I. Introduction

The primary utilization of fish should doubtless be as food for human beings. Fishery being, however, either seasonal or fluctuating, the yield varies within wide limits. During periods of great abundance, it has up till now been impossible to preserve the surplus of this very perishable raw material in a state fit for human consumption; hence the industrialization of excess fish in the manufacture of oil and guano, and later “fish scrap” and fish meal for animal feed. The manufacture of an “edible” fish meal is so recent a development that it has hardly gone beyond large-scale experimentation.

1 Present address: Straumsgrend per Bergen, Norway.
In the following pages a general picture of the fish meal industry will be given. The basic principles will be explained; the most important industrial methods will be described and also some new principles that may prove of interest in its future development. Search for improved methods continues. The aim is not only to raise yields which in the early days of the industry were exceedingly low, but also to meet the increasingly rigid requirements for a product of superior quality. Statistical information on the fish meal industry is presented. The properties of the meal will be discussed, mainly its nutritive value in relation to manufacturing details.

The literature on fish meal manufacture is remarkably scant.

II. Preservation of Raw Material

A. General

With the manufacture of more valuable products it became necessary to give more attention to the quality of the raw material. This was even more necessary when the product was offered to the food industry. Preservation presented quite a problem. In many fishery districts it was out of the question to provide "reduction" capacity to cope with the peak landings. Raw material had to be left in storage bins to be worked off gradually. In northern Europe, notably Norway, the main season is winter and putrefaction is considerably retarded by the low temperature; even so the fish cannot be kept very long before serious deterioration sets in.

Sprinkling with salt was long the only means of prolonging the useful life of the raw material. The salting of herring has thus been very helpful and has been widely used for short- and long-term storage. But if fish were to be kept for longer periods, the use of salt had serious inconveniences. Firstly, an addition of up to, say, 4% salt meant heavy extra cost. Next, the preservative action of salt is only relative; after a while the raw material starts to decompose. It becomes difficult to treat in the reduction plant, yielding a dark oil with high acidity and a meal with an appreciable amount of free ammonia, a sign of incipient putrefaction. The salt content of the meal would be rather high (8–10%) and modern "whole meal" production would have been out of the question. All the salt added in this process is found in the finished meal; a mild preservation with, say, not more than 2% salt would give a meal with about 10% salt. For this reason the use of salt has now been largely abandoned.

The decomposition of the raw material for fish meal manufacture is caused by both bacteria and digestive enzymes from the fish intestines. Aerobic proteolytic bacteria are very active, while some of the anaerobic
ones are less dangerous. It is therefore often observed that the raw material keeps better in the center of large piles than on the surface. The activity of the microbes increases very rapidly from 0°C. up to about 25°C. Above this temperature the spoilage is caused largely by enzymes. This action can be very rapid indeed, 24 hours sometimes being sufficient to convert a bin of sound fish to a soup or a porridge impossible to handle in the factory.

Preservation of fish for meal manufacture is made easier by the fact that fairly great amounts of preservative may be used. The fish reduction process is a very drastic one; quite a few added volatile or easily decomposable compounds can thus be eliminated. The question of total cost, however, must of course be considered.

Thus a great number of compounds have recently been tried, chlorine, chloramine and other chlorine compounds, sulfurous acid, benzene, etc. But only two have proved to be of real use, namely, formaldehyde and sodium nitrite.

**B. Formalin**

The addition of formaldehyde solution remarkably improves the keeping quality of fresh fish; the effect is of course largely dependent on the prevailing temperature.

In order to obtain even distribution, the commercial 40% product should be diluted at least 1:2 and added by means of a mechanical spreading device. The amount of formaldehyde needed—of the order of 0.5 gallon per ton—varies with the temperature, the raw material, and the required storage time. For short-term preservation up to a maximum of a fortnight at temperatures up to 15°C, formaldehyde alone has proved an excellent preservative. It not only checks the putrefactive bacteria, but also has a most beneficial action on the soft tissue, rendering it more easily pressable after cooking. For longer periods of preservation, however, this hardening action on the skin, especially on coarse raw material, can be a great inconvenience. Formaldehyde is indeed seldom used alone, and most often in combination with nitrite.

**C. Sodium Nitrite**

This compound, due to its bacteriostatic properties and the ease with which it is eliminated during fish meal manufacture, is a most valuable aid to the industry. Its bacteriostatic properties have been very carefully investigated by Tarr (1943). Its extensive use in the fish meal industry dates from investigations by Notevarp and Bakken (1955). Sodium nitrite is a poisonous substance; for this reason the preservation must be conducted in such a way as to leave only traces of the compound in the finished meal. In Norway the limit, for home consumption,
was for long fixed at 0.02%, twenty times less than the dose where the first biological symptoms could be noted. Actually its use is subject to further technical and biological investigations. To preserve raw fish effectively for a period of several weeks, as much as 2–3 lb. nitrite per ton of fish may be needed; if all this nitrite passed into the meal, a product with quite a prohibitive dose of preservative would result. A number of happy circumstances tend to reduce the quantity of nitrite, and these processes start in the fish storing bins. The amount of nitrite to be used must therefore be carefully calculated according to the storage time and the prevailing temperature. This requires considerable experience, but can be worked to a very fine degree of accuracy. Most of the remaining nitrite will be eliminated during the reduction process. During cooking of the fish, no such reduction takes place, while the drying process and the stick-water-concentration process decompose most of the nitrite left. Then during storage of the meal the remaining nitrite can be completely eliminated, but as this process is slower a thorough control during preservation with sodium nitrite is needed to avoid complications. It is then possible to store the fish for several months without detriment to the finished meal. The nitrite may be sprinkled over the raw material with good results, as it has a remarkable facility of diffusing through the whole mass. But in practical operation it is always added in solution by means of automatic devices which assure very uniform dosification. While the bacterial decomposition is very effectively counteracted by nitrite, enzymic processes continue and after some time the raw material will contain considerable quantities of soluble protein. This seldom interferes with the manufacture. The raw material usually keeps sufficiently firm to be worked in the ordinary cooking-pressing installations. The use of these modern preservatives in the fish meal industry has proved to be of great advantage. The resulting meal is of excellent quality; it is free of putrefaction, as indicated by smell and taste and as measured by volatile nitrogenous compounds. The color of such meal is slightly more reddish when newly produced. The oil resulting from the preserved raw material is also first grade, the nitrite and/or formaldehyde having checked the formation of off-color and free fatty acid. It might be expedient to repeat, however, that the preservation of fish with these ingredients must be carried out under the strictest control.

III. Principles of Manufacture

The simplest way of manufacturing a fish meal would be to mince the raw material, and then allow it to dry naturally or by artificial means. Only in the case of very lean fish, offal from canneries, or heads and
bones from stockfish manufacture and the like, can an acceptable product be manufactured in this way. In order to understand the whole process of rational fish meal manufacture, it will be expedient to consider the quantitative composition of the raw material. The matter will be simplified in the following example by assuming a raw material of the following composition, using round figures.

<table>
<thead>
<tr>
<th>Per 100 lb.:</th>
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<tbody>
<tr>
<td>Water ............... 68 lb.</td>
</tr>
<tr>
<td>Fat ................. 12 lb.</td>
</tr>
<tr>
<td>Nonfat solids:</td>
</tr>
<tr>
<td>Protein 16</td>
</tr>
<tr>
<td>Minerals 4</td>
</tr>
<tr>
<td>... 20 lb.</td>
</tr>
</tbody>
</table>

The biggest yield of meal from this raw material is obtained by simply drying off about 65 lb. water. The remainder will then have the following composition:

| Water ............... 3.5 lb. (≈ 10%) |
| Fat ................. 12 lb. (≈ 34%)  |
| Nonfat solids ...... 20 lb. (≈ 56%)  |

\[ \frac{68 - 3.5}{20} = 64.5 \text{ lb.} \]

Such a product would contain far too much fat to be salable. Furthermore, no valuable oil would be recovered. A process implying direct drying is therefore practical only with raw material containing 2% fat or less.

Another drawback of the above process is that it is necessary to remove by drying an amount of water equal to about twice the weight of the finished meal—in our example 68 - 3.5 = 64.5 lb. This is an operation which involves heavy fuel expenses.

For these reasons the manufacture of meal from fatty raw material always starts with a precooking process followed by a pressing operation of the cooked stuff. During heating the protein matter is coagulated, the mass can be pressed and, if the cooking has been carried out properly, a press-cake with as little as 55 or even 50% water can be obtained. Equally important, during heating the fat cells containing the oil are ruptured, and a good yield of oil is obtained when the liquid is separated from the press-cake.

A reduction in moisture content from the original 68% down to 50% in the press-cake may not appear very significant. But recalculated into pounds of water per total weight the result is nevertheless astonishing. Together with the press liquor about one-fifth of the fish solids are lost, this proportion of solids being soluble in water. The press-cake will then
consist of only 16 lb. nonfat solids. Assuming a residue in the cake of about 2 lb. oil, i.e. 5.5%, which is somewhat high but quite a common figure, the press-cake will have the composition given below. The composition of the finished meal is also given.

<table>
<thead>
<tr>
<th></th>
<th>Press-cake</th>
<th>Meal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (lb.)</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>Fat (lb.)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Solids (lb.)</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td><strong>36</strong></td>
<td><strong>20</strong></td>
</tr>
</tbody>
</table>

Of the 68 lb. water originally present, 50 lb. has been removed in the pressing; only $18 - 2 = 16$ lb. needs to be removed by evaporation during the drying process. This represents a very considerable saving in fuel expense. One may get by with only one quarter of the fuel, and yet end up with a prime low-fat meal and 10% yield of oil.

These advantages have been bought at the expense of 20% of the total solids, a very serious reduction in the meal yield. The actual figure is in effect still larger, as only 20 lb. meal is obtained as against 35.5 lb. by direct drying. But 12 lb. of this latter amount is fat which is not desirable in the feed. Indeed, the meal is valued according to its protein content only, and the 12 lb. fat will therefore, for the manufacture, represent a loss.

Many efforts have been made to recover the losses due to the glue-water, or stickwater as it is termed in the United States. Such recovery started only 10-15 years ago on an industrial scale, beginning by concentrating the glue-water to a paste with about 50% solids content. This product is manufactured and sold as such under the label, “Concentrated Fish Solubles,” or incorporated into the meal by mixing with the minced press-cake before drying. This is the product now known in Europe as “whole meal.” The manufacture of such whole meal gives about 20-25% higher yield.

IV. Manufacturing Methods

The bulk of all fish meal produced is processed after precooking and pressing the raw material. Simple and primitive methods have been described by the present writer (Sparre, 1953). Mechanical devices are now indispensable in plants of all sizes and will be reviewed below.

A. Handling of Nonfatty Raw Material

1. Simple Direct Drying

The raw material, consisting of fresh fish offal from freezing plants and salting establishments, is cut in a disintegrator and passed through
a so-called flame dryer. This consists of a steel cylinder mounted on trunnions, given a slow rotation. Inside the cylinder, longitudinal flights lift the material and allow it to fall through the path of the hot gases passing through the dryer concurrently with the meal. After leaving the dryer the meal is ground, cooled, and sacked, thus completing the process.

This method can be used for most nonfatty fish. The dryer must be able to withstand high temperatures. The gluey water that is released upon heating is likely to cause difficulties unless the inlet temperatures are very high.

2. Drying with Recirculation

As was mentioned, the crude material when coagulated by the heat sets free large amounts of gluey water which cause the material to stick and cake together, forming lumps that adhere to the heating surface and interfere greatly with efficient drying. By pressing the mass, the subsequent drying takes place without inconvenience. But if it is desired to avoid the pressing operation, the difficulties can be overcome by recirculation of part of the dried material. The minced fish then enters the dryer intimately mixed with a portion of already dried meal. This forms a semidry feed which gives no trouble in drying! It is often an advantage to dry in two steps—two dryers placed in series. Part of the semidry material from the first dryer with, say, 30% moisture is recirculated. In this case a high percentage of admixture is needed. If, for instance, the original raw material contains 80% moisture, an amount of recirculated material equal to 1.5 times the weight of raw material is required to obtain a mixture with about 50% moisture. For some raw material it will be found necessary to use a much higher proportion of admixed product. As calculations show, a proportion of 1:5 still gives a mixture with 38% water. Such a mixture can, however, be dried in the flame dryer very easily.

When working with fattier raw material, it may be an advantage to press the warm semidry mass before completing the drying. This will yield a less fatty meal but will, on the other hand, give rise to loss of solids with the press liquid. In other words, we have here a transition process to the orthodox wet rendering.

B. OLD REDUCTION METHOD

We shall now briefly describe this process, but it will be unnecessary to enter into details regarding the machinery used. Only the more important characteristics will be mentioned. Essentially the process consists of cooking, pressing, and drying operations, with separation to recover the oil from the press liquid.
During the early period of the industry, the manufacture consisted of a discontinuous batch process (see Anonymous, 1945). The raw material was cooked in open vats with direct steam. After some sort of preliminary draining the cooked mass was wrapped in burlap cloth and pressed in hydraulic presses, or even simple screw presses. The drying of the chopped press-cake was soon carried out in continuously working mechanical dryers, cylinders heated externally, in flame dryers with the stuff to be dried in direct contact with the fuel gases, and indirectly in steam-heated ovens.

Figure 1 is a flow sheet representing the fully developed process including glue-water recovery (see under C “Whole Meal”). The fish are here fed into a continuously working cooker, commonly a long horizontal cylinder fitted with a transporting screw and a number of inlets for direct steam along the total length of the cylinder. The mass is thus gradually heated to about 100°C, this temperature being reached at the outlet.

The cooking is a key operation. It is essential that the material be properly coagulated during the cooking; if not, a lot of trouble is experienced during the pressing. A badly coagulated material will give a press-cake with excessive moisture and fat content, while the oil separation of the press liquor will be difficult and incomplete. Often the press will not “take” the badly cooked material; a soft fluid mass oozes through the perforations. Various raw materials require different cooking. It should be noted that the coagulation is a function not only of the temperature but also of the time. Duration of the cooking must be such as to give sufficiently long contact, say 15 minutes, between inlet and outlet.

Old, partly decomposed stuff is difficult to handle, but too fresh fish also cause trouble. Very often the addition of coagulating agents will be found helpful. Calcium chloride has been widely used for this purpose. It has the inconvenience of forming lime soaps with the fatty acids, clogging screens and presses. For this reason formaldehyde is now most commonly employed; the continuous addition of a few pints per ton often converts the most difficult raw material into a perfectly coagulated product, ready for the press. During cooking all the live steam added of course condenses in the mass. This is therefore diluted with some 15-20% of water. As long as the press liquor went to waste this was of no great consequence. But the cooked mass contains so much liquid and also so much fine sludge, that it has to pass a prestrainer before it can be fed to the press. The sludge especially creates great difficulties in the pressing operation, since it clogs the pores of the press-cake. This sludge is effectively recovered in the sludge centrifuges, designed for this pur-
pose. By putting in a rotary screen, with perforations of about \( \frac{3}{4} \)-inch, it is in many cases possible to increase the press capacity 100% or more.

There are different types of continuously working screw presses, with single or double screw, strainer surface of perforated plates or rods, etc. During transportation through the press cylinder the moisture and dissolved solids together with the oil, and an inevitable amount of suspended matter, are squeezed out. A satisfactory press-cake may contain

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**FIG. 1. Flow sheet for manufacture of fish meal and fish oil.**

1. Fish storage
2. Screw conveyor
3. Cooker (indirect)
4. Rotating screen
5. Press (double screw)
6. Press-cake disintegrator
7. Mixing screw
8. Rotatory dryer
9. Pneumatic conveyor (fan)
10. Meal collecting cyclone
11. Meal conveyor
12. Vertical sifter
13. Hammer mill
14. Pneumatic conveyor
15. Bagging cyclone
16. Separating magnet
17. Distribution screw
18. Automatic weight
   A. Fish meal
   B. Fish oil
19. Sludge separator
20. Oil centrifuge
21. Glue-water concentrator
as little as 50% moisture with, say, 3–5% fat. Obviously the result of pressing directly determines the quality of the meal. The performance of the press must therefore be closely watched, and feeding of the raw material to the cooker and thus the total capacity of the installation must be governed by the press. The press liquid contains more or less sludge that has passed through the press openings. This interferes with proper oil separation, besides representing a considerable loss of meal. Most of it is therefore recovered on rotating or vibrating screens and, being very oily, it is often returned to the cooker. Preferably it is re-heated and pressed in a separate sludge press and added directly to the dryer. Continuous sludge centrifuges have appeared on the market, and are now extensively used. These separate the sludge with low enough fat content so that it can be dried without further treatment.

The cake from the press is ground in a chopper in order to facilitate an even drying, and then enters the dryer. Externally heated dryers are now all but obsolete. Rotating dryers with steam-heated tubes are common. But in the modern fish meal factories working at high capacity—up to 1000–1500 tons of raw material per 24 hours—some form of direct flame dryer is generally used. The drying has so important a bearing on the quality of the finished product that it will be discussed later in somewhat more detail.

The dried material generally contains about 8–10% moisture. It is transported to the milling section, frequently by air blowing but screw conveyors, belts, etc. are also used. The ground meal is sacked and stored in a way that allows it to cool and avoid spontaneous heating.

In this old process the press liquor, after passing the sieves, goes to the oil separation plant. Previously a system of settling tanks was employed for this purpose. This is now obsolete, a better oil and higher yield being obtained by the use of continuous centrifugal separators. These modern devices are so constructed that the fine sludge, which would otherwise choke the centrifuges in a very short time, is eliminated, either continuously or intermittently. The glue-water resulting from this separation generally contains 0.5–1% oil and 5–7% nonfatty solids. This glue-water was formerly wasted; this was a very serious drawback of the original wet process.

C. "Whole Meal" Methods

1. General

The loss of solids in the glue-water, as was mentioned, may amount to 20% of the total amount present in the raw material. In other words, by recuperating this loss we should get 25 lb. fish meal from 100 lb. fresh fish, instead of 20 lb. Many attempts have been made to recover
the solids from the glue-water. In Norway, as early as the first world war, the glue-water was evaporated and reincorporated into the press-cake during drying. But this practice was discontinued, since the price of such meal was reduced because of its large proportion of water-soluble protein. This fraction is very different from the fiber protein, and the erroneous conclusion was arrived at that this new “full meal” or “whole meal” was an inferior product.

It was not until the high content of water-soluble B vitamins in the glue-water was demonstrated that real interest was shown in the recovery of the glue-water solids. A new product called “fish solubles” came on the market in the United States. This was glue-water, concentrated to about 50% total solids content, often after acidification and refining to remove sludge and excess fat. In other parts of the world the manufacture of “whole meal” was again initiated. A product was obtained which retained all the water-soluble vitamins of the raw material. It also became evident that the water-soluble protein very efficiently balances the fiber protein of the meal. This will be discussed later.

2. Whole Meal via Solubles

The simplest way of accomplishing this 100% utilization of meal production would be to incorporate the concentrated fish solubles into the press-cake and, after thorough mixing, pass the whole through the dryer. This is then a modification of the old wet process. The evaporation involves heavy expenditure of steam. Every effort was therefore made to obtain the glue-water without undue dilution with condensed steam. This gave rise to the “indirect cooker,” where the raw material is heated indirectly by allowing steam to condense in an outer jacket of the cooker. Then, in order to get sufficient heating surface without increasing cooker dimensions, the transporting screw was made hollow, also admitting steam. In fact, in a modern “indirect cooker” the heating surface due to the screw is larger than that of the jacket, possibly in the proportion 2:1. The technical problems connected with this construction, e.g., the elimination of the condensate from the screw, need not occupy us here. The “indirect cooker” is a sturdy and reliable construction and an important part of the whole meal installation. It is evident that all subsequent heating, e.g., of the glue-water before oil separation, must be done with indirect steam in coils or with the more modern heat exchangers, instead of by blowing steam into the liquid. It may be mentioned here that quite a different type of indirect cooker has lately been tried with great success. It is the “tubular” cooker, heated indirectly by means of fuel gases.
Concentration of the glue-water in multistage evaporators presents some difficulty. Problems of scale formation have not been entirely overcome, and for certain raw material can be very serious. It is now becoming customary to pass the concentrate through oil separators before incorporating it into the press-cake. Thus extra oil may be recovered, and the resulting whole meal has a lower fat content. In order to accomplish this oil separation, and also to get a concentrate that is not too viscous for blending, the concentration is seldom carried beyond 35% total solids. The concentrate when hot is then still fairly fluid and readily absorbed by the moist press-cake. The heavier concentrates have a tendency to form a coating on the outside of the particles. This will result in a more hygroscopic, sticky meal after drying. A concentrate that is more readily absorbed can also be obtained by carrying out the concentration at higher temperatures, under pressure. Such a procedure permits very considerable saving in fuel. As a matter of fact, the evaporation can be effected without extra expenditure of steam. Working with temperatures in the three stages of the multiple-effect evaporator of e.g., 160°, 150°, and 130°C, respectively, the steam leaving the third stage can be used for cooking the raw material. The greatest advantage of the method, however, is that the same large volumes of fresh water, in many places difficult to get, would no longer be needed. Due to the breakdown of the gelatinous protein in the glue-water, with formation of less viscous albumoses, a concentrate of up to 50% solid matter can easily be added to the press-cake. This represents a welcome relief for the dryers, the capacity of which is heavily taxed with the introduction of whole meal manufacture. Passage of the glue-water through the evaporator is so rapid that the valuable growth factors seem to be but little affected, with the exception of pantothenic acid. This point will be discussed later. Possible adoption of this process of pressure evaporation is, indeed, dependent on the effect it will be shown to have on meal quality. For instance, the darker color of such a “whole meal” is considered by many to be a disadvantage from the selling point of view.

3. Recirculation Method

Instead of concentrating the glue-water and then adding it to the press-cake, the opposite procedure may be adopted, namely, partially drying the press-cake and then adding the glue-water without previous concentration. Dry meal absorbs the liquid with great difficulty but, before the finishing stage when about 25-30% moisture remains in the press-cake, the absorption is effected very readily. The drying process must therefore be carried out in two stages, e.g., drying to 25-30% moisture in one dryer and adding the glue-water, and finishing the proc-
ess in a second dryer. A number of modifications of the method exist. The finished meal is of excellent quality; but the fuel consumption is necessarily high, as the evaporation of large amounts of water is carried out in the dryer in one stage, thus not taking advantage of the economy of multiple-effect evaporation.

D. Other Reduction Methods

By far the bulk of fish meal is manufactured according to one of the methods so far described. But the possible variations are legion. Thus in Europe a variety of compact equipment is built for marine installation. Many consist of quite novel types, cookers heated by means of fuel gases and consequently requiring no steam, compact disk presses instead of the ordinary horizontal screw presses, flash treatment dryers, etc. Detailed descriptions of such equipment, of course, cannot be given in this short chapter.

Fundamentally new reduction processes have recently been suggested; most have actually been tested in practice, but are probably being used on only a very limited scale. It is not unlikely, however, that the wet rendering methods will sooner or later be supplanted by more rational ones. This will of necessity be a slow evolution because of the truly amazing capacity of the modern wet rendering equipment, and also because of the enormous capital now invested. But in this general survey it will be of interest to consider some of the new principles that might in time replace the methods now in practice.

1. Dry Rendering

The dry rendering process is well known in the slaughterhouse industry. In the manufacture of fish meal, where limited amounts of raw material are available, it is generally employed in smaller units. To install dry rendering equipment for treatment of 1000 tons or more of raw material per day is hardly reasonable. The characteristic feature of this method is that the fish is dehydrated before pressing. The drying generally takes place under vacuum and therefore, due to the low temperature, a meal with excellent nutritive properties is obtained. The process on a reduced scale is essentially a batch operation, although it can be made semicontinuous, e.g., by alternately filling and discharging two dryers from one preheater. The dryer is a steam-jacketed cylinder that rotates or has a stirring device. The drying operation generally requires several hours, and must be stopped at a definite moisture content. Dried to less than 8% moisture, the fat cannot be pressed out properly. The pressing is mostly carried out in discontinuous hydraulic presses, working with a pressure of 30–40 atm. The fat content of the resulting
press-cakes can then be as low as 10%, and the hard compact cakes, present-ing but a small relative surface, are very resistant to rancidity and may be stored for a considerable period. The oil from such dry rendering is much darker than the wet rendered oil, having dissolved coloring matter during the dehydration process, but is often readily bleached and refined.

Big dry rendering plants can be made to work continuously, with regard to both the vacuum drying equipment and the high pressure expeller. But the operation nevertheless requires much manual labor and is therefore not considered economical for large capacities. The fuel consumption is also large, since all the water has to be evaporated in single-stage operations. An advantage of the method is that practically all sorts of raw material, fat and lean, fresh and decomposed, can be worked up with equal ease.

2. Dehydration in Oil

A modification of the above method, which has been tried out on both fish and marine mammals, consists in dehydrating the raw material in a bath of oil. In such equipment the contact with the heating surface is excellent, and it is kept clean and free of scorching material on account of the oil. The drying under vacuum takes place rapidly, and this part of the process has always been quite satisfactory. The pressing to obtain a pure oil and a fairly lean press-cake has met with less success. In any case the method has in this respect the same drawbacks as the straightforward dry rendering. It is felt that unless solvent extraction proves economically feasible in the fish meal industry, the latter methods will not prove successful.

3. Solvent Extraction

These processes are so well known, being carried out on a huge scale on many different raw materials, that they need not be described here in detail. Only a few facts relating to fish as raw material will be pointed out. A characteristic feature of the old extraction processes is that the stuff to be treated must be dried beforehand. That is, the starting material may be an already finished fish meal, produced by one of the methods described, wet or dry rendering. From this dry mass the oil is extracted by means of a liquid sufficiently volatile and a good fat solvent. The extraction can be carried out as a batch process or continuously, in both cases in countercurrent fashion, the fatty material being brought in its original state in contact with a miscella already containing dissolved fat; then, as the meal becomes exhausted, it gradually encounters the pure solvent. In a batch operation this means extracting the meal
with a weak miscella and washing the once-extracted mass with pure solvent. The reason for this is of course to obtain the highest possible fat concentration in the miscella before distilling. This distillation to liberate the fat and to recover the solvent is a fuel-consuming operation, and frequent repetition entails considerable loss of solvent.

In practical operation the fat content of the extracted fish meal is around 1–2%. The meal then has a light color and should be fairly odorless. The smell of solvent should also have been carefully removed by blowing with dry steam. The meal is now less prone to rancidity, but after a time there frequently occurs a reversion of odor that may be objectionable. Another characteristic of extracted meal is its dustiness, which is sometimes overcome by adding less unsaturated neutral fat. The protein content of such meal is very high, generally in the neighborhood of 80%, and this sometimes makes it less convenient for use in feed mixes.

The color of the extracted oil is generally very dark, especially if chlorinated solvents, such as trichloroethylene or carbon tetrachloride, have been used. The price obtained for such an oil is therefore hardly sufficient to pay for extraction expenses. The better price commanded by the protein-rich meal is of course counteracted by the reduced tonnage resulting after the fat elimination.

Another difficulty very often met with in fish meal extraction is caused by the finely distributed solid particles—the "fines"—which can be eliminated only by costly operations.

As was stated, we believe that extraction of dried fish meal will not become a standard procedure in the fish meal industry for many years. The so-called wet extraction may be more advantageous. The principle underlying this method is the following.

4. Wet Extraction

The fish or offal, in its original wet state, is mixed with a fat solvent of fairly high boiling point, immiscible with water. The mixture is heated indirectly by means of steam. The water, together with part of the solvent, evaporates. The vapors condense and the two phases, water and solvent, separate. The solvent returns to the process. When the moisture content of the raw material has reached, say, 10% the dehydration is discontinued, the miscella drawn off, and the fat separated from the solvent by distillation.

The water in this process is removed by so-called azeotropic distillation. The mixed liquid solvent/water boils at a lower temperature than either of the two components, and the vapor will have a fixed com-
position. A solvent employed for azeotropic distillation in Europe is perchloroethylene. This forms with water an azeotropic mixture boiling at 87.7°C, the vapors containing about 84% by weight of perchloroethylene. According to an American patent, trichloroethylene is preferred. These chlorinated solvents have the advantage of being noninflammable, but extract much coloring matter from the raw material and are corrosive and poisonous, so that traces must be thoroughly expelled from the finished meal and oil.

The loss of solvent has been given as about 1% by weight of the raw material treated. The use of the cheaper hexane or other volatile hydrocarbons might therefore be preferred, were it not for the fire hazard. The fuel expense of azeotropic distillation is also high; not only is the moisture in the raw material driven off in single-stage evaporation, requiring more than 1 lb. steam per lb. water evaporated, but also substantial amounts of solvent are evaporated over and over again, and the latent heat of the vapors is lost.

Several small wet extraction installations are operating, mostly on fish livers, viscera, etc. It is doubtful, however, if the process can be adapted to full-scale fish meal manufacture.

It has been proposed to combine the process with the orthodox cooking/pressing process. In this case only the press-cake would be solvent-extracted. This would yield the bulk of the oil as prime quality oil and would greatly reduce cost of equipment and operation of the azeotropic distillation plant. It would require, however, extra cooker and press, besides apparatus for concentration of the press liquid. This operation carried out in a multistage evaporator would, on the other hand, be much more economical. Such a combined process has apparently not gone beyond the experimental stage.

We feel it should be sufficient to mention briefly a few further methods for fish meal manufacture, patented and conducted on a semicommercial or pilot plant scale. They include the following.

5. Use of Supersonics

Both German and British methods for such processes have been published. The “ultrasound” is generally produced by some sort of hammer mill. The vibrations employed seem to be about 10,000 per second, in other words not quite “supersonic.” The vibration is transmitted to the liquid containing the fatty raw material. Part of the fat is then driven out, at a low temperature. The difficulties in recuperating the solid matter are considerable, except in the case of bones where the process seems to have met with some success.
6. Solubilization Processes

These methods do not produce fish meal, properly speaking, but semiliquid pastes, sometimes called "liquid fish." They seem to have been inspired by the success of "condensed fish solubles." Apparently lean fish or fish waste is intended to be used in these processes, but it should also be possible to use herring or other fatty fish by introducing a cooking and pressing operation.

One method consists in treating the fish at a high temperature (100–150°C.) with strong acid, e.g., sulfuric acid. Working at a pH as low as 3.0 or even lower, most of the fish is dissolved in the course of 3–4 hours. The liquid is then neutralized and condensed to a paste with, say, 50% total solids in multiple-effect evaporators.

The solubilization may also be effected through enzymes by adding commercial proteolytic ferments or employing those already present in the digestive tract of the fish. During the period when the fish are feeding, the gastric juices are very active and may liquefy the fish protein in less than 24 hours. The bones, however, remain and must be treated separately. As far as is known this principle has been tried only in pilot plant operation.

Digestion of the fish by means of alkali has been tried in Great Britain. While the yield and quality of the oil are found to be very good, the utilization of the protein matter has proved a difficult problem, due to the destructive action of the alkali. The process has therefore little hope of proving successful.

In connection with this short review of methods of fish meal manufacture, it might be expedient to mention one characteristic common to many of them: the amounts of malodorous gases emanating from the drying operation. All efforts to eliminate this smell, by washing with water, treatment with chemicals such as chlorine, ozone, etc., have proved unsuccessful. The only effective method so far proposed is to burn the gases with or without condensing the water vapor they contain. If the gases are exposed to temperatures above 500°C., the smell is completely eliminated. The remaining problem is then how to utilize the heat thus created so as not to spend an excessive amount of fuel oil.

V. Fish Meal Production: Statistics

Fish meal is a product now firmly established on the market, and produced in many parts of the world. Since prewar days the production has about quadrupled, and is apparently still increasing.

Table I has been compiled from data issued by the Food and Agriculture Organization, and will suffice to give a general impression of the importance of the industry.
<table>
<thead>
<tr>
<th>Area</th>
<th>1938</th>
<th>1948</th>
<th>1952/54(^b)</th>
<th>1955/57(^b)</th>
<th>1958/60(^b)</th>
<th>1960</th>
<th>1961</th>
<th>1962</th>
<th>1963</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peru</td>
<td>na(^a)</td>
<td>1.1</td>
<td>12.6</td>
<td>35.2</td>
<td>339.2</td>
<td>558.3</td>
<td>839.8</td>
<td>1,111.4</td>
<td>1,159.2</td>
</tr>
<tr>
<td>United States</td>
<td>185.6</td>
<td>195.5</td>
<td>297.5</td>
<td>355.9</td>
<td>339.5</td>
<td>351.1</td>
<td>382.3</td>
<td>393.8</td>
<td>208.3</td>
</tr>
<tr>
<td>Japan</td>
<td>190.3</td>
<td>34.3</td>
<td>98.2</td>
<td>142.8</td>
<td>261.6</td>
<td>312.7</td>
<td>362.2</td>
<td>390.9</td>
<td>na(^a)</td>
</tr>
<tr>
<td>South Africa</td>
<td>3.5</td>
<td>10.7</td>
<td>95.9</td>
<td>89.4</td>
<td>124.2</td>
<td>148.0</td>
<td>189.1</td>
<td>214.0</td>
<td>238.3</td>
</tr>
<tr>
<td>Scandinavia</td>
<td>110.6</td>
<td>140.5</td>
<td>238.0</td>
<td>238.4</td>
<td>205.7</td>
<td>198.6</td>
<td>215.9</td>
<td>217.1</td>
<td>238.2</td>
</tr>
<tr>
<td>Soviet Union</td>
<td>na(^a)</td>
<td>10.9</td>
<td>27.4</td>
<td>40.9</td>
<td>63.9</td>
<td>85.1</td>
<td>100.6</td>
<td>112.2</td>
<td>na(^a)</td>
</tr>
<tr>
<td>Iceland</td>
<td>23.3</td>
<td>41.2</td>
<td>27.2</td>
<td>39.7</td>
<td>56.4</td>
<td>55.8</td>
<td>70.7</td>
<td>81.9</td>
<td>87.7</td>
</tr>
<tr>
<td>Chile</td>
<td>na(^a)</td>
<td>0.8</td>
<td>7.8</td>
<td>15.1</td>
<td>30.2</td>
<td>42.3</td>
<td>58.0</td>
<td>91.6</td>
<td>90.4</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>40.0</td>
<td>60.1</td>
<td>82.3</td>
<td>89.4</td>
<td>77.8</td>
<td>76.2</td>
<td>73.0</td>
<td>72.4</td>
<td>75.3</td>
</tr>
<tr>
<td>West Germany</td>
<td>73.6</td>
<td>16.6</td>
<td>67.5</td>
<td>79.8</td>
<td>83.7</td>
<td>82.9</td>
<td>68.4</td>
<td>81.4</td>
<td>74.0</td>
</tr>
<tr>
<td>Angola</td>
<td>0.1</td>
<td>14.2</td>
<td>41.1</td>
<td>71.8</td>
<td>55.3</td>
<td>44.8</td>
<td>55.3</td>
<td>33.0</td>
<td>87.7</td>
</tr>
<tr>
<td>Total</td>
<td>627.0</td>
<td>525.9</td>
<td>995.5</td>
<td>1,198.4</td>
<td>1,637.5</td>
<td>1,955.8</td>
<td>2,415.3</td>
<td>2,799.1</td>
<td>na(^a)</td>
</tr>
</tbody>
</table>

\(^a\) Figures not available.

\(^b\) Average yearly production based on total for 3 years.
By far the bulk of the production consists of meal from the fatty fishes: herring, sardines, pilchard, maasbanker, menhaden. Small amounts of white fish meal, fish scrap from offal and from crustaceans and other aquatic animals, and "fish solubles" for the United States production, are also included.

Table I illustrates the meal production of Japan, Norway, Peru, United States, and other major producers. In this table, the amounts of "condensed fish solubles" are not included in the figures for the United States. The production of such concentrates has in latter years amounted to some 100,000 metric tons per year. The most interesting feature in this development is the spectacular change that has taken place in relative production by the leading manufacturing countries and the unique upsurge of Peru, only recently, followed by Chile.

The catch required for this massive fish meal production of Peru (1963) exceeds that of the entire Soviet Union, thus bringing this South American country to the position of second ranking nation in terms of landed fish, the overwhelming majority (96%) consisting of "anchoveta," converted into oil and fish meal by the reduction plants. American, European, and Japanese capital have strongly contributed to this Peruvian boom.

As indicated, Chile is entering a similar expansive development with a rapidly growing fish meal industry, also with foreign capital, some of which comes from the Union of South Africa. The figures for its fish meal output are expected to mount considerably, beginning with 1964.

Before the war, the United States and Japan competed for first place with yearly productions around 200,000 tons. The United States output has been fairly constant, showing a small regular increase and reaching 270,000 tons in 1961 after a peak of about 320,000 tons (exclusive of "solubles") in 1959.

Japan's production on the other hand dropped drastically after the war, but then steadily recuperated so that production today lies around 400,000 tons, second only to Peru. A major factor in this development has been the large scale floating processing units which are dispatched on long range expeditions to the Bering Sea and to African waters off Angola. Temporarily, these ships have also served off the coasts of Chile and Peru. (See also Chapter 12, p. 363, of this volume.)

The third classical fish meal producer, Norway, steadily increased its production during the postwar period to attain in 1954–56 first place, with some 250,000 tons per year. Then, due to failure of the herring fisheries, the tonnage suffered a serious decline.
Fish meal production in Africa before the war was practically non-existent. The diagram shows how the output climbed, to about 100,000 tons in 1953, remaining fairly constant until very recently.

Finally, Table I shows the spectacular rise of the Peruvian fish meal industry from practically nil in 1953 to 1,159,200 tons in 1963.

VI. Properties of Fish Meal

A. General

The bulk of fish meal now produced is used in animal feeds. It usually finds its way to the big feed-mixing mills, but in many parts of Europe is still used on the individual farm. In some places it is shipped in the form of fish scrap, but is mostly put up in the form of ground meal. It should then be fairly uniform in particle size, free from bone splinters, fish eyes, and other coarse matter retained by an 8-mesh sieve. The fraction passing 50-mesh is still fairly great. Such meals, however, are not excessively dusty, on account of the fat. In extracted meals on the other hand with a fat content as low as 1–2%, the dust is often a nuisance.

The color of newly produced fish meal is mostly grayish green; with time, more rapidly after storage at high temperatures, it takes on a yellowish brown color apparently without detriment to its nutritive quality. The smell is characteristically "fishy," and in time becomes rancid.

It should be noted that much inferior fish meal and fish scrap do not correspond to this description.

The danger of fish meal as a carrier of Salmonella germs has received much attention lately, and it goes without saying that precautions must be taken to avoid this contamination. This is not difficult if the production is carried on uninterrupted from cooking to bagging, and no sweepings from dirty floors, etc. are added to the meal.

The commercial quality of fish meals is generally indicated in a "routine" analysis, giving the percentage of protein, fat, ash, and moisture. Conventional methods of analysis and calculation must be followed. The sum total of the above items is found to be close to 100%, indicating that the meal does not contain substantial quantities of other compounds, such as cellulose, sugars, etc. An exception to this is found in the case of fish liver meal.

The relative proportions of the four ingredients vary within wide limits, depending on the species of fish used, but much more important is the relative amount of fish bones in the raw material, the thoroughness
with which the oily matter has been expelled, and the final moisture content of the meal. The composition of fish meals of different origin has been given by Creach (1950). However, it is not possible to set down norms for meals from various parts of the world. It must suffice to give here the following limits:

<table>
<thead>
<tr>
<th>Component</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>6-10%</td>
<td></td>
</tr>
<tr>
<td>Fat</td>
<td>5-12%</td>
<td></td>
</tr>
<tr>
<td>Protein</td>
<td>60-75%</td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>10-20%</td>
<td></td>
</tr>
</tbody>
</table>

A moisture content of less than 6% is rarely encountered since it is hygroscopic, an excessively dry meal would soon readjust its moisture content in accordance with the humidity of the atmosphere. The packing of meal in the fairly moistureproof polyethylene-coated bags will retard such a process. Meal with moisture higher than 12% is likely to get moldy, and will probably be rejected by the user.

It is difficult to produce from oily fish a meal with less than 5% fat. This would mean a press-cake with as little as 2.5-3% fat, which seems to be a practical limit. Extracted fish meal may show 1% fat or less, depending upon the exhaustiveness of the extraction. In general, the sooner after manufacture the meal is extracted, the easier the extraction becomes. On the other hand, meal from white lean fish may show 1% fat or less, even without cooking and pressing.

If the reduction process is carried out carelessly, when the raw material has not been completely coagulated and hence the pressing has been inefficient, it is not uncommon to get fish meals with 12-14% fat. Some raw materials are more difficult to handle than others. Newly caught fish generally tend to give a fatter meal. The same is true of partly decomposed raw material, which does not yield so firm and dry a press-cake. It should be mentioned in this connection that the apparent fat content of fish meal seems to decrease 2-4% during storage. This is due to the fact that the oxidized and partly polymerized fat is not so easily extracted with the solvents used in the analytical routine. The different solvents also behave differently in this respect.

The ash, that is the mineral matter, is derived mainly from the fish skeleton. The ash content is therefore especially high when fish heads and other offal is employed. The ash consists mainly of calcium phosphates; it is a valuable ingredient in the feed mixes, and meal with high ash and correspondingly lower protein content is in many cases preferred to the protein-richer meals. The mineral matter of the meal contains in many cases a high proportion of chlorides. This may come from
the salt used for preservation purposes, or from chlorides used to improve coagulation of the cooked mass. This salt, while not detrimental, adds nothing to the commercial value of the meal. Sun-dried meals from primitive plants often contain sand, clay, and other foreign matter.

The protein content varies inversely with the other ingredients, being therefore especially high in dry low-fat meals. This explains the fact that some meals contain as much as 75% protein, while others contain less than 60%, perhaps nearer to 50%, if they have high ash and fat contents.

The valuable B vitamins and other growth factors contained in fish meal of course represent so small a quantity by weight that they do not modify its percentage composition. Nor are determinations of these compounds generally included in the routine analyses.

B. PROTEIN

Fish meal is mainly a protein feed and must, therefore, be rightly valued as such, in the first place on the basis of its percentage of "crude protein"—i.e., percentage nitrogen multiplied by the conventional factor 6.25.

Such a valuation is, however, very incomplete. A first requirement is of course that this protein should be digestible. The determination of digestibility of fish meal, carried out in vitro by means of pepsin and hydrochloric acid, gives values generally considered to be in fair agreement with biological tests, and can be carried out with an insignificant expenditure of time and money compared with feeding tests on animals.

A good fish meal should show a protein digestibility of 92–95% (based on total protein content). Very rarely higher figures are found. On the other hand, meals manufactured from decomposed raw material or by faulty processing, such as overheating during the drying operation, spontaneous heating during storage, or storage for years—such meals will show a low digestibility. In extreme cases, less than 80% and even lower digestibilities may be found.

Often a distinction is made between "crude" (total) and "pure" protein. The latter is the nitrogenous matter precipitated by a certain alum-copper reagent, which leaves amides, meat bases, urea, etc. in solution. This latter fraction is especially abundant in the glue-water, where it may amount to 30% or more. "Whole meal" consequently also contains more "amides" than "ordinary" meal. Occasionally "pure digestible protein" is also indicated in analyses. As will be clear from the following considerations, an evaluation of the nutritive properties from such data is not justified. Often a determination of "water-soluble" protein or
“water-soluble N” is carried out. This is an easy way of recognizing a “whole meal” in which in most cases the water-soluble N amounts to 18–20% of the total N, while for an “ordinary” meal 6–7% is customary. Of course all kinds of intermediary values may be found, depending upon the extent to which the glue-water solids have been recovered.

The real value of a protein feed is measured by its relative content of “essential” amino acids. Complete analyses of most of the commercially important proteins are now available, giving the composition of the amino acids with a high degree of accuracy. Such tables are no doubt given elsewhere in this volume and show how favorably fish protein compares with many other proteins with regard to amino acids. As further illustration, Table II (Boge, 1960) is given here, showing all the important amino acids in herring, in herring meal, and in the intermediary products press-cake, glue water, etc.

It should be noted that besides the 10 amino acids generally considered “essential”—the first 10 in Table II—a few of the others are also important in nutrition. The fairly high content of cystine, for instance, has a sparing effect on the essential methionine. The same thing applies

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Herring</th>
<th>Press-cake</th>
<th>Glue-water</th>
<th>Meal</th>
<th>Whole meal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arginine</td>
<td>7.14</td>
<td>8.15</td>
<td>5.38</td>
<td>8.10</td>
<td>7.86</td>
</tr>
<tr>
<td>Histidine</td>
<td>1.87</td>
<td>2.03</td>
<td>1.21</td>
<td>2.10</td>
<td>1.84</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>6.20</td>
<td>6.75</td>
<td>1.98</td>
<td>6.70</td>
<td>6.12</td>
</tr>
<tr>
<td>Leucine</td>
<td>7.14</td>
<td>7.45</td>
<td>3.29</td>
<td>7.60</td>
<td>6.85</td>
</tr>
<tr>
<td>Lysine</td>
<td>8.34</td>
<td>9.05</td>
<td>4.57</td>
<td>9.06</td>
<td>8.18</td>
</tr>
<tr>
<td>Methionine</td>
<td>2.56</td>
<td>2.65</td>
<td>1.32</td>
<td>2.72</td>
<td>2.49</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>3.57</td>
<td>3.85</td>
<td>1.61</td>
<td>3.87</td>
<td>3.55</td>
</tr>
<tr>
<td>Threonine</td>
<td>4.1</td>
<td>4.07</td>
<td>2.24</td>
<td>4.19</td>
<td>4.0</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>0.78</td>
<td>0.82</td>
<td>0.16</td>
<td>0.81</td>
<td>0.72</td>
</tr>
<tr>
<td>Valine</td>
<td>5.38</td>
<td>5.74</td>
<td>2.57</td>
<td>5.85</td>
<td>5.33</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>3.0</td>
<td>3.27</td>
<td>0.72</td>
<td>3.30</td>
<td>2.89</td>
</tr>
<tr>
<td>Cystine</td>
<td>1.4</td>
<td>1.6</td>
<td>0.42</td>
<td>1.6</td>
<td>1.3</td>
</tr>
<tr>
<td>Glycine</td>
<td>6.31</td>
<td>5.4</td>
<td>10.2</td>
<td>5.66</td>
<td>6.28</td>
</tr>
<tr>
<td>Alanine</td>
<td>7.64</td>
<td>7.71</td>
<td>7.29</td>
<td>7.45</td>
<td>7.45</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>9.42</td>
<td>9.90</td>
<td>4.96</td>
<td>9.82</td>
<td>9.10</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>11.44</td>
<td>12.05</td>
<td>7.73</td>
<td>12.03</td>
<td>11.75</td>
</tr>
<tr>
<td>Proline</td>
<td>4.23</td>
<td>4.34</td>
<td>4.6</td>
<td>4.32</td>
<td>4.6</td>
</tr>
<tr>
<td>Serine</td>
<td>4.1</td>
<td>4.5</td>
<td>ca. 2.9</td>
<td>4.63</td>
<td>4.15</td>
</tr>
</tbody>
</table>

*a* Values given as % of crude protein (N X 6.25).

*b* Norwegian winter herring.
to tyrosine with regard to phenylalanine, while for poultry the simple glycine—alpha-amino acetic acid—is of importance.

The difference between the protein in meal and in glue-water is most striking. In the glue-water, the content of all the amino acids—with the exception of glycine—has been reduced, in many cases to 50% or even less. The sum total of all the acids makes only some 65%, while for a pure protein this figure should be in the neighborhood of 110 (taking into account the water added during hydrolysis). This proves that much of the nitrogenous matter is not protein at all, being made up of a variety of “amides” and meat bases.

The protein of the glue-water may be exposed to destructive heat during concentration. When this is carried out at low temperatures the damage is negligible. In most multiple-effect evaporation the liquid will remain at temperatures above 100°C. for longer or shorter periods, depending upon the construction of the evaporator; if this is designed to work under pressure in all its stages, the high temperatures occasion serious losses of several of the amino acids. The acids that suffer most during high temperature evaporation are cystine, histidine, and tryptophan. They are the same acids that are sensitive to hard drying. It is astonishing though that the lysine, sensitive as it is to excessive drying, does not seem to suffer under this treatment.

The glue-water is lacking chiefly in tryptophan, cystine, isoleucine, and tyrosine. The protein is therefore highly “unbalanced” or incomplete. Laksesvela (1958) fed chicks on glue-water (or concentrated solubles) as the only source of protein, but the animals did not survive. They invariably died after 2–3 weeks whether the protein was fed at a high or low level.

This, however, by no means proves that the “whole meal,” containing as it does a substantial portion of glue-water protein, is an inferior product. The contrary is often the case.

Compare the amino acid content of meal and whole meal with that of the raw material. It will be seen that the latter is practically identical with whole meal—as indeed it should be—while the “ordinary” meal and the press-cake from which it is derived have a somewhat different composition. It contains a slightly higher percentage of essential amino acids. On the other hand, the proper balance of the acids must have been altered and this is clearly reflected in the feeding tests.

In a series of experiments, where herring meal was the only source of protein, Laksesvela varied the proportion glue-water protein/fiber protein in the feed. Optimum feeding results were obtained with glue-water protein proportions of 15–45%. Beyond this latter figure the protein
efficiency rapidly decreased, and with more than 60% glue-water protein the results were fatal.

Contrary to what might be expected, a proportion of glue-water even considerably higher than that in whole meal thus gives optimum results in chick feeding. It must be borne in mind, however, that in "practical" diets, of which other proteins besides fish meal form a substantial part, this need not always apply; the actual value can be ascertained only by means of feeding tests.

The protein of the raw material is profoundly altered during the reduction process. The cooking operation partly coagulates the water-soluble albumins and globulins, which are originally present in soluble form. On the other hand, soluble gelatin is formed from the collagenous tissue and from the bones. Some of this is doubtless broken down further to albumoses, etc. But the cooking should not cause major alteration in the amino acid balance. Its influence on the protein value has so far received little attention.

On the other hand, it has been definitely proved that the drying may influence the quality of the protein. The work of Deas and Tarr (1949) and Clandinin (1949) may be referred to as an example. Indirect drying by means of steam is considered to be a mild treatment for the presscake, and meal thus dried is generally of excellent quality. However, the possibility of overheating the charge in contact with the hot steam tubes cannot be ruled out entirely and, on the other hand, meals dried in flame dryers are often of the very highest grade. If the drying is so carried out that moisture from the interior of the wet particles diffuses sufficiently rapidly towards the surface, this surface will remain moist in the hot parts of the dryer. The temperature of this surface then tends towards a condition of equilibrium, the so-called wet bulb temperature, which can be kept close to the adiabatic saturation temperature of the hot gas entering the dryer. If the temperature is thus kept down by the moisture, it is not difficult to keep the material at any moment below, say, 100°C.

Work carried out at the Norwegian Herring Meal Institute has shown that the inlet temperature of the gases in the flame dryer may be even as high as 500–600°C. (about 950–1100°F.) without damaging the meal, provided the outlet temperature is kept well below 100°C. (212°F.). This is confirmed by Clandinin (1949), who found no difference between meal dried in a very high vacuum (25 mm. mercury) and meal flame-dried at 85°C. A short passage through the dryer under these conditions is of no consequence, while high outlet temperature in an incorrectly conducted drying operation will give a meal with reduced digestibility and loss of amino acids. The amino acids most easily damaged are: lysine; cystine; tryptophan; and histidine.
The fact that the amount of an amino acid is found to remain constant after heat treatment does not necessarily mean that the acid in question is still available as a nutritional factor. In view of the importance of lysine and the ease with which it is altered, the amount of so-called "available lysine" was studied by Carpenter and Ellinger (1957). The drop in "available lysine" proves to be a good indicator of the damage done to a protein, for instance by excessive heating. But restoring the lysine to its original level by adding synthetic acid does not remedy the damage, unless other acids affected by the thermal treatment are also added.

The remarks made here on damage caused by severe drying also refer to spontaneous heating of the meal during storage, a phenomenon to be discussed later. In this case also the protein value of the meal is reduced by the destruction or immobilization of the 4 amino acids mentioned above.

Study of the distribution and availability of amino acids in herring proteins has contributed to our knowledge of protein utilization in general. Improper balance between the amino acids may very easily lead to a serious condition because of amino acid antagonisms, the resulting unhealthy state being not merely due to the shortage of an amino acid as building material. Moreover the antagonisms may be very complex, in addition to those of simpler type such as the well-known inhibitory action leucine may have upon isoleucine. The balance between the amino acids frequently appears to be more important than protein level (Laksesvola, 1961). The addition of even some of the "unessential" amino acids may be of advantage to the protein value of the feed.

The protein value of the meal is not constant indefinitely. For a period of a few years of proper storage no diminution of the nutritional value is observed. But gradually, even though the protein percentage (as measured by N × 6.25) is constant, the protein value is increasingly reduced; after 10–15 years the reduction may be very severe. The reason for this is not yet clear, but may have to do with an "immobilization" and consequently an altered balance of the amino acids.

C. Fat

The fat in fish meal is considered of little or no commercial value. The meal is evaluated on a protein basis, and the fat present reduces the protein percentage correspondingly. Liberal use of high-fat meal gives a "fishy" taste to the bacon or meat of animals fed on it. This drawback does not exist in careful feeding, with gradually diminishing amounts of meal.

The fat remaining in the press-cake is of the same highly unsaturated
nature as the oil recovered during the pressing operation. Its exact composition may be somewhat different, with a higher free fatty acid value and more lecithin and cholesterol.

The fat in newly produced fish meal is already quite oxidized, and the fatty matter that can be extracted by organic solvents is more like a dark polymerization product. As the meal gets older this process continues. The fat incidentally gets more difficult to extract, and analysis of an old meal will therefore register a lower fat percentage than in fresh meal.

The oxidation is also accompanied by a darkening of the color of the meal, often giving rise to unevenness of color in the same lots. Even more important is the tendency of the meal to spontaneous heating during storage or shipment. This is directly traceable to the oxidation of the fat which gives off considerable heat of reaction. If the sacks are stacked so compactly that this heat cannot escape, the oxidation continues at an increasing rate and the whole mass may char, become red-hot, and perhaps even burst into flame. The complicated reactions with formation of peroxides, further oxidation, polymerization, and decomposition are still far from being completely understood, and need not be discussed here.

The prevention of this self-heating is of course very important. By allowing the reaction to be carried to completion in the manufacturer's warehouse, with the temperature under control, the meal will have "matured" and should be safe. Many cases of incomplete "maturing" have, however, given rise to fires during transport or storage in the receiver's warehouse. Packing the meal in sacks practically impermeable to air is a measure in the opposite direction. The use of polyethylene-lined bags has given results so good that the danger of spontaneous heating has been overcome (Arnesen et al., 1962). The oxidation has also been controlled recently by the addition of antioxidants. Meade in the United States (Meade, 1956) and later European workers have employed butylhydroxytoluene (BHT) for this purpose with great success. The addition of small amounts of BHT, about 0.02%, seems to prevent the spontaneous heating completely. The oxidation takes place at a rate so slow that the heat of reaction is given off to the surroundings without occasioning marked increase in temperature. Meal where the fat is stabilized with BHT keeps its original color for a considerable time. The smell is less rancid and, as might be expected, the fat seems to possess a higher nutritive value. On the other hand, no preservative action on labile amino acids, hence no improvement of the protein value after the addition of BHT, has been demonstrated.

Efforts to secure safe storage of fish meal without running the risk of spontaneous heating are continuing with a view to allowing the goods
to be shipped in bulk. This is a more difficult proposition, although the same principles apply. The handling of fish meal in bulk, storage in silos, etc. would be of great economic advantage.

D. MINERALS

The mineral matter in fish meal consists mainly of calcium and phosphorus in the form of calcium phosphates. The meal may contain.

- **Calcium**: 3.0–6.0% (CaO 4.0–8%)
- **Phosphorus**: 1.5–3.0% (P\(_2\)O\(_5\) 3.5–7.0%)

This is an additional nutritive value of fish meal, since these elements form part of the animal skeleton. Fish meal plays in this respect a particularly important role, since it contains 10–15 times as much calcium and 4 times as much phosphorus as the most commonly used oil cakes. The meal manufacturer need not worry about these mineral components; the phosphates from the raw material are encountered in the meal regardless of the conditions of manufacture.

Apart from the phosphates—and possibly some chloride—the fish meal, like all other marine products, contains a number of “trace elements” or “oligoelements.” They are present in infinitely small amount, but are nevertheless of the greatest importance for vital functions.

The order of magnitude of some of these elements is shown in the tabulation.

<table>
<thead>
<tr>
<th>Elements</th>
<th>mg. per kilogram (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc</td>
<td>70</td>
</tr>
<tr>
<td>Iodine</td>
<td>70</td>
</tr>
<tr>
<td>Iron</td>
<td>250</td>
</tr>
<tr>
<td>Copper</td>
<td>7</td>
</tr>
<tr>
<td>Manganese</td>
<td>4</td>
</tr>
<tr>
<td>Cobalt</td>
<td>0.04</td>
</tr>
</tbody>
</table>

The fish meal of the diet may therefore be of value in controlling an insufficient intake of minerals, even if the direct addition of minerals is to be recommended. As far as iodine is concerned, the amount present in fish meal is generally sufficient to take care of the requirement.

E. VITAMINS

Fish meal does not claim to be a particularly rich vitamin concentrate although we generally find that it contains a fair amount, especially of the B group factors. The fat-soluble vitamins are seldom present in significant amounts, the less so the more fully the oil has been eliminated during the reduction process. Vitamin A being very easily oxidized may be con-
sidered as virtually absent from the meal, while many types, especially those from fatty fishes may sometimes afford a certain supply of vitamin D.

Most fishes contain fair amounts of all the B vitamins. Thiamine is rarely very abundant in the usual raw material for meal manufacture, the vitamin being furthermore easily destroyed by enzymic action. The small amounts of folic acid are easily oxidized!

The factors that have been most carefully examined, especially in connection with herring meal manufacture, are riboflavin, pantothenic acid, niacin, and cobalmine (vitamin B₁₂). The variations in these components are not so marked that they need occupy us here. Apparently niacin fluctuates the most.

During storage of the fish in the bins no appreciable loss of vitamins occurs. Efforts to increase the riboflavin through fermentation have not been successful. During the cooking/pressing operation as a general rule about half the vitamins pass into the glue-water. The reduction process would therefore cause serious loss of vitamins unless the glue-water were reincorporated in the meal (or made into a separate condensate).

We should then expect whole meal to contain considerably more vitamins, and indeed we frequently find twice as much pantothenic acid and niacin in the whole meal. Riboflavin and B₁₂ are not taken up to such an extent by the glue-water. In this case, when the vitamins are expressed in mg. per kg. of sample, the difference between ordinary meal and whole meal is not so striking. The following data from Boge (1956) illustrate this.

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Meal</th>
<th>Whole meal</th>
<th>Glue-water</th>
<th>Solubles (^a)</th>
<th>Herring (winter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riboflavin</td>
<td>5.1</td>
<td>7.3</td>
<td>2.2</td>
<td>12.9</td>
<td>2.65</td>
</tr>
<tr>
<td>Pantothenic acid</td>
<td>15.2</td>
<td>30.6</td>
<td>10.0</td>
<td>54.5</td>
<td>10.4</td>
</tr>
<tr>
<td>Niacin</td>
<td>61.0</td>
<td>126.0</td>
<td>35.2</td>
<td>221</td>
<td>35.9</td>
</tr>
<tr>
<td>Vitamin B₁₂</td>
<td>0.21</td>
<td>0.25</td>
<td>0.074</td>
<td>0.36</td>
<td>0.1</td>
</tr>
</tbody>
</table>

\(^a\) Calculated to 50% total solids.

The stability of the vitamins considered is quite good, with the exception of pantothenic acid. This latter frequently shows 50% loss or more under severe drying conditions. For the other vitamins, at outlet temperatures of less than 100°C. and with a reasonably good distribution of the material in the dryer, no serious loss of B vitamins need be feared. The shorter the drying period, the less the reduction.

As was the case with the amino acids, the B vitamins of the glue-water also undergo serious loss when the boiling temperatures are high.
and the processing time is long. Here too the pantothenic acid is the most sensitive vitamin.

The relation between vitamin B\textsubscript{12} and the “animal protein factor” (APF) is far from clear. B\textsubscript{12}, as has been observed, is remarkably resistant during the reduction process. This need not necessarily apply to the unidentified factor or factors.

VII. Utilization of Fish Meal

A. As Animal Feed

By far the greatest use for fish meal today is as an ingredient in animal feed mixes. Only the really inferior grades such as that produced by primitive means, sometimes dried in the open and put up as unground scrap often contaminated with sand and clay, are sold as fertilizer.

The good grades of fish meal are free from such contamination and free from insects, molds, and pathogenic germs. They constitute a valuable addition to the diet of our farm animals. Indeed, fish meal has come to be considered virtually indispensable for pigs and poultry.

The success of fish meal arises in the first place from the great nutritional value of its chief constituent, the protein. As was pointed out, fish meal is exceptionally well balanced as regards the amino acid distribution of its protein. This is of value even in the mixed feeds. Most vegetable feed does not provide sufficient methionine and/or cystine and/or lysine and is often lacking in tryptophan, even if the protein content is fairly high. It is evident that the richer a feed component is in essential amino acids, the greater is its value.

Because of the ability of ruminants to synthesize amino acids in the rumen by means of microorganisms, such animals are less dependent on the composition of the protein than are pigs and poultry. Nevertheless, cows with high milk production may well benefit by receiving additional important amino acids through the feed. Fish meal is normally used in feed mixed with vegetable cakes, where 10–40\% of fish meal may be used. It is also particularly important that no serious decomposition of fish meal takes place through deamination in the alimentary canal of the ruminants, as is the case with much protein matter.

Fish meals may likewise be used for oxen and young animals, and for sheep and goats during stall feeding.

Fish meal is considered too expensive an article, however, to find extensive use in the feeding of ruminants, which it is felt could do without it from the point of view of both protein quality and vitamin content.

The real outlet for the meal is in the feeding of pigs and especially in the raising of poultry. Here the quality of the protein and the vitamin content is of greater importance. But more than any other single factor,
the presence of the unidentified animal protein factor or factors has been investigated, although these compounds have not been determined quantitatively. Their presence is demonstrated beyond doubt through the growth stimulation in pigs and poultry. While this factor is doubtless present in varying amounts in different types of meal, and while the response to it is variable and dependent upon many external conditions, the following example from a Norwegian experiment (Laksesvela, 1954) is illustrative. In a continuous series of 13 trials carried out with a view to ascertaining the nature of the action of APF in herring meal upon chickens in the first 6 weeks of life, an addition of 7% herring meal resulted in weight increase of about 11% compared with the control receiving only vegetable protein in the feed.

A similar effect was shown by slaughter pigs. When ready for the slaughterhouse (90 kg. live weight), the growth was 5-12% greater in pigs that had received a supplement of herring meal than in control animals receiving vegetable food. These results were obtained with a total herring meal consumption of 5-10 kg. per animal, calculated on an average of 5 experiments. The rations in these cases were intended to be complete and of the same weight in respect to protein, vitamins, and mineral matter.

B. For Human Consumption

The transition from fertilizer fish scrap to high grade fish meal for feeding purposes was not a revolutionary one; it simply implied a steady improvement in quality. Thus it is not unlikely that fish meals, produced according to one of the "orthodox" methods may become a product fit for human consumption.

The lack of protein of high nutritional value is a most serious world problem, especially in the tropical countries, and for a long time the FAO (Food and Agriculture Organization) (Cutting and Bakken, 1957) has been engaged in a study of a solution. Through the United Nations Children's Fund, a series of large-scale tests have been conducted in a number of countries to assess the acceptability of such products. The tests comprised both nondeodorized and flavorless meals.

The first type simply consists of fish meal prepared from either whole fish or fish with most of the bones removed. It requires handling under improved hygienic conditions, standardization, and packaging assuring protection against humidity, oxidation, and insect attack. According to investigations such meals are acceptable in many parts of the world, a strong flavor being often preferred and incorporation of the meals in local traditional dishes being fairly easy. This, according to the FAO, does not mean that any fish meal intended for fodder will be accepted. Even where strongly flavored meals are favored, people will
not tolerate off-flavor of a type unfamiliar to them. The production of edible fish meals suitable for the different markets may well present its initial difficulties.

The production of a deodorized “neutral” fish flour, that can be directly incorporated for instance into meal for bread making, is quite a different proposition. It must of necessity be a costly process, involving as it does some form of solvent extraction to remove the fat mainly responsible for the fishy odor and unavoidable rancidity. The difficulties encountered have been summed up by Cutting as follows:

To remove the last traces of fishy taste and odor, and to obtain a product in which these properties do not reappear after some time in storage.

To find methods where the processing does not result in reduced biological value of the protein.

To carry out industrial production on an economical basis.

Although these problems were tackled years ago, methods are still in an experimental stage. The most promising results to the writer’s knowledge have been obtained by the Fishing Industries Research Institute, Cape Town, where a pilot plant with daily production of 1–2 tons of extracted meal was, at least until recently, in operation. This process was briefly as follows.

Crude maasbanker meal is given 5–7 extractions with a solvent mixture consisting of 9 parts 96% alcohol and 1 part ethyl acetate. The extractions are carried out with mechanical agitation at the boiling point of the solvent, about 80°C. After the final wash the solvent is stripped from the meal under vacuum.

The method is stated to be simple in operation, relatively inexpensive, and capable of industrial application to the cheapest available raw material.

The development of such a method required a considerable amount of research. The fishy odors and flavors had to be removed and the reversion of odor had to be prevented. The biological value of the protein must be left unimpaired. Practical difficulties also cropped up, such as removal of the fishy odors and flavors of the spent solvent before it could be re-used in subsequent batches.

In spite of the apparent success of this method, it is still a question whether extraction of the already dried meal will prove to be the most advantageous solution.

The drying process gives rise to odors and flavors that are most difficult to remove completely. The extraction of the wet press-cake might give more satisfactory results. In the case of the higher priced products,
the more costly method of wet extraction, for instance through azeotropic distillation, might prove to be economically feasible.

Efforts have been made to mask the residual or reappearing odor with flavoring agents. An interesting development in this direction is partial enzymic digestion of the fish meal protein. The faint peptonized odor thus developed—not unlike that of meat extracts—may be satisfactory for many purposes, and perhaps does not require complete removal of the fat, especially if the original product is not strongly rancid.

The modern dehydration methods are a step in the direction of producing high grade products capable of being “reconstituted” with water, and thus resembling in texture and taste the original product. In applying this principle to fish, it is found advisable to work with cooked minced fish. Such a product could be reconstituted, and thus used in prepared dishes such as fish cakes, pies, etc. According to Cutting (1955), dehydrated fish was produced on a pilot plant scale in the United Kingdom during the war. Stored under nitrogen gas in hermetically sealed tins, it remained edible for 2 years under temperate conditions and for 6 months under tropical conditions.

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