Oil from Deep Water Fish Species as a Substitute for Sperm Whale and Jojoba Oils

D.H. BUISSON[1], D.R. BODY[2], G.J. DOUGHERTY[3], L. EYRES[4] and P. VLIEG[2]

ABSTRACT

The lipid fraction of the deep water fish species orange roughy (*Hoplostethus atlanticus*), black oreo (*Allocyttus* sp.) and small spined oreo (*Pseudocyttus maculatus*) had wax esters with even carbon numbers over the range C_{30} to C_{46} as the major components. The component acids and alcohols of the wax ester fraction were analyzed by gas liquid chromatography and compared with those of jojoba and sperm whale oils. Orange roughy oil was refined and deodorized and its chemical, physical and mechanical properties were determined. Hydrogenation of orange roughy oil produced a range of white crystalline waxes with melting points between 34 and 66 C. The characteristics of these waxes were very similar to those of hydrogenated jojoba oil and spermaceti. Lubricant tests performed on sulfurized orange roughy oil indicated it is comparable to sulfurized jojoba and sperm whale oils as an extreme-pressure additive in lubricants. The results show a sound technical basis on which to consider an industry based on orange roughy oil and the oreo oils as replacements for sperm whale oil and as substitutes for jojoba oil. Applications for the oil could be in the cosmetic and high-grade lubricant fields, the waxes in the polish, textile, cosmetic and pharmaceutical industries and the sulfurized derivative of orange roughy oil in the lubricant industry.

INTRODUCTION

The catching of the deep sea teleost fish orange roughy (*Hoplostethus atlanticus*), black oreo (*Allocyttus* sp.) and small spined oreo (*Pseudocyttus maculatus*) from depths of up to 1,200 m has recently been commercialized within the New Zealand 200-mile Exclusive Economic Zone (EEZ). The orange roughy is caught primarily for its white edible flesh, but increasing importance is being placed on the oil from this and other species.

The species *H. atlanticus*, thought to be the same as the single example of a fish called *H. gilchristi*, was found by Mori et al. to contain wax esters exclusively in the muscle lipids (1). Other work confirmed that the oil found in the muscle lipid of orange roughy is predominantly wax esters, with a minor amount of triacylglycerols (2). Production of oil from the orange roughy alone could potentially be 2,500 tons/yr based on the Government Controlled Total Allowable Catch. The oils, or more correctly liquid waxes, are obtained as by-products from the fish and can be recovered from fish waste either at sea- or shore-based plants.

The major current sources of liquid waxes (3,4) are the protected sperm whale (*Physter macrocephalus* and *P. catadon*) and the desert shrub jojoba (*Simmondsia chinensis* [Link.] Schneider). However, there are problems as to the supply of oil from these sources, which tend to keep the oil cost high. Thus, there is a commercial potential for the oils from orange roughy and the oreo species.

This study compares the properties of orange roughy, oreo species, jojoba, and sperm whale oils and suggests that orange roughy oil might replace sperm oil or substitute for jojoba oil. In the hydrogenated form, it could substitute for hydrogenated jojoba oil, spermaceti or other waxes of commercial importance such as carnauba and candelilla. The sulfurized form could substitute for sulfurized sperm or jojoba oils.

[1]Division of Horticulture and Processing, DSIR, Private Bag, Auckland, New Zealand.
[2]Applied Biochemistry Division, DSIR, Private Bag, Palmerston North, New Zealand.
[3]Chemistry Division, DSIR, Private Bag, Petone, New Zealand.
[4]Abels Ltd., PO Box 9573, Newmarket, Auckland, New Zealand.

MATERIALS AND METHODS

Source of Fish and Oils

Orange roughy, black oreo and small spined oreo were harvested, frozen on board the catching vessel and maintained at -30 C until required from vessels operated by Ferons Ltd., Fletcher Sovrybflot, High Seas Fisheries Ltd., Sanmar Ltd. and Wanganui Trawlers.

Samples of orange roughy oil recovered commercially were obtained as by-products of the fish meal operations from the vessels operated by Fletcher Sovrybflot Fishing Ltd. and High Seas Fisheries Ltd.

Samples of commercial sperm whale oil and spermaceti were obtained by the New Zealand Embassy in Tokyo from Nihon Hogei Co. Ltd., Tokyo, Japan.

Analysis of Lipid Level at Various Sites in the Fish

Six specimens of each species were taken from a random sample caught during December 1980.

Each specimen was divided into five sites: the head, removed along the line through the implant of the pectoral fin at right angles with the lateral line; the gut, including all organs in the abdominal cavity; the flesh, comprising two boneless, hand-skinned fillets; the skin from the fillets, including any subcutaneous fat; and the frame, consisting of the tail and remaining bones, fins and tissue.

Skin samples were cut into strips and then homogenized. All other samples were homogenized prior to analysis.

The oil content of each of the sites of the fish was determined by the method of Folch et al. (5) and the oil content of the fish was determined by summation. The results of the analyses of the six fish were averaged.

Analysis of Lipid

Extracted samples of oil from the whole fish were fractionated into their individual lipid categories by silicic acid column chromatography as described previously (6-8). The major lipid constituents (wax esters and triacylglycerols) released their representative acyl- and alkyl-derivatives following direct transesterification with boron trichloride/methanol/benzene (6,7,9). Fatty acid methyl esters and fatty alcohols were separated by silicic acid column chromatography with chloroform.

Fatty esters and alcohols were analyzed by gas liquid chromatography (GLC) using established conditions with precalibrated 10% ESGG-X and 3% JXR packed columns (6-8,10). Confirmation of the identification of various unsaturated isomers was determined by comparing their hydrogenated products with those of authentic saturated derivatives (10).

Wax esters were determined by GLC with short (0.65 m x 0.2 cm) 3% JXR columns (6,7) and the distribution pattern of the wax esters was compared according to their

total carbon lengths.

Analysis of Commercial Oil

Analyses of the intact oils for wax esters and triacylglycerols were determined by GLC using a (0.5 m × 0.16 cm) glass column packed with 3% OV-1 on 100/120 mesh Gas Chrom Q (Applied Sciences). The temperature of the injection port was set at 350 C, the detector temperature at 370 C and the column temperature was programmed from 120-355 C at a rate of 10 C/min. Carrier gas (N_2) flow rate was 21 mL/min. Area percentages of the peaks were calculated and normalized with no correction factors using a Columbia Scientific Computing Integrator.

Methods of Bleaching, Deodorizing, Hydrogenating and Sulfurizing Orange Roughy Oil

Activated earth bleaching under vacuum was done on a laboratory scale to simulate commercial bleaching equipment. The mixture of oil and 1% activated earth was heated at 105 C for 15 min under reduced pressure (50 mm Hg) attained by a water pump and then vacuum-filtered.

Deodorization was undertaken in a laboratory deodorizer under reduced pressure (5 mm Hg) using stripping steam of 3% at a temperature of 250 C for 15 min.

Hydrogenation was done in a vessel using 0.2% nickel catalyst (Resan 22) at 200 C and a hydrogen pressure of 30 psi (ca. 1,500 mm Hg). The reaction was monitored by changes in the iodine value. After reaching the desired degree of hydrogenation, the wax was bleached with 1% activated earth and citric acid (100 mg/L) and then filtered with filter aid (0.5%) while hot, cooled using a votator, and packaged.

The refined and deodorized oil was sulfurized by heating the oil at 160 C and slowly adding, with constant stirring, 15% by weight of sublimed sulfur in the presence of 0.1% by weight of zinc oxide catalyst. After reaction or dissolution of the sulfur, the mixture was maintained at 170-180 C for 3 hr with continuous stirring, then blown with air for 3 hr at 130 C to remove volatile, sulfur-containing compounds.

Analysis of Orange Roughy and Hydrogenated or Sulfurized Orange Roughy Oil

The test methods used for characterizing the orange roughy oil are outlined as follows (using AOCS methods).

Color	Lovibond color using Method BS 684 (11)
FFA (as oleic)	AOCS Ca 5a-40
Peroxide value	AOCS Cd 8-53
Iodine value	AOCS Cd 1-25

Refractive Index was determined at 45 C using a Bellingham Stanley refractometer.

The sulfur content in the sulfurized oil was measured using Method IP 61/65 and ASTM D129-64 (see below).

Nuclear magnetic resonance (NMR) spectra were undertaken on a Varian FT-80A NMR operating at a Carbon-13 frequency of 20 MHz. Samples were dissolved in deuterochloroform and the spectrum obtained by accumulating transients from 5,649 45-degree pulses at intervals of 0.819 sec.

Mechanical Tests

Test methods used refer to the latest Institute of Petroleum (IP) and American Society for Testing Materials (ASTM) standard test procedures as follows.

Kinematic viscosity	IP 71/80, ASTM D445-74
Viscosity index	IP 226/80, ASTM D2270-79
Density	IP 160/68, ASTM D1298-67
Pour point	IP 15/67, ASTM D97-66
Total acid no.	IP 139/65, ASTM D974-64
Flash and fire point	Cleveland open cup IP 36/67, ASTM D92-72
Flashpoint	Pensky-Martens closed cup IP 34/80, ASTM D93-77
Four ball extreme pressure test	IP 239/79
Copper corrosion classification	IP 154/78, ASTM D130-75
Foaming characteristics	IP 146/80, ASTM D892-79

The permitivity and conductivity were determined by the Physics and Engineering Laboratory, DSIR, Report No. S9637 as follows.

The sample of the oil was taken directly from a sample bottle of supplied oil to the test cell with no further treatment. The test cell was cleaned, rinsed in distilled water and dried before use. The cell was not cleaned between successive fillings. The ambient temperature was 22 ± 1 C.

The permitivity of the oil was determined at a frequency of 1.6 kHz and at a peak electrical stress of 2.5 Vmm^{-1}. The uncertainty of this result was estimated not to exceed ± 5% over four successive measurements.

After each permitivity measurement, the test cell was shorted for 1 min before beginning the conductivity test. The cell resistance was measured 60 sec after applying a DC voltage which subjected the oil to an electrical stress of 70 Vmm^{-1}. Over four successive measurements, the uncertainty of the result was estimated not to exceed ± 20%.

RESULTS AND DISCUSSION

Location and Quantity of Oil in the Fish

The quantities of oil in the orange roughy, black oreo and small spined oreo varied markedly, depending on the site of the fish being considered. Table I shows details of the percentage share of the total fish of the various sites and of the percentage oil in the whole fish and in each of the sites of the fish. The 9.9% average lipid content in the orange roughy fish muscle is much higher than the 4.5% muscle lipid reported by Hayashi and Takagi (2) on one specimen of orange roughy but is similar to the 8.0% for one specimen of the species *H. islandicus* reported by Kaufmann and Gottschalk (12) earlier. The sample fish used by Hayashi and Takagi may have been under either unusual conditions of habitat or exhaustion, two factors which can affect the fat level (13). Included in Table I are details of how the total oil content is distributed throughout the fish. The striking point is that the orange roughy head (ca. 39% of the body weight of the fish), which is usually discarded, contains 44.1% of the total oil content; the black oreo and small spined oreo—in each case, ca. 49% of the body weight of the fish. The amount of oil in the heads indicates the necessity to process the heads for maximal oil recovery.

Lipid Composition of the Fish Species

Lipid compositions of the total oils from orange roughy, oreo species, sperm whale and jojoba oil (14) are compared in Table II. Whole fish lipids of the orange roughy and black oreo and small spined oreo are characterized by the high levels of wax esters (95, 92 and 96%, respectively) and very small amounts of triacylglycerols (3, 5 and 3%, respectively). Small amounts of sterols and phospholipids were also detected. The levels of wax esters found compare closely with that found in jojoba oil (97%) and are considerably higher than that found in sperm whale oil (66%). Although triacylglycerols are not listed as being present in jojoba oil (15), Hamilton (16) suggested there are traces.

The composition of orange roughy oil (Table II) agrees reasonably well with that found by Mori et al. (1) for the related *H. gilchristi*, and Kaufmann and Gottschalk (12)

TABLE I

Site Percentage, Oil Content and Percentage of the Total Oil Content of Each of Five Sites for Orange Roughy (*H. atlanticus*), Black Oreo (*Allocyttus* sp.), and the Small Spined Oreo (*P. maculatus*)

	Share body wt (%)			Oil content (%)			Share oil (%)		
	Orange roughy	Black oreo	Small spined oreo	Orange roughy	Black oreo	Small spined oreo	Orange roughy	Black oreo	Small spined oreo
Whole fish				17.6	14.5	5.7			
Head	38.6	48.0	47.1	20.2	16.0	5.8	44.1	49.7	48.8
Gut	8.0	9.0	8.3	24.1	12.0	3.0	11.0	12.0	4.2
Skin	3.4	5.9	2.4	43.9	23.4	23.2	8.4	8.4	9.6
Frame	13.1	11.7	11.3	21.2	21.1	8.6	15.9	15.3	16.6
Muscle	36.3	23.7	29.1	9.9	7.6	4.1	20.4	14.7	20.8

TABLE II

Total Lipid Composition of Orange Roughy (*H. atlanticus*), Black Oreo (*Allocyttus* sp.), Small Spined Oreo (*P. maculatus*), Sperm Whale Oil (*P. macrocephalus*) and Jojoba (*S. chinensis*) Oils

	Orange roughy (%)	Black oreo (%)	Small spined oreo (%)	Sperm whale (%)	Jojoba (14) (%)
Wax esters	94.9	91.5	95.6	65.8	97.05
Triacylglycerols	3.1	4.8	2.5	30.1	—
Cholesterol/alcohols	1.0	2.7	1.5	4.0	2.45
Phospholipids	1.0	1.0	0.4	0.1	—
Others	—	—	—	—	0.52

found that *H. islandicus* had a similar lipid composition containing ca. 90% wax ester. In contrast, a similar species to the oreos, the black oreo (*Allocyttus verrucosus*) found off South Africa, had a lipid composition containing 76.3% wax esters and 17.3% triacylglycerol (17). These wax ester levels are lower than those found in New Zealand deep water fish species and perhaps reflect food and depth conditions in the New Zealand 200-mile EEZ.

Components and Composition of the Wax Esters

The principal components of the wax esters of orange roughy and the oreo species (Table III) are of C_{34}-C_{42} lengths. This contrasts with the shorter chain lengths of C_{28}-C_{36} found in sperm whale oil and the longer chain lengths found in jojoba oil.

The fatty acid components of the orange roughy wax esters (Table IV) are primarily 16:1, 18:1, 20:1 and 22:1 acids. Significant amounts of the saturated acid 16:0 were found in the oreo species. The fatty alcohol components (Table IV) are primarily of 18:1, 20:1 and 22:1 alcohols in all species but there are significant amounts of 16:0 in both the oreo species. The distribution of fatty acid and fatty alcohol moieties in the wax esters of orange roughy and the two oreo species for deep sea marine-derived wax esters is similar to that discussed by Sargent (18). Wax esters generally found in marine organisms, e.g., copepod *Calanus hyperboreus* (18), and in marine animals, e.g., castor oil fish *Ruvettus pretiosus* (19), consist primarily of 16:0 and 18:1 fatty acids and 16:0 and 18:1 fatty alcohols (20,21). The composition of the wax ester components of orange roughy oil is similar to that obtained for *H. gilchristi* by Mori et al. (1). There are, however, significant differences in the results obtained for wax ester lipids in *H. islandicus* (12), which had fatty alcohol components and compositions of 18:1 (55%), 14:0 (19.9%) and 16:0 (15%). These differences in fatty acid and fatty alcohol components may be attributable to the different composition of the diets, the depths at which the fish dwell and even the surrounding conditions (18). However, little work has been undertaken on the food chain of fish at these

TABLE III

Gas Chromatographic Composition of the Wax Ester Fraction of the Total Lipid of Orange Roughy (*H. atlanticus*), Black Oreo (*Allocyttus* sp.), Small Spined Oreo (*P. maculatus*), Sperm Whale (*P. macrocephalus*) and Jojoba (*S. chinensis*) Oils

Carbon no.	26	28	30	32	34	36	38	40	42	44	46	48
Species												
Orange roughy			0.2	2.1	11.4	16.7	24.8	23.4	14.8	5.5	1.1	
Black oreo			0.5	3.5	11.6	21.8	21.3	19.8	10.8	6.1	4.6	
Small spined oreo			0.5	2.9	9.3	18.3	26.2	25.4	12.8	4.3	0.3	
Sperm whale	4.7	14.0	21.1	23.2	19.9	11.7	4.4					
Jojoba (15)						1.6	6.23	30.56	49.50	8.12	0.86	0.16

TABLE IV

Percentages of Fatty Acids and Fatty Alcohols of the Whole Fish Wax Esters of Orange Roughy (*H. atlanticus*), Black Oreo (*Allocyttus* sp.), Small Spined Oreo (*P. maculatus*), Sperm Whale (*P. macrocephalus*) and Jojoba (*S. chinensis*) Oils

	Species									
	Orange roughy:		Black oreo:		Small spined oreo:		Sperm whale:		Jojoba (14):	
Carbons and double bonds	% fatty acid	% fatty alcohol	% fatty acid	% fatty alcohol	% fatty acid	% fatty alcohol	% fatty acid	% fatty alcohol	% fatty acid	% fatty alcohol
Saturated										
<14:0							21.6			
14:0	1.2		4.1	1.9	6.8		9.4	8.0		
15:0	tr		0.8	tr	0.7		0.9	1.4		
16:0	1.0	7.3	15.5	20.8	8.1	9.4	5.1	39.5	1.2	0.1
17:0	0.7		1.1	0.8	3.8		0.4	1.1		
18:0	0.3	8.1	3.2	2.3	3.7	0.9	1.5	7.7		0.2
19:0				0.6				0.2		
20:0	tr		0.2		tr		tr		0.1	
22:0	tr		tr		tr		tr		0.1	
24:0	tr		tr		tr		tr		0.2	
Unsaturated										
14:1	0.5		0.3		0.4		19.6			
15:1	tr		0.7		0.1		0.2	0.2		
16:1	11.8		7.9		10.9		15.6	4.1	0.3	
17:1	1.0		0.8	0.8	3.7		1.3	1.0		
18:1	56.0	34.6	26.9	19.0	32.8	23.3	17.8	35.4	10.1	0.7
18:2	1.9		1.0		0.9		0.5		0.1	
20:1	17.8	30.6	15.8	29.6	16.5	33.7	3.9	1.4	71.3	43.8
22:1	7.8	13.8	11.6	20.3	9.5	31.6	1.4		13.6	44.9
23:1	tr		1.8		2.1		0.8			
24:1	tr	5.4	8.3	3.9	tr	1.1	tr		1.3	8.9

TABLE V

Characteristics of Orange Roughy Oil (*H. atlanticus*) Produced Commercially from a Fish Meal Plant, Sperm Whale Oil (*P. macrocephalus*), Jojoba Oil (*S. chinensis*), Spermaceti Wax and Their Hydrogenated Derivatives of Orange Roughy and Jojoba Oils

	Oils					Solid waxes				
	Orange roughy					Hydrogenated orange roughy				
Characteristic	Crude (1")	Bleached (5¼")	Deodorized	Sperm whale	Jojoba	1	2	3	Spermaceti	Jojoba (25)
Color	30y 9R	5.1y				2.0y 0.2R	White	White	White/yellow	White
Iodine value (Wijs)			86.7	59-82	82	53.2	20.5	1.0	3-4	4
Melting point (C)						48.4	58.9	66.0	47.1	67.0
Freezing point (C)			0		7-10					
FFA (as oleic) (%)	0.3	0.3	0.2							
Peroxide value (meq/kg)	8.0	0	0.1							
Refractive index			1.4556		1.4570					
Wax ester (%)			93	70						

depths or on species such as the orange roughy and oreo species. It is known, however, that the fatty acid components of the lipids in zooplankton in the upper waters resembles phytoplankton in chain length distribution in having C14, 16, 20 and 22 as major acid moieties whereas deeper water zooplankton has 18:1 fatty acid as the major acid (22).

The components of wax esters in jojoba oil are primarily 20:1 and 22:1 fatty alcohols and 20:1 and 22:1 fatty acids. These fatty acids compare with the 18:1 and 20:1 in the marine species and result in longer chain wax esters in the jojoba oil.

Composition and Properties of Orange Roughy Oil after Processing

Orange roughy oil produced commercially from a fish meal plant is orange-colored with the analytical characteristics shown in Table V. Jojoba oil and sperm whale oil characteristics are shown for comparison. After bleaching and deodorizing, the majority of the color was removed and an odorless oil was produced with improved characteristics (Table V).

A batch of orange roughy oil was hydrogenated to various degrees of hydrogenation and compared with spermaceti and hydrogenated jojoba oil. The degree of hydrogenation was measured as the change in iodine value. The characteristics of three hydrogenated orange roughy oils, spermaceti and hydrogenated jojoba oil, are compared (Table V). The hydrogenated orange roughy oil is a pure white, crystalline wax with no detectable odor and its characteristics compare favorably with both spermaceti and hydrogenated jojoba oil. The range of melting points (33-36 C) available through partial hydrogenation indicates that the melting point range shows a linear inverse relationship with iodine values of over the range used (1-76 Wijs).

TABLE VI

Properties of Refined and Deodorized Orange Roughy (*H. atlanticus*), Jojoba (*S. chinensis*), and Rapeseed (*Brassica* sp.) Oils and for Comparison of a Typical Hydraulic Oil: Physical Properties of the Sulfurized Derivative of Orange Roughy Oil and of Mixtures of Orange Roughy and Sulfurized Orange Roughy Oils in Base White Oil

				Oil					Base white oil[a] +		
IP	ASTM			Orange roughy	Jojoba	Rapeseed	Hydraulic[b]	Sulfurized orange roughy	–	2.5% Orange roughy	2.5% Sulfurized roughy
71/80	D445/74	Kinematic viscosity, mm^2/sec (centistokes) at:	20 C	39.24		78.43	80.9				
			25 C	32.55	58.4(18)						
			40 C	20.04			30.64	873.9	12.06	12.15	13.29
			60 C	11.84							
			80 C	7.79							
			100 C	5.52		8.12	5.33	87.51	2.99	3.09	3.26
126/80	D2270/79	Viscosity index		240	232(25)	214	107	187	100	114	113
160/68	D1298/67	Density at: 20 C (kg/L)		0.8683	0.863(24)	0.917	0.866				
		15 C		0.8711					0.8417	0.8427	0.8443
15/67	D97-66	Pour point (C)		9	10(25)	-21	-24	18	-12	-9	-9
139/65	D974-64	Total acid no. (mg KOH/g)		0.08				1.28			
36/67	D92-72	Cleveland open cup									
		Smoke point (C)		222	195(25)	270	190				
		Flash point (C)		285	295(25)	324	211	232			
		Fire point (C)		320	338(25)	360	239	278			
34/80	D93-77	Flash point, Pensky-Martens closed cup (C)		261		250	190	207	181	181	179.5
239/79	–	Fourball extreme pressure test (10-sec runs)									
		Mean hertz load (kg)		22	21.2(25)	23	38				
		Initial seizure load (kg)		63		63	100				
		Weld load (kg)		141	160(25)	141	178				
		Fourball wear test mean wear scar diameter (mm)									
		(40-kg load at 75 C for 1 hr)		0.66							
		Permitivity at 22 C		2.8							
		D.C. conductivity (psec cm^{-1}) at 22 C		550							
154/78	D130-75	Copper corrosion classification									
		(3 hr at 100 C)						4a	1b	1a	1b
61/65	D129-64	Sulfur content (% wt)						12.32	0.02	0.07	0.41
–	D1401-67	Emulsion characteristics:									
		(Time for emulsion to reduce to 3 mL or less, min)							1	15	
		Amount of oil, water and emulsion remaining at 60 min (mL)							–	–	40-17-25
146/80	D892-79	Foaming characteristics: sequence I									
		Foam tendency/stability (ml)							–	40/0	70/0
		Foaming characteristics: sequence II							–	10/0	20/0
239/79	–	Fourball extreme pressure test									
		(10-sec runs)							–	50/0	60/0
		Mean hertz load (kg)							19.2	21.5	34.1
		Initial seizure load (kg)							50	56	79
		Weld load (kg)							141	141	224

[a]Mobil Whiterex 307.

[b]Mobil DTE 24.

This could enable it to be formulated similarly to that of soft spermaceti or soft jojoba oil (23). The possible cosmetic uses of hydrogenated orange roughy oil could follow the patterns already established for solid jojoba wax, spermaceti and hydrogenated sperm whale oil.

Physical and mechanical properties of refined and deodorized orange roughy oil are listed in Table VI. Similar properties for jojoba oils (18,24,25) and rapeseed where available, and of a typical mineral hydraulic fluid are included. These results show the close comparison of the mechanical and lubrication properties with jojoba oil.

The kinematic viscosities of orange roughy oil place it in the SAE 10 viscosity grade at 100 C (26) whereas at 40 C, it is in the ISO industrial lubricant viscosity grade VG 22 (27). These viscosity grades cover hydraulic oils and light lubricating oils. The significance of the high viscosity index of orange roughy oil is demonstrated as the orange roughy oil is only half as viscous as the hydraulic oil at 20 C, although their viscosities at 100 C are similar. The wear and pressure test results indicate a close similarity in mechanical properties between orange roughy and jojoba oil. Wax ester oils are usually used as sulfurized derivatives (4,24). Sperm whale oil has been used extensively in the sulfurized form as an extreme-pressure and antiwear additive in differential and transmission lubricants, in hydraulic fluids that need a low coefficient of friction and in cutting and drawing oil. Results have shown (4,14) that, on the basis of performance evaluations, the characteristics of sulfurized jojoba oil and sulfurized sperm oil are remarkably similar.

Results of the sulfurization of orange roughy oil have shown it can be readily sulfurized; the final product in this study contained 12.32% by wt sulfur. The infrared spectrum showed no major changes from the original oil but ^{13}C NMR spectra indicated the disappearance of the carbon-carbon double bonds and formation of carbon-sulfur bonds.

Table VI shows the results obtained in the standard test procedures for sulfurized derivative of orange roughy oil. The very considerable increase in viscosity of the sulfurized oil indicates that a considerable degree of cross linking of the oil has occurred in the sulfurization process. Other properties are not radically altered except that the acidity of the sulfurized oil is considerably higher. The copper corrosion result of 4a indicates overall blackening of the copper plate.

Table VI also compares the properties of the preparation of orange roughy oil and sulfurized orange roughy oil in a lubricant base of pharmaceutical white oil (Mobil Whiterex 307) at a level of 2.5%. Both solutions remained stable after storing for 24 hr at 0 C with no phase separation or sedimentation observed. This is similar to the OK solubility obtained for both sulfurized jojoba and sperm whale oils (4) in similar white oils.

In the emulsion separation time test, the solution of sulfurized orange roughy oil formed an emulsion which did not separate in the 60-min test period.

The copper corrosion classifications of 1a for the blended orange roughy oil lubricant and 1b for the blended sulfurized orange roughy oil lubricant are very much less than the 4a classification of the sulfurized oil alone and is identical to the 1a and 1b classifications obtained for sulfurized jojoba oil (4).

Extreme pressure tests gave similar values for the white oil and orange roughy oil in the white oil. However, in the test on the 2.5% sulfurized orange roughy oil solution, the initial seizure load was increased from 50 to 79 kg, the weld load from 141 to 224 kg and the mean hertz load was increased by 78% from 19.2 to 34.1 kg. Such a performance with only 2.5% of the sulfurized orange roughy oil in the white oil solution clearly demonstrates the extreme pressure properties of this material and indicates that sulfurized orange roughy oil may have considerable potential as an extreme pressure additive for lubricants.

No acute toxicity skin tests or acute oral administration tests have been undertaken on orange roughy or oreo oils but the fish are sold extensively as table fish. Such tests on jojoba oil (15,28) indicated no unsatisfactory results.

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