QUALITY FISH MEAL: SPECIFICATIONS AND USE IN AQUACULTURE AND FUR FARMING

Nils Chr. Jensen
Esbjerg Fiskeindustri
Esbjerg, Denmark

INTRODUCTION

Esbjerg Fiskeindustri was founded in 1989 through a merger of Andelssild and Vestjysk Fiskemelsfabrik, and is owned by the suppliers. More than 130 fishing vessels ensure an annual supply of about 750,000 metric tons of fresh raw materials. The daily production capacity is 7,000 metric tons of raw materials and the production is carried out in four independent process sections. Esbjerg Fiskeindustri is the world's largest single producer of quality fish meal and fish oil and handles half the total Danish production of fish meal and oil. The products are marketed under the trademark 999.

The raw material consists of small fish normally not used for human consumption, such as sand eel (*Ammodytes* sp.), Norway pout (*Trisopterus esmarki*) and sprat (*Sprattus sprattus*). During the sand eel season, from April to July, 70% of the annual catch is landed.

PRODUCTION OF FISH MEAL AND FISH OIL

Immediately after catching, the fish is cooled by measured quantities of ice, which ensures that the raw materials are absolutely fresh when landed.

Before landing, reports are submitted concerning the nature and freshness of the catches. On this basis the factory evaluates which product can be made from the raw materials and which process section is best suited. When the ship arrives, efficient suction equipment ensures prompt unloading, and the fish are then passed on for direct processing.

Representative samples are drawn from each cargo and analyzed for freshness of raw material, expressed by the TVN value (total volatile nitrogen) in milligrams nitrogen per 100 grams of fish. A low TVN indicates fresh fish. The pricing system rewards fresh raw materials and contributes to the landing of top quality fish. For the fishermen, there may be an economic gain of up to 50% by landing fresh fish. Fresh fish is a must when producing quality fish meal for aquaculture and fur farming.

Author's address: Esbjerg Fiskeindustri, Fiskerihavnsgade 35, Postboks 1049, DK-6700, Esbjerg, Denmark.

Table 1. Percent composition of fish meal.

	Average	Minimum	Maximum
Protein	72	68	74
Oil	8	5	10
Ash	14	11	18
Water	7	4	10
Salt	2	1	3

The raw materials are processed by boiling, pressing, separation, evaporation, and drying. The processing generates about 22% fish meal and 6% fish oil. During all key stages of the production, quality is controlled and samples are drawn for laboratory tests. Analyses on final products are also performed.

The composition of fish meal depends on the raw material; a general composition of fish meal is shown in Table 1. Fish meal protein contains all the essential amino acids. The fish meal has a high content of lysine, methionine, and cysteine, and a high digestibility and biological value, which makes it a well suited ingredient in diets. The oil in the fish meal is protected against oxidation by 150 ppm ethoxyquin.

The Danish Association of Fish Meal and Fish Oil Manufacturers has sponsored several experiments at the National Institute of Animal Science and the Danish Trout Culture Research Station to develop new products.

The research involves different process conditions, mixed feeds, and different species of animals (ruminants, mink, piglets, and trout). The experiments have proved that there can be a great difference in the feed utilization and daily gain response depending on the quality of the raw material used for the production of

Table 2. Feed evaluation of different fish meals.

Drying method	TVN in raw fish	High feed intake		Low feed intake	
		BVa	WG %	BVa	WG %
Indirect steam drier	30	0.49	1.42	0.50	1.17
	130	0.46	1.42	0.46	1.05
Freeze drier	30	0.52	1.45	0.51	1.07
	130	0.45	1.34	0.42	1.11
Roller drier	30	0.56	1.46	0.53	1.06
	130	0.46	1.28	0.44	1.14

TVN = Total volatile nitrogen. BVa = Biological value. WG = Daily weight gain.

fish meal (Danish Association 1983). The overall conclusion is that fish meal produced from fresh raw material is a highly nutritional product.

THE INFLUENCE OF RAW MATERIAL QUALITY AND PROCESS ON THE FEED VALUE

To prove the effect of raw material quality on fish meal feed value for trout, the Danish Trout Culture Research Station carried out a series of tests in collaboration with the Technological Laboratory, Ministry of Fisheries (unpublished data).

In four repeated experiments with different raw materials, fish whole meal and presscake meal produced in a pilot plant were compared in feeding tests with rainbow trout (*Salmo gairdneri* Richardson, 1836). The fish meals were produced from fresh raw materials (TVN less than 50 mg N per 100 g) and stale raw material (TVN greater than 150 mg N per 100 g). The stale raw material was from the same batch of fish as the fresh, but stored for some days at ambient temperature.

The same conclusion can be drawn from the four tests. The best daily gain response is obtained with fish whole meal produced from fresh raw materials, followed by presscake meal from fresh fish, presscake meal from stale raw material, and whole meal from stale raw material.

The difference between the presscake meals is minor compared with the difference between the whole meals. The solubles from fresh fish contain a lot of nutrients, whereas the solubles from stale fish contain water-soluble toxic compounds. This explains the difference between the whole meals and why the presscake meal from stale fish is better than the whole meal from stale fish.

To prove the effect of gentle drying and quality of raw material on fish meal quality for trout, Esbjerg Fiskeindustri in collaboration with Atlas Industries and the Danish Trout Culture Research Station have done some experiments (Fosbøl 1985, Jensen 1986).

In the tests, various methods of drying were compared and the feed value of the fish meals was determined by growth experiments with rainbow trouts in aquaria at 12°C. The pilot plant drying methods comprised normal industrial indirect steam drying, freeze drying, vacuum drying, hot-air drying, and roller drying.

The experiments show that gentle drying does not produce quality improvements over drying performed in a steam heated disc-drier operated under normal conditions.

The quality of the raw material is probably the most important parameter. It has the greatest influence on the fish meal quality, particularly when good production practice is established. Some of the results are shown in Table 2. (Details from the experiments are presented in Jensen 1986.)

The experiments were planned as factorial experiments with the following factors :

Quality of raw material. Two levels: TVN 30 mg N per 100 g and 130 mg N per 100 g.

Drying method. Three levels: Indirect steam heated disc drier (conventional process), freeze drier (low temperature process), and roller drier (high temperature-short time process).

Feed intake. Two levels: High (0.45 g protein and 0.21 g oil per day per 100 g trout), and low (0.45 g protein and 0.13 g oil per day per 100 g trout).

The raw material with TVN 30 was fresh, and the raw material with TVN 130 was deteriorated but was not putrid. The feeding levels were low to show differences (if any) in the feed utilization. The feed was produced as moist pellets and consists of fish meal, fish oil, starch, blood meal, whey, lecithin, alginate,

Table 3. True digestibility of fish meal to mink.

Drying temperature °C	TVN mg N/100 g in raw material		
	22	53	93
60	94.5	94.3	93.7
95	94.8	94.0	93.8
140	93.0	91.7	88.9

vitamin mix, and water.

The feed evaluation including the apparent biological value (BVa) and the daily weight gain (WG %) is shown in Table 2. There are no practical differences related to the drying methods in the utilization of the experimental diets based on fish meal produced from the same raw material. This means that gentle drying does not produce quality improvements over drying performed in a steam heated disc-drier operated under normal conditions.

The quality of the raw material had an influence on utilization; the value of the diet decreased with increasing deterioration of the raw material.

Gulbrandsen and Hjertnes (1986) have carried out similar tests with mink. They tested the true digestibility of fish meal to mink as a function of drying temperature and raw material quality. They concluded that fish meal temperatures of over 100°C during drying reduces the quality of the fish meal (see Table 3). There is also a slight decrease in true digestibility with increasing TVN in the raw material.

Pike et al. (1990) refer to other Norwegian experiments with temperature exposure of fish meal and true protein digestibility in adult male mink, with the same conclusion: fish meal temperatures of over 100°C during drying reduces true digestibility.

A common conclusion concerning fish meal for aquaculture and fur farming can be drawn: The best products are obtained with fish whole meal produced from fresh raw materials that have been processed under conditions where the temperature in the product have been below 100°C.

FISH MEAL FOR AQUACULTURE

Production of fish in aquaculture is increasing worldwide with an increasing demand for quality fish meal.

Environmental problems caused by nitrogen and phosphorus from fish farming will in the future put demands to the fish farmers and feed producers to minimize this pollution. At that time there will be a need for a highly digestible fish meal with a low phosphorus content.

Table 4. Composition of dry pellets for trout.

	Protein %	Fat %	Carbo-hydrate %	Metabolizable energy kcal/kg
1950–1960	35	5	30	2,200
1960–1970	40	7	23	2,500
1970–1980	53	11	12	3,100
1980–1987	50	20	10	3,800
1987–	42	24	19	4,300

Table. 5. Composition of wet mink feed.

Fish offal	50%–60%
Fish silage	5%–10%
Industrial fish	0%–10%
Poultry offal	5%–10%
Fish meal	0%–6%
Vitamin mix	5%
Barley	5%
Metabolizable energy	1,000 kcal/kg

In Denmark the composition of dry pellets for trout has changed during the last years to reduce the pollution problems: The energy content has increased because the protein level is lower and the fat content is higher (Table 4) (Alsted 1990). The latest types of feed are produced by extrusion.

The dry pellets are based on fish meal and fish oil and the demand for highly digestible protein (fish meal) increases with decreased protein level in the dry pellets.

FISH MEAL FOR FUR FARMING

In Denmark there are two types of feed for minks: wet feed, based on fish offal and whole fresh industrial fish; and dry pellets based on fish meal. The wet feed also contains up to 6% fish meal (see Table 5), while the dry pellets contain up to 50% fish meal. The composition of the dry pellets is 30%–45% protein, 15%–25% fat, and 3,000–3,850 kilocalories per kilogram metabolizable energy.

The Danish mink feed producers prefer presscake meal both for wet feed and dry pellets, to guarantee the feed value. They know they never will get the best fish meal—a whole meal produced from fresh fish,

Table 6. Percent composition of different types of 999 fish meal.

	Standard fish meal	Presscake meal	Whole meal aquaculture
Protein	71.4	74.1	72.2
Fat	8.0	6.5	8.2
Moisture	6.4	6.1	9.5
Salt	2.8	0.9	1.0
FFA of oil*	21	12	12
Lysine	5.0	5.8	5.8
Methionine and cysteine	2.2	3.0	2.9

*Free fatty acids.

which is preferred by the mink feed producers in Finland.

FISH MEAL SPECIFICATIONS

An example of the composition of a standard fish meal, a presscake meal, and a whole meal recommended for aquaculture and mink feed is shown in Table 6. The content of selected amino acids in standard fish meal—produced from unspecified raw materials—is lower than in the presscake meal and the aquaculture meal produced from fresh raw materials.

The raw materials that Esbjerg Fiskeindustri uses for production of fish whole meal for aquaculture and fur farming have an average maximum TVN of 60 mg N per 100 g, and no fish has TVN over 80 mg N per 100 g. The digestibility of whole meal is greater than presscake meal.

In conclusion, quality fish meal ideal for aquaculture and fur farming can be specified as whole meal made of fresh raw material produced under mild conditions.

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QUESTIONS AND ANSWERS

Q. What does your specification of multi-enzyme at 88% refer to?

A. This is a three enzyme mix. You can compare it with TORRY-pepsin. The Danish regulation requires that chemical analysis. With a very fine ground fish meal, your enzyme digestibility will increase and you have to be very specific about chemical analysis.

Q. Are medications added to fish meal or fish oil, and if so, what kinds and how much?

A. No, we don't add medication.

Q. There's no disease problem with it?

A. It's a problem in the industry, especially in Denmark. In Denmark most of the farming is fresh water trout. And of course there are diseases. When you take these trout to seawater, 99% run into disease, but you can cure them.

Q. This morning we heard that you get the best quality when you have warm temperature in the drier as low as 70. Now you say up to 95 you still have good product. Who is right and who is wrong?

A. I would say our trial and the Norwegians' trial with mink digestibility show the same results. When the Norwegians compare the LT 94, the Norse mink, you can see a difference—but you also have two quality differences, such as the LT meal is produced from fish with TVN below 50. The Norse mink is produced with TVN below 90. So two parameters change, both the raw material quality and the temperature. The quality of the raw material is the most important factor. Second is how you process it. Of course, if you aren't right you destroy the protein. But as long as you have water in your product, and evaporate water, you don't exceed those temperatures.

NEW PRODUCTS, PROCESSING POSSIBILITIES, AND MARKETS FOR FISH OIL

Baldur Hjaltason
Lýsi Hf
Reykjavik, Iceland

Although fish oil has been used as a fuel in some parts of the world for centuries and has been commercially available since the beginning of the century for industrial purposes, it was only 50 years ago that it became a commercial source for human consumption.

When we refer to fish oil we usually mean oil produced from fatty pelagic fish. Today fish oil is a by-product of the fish meal industry. In production, the main emphasis is on fish meal, which is still more valuable and more in demand than fish oil.

Fish liver oil, on the other hand, is produced only from the liver of the fish. In some cases it has therapeutic value and is an important source of vitamins A and D. Documentation from 1657 indicates that cod liver oil was helpful against night-blindness, and in 1770 Dr. Samuel Kay, a physician at Manchester Infirmary in England, gave a lecture on his studies of how cod liver oil helped against rheumatism. In 1920 it was discovered that cod liver contained vitamins A and D (Anonymous 1984). After the Japanese started production of synthetic vitamin D, cod liver oil lost its identity and did not recover until 1979 when the discussion of the health benefits of omega-3 fatty acids began.

Because of its physical characteristics, fish oil was at first mainly used for industrial purposes, such as in the leather industry, for making soaps, and in the manufacture of paints. As processing technology became more sophisticated, a new possibility emerged for the food manufacturers to use fish oil in shortenings, margarine, and fats for the baking and confectionery industry. Margarine was invented in 1869 because of the shortage of butter in Europe. In the beginning rendered beef fat was used, but in the early 1900s after the hydrogenation process was developed to produce hardened fat from liquid oils, a huge new marked for fish oil opened. Since then the market for fish oil has developed slowly. During the last decades we have also seen immense changes in the world oil and fat production where both soya oil and lately palm oil production has increased considerably. Today fish oil accounts for only 2% of the total world market for edible fats and oils. Although a number of countries produce fish oil, there are only seven major producers: Chile, Denmark, Iceland, Norway, Peru, the USA, and Japan. Japan is the largest single producer of fish oil (Figure l).

Commercial fish oil is usually composed of over 90% triglycerides, each usually containing three different fatty acids. An additional 8% consists of mono- and diglycerides and other lipids such as phospholipids. The unsaponifiable portion that accounts for an additional 1.5% to 2.0% consists principally of sterols, glyceryl ethers, hydrocarbons, and fatty alcohols, along with the fat-soluble vitamins A, D, and E. The residue contains other components in small quantities. Fish liver oil has the same characteristics, but usually contains more unsaturated fatty acids and a higher amount of the vitamins since the liver acts as a vitamin reservoir for fish.

What makes fish oil different from other oils is mainly the unique variety of fatty acids it contains (Table 1). Another factor is the high degree of unsaturated fatty acids. The amount and variety of the fatty acids in fish oil varies from one fish species to another, and also with the season of the year, fish diet, fishing location, ocean temperature, nutritional and spawning state, etc. Only eight to ten fatty acids make up 85%–90% of the total. Also of interest is that fish oil contains a high amount of fatty acids with the first double bond between the third and fourth carbon atom, counted from the terminal methyl group. This family of fatty acids is called the omega-3 fatty acids and is found primarily in oil of marine origin. In contrast, vegetable oils contain mainly unsaturated fatty acids from the omega-6 family and animal fat from the omega-9 family. Human metabolism differentiates between the position of the first double bond, i.e., omega-3,

Author's address: Lýsi Hf, Grandavegur 42, P.O. Box 625, 121 Reykjavik, Iceland.

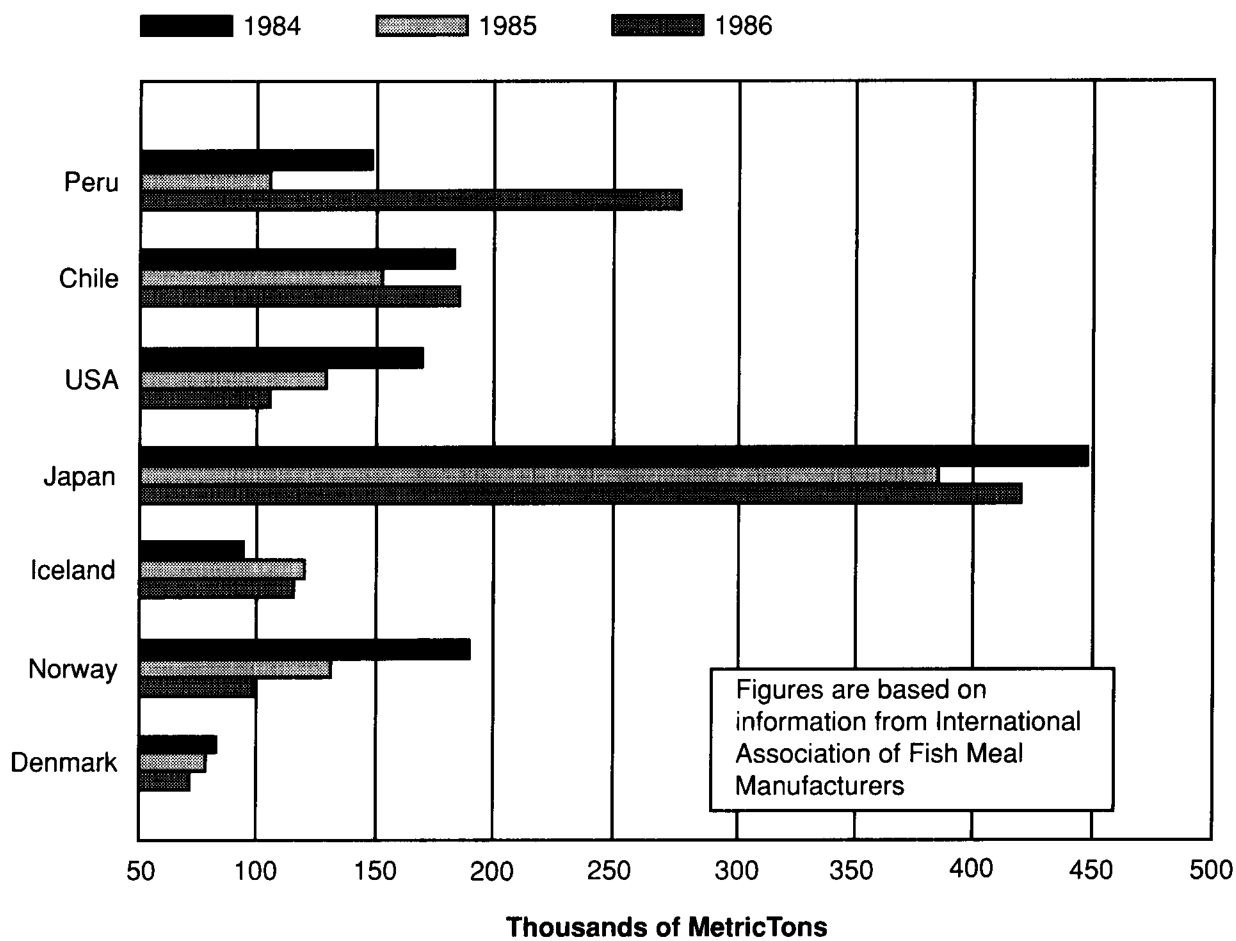

Figure 1. Fish oil production in seven major fish-producing countries, 1984–1986.

omega-6, or omega-9.

As far back as 1956, data were published showing that intake of fish oil had a cholesterol-lowering effect for humans. This was the first indication that fish oil and fish diet guard against coronary diseases (Nelson 1972). In 1972 Dyerberg and co-workers published findings that the low incidence of coronary heart disease in Greenland was related to their diet, and especially to their high intake of the eicosapentaenoic polyunsaturated fatty acid (EPA) of the omega-3 family (Bang and Dyerberg 1972, Dyerberg et al. 1978). Only then did the scientific community become aware of the health-related roles of the omega-3 fatty acids. At first, researchers studied the hypolipidaemic and anti-thrombotic effects of EPA, but after the discovery of prostaglandins and the extensive work on metabolites, it had become apparent that omega-3 fatty acids played an important role in inflammatory diseases and the immune system of the human body (Lands 1986, Kinsella 1987). Results now indicate that consumption of omega-3 fatty acids can help people suffering from arthritis, asthma, and certain types of cancer. Research is also being conducted on the role played by omega-3 fatty acids in the central nervous system and in growth and development (Simopoulos 1986, Horisberger and Bracco 1987).

The Second International Conference on the Health Effects of Omega-3 Polyunsaturated Fatty Acids in Seafood, held in Washington, D.C., March 1990, concluded that all human diets should include omega-3 fatty acids, and a concern was expressed that steps should be taken to stop marketing enteral and parenteral formulas that fail to include any omega-3 fatty acids. Furthermore, new evidence with an extremely high level of statistical precision, from the NHLBI study (National Heart, Lung and Blood Institute), suggest that the daily dietary intake of 0.5 to 1.0 grams of long-chain omega-3 fatty acids per day reduce the risk

Table 1. Fatty acids found in fish oils.

12:0	17:Branched	19:0	22:0
14:0	17:0	19:1	22:1 n-11
14:1	17:1	20:0	22:2
15:Branched	18:Branched	20:1	22:3 n-3
15:0	18:0	20:2 n-9	22:4 n-3
16:0	18:1	20:2 n-6	22:5 n-3
16:1	18:2 n-9	20:3 n-6	22:6 n-3
16:2 n-7	18:2 n-6	20:3 n-3	23:0
16:2 n-4	18:2 n-4	20:4 n-6	24:0
16:3 n-4	18:3 n-6	20:4 n-3	24:1
16:3 n-3	18:3 n-3	20:5 n-3	
16:4 n-4	18:4 n-3	21:0	
16:4 n-1	19:Branched	21:5 n-2	

Source: Leatherhead 1986.
n = position of first double bond counted from methyl group.

of cardiovascular death in middle-aged American men by about 40%.

These findings have been published in the scientific press and have been taken up by the commercial media. This caused a sudden interest in high-quality fish oil, high in omega-3 fatty acids. The fish oil producers and the processors were not ready for such a demand, since up to now almost all fish oil had been hardened. During hydrogenation, polyunsaturated omega-3 fatty acids are partly saturated and their health benefits ruined.

Fish oil today is produced in fish meal factories as a by-product. After the fish are landed, they are stored in holding pits at the factory until they are fed into the cooker. Steam is used for cooking, and the temperature rises to 100°C while the raw material goes through the cooker. In the next step the liquid is removed, consisting of water, oil, and fine solids, usually in a twin screw press. Then the decanter removes small particles before centrifugation where the oil is separated from water. Finally, the fish oil is cooled and stored. The oil from this process is defined as crude fish oil. Guidelines for crude fish oil characteristics are shown in Table 2 (Young 1986).

Figure 2 is a flow diagram for the classical processing of crude fish oil. The acid pretreatment step is intended to remove any gum material or phospholipid that might interfere with the quality of the final product. Usually acid pretreatment is not needed for fish oil. The second step is refining. Crude fish oil always contains some amount of free fatty acids that can have deleterious effects on the final product. The amount of free fatty acids varies mainly in accordance with the freshness of the raw material used in fish meal production. The most common way to remove the free fatty acids from the oil is to saponify them by adding diluted caustic soda to the oil. They are easily removed afterward with water in a centrifuge. The caustic soda also reacts with the triglyceride but at a much slower rate. Finally the oil is dried before the bleaching process (Proceedings Lipidforum Symp. 1986, Griffith 1986).

Usually, fish oil has a rather unattractive dark reddish color. This can be removed by adding powdered clay or earth that absorbs the color components. Then the oil is filtered to remove the bleaching material.

At this stage the oil is ready for hydrogenation. Hydrogen is added to fish oil in the presence of a catalyst to reduce the number of double bonds and saturate the fatty acids. The melting point is controlled by the degree of saturation and is checked by measuring the iodine value or refractive index. After the desired melting point is reached, the catalyst is removed from the oil by filtration.

It is sometimes necessary to repeat the refining and bleaching steps. After a second bleaching, the color of the final product can be more easily controlled and it is also beneficial to remove traces of impurities that might be left in the oil. The second refining removes the free fatty acids that formed during the bleaching and hydrogenation process.

The last step is deodorizing, which removes the volatile compounds that are the main cause if the strong fishy odor and flavor. Among the known compounds removed by deodorizing are aldehydes, ketones, alcohols, hydrocarbons, and compounds formed by heat decomposition of peroxides and pigments (Griffith 1986). The concentration of these compounds is usually between 200 and 1,000 ppm before deodorizing. During deodorizing the oil is heated to 200°–250°C in a vacuum of 1–3 mm mercury and then stripped with steam, which removes the unwanted components. The oil then is cooled and is ready for use in the food industry.

Due to the health benefits of omega-3 fatty acids, there is increasing interest among food manufactures to start using liquid fish oil instead of hydrogenating it. So far unhardened fish oil has few applications because of its fishy flavor and stability problems. The highly polyunsaturated omega-3 fatty acids can be easily oxidized if not protected against oxidation and handled with care. If fish oil is used in the food industry as a source of omega-3 fatty acids, the producers must guarantee a certain shelf life. The oil must also be able to endure baking and cooking procedures without deterioration. This creates a certain dilemma for the fish oil producers, since the fish oil is a by-product.

Table 2. Guideline values for crude fish oil characteristics.

Moisture and impurities	Usually 0.5%, but sometimes 1%	
FFA (as oleic acid)	Ranges from 1% to 7%, but more usually 2% to 5%	
PV	3 to 20 meq/kg	
AV	4 to 60	
IV	Capelin	95–160
	Herring	115–160
	Menhaden	150–200
	Sardine	160–200
	Anchovy	180–200
Color	Up to Gardner 14	
Iron	0.5 to 7.0 ppm	
Copper	Less than 0.3 ppm	
Phosphorus	5 to 100 ppm	
Sulfur	Levels of over 30 ppm will usually result in difficulty with hydrogenation	

Source: Young 1986.
FFA = free fatty acids; PV = peroxide value; IV = iodine value; AV = anisidine value.

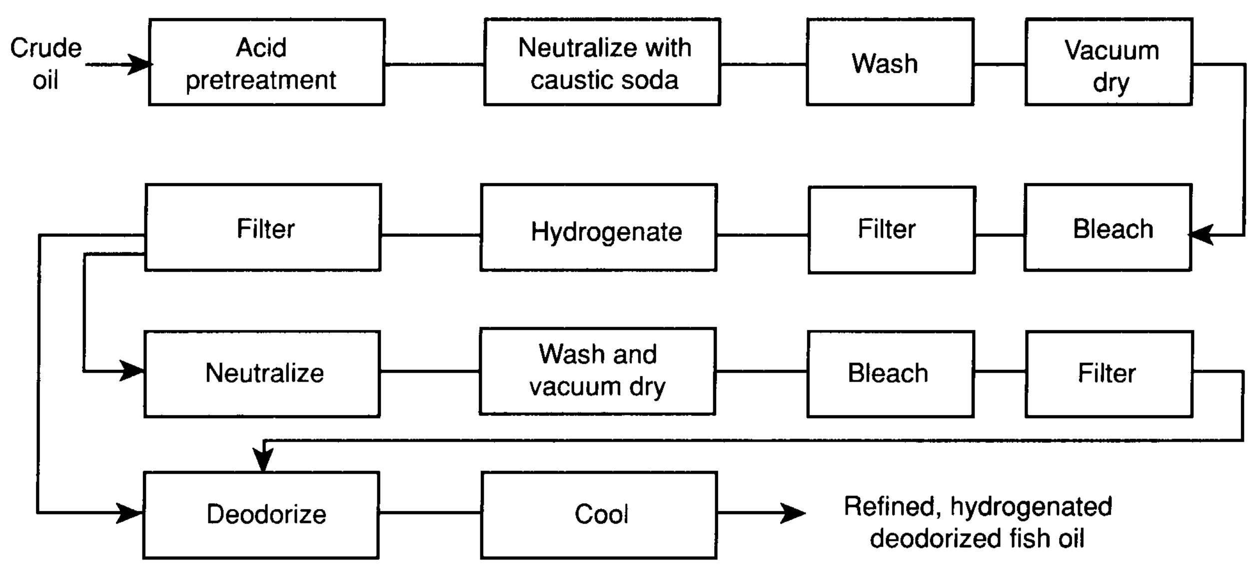

Figure 2. Flow diagram for processing crude fish oil.

Table 3. Partition of lipids in capelin into fish meal and oil.

	Capelin, whole	Meal	Oil
Total lipids (TL), % of dry matter	32	13	100
Percentage of TL in whole fish	–	40	60
Neutral lipids, % of TL	77	60	97
Phospholipids, % of TL	16	24	1
Fatty acid			
14:0	6.7	4.5	8.1
16:0	11.3	15.9	9.0
18:0	1.3	2.0	1.1
16:1	8.2	7.6	8.7
18:1	17.3	16.0	17.4
20:1	20.5	10.0	24.9
22:1	15.6	7.1	19.5
20:5 n-3	5.3	10.5	2.9
22:6 n-3	7.4	17.9	1.7
Total n-6	1.5	2.0	1.4
Total n-3	15.3	31.6	6.3

From N. Urdahl and E. Nygaard (1970) (unpublished data).
Source: Opstvedt 1985.

When the raw material arrives at the factory, it is usually several days old, and a few more days may go by before it is processed. This means that the raw material used is not fit for human consumption, and therefore the oil is often of low quality. When the fish oil is hydrogenated, the crude oil quality is not so crucial since by hardening the oil, the polyunsaturated fatty acids are saturated. This means that oxidation problems are more or less eliminated, so we should not get an offensive flavor in the fully processed oil. But if the fish oil is not hydrogenated, higher-quality crude fish oil is needed. This means it is necessary to look into other production possibilities besides improving the process.

It is worth noting that the oil part of capelin fish meal contains higher amounts of EPA and DHA (docosahexaenoic acid) of the omega-3 family than unprocessed capelin fish oil. The reason is that most of the phospholipids that contain EPA and DHA are still in the fish meal, while the fish oil consists almost exclusively of mono-, di-, and triglycerides (Table 3) (Opstvedt 1985). The conclusion is that in order to obtain the highest-quality fish oil, preferably with the same composition as in the fish, the emphasis must be on the production of fish oil, with fish meal treated as a by-product.

In the vegetable oil industry, oil is the main product and meal is a by-product. By using fresh fish as a raw material and appropriate solvents, the mono-, di-, and triglycerides and phospholipids can be extracted from the fish. The greatest disadvantages of this method are the high cost, limited number of food-grade solvents that can be used, and the large volume of solvents needed. However, high-quality oil can be obtained with this method.

Recently another extraction method has become commercialized. This is Supercritical Fluid Extraction (SCFE), which has been applied to several processes in the food industry. SCFE utilizes the special properties of gas above its supercritical temperature and pressure to extract or fractionate compounds (McHugh 1986). Partly due to economics, this method has been used only to remove undesirable components from fish oil or to separate EPA and DHA from fish oil (Northwest and Alaska Fisheries Center 1985).

Fish oil producers today have many possibilities to improve the quality of crude fish oil. Improved processing technique and better stabilizers offer higher-quality oil to the food industry.

In all fish oil production, the quality and freshness of the raw material is of greatest importance. After being caught, the fish should be kept on ice until it is processed. Chemical parameters such as TVN (total volatile nitrogen) should be monitored to check the freshness. During processing, heating should be kept to minimum. In the presence of water and pro-oxidants such as copper and iron, fish oil can be easily oxidized. Heat accelerates the oxidation process to a great extent and can also cause isomerization, polymerization, and loss of essential polygenic fatty acids.

The use of anti-oxidants early in the process is also of great importance. Low-quality fish oil can never be upgraded by adding anti-oxidants, but high-quality crude oil with anti-oxidants is much more stable during processing and less prone to oxidation than fish oil with no anti-oxidants. Tests in Iceland have shown that the processing of fish oil—such as refining, bleaching, and deodorizing—reduces its stability if no anti-oxidants are added to the crude oil and after each processing step (Thorison 1990).

When liquid fish oil is used for human consumption, it is often necessary to add a winterization step to the process. During winterization the oil is cooled to remove solid fat fractions that would normally cloud, at refrigerator temperature, oil that is liquid at room temperature. This also increases the amount of omega-3 fatty acids in the oil.

Due to increased ocean pollution, fish oil produced from fish caught in polluted waters contains some pesticides, polychlorinated biphenyls, and other undesirable contaminants. This is now a problem for the fish liver oil producers since the liver collects these contaminants. During deodorizing some of the components are removed. Deodorizing can hardly be called a gentle process, especially for highly unsaturated oil. Therefore, oil processors have started to use a high-vacuum, molecular distillation apparatus to remove impurities. The high-vacuum, molecular distillation process also removes the vitamins, some cholesterol, and some oxidation products, and therefore purifies the oil and makes it more stable against oxidation.

Let's now look at the markets. The market for liquid fish oil for human consumption can basically be divided into three areas.

- As a commodity for the food industry.
- As a health food.
- As a pharmaceutical.

From a theoretical point of view, fish oil may be used in any food item that contains fat. The problem that must be solved is how to introduce fish oil into food products without making them taste fishy. The most promising food application seems to be in margarine, salad oil and salad dressing, mayonnaise, and several types of spreads and pastes. The International Association of Fish Meal Manufacturers (IAFMM) started trials in the United Kingdom in 1985 using fish oil from different sources at different levels in several foods. The products included were French dressing, salad cream, frankfurters, salami, margarine, and mayonnaise (Table 4). The trials in general were successful since they show it was possible to produce food acceptable flavor that contains fish oil. In Denmark this past year, a commercial margarine product was launched containing 20%–25% unhydrogenated fish oil and 75%–80% vegetable oil (Barlow and Young 1988).

Table 4. Tasting results for foods prepared with refined fish oil.

Food type	Food made	Taste comment
Spreads and pastes	Fish spread	Acceptable
	Cheese spread	Good
	Peanut butter	Acceptable
Salads and salad dressings	Salad cream	Acceptable
	Mayonnaise	Production problems
	Coleslaw	Poor
Dairy products	Yogurts	Poor
Oils and oil blends	French dressing	Good
	Canned fish oil	Good
Sausages, smoked and spiced foods	Salami	Good
	Pork sausages	Good

Source: Young 1990.

In order to include fish oil in infant formulas and in baked products, processors have been looking into the possibility of using microencapsulated fish oil in order to solve the stability problem of the oil. The microencapsulation technique offers a very promising solution. It is based on forming sub-miniature capsules or microcapsules consisting of a shell and fill material. Typical microcapsules are small enough to be used as a free flowing powder or suspended in water. The disadvantage is that the volume of coating material is still very large compared to the fill material. This is now a commercial product.

In the fats and oils industry, intensive research work is in progress in the field of enzymatic modification, such as interesterification. Cocoa butter equivalents are now produced by interesterifying mixtures of oils and fats (Posorske et al. 1987). Besides making triglycerides high in omega-3 fatty acids, enzymatic modification opens up the possibility of modifying fish oil as a replacement for more expensive fat and oil sources, or even to tailor-make triglycerides for specific uses.

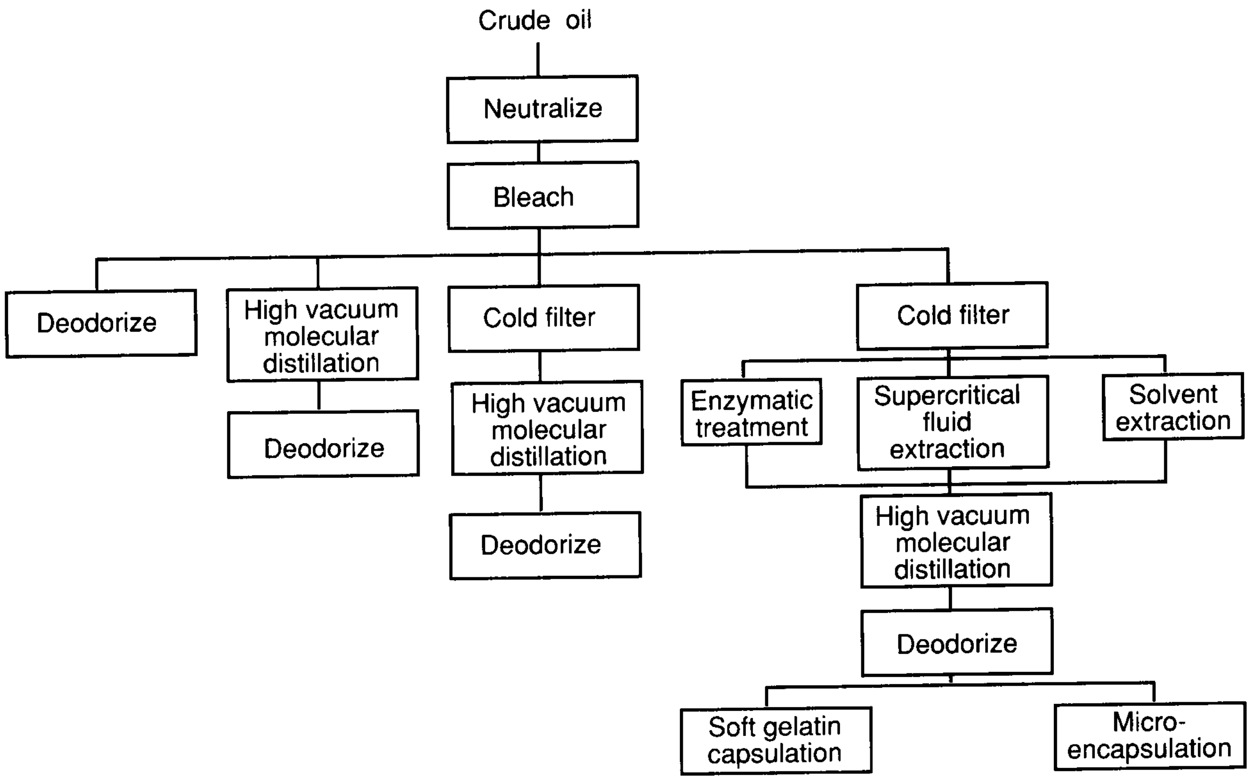

Figure 3. Processing possibilities for unhardened fish oil.

Figure 3 shows some processing possibilities for unhardened fish oil.

It is very difficult to estimate the market for unhydrogenated fish oil. But it would not be unreasonable to estimate the U.S. and European market, based on fish oil as a supplier of omega-3 fatty acids at 150,000 tons per year. This is based on daily dietary intake of 1.0 gram of long-chain, omega-3 fatty acids.

Although cod liver oil has been sold for many years as a health food, a great demand has developed in the last few years from the health food industry for fish oil containing high amounts of omega-3 fatty acids, especially EPA and DHA. Several fish oil products are now on the market. Most of them are based on fish oil in which the omega-3 content has been increased with cold filtration, solvent extraction, SCFE, enzymatic treatment, or a combination of these. There are also on the market omega-3 fatty acid mono-esters and free fatty acids produced from fish oil. Most of these oils are highly unstable, and although anti-oxidants and vitamin E have been added, the oil must be specially protected. Most of these products are encapsulated in a soft gelatin capsule that protects the oil.

It has been proven that fish oil dramatically affects the biological activities in the body (Galli 1988). Many clinical tests are under way, and the pharmaceutical industry has shown interest in the therapeutic application of fish oil concentrates. Whether the results can be harnessed into useful specific therapies remains to be seen. At least one company has registered encapsulated fish oil as a drug in Europe for lowering blood fat. Many patent applications have been approved making claims that omega-3 preparations act as anti-cancer agents, and that they could be used for prophylaxis or treatment of vascular disorder, or even treatment of disorders like Raynauds disease. How big the pharmaceutical market will be depends on the results of the tests. The drug companies will always demand the most purified, highest-quality fish oil from the fish oil industry, and therefore has set standards for the fish oil processing industry.

During the last ten years, we have seen a new market develop in aquaculture for fish oil as an ingredient in fish feed. Lipids from wild fish contain comparatively high levels of omega-3 fatty acids. The marine species that are farmed today must get their omega-3

Table 5. Potential use of fish oil in fish feeds, 1990.

Fish species	Area	Fish production (metric tons x 1,000)	Dry feed (metric tons x 1,000)	Fish oil inclusion in diet (%)	Fish oil amount (metric tons x 1,000)
Salmon	W. Europe	135	225	15[1]	34
	Far East	30	50	15[1]	8
	N. America	25	40	15[1]	6
	S. America	7	12	15	2
Trout	Europe	182	328	10	33
	N. America	80	145	10	15
Catfish	N. America	150	300	2.5	7
Shrimp and prawns	Far East (intensive)	120	240	5	12
	Far East (semi-intensive)	180	180	5	9
	S. America (semi-intensive)	30	30	5	2
Eels	Far East	100	200	15[5]	30
	Europe	8	16	15	3
Yellowtail	Far East	150	150[3]	12[5]	20
Milkfish	Far East	300	150[4]	10	8
Crayfish	N. America	50	10[2]	5	1
Total			2,076		190

[1] Diets produced by cooker extrusion, allowing oil content of finished diet up to 25%.
[2] Only a small proportion of crayfish produced likely to receive mixed feed.
[3] Some fish oil likely to be used in moist feeds. Also will move to dry feeds because of pollution problems caused by moist feeds, especially in Japan.
[4] Low-cost, carbohydrate-rich diet fed to milkfish with 10% to 15% fish meal in dry diets. However, maybe fish oil will also be included in the diet. Amount of mixed feed used is limited; also use waste products fed directly.
[5] Watanabe 1988.

Source: Pike 1990.

fatty acids in the diet. Since the omega-3 polyunsaturated fatty acids are an important part of the marketing image of fish as a healthy food, fish oil has become a vital feed ingredient. Recent studies also indicate that omega-3 polyunsaturated fatty acids from fish oil protect the fry from various diseases by improving the immune system.

Production of farmed fish and crustaceans is currently over five million metric tons annually, but only part of this production receives mixed feed. The estimated dry feed requirement in 1990 is 2,076,000 metric tons. The amount of fish oil needed in the feed is in the range of 190,000 metric tons and will likely continue to grow in the coming years (Table 5) (Pike 1990).

Although the emphasis has been on the marketability of the health benefits of fish oil, it is known that fish oil and fish liver oil contain other interesting compounds. With improved separation techniques and more gentle processing methods, these oils might play an even more important role in the pharmaceutical and health food industry in the near future.

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QUESTIONS AND ANSWERS

Q. When Joel Cowger spoke yesterday on white fish meal production, he said to burn the pollock oil you produce, or any fish oil you produce in Alaska for fuel because you can't make any money from it.

Is the process used here to produce fish meal and oil damaging to the oil in any way, or is it simply a matter of economics? I noticed on one of your graphs that the omega-3 content in Alaska pollock liver oil is quite high.

A. In producing crude oil and raw material, freshness is the most important thing. When you start processing the oil after that, then you have to be very careful about the processing techniques. Pollock oil also contains some vitamins, and it has been sold as a very good omega-3 source in fish feed, especially eel feed in Taiwan. It is very possible to use that oil for human consumption as a food ingredient. One has to be careful to keep the oil separate, have everything clean around it, and treat it very gently. But you need to process further than crude oil.

Q. Is the production of fish meal and oil in Alaska a problem of oil quality, if they do not separate the livers out on pollock?

A. Fish liver oil contains vitamins, and it is not logical to include it in food simply because you would get an overdose of vitamins. You can add it effectively only up to a certain point. In order to collect liver oil you must separate it by hand, and process it separately. The cost is prohibitive because fish liver oil must compete with vegetable oil prices. I am convinced that food processors will not be able to, or be willing to, pay any high premium for fish oil. It has to compete with soybean oil, corn oil, etc.

Q. Almost all the pollock landed in Alaska is held in RSW vessels, refrigerated sea water, and delivered at most within two days of catch, more like 24 hours of catch. Do you know of any effect on the raw material that might have? What about salt uptake in the livers?

A. The problem with collecting livers at sea is that most of the bottom trawlers, factory trawlers, are now mechanically gutting the fish, and that means that a special person separates the liver. The best thing is to put the liver into a plastic cube and ice it, and if you process it within four or five days, you will able to get quality fit for human consumption.

Q. I'm referring to the trawlers that deliver whole fish to shore-based plants where the pollock has been in RSW tanks for 24, 30, to 36 hours.

A. If it is well cooled, you could get the liver. If you get it out within 24 hours, you would be able to process with good quality. The condition of the fish is also important. If it is close to a spoiling stage, etc., the liver deteriorates fast.

Q. Is there a market for fish oil in the manufacture of soaps?

A. Not any more. Now there are cheaper sources of oil. Fish oil is not competitive in most of the industry any more. Today we have only limited use for fish oil—in the margarine and shortening industry as hydrogenated oil, and also in fish feed. There is a good possibility in the near future that food manufacturers will use fish oil in blends with vegetable oil. The dietary recommendation is that you should have approximately the ratio of 4:1 vegetable oil:fish oil.

Q. I am from a developing country. If fish oil is used in the manufacture of soaps, is there a problem with deodorizing? Or is the manufacturing process a deodorizing process as well?

A. If you use it as a soap, you would first partly hydrogenate it in order to get the right saturated state of the fatty acids. When you do that, you solve most of your off-flavor problems.

Q. In an early slide, you showed a specification that listed a tolerance for sulfur. What's the source of that sulfur? It shouldn't be in refined fish oil unless you have contamination from protein.

A. Some proteins contain sulfur, and when the protein deteriorates and breaks down, some of the sulfur is released to the oil, I believe.

Q. Was that specification for hydrogenated oil?

A. Yes. Sulfur affects the catalyst in the hydrogenation process. The cost of hydrogenation increases because you have to add an extra dose of metal catalysts.

Q. (Mr. Nelson) At our laboratory we've been doing extraction work in fish oils. We're now able to obtain esters at 95% purity of both EPA and DHA.

Q. (Mr. Goddard) In our salmon processing plants in Kenai we have available to us on the order of one million pounds of salmon heads a year. Is there any economically viable application for extracting omega-3 oils from salmon heads that could be done in a small application without an attendant meal plant?

A. There is already a small market for salmon oil in capsules as a health food. And also from a marketing point of view, people prefer to have omega-3 oils from salmon to other types of fish. So that is an advantage. But I have seen nothing of the salmon oil—maybe it's not so different in fatty acid composition from other modified oils. This comes around again to the cost of producing it. Is your oil competitive with other oils similar in composition? There is a market for this; I would estimate 50 to 100 tons a year.

Q. Out of a million pounds of salmon heads, how much oil do you think could be produced?

A. Fifteen percent.

Q. That would be substantial. That would be something on the order of 50 to 70 tons.

A. In our company, we have looked at the fatty acid composition of the salmon viscera, and we found the oil very disappointing in omega-3 fatty acid content. But the oil from the head must be very interesting.

Q. As a commercial application from a processor's viewpoint, it would be a lot easier to segregate the heads and to deal with them than the viscera. I'm assuming that a simple boiling process would be sufficient for extracting most of the oil and then follow with some sort of crushing.

A. Yes. Also I think it would be very interesting to look at the composition of the oil. How much is phospholipid, how much is triglyceride; if you could get some of the phospholipids out, you would have much stronger marketing potential. So you should look at your method of producing with this in mind. Not only look at triglycerides, but look at the type of fat left in the head after boiling and separating the oil.

Q. Boiling and separating is probably the simplest.

A. Yes, that's the simplest, to grind it very well, and then to boil it and press it out. I'm certain you will get all the oil you would like to get out of the flesh of the head.

Q. What do you estimate for the commercial value of something like that in raw form?

A. I estimate you would get $2,000 to $3,000 a ton.

Q. If we can produce 50 tons a year, that makes it interesting.

A. You have to be very careful to have a balance between the demand and the supply, because you could overflow the market.

Q. I have a question about environmental contaminants in fish oil. I'm wondering whether you regularly analyze your products or your crude oil.

A. Yes, we do.

Q. Is it a consumer issue?

A. No, we do it on a regular basis because with this modern analytical technique you can detect pesticides and some foreign bodies in almost any oil, to one part per trillion. We monitor the levels, although they are far below any legal limits. This is a routine analysis, and I am pleased to confirm that we have a reduction of compounds like DDT and PCBs. The contaminants are usually in very closed areas such as fjords, and they are far below the legal levels. On the other hand, consumers are scared if they know there are even small traces of any contaminants in the oil. Therefore one has to be very careful about removing contaminants in order to state that the oil is contaminant free.

Q. And are they actually removed, or are they altered by the processes?

A. Removed. They are absorbed through the bleaching clay, and then during the deodorizing process most of the volatile compounds are distilled off. Further removal occurs if we use supercritical extraction, or high-vacuum molecular distillation. We use the latter processes mainly for special health products and for pharmaceutical products because they must be completely free of any contaminants.