which have a different turbidity will also cause a slick along the interface zone. In one case slicks were associated with large flocks of ducks which had grouped on the surface of the sea. All of these slicks have different appearances from each other but in some cases can be confused for fish slicks which complicated the identification problem considerably.

Mineral oil slicks are invariably easily recognized due to their high reflectivity and colour variation over the surface of the slick. The mineral oil slicks form roughly circular patches on the surface with a greatly increased reflectance over the sea water (figure 5.3-1). These type of slicks are coloured in that they appear bluish-grey with a considerable amount of structure within the patch. In some cases the structure loosely resembles concentric rings similar to the interference pattern one sees in small patches of oil on



MINERAL OIL SLICK

FIGURE 5.3-1

water. These slicks are readily seen at normal incidence due to their increased reflectance over that of sea water. This is true both in the shallow areas where the bottom is visible and in the deeper regions where the water appears as a rather dark background. The mineral oil slicks do not appear to be a problem for identification and separation from fish related slicks. Although at a low observation angle both of these types of slicks may appear the same, as the angle of observation is increased the mineral oil slicks remain easily visible and show considerable structure and colour.

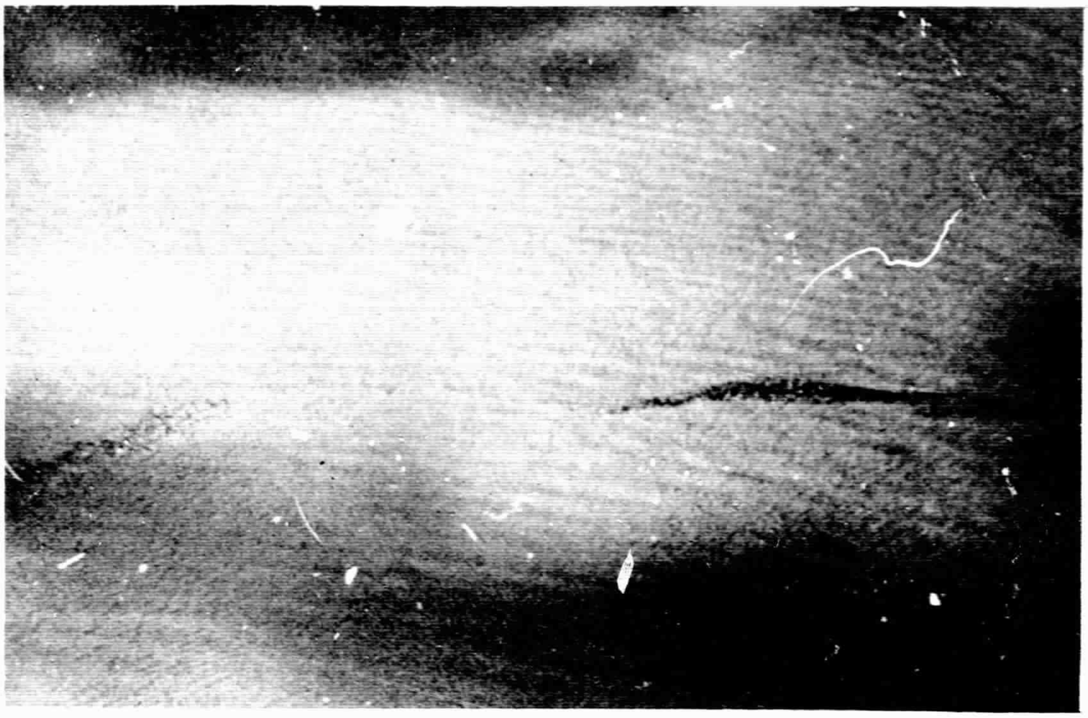
It has been found in the laboratory that the mineral oils form a continuous film on sea water and spread very smoothly without breaking up into small droplets. During the period of spreading as the oil film thickness changes the interference effects of the oil become apparent and multi-coloured reflections occur. The mineral oils have also caused an increase in normal incidence reflection when applied to the surface of sea water, as expected by the index of refraction change which occurs. These laboratory observations agree very well with the observations of the mineral oil slicks as they appear on the open sea.

Wind slicks have very similar properties to the fish related slicks. Although they may appear in obvious long thin threads on the ocean surface which can be easily recognized, they occasionally appear as rather round zones of smooth water, and this can be quite deceptive (figure 5.3-2). These slicks only appear at low observation angles and disappear as the angle of observation approaches 90° to the horizontal. They do not change position rapidly enough to be recognized due to motion alone. However, in most cases the recognition process is done by association with other thread type wind slicks in the same area. A variety of wind slicks were photographed in colour and black and white to provide a comparison with the fish related slicks.

Another type of slick which appears primarily as an elongated region of smooth water is over the interface regions between different water zones (figure 5.3-3).

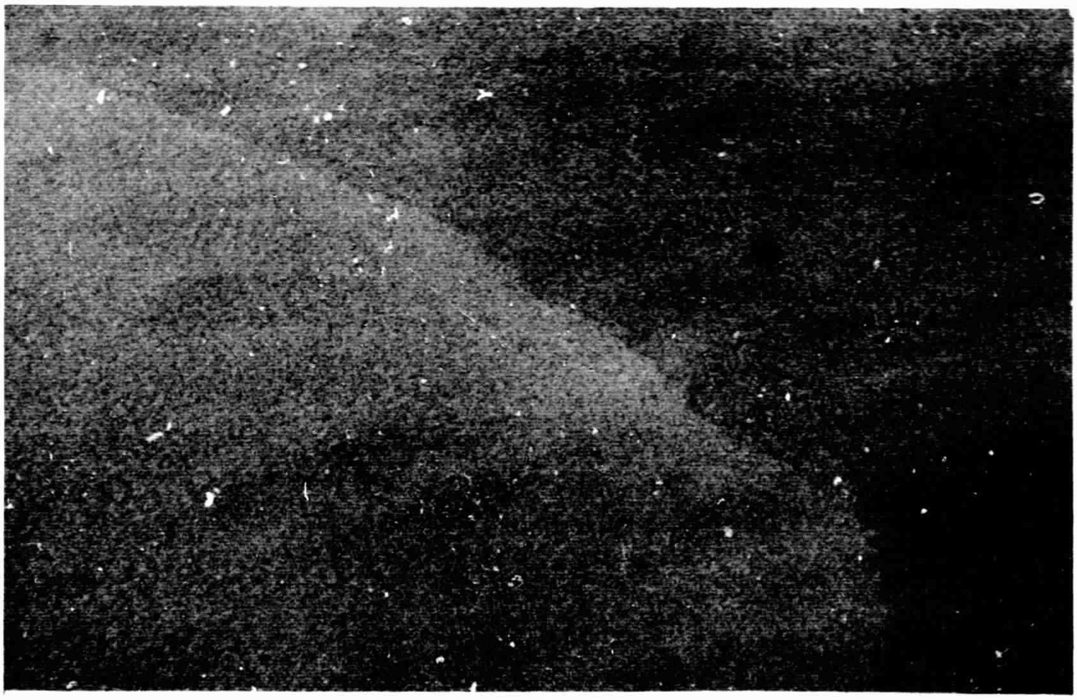
WIND SLICKS

FIGURE 5.3-2



INTERFACE SLICK

FIGURE 5.3-3



WATER DOME INTERFACE

FIGURE 5.3-4

This type of slick was observed and photographed after a storm had been in the area and the sea water was settling down and the turbidity decreasing. When two zones of water of different colour (figure 5.3-4), one being more brownish than the normal light green, were mixing, the interface region had a slick on the surface that ran all the way along the interface. These slicks were only observable at low observation angles and as the observation angle was increased the slick would disappear leaving the interface clearly visible due to the sea water colour difference.

One of the most deceptive slicks in terms of causing confusion with fish related slicks was caused by large flocks of ducks on the sea surface. The ducks form very large densely packed groupings of up to approximately 500 birds on the surface. The presence of the flock calms the water so that a slick forms which has all of the properties of the fish related slicks. When the aircraft goes directly over the slick a dark patch is seen in direct correlation with the position of the slick. From 3000 feet, individual objects were observed to make up the group but it was not until a low altitude pass was made, after a passing fishing boat had frightened the flock, that the individual birds were recognized. From high altitude it would be very difficult to resolve the individual birds well enough to be able to differentiate between ducks and a school of tuna fish. The observed birds were of a dark colour, giving the appearance of fairly large submerged fish, and when they took off in flight they assumed a loose V-formation, which is characteristic of fish of the Dolphin family. Thus with no ground-reference by which the judge speed the high-level survey gave complete ambiguity. This effect would possibly be enhanced if the birds were on shallow water with a clearly visible bottom, since all sense of stereoscopic vision is lost, although with experience patches of vegetation may be useable as ground-references for estimating speed. Light coloured gulls would probably not cause this problem.

5.4 SLICKS AND COMMERCIAL FISHING

The usefulness of any method of detecting fish slicks must be directly related to the importance of the information to the commercial fishing fleets and to the oceanographic service organizations which plot and inventory the fish locations and population density. This means that identification and time span of reporting is of primary importance. In terms of the inventory problem and long term planning for the commercial fishing fleets, the requirements are relaxed in that a time span of 1 week and positive identification of the majority of the fish in an area would be adequate. However, for a particular area, which is going to be fished by a commercial fleet, the time lag between sighting and identification and reporting to the fishers must be as short as 10 minutes.

The low time lag requirement comes about due to the techniques used to fish for bait fish which are to be used for their protein and oil content. The present system uses spotter aircraft, which are typically small single engined high wing aircraft, which fly over the coastal areas in the vicinity of the fleet until they spot the schools of fish. The spotters look primarily for the school beneath the surface and may or may not use slicks as indication of a good area to look for schools. The correlation between schools and oil slicks is not widely recognized or proven at this time. After sighting a substantial school of fish, the spotter will direct the commercial vessels into the area to deploy the net laying boats. If during this stage high powered sonar soundings are made to determine the shape of the school beneath the surface, the fish may go to the bottom and hide in the mud. When the fish sound in this fashion they drop below the level of the weighted nets and the fishing vessel must go onto a newly sighted school. If the fish do not sound, the small boat which deploys the net will circle the school under direction from the spotter aircraft overhead and eventually close the circle around the fish school. When this is done the net is gradually tightened up to increase the density of fish in the net area. A large syphon hose is then dropped into the closed net area and the school of fish is pumped into the hold of the ship. This technique requires continuous communication between the fishing vessels and the spotter aircraft.

In one instance it was reported that a fishing vessel was directed to an area which had a large school of fish in it by the spotter aircraft. On arriving in the area the vessel captain used low power sonar to search the area and found a school of fish which were hidden in a muddy zone invisible to the spotter aircraft. In contradiction to the directions of the spotter the vessel deployed its nets around the muddy zone and made a catch estimated at three times as large as the visible school. This is mentioned only to point out that remote sensing techniques used alone are subject to errors due to the lack of visibility and the final choice of net deployment will depend on both air sighting and sonar measurements.

In other instances the fishing vessel captains have reported using visual sightings of the slick areas as a basic guide for directing the fleet. The slicks can be seen from very low angles of observation but as they may not have a direct positional correspondence with the fish schools it only serves as a general guide. While flying over the fleets in operation in the Fort Myers area, it was observed that there was a large number of non mineral oil slicks near the area where the boats were working.

Section 6

SUMMARY OF THE OPTICAL PROPERTIES

6.1 ABSORPTION BY THE OILS IN THE ULTRAVIOLET

The fish and mineral oils show characteristic absroptions in the ultraviolet region 2800 - 4300 Å. At the lowest wavelengths the absorption by fish oil films of 25μ thickness ranges from 11 to 92%. The mineral oils are more absorbing, the transmission through a 1μ film ranges from 1 to 9% at 2900 Å.

The characteristic absorption curves of the oils should allow the oils to be identified by transmission measurements at two or more wavelengths in the ultraviolet region. For a practical remote sensing instrument two possibilities were considered. Firstly that light reflected at the oil/water interface passing twice through the oil film might be examined. Calculations showed that at normal incidence and assuming no absorptions, this component is less than 10% of the light reflected at the air/oil interface which itself is only 4% of the incident intensity. This possibility therefore offers a 10% variation in the received signal between complete absorption and no absorption in the oil film assuming a smooth surface and uniform film thickness and is unlikely to be practical.

The second possibility investigated was that in shallow seas the light reflected from the sea bed and emerging through the surface after passing through the oil film would exhibit the characteristic absorptions in the ultraviolet. Published figures (2) concerning the transmission of sea water in the visible range give pathlengths for an intensity reduction to 1% of 28 fathoms in clear coastal water and 84 fathoms in clear ocean water. The experimental data in section 4.5 show that the transmission of ultraviolet radiation is only slightly less than visible radiation. It was observed on the field trip study that the sea bed was visible in depths of less than 30 fathoms, but photographs in the ultraviolet at 3090 Å and 3350 Å did not show up oil slicks as dark patches on a lighter sea background. This may have been due to the oil films being too thin to produce sufficient absorption. At 3090 Å the absorption by herring oil films of 25μ thickness is only 10% and the actual oil slicks photographed may have been much thinner.

6.2 REFLECTIVITIES OF THE OILS

When the absorption indices of the oils were calculated it was found that they were too small to affect the selective reflection properties of the oils in the ultraviolet so that the reflectivity of the oils is determined only by their refractive index. The highest absorption index of the fish oils was 0.0025 at 3000 Å which is small compared with a typical refractive index of about 1.5.

The refractive indices of the oils do not vary appreciably between the wavelengths 3090 and 4500 Å. The fish oils have similar values ranging from 1.50 to 1.53. At 6500 Å values found by other workers range from 1.46 to 1.48 so that although fish oils show some dispersion it is small in the ultraviolet part of the spectrum.

The state of the oil film on the surface and the presence of waves effect the reflection properties of the surface. Fish oils spread quickly on a distilled water surface but on sea water they spread much slower and tend to break up spontaneously. If the surface is agitated the <u>visible</u> film breaks up to form small lenses on the surface although a monolayer film (3) may still remain. Evidence for a monolayer film on sea water was produced by the refractive index determinations on films. They gave values smaller than those of the bulk oil and close to the refractive index of water. After agitation of the film the reflectivity at normal incidence is close to that of water.

There is an obvious difference in the spreading properties of fish and mineral oils on sea water. Mineral oils spread more quickly and are more stable so that even after agitation of the surface a visible film remains which has two to three times the reflectivity of sea water.

By considering a sinusoidal waveform on the surface it is apparent that some parts of the waveform are more effective in reflecting light to an observer because of the varying curvature along the waveform. Looking vertically downwards on a surface wave with the ratio of amplitude to wavelength equal to 0.25, the weighted mean angle of incidence is not 0° but 32° 36'. It follows that the difference in reflectivity between a rough sea surface and a smooth surface is greater at larger angles of observation (measured from the normal) and that at normal observation the light from a surface where waves are present is polarized whereas from a calm surface the light is unpolarized. These considerations may be valuable if the presence of oil on the surface has the effect of calming the sea. Observations on the field study lead to the conclusion that the fish oil slicks are visible because of a surface calmness phenomena rather than because of a definite increase in reflectivity of the surface. When directly above the slicks they cannot be observed which suggests that the oil does produce a surface calmness which is more visible at oblique angles of observation and that the oil is in the form of small lenses as was found in the laboratory, although a monolayer film may still be present. In complete agreement with the laboratory studies the mineral oil slicks can be seen from directly overhead and have a greater reflectivity than the surrounding water.

The mechanism of the calming effect of oil on the sea can be found in the differences in the surface tension and viscosity of oil and water. An oil monolayer reduces the surface tension and therefore reduces the tendency of ripples to form and subsequently grow in size and form waves. The much greater (100 to 1) viscosity of oil increases the damping action on any ripples that do form.

The results obtained from the dual beam reflectivity measurements on the oils and oil films confirm what has already been found. At an angle of incidence of

30° the reflectivity of the oils range from 1.8 to 2.5 times that of water while at 60° the relative reflectivities are smaller. The reflectivities are approximately in agreement with those preducted by the refractive index. There is little variation of reflectivity with wavelength. The reflectivities of the oil films are lower than those of the bulk materials. At an angle of incidence of 30° there is a large range in values which may be caused by the spreading properties of the oils. Again little variation in reflectivity with wavelength is found. The reflectivity of the fish oil films measured after agitation is similar to that of water at both 30° and 60° angle of incidence while agitation of the mineral oil films produces no change in the reflectivity of the subsequently still surface.

6.3 VAPOUR ABSORPTION SPECTRA

No absorption peaks were detected in the range 3800 - 6000 Å. There may be absorption bands around 2000 Å, to be expected from theoretical considerations, but these wavelengths are too short for passive remote sensing.

In the infrared region 2.5μ to 14μ, the mineral oils and cod liver oil vapours show strong absorption lines in a 10 cm pathlength. The partial pressure of vapour in the cell was close to that of the saturated vapour at 25°C. The mineral oils gave a strong absorption at 3.4μ, and weaker lines at 7.3 and 6.8μ, all carbon-hydrogen vibration lines. Cod liver oil vapour gave a weak line at 3.4μ and strong lines at 8.1 and 12.8μ. The two fish oils which gave the strongest lines were also the two freshest oils. They had been prepared and kept under nitrogen, so that the vapour pressure of the oils may depend on their age and state of oxidation.

6.4 CONCLUSIONS AND FUTURE WORK

The results of this study show that the ultraviolet optical properties of the fish oils do not readily lend themselves to remote sensing. The fact that the optical properties of the bulk oil and the agitated oil film are completely different indicates that the physical properties of the films are a critical factor for the fish oil.

The most significant property of the oils in the form of films on the ocean's surface is the difference in reflectivity between the fish oils and mineral oils caused by the different spreading properties of fish and mineral oils. Fish oil slicks are visible only by virtue of their calming effect on the surface and are therefore more visible at oblique angles of observation.

The absorption properties of the fish oils in the ultraviolet should enable them to be classified in a laboratory instrument but there does not appear to be a good possibility of a remote sensing device based on these properties. No advantage is to be obtained by working in the ultraviolet part of the spectrum as far as remote sensing is concerned.

The absorption spectra of the oil vapours in the infrared show differences between fish oils and mineral oils. Here it appeared that the state of freshness of the fish oils is a factor in determining its absorption spectra. These tests should be done with very fresh fish oils to test for rapid oxidation effects and loss of volatile components.

The fact that fish oils break up into small droplets on sea water suggests that the scattering properties of the sea surface would be modified by the presence of fish oils and this should be further investigated. Analyses of the light scattered from the surface should reveal the presence of the fish oil. One possibility is to use a laser beam as the light source and pick up the back scattered light as the beam scans the ocean surface. The laser output could be modulated so that a phase sensitive detection system would distinguish between the scattered laser light and the scattered sunlight. Such a system would be operative by day or night.

It appears feasible to detect fish oil slicks in the infrared spectrum by virtue of the surface temperature modifications caused by the slicks. The energy loss of wave damping is absorbed in the surface film and furthermore, cooling by evaporation is inhibited. Scanning systems are proposed which employ mosaic detectors for spatial filtering purposes. Localized patches having a temperature differential with the surrounding sea could be detected at high sensitivity by this technique and it appears a promising method of locating fish. It could be used in conjunction with correlation spectrometry applied to iodine vapour detection which is believed to be associated with primary fish food and which would be a more general detector of potential fishing areas. Fish oil slick detection could also be used in conjunction with chlorophyl detection methods which would provide a general indication of biologic productivity.

Regional methods of identifying sources of primary fish food provide long term forecasting approaches which potentially form an ideal complement to fish identification methods giving short term forecasting.

REFERENCES

2 G.L. CLARKE — Oceanology International, Nov./Dec., 41, 1967

3 R.S. BURDON — Surface Tension and the Spreading of Liquids, C.U.P., 1949