MFR PAPER 1138

Spoilage and Shelf Life Prediction of Refrigerated Fish

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ABSTRACT—Previous research by at least three separate investigating teams has shown that the spoilage of lean fish occurs at constant rates at temperatures above freezing and that there is a linear relationship between spoilage rate constants and storage temperatures. These findings are useful because they permit researchers and laymen to predict the shelf life of fish for any condition within the limits covered by the research. Mathematical or graphical methods may be used for arriving at the prediction. A device has been developed that simplifies the prediction.

SPOILAGE AND SPOILAGE RATE FACTORS

Two factors are prominent in the degradation of the quality of refrigerated foods and in the rate that spoilage occurs. These are spoilage bacteria and the temperature at which the foods are stored. However, other factors affect the spoilage process as well.

Seafoods are among the most perishable of foods, and it is important that we study the factors that affect their quality.

Bacteria

The role of bacteria in the spoilage of seafoods is well documented (Shewan 1962). The more active types of spoilage bacteria have been identified and their effects on the substrate have been defined (Shewan 1962; Castell and Mapplebeck 1952; Castell and Andersen 1948; Castell and Greenough 1957; Adams et al. 1964). The rate of spoilage is dependent on the number of bacteria (to a certain extent) and on the type of bacteria, since some types are more effective spoilers than others (Adams et al. 1964; Lerke et al. 1965; Licciardello et al. 1967). However, the role of bacteria may be insignificant after a certain amount of bacterial activity has occurred. A recent publication (Huss et al. 1974) lends some support to the probable lack of direct relationship between bacterial numbers and spoilage rate.

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Temperature

The role of temperature on the spoilage rate in foods, as it is for any chemical reaction, is well known. The temperature not only affects the rate of spoilage reactions, which involve both bacterial and autolytic enzymes, but it also affects the rate at which bacteria multiply. Thus, while the generation time for *Pseudomonas fragi*, a common fish-spoilage bacterium, is about 12 hours at 32°F, it is only about 2 hours at 55°F (Duncan and Nickerson 1961). Obviously, the rate of production of bacterial enzymes parallels to some degree the growth rate of bacteria, and the spoilage rate is in turn affected by the quantity of enzymes produced (at least up to a point).

The effect of temperature on the rate of spoilage of seafoods has been measured. Spencer and Baines (1964) reported that the spoilage rate of white fish is related approximately linearly to the temperature at which the fish are stored in the range −1° to 25°C. They concluded that the effect of temperature on the spoilage rate was expressed approximately by the Arrhenius equation over a large part of the temperature range they employed. They reported activation energies of 15,000 to 18,000 cal/mole. James and Olley (1971) reported activation energies that were in agreement with those of Spencer and Baines (1964). Charm et al. (1972) reported similar findings for holding temperatures in a narrower range. They used an expert organoleptic panel of defined precision (Learson and Ronsivalli 1969). In this work, the activation energies reported were in a relatively narrow range at slightly above 18,000 cal/mole. The reduced range in the data by Charm et al. (1972) is attributable to the precision of the organoleptic panel used in the study. As in the earlier work, Charm et al. (1972) found a linear relationship between the spoilage rates and the temperatures of holding in the range 32°-46°F. They also found that when fish were held at a variety of temperatures, the spoilage rate for any given temperature remained constant regardless of the temperature sequence that was followed.

Other Factors

While the effects of both spoilage bacteria and holding temperatures on the spoilage of fish have received considerable study, little work has been done to identify the role of packaging and oxygen as significant factors in the spoilage rate of fish. Evidence of the possible role of oxygen was found in experiments involving the preservation of fish with radiant energy. When fish were packaged in gas-impermeable containers such as polyester and aluminum laminated pouches and metal cans, they had a longer shelf life than similar fish samples packaged in gas-permeable pouches such as polyethylene (Tinker et al. 1966). Measurements of oxygen in the headspace of containers demonstrated falling values for oxygen in the gas-impermeable containers (about 1 percent remaining in the headspace) within one month's time whereas the oxygen concentration in the headspace of the polyethylene pouches was equal to that in the atmosphere (Ronsivalli and Tinker 1969). It has been demonstrated that the more active spoilage bacteria normally found in fish are

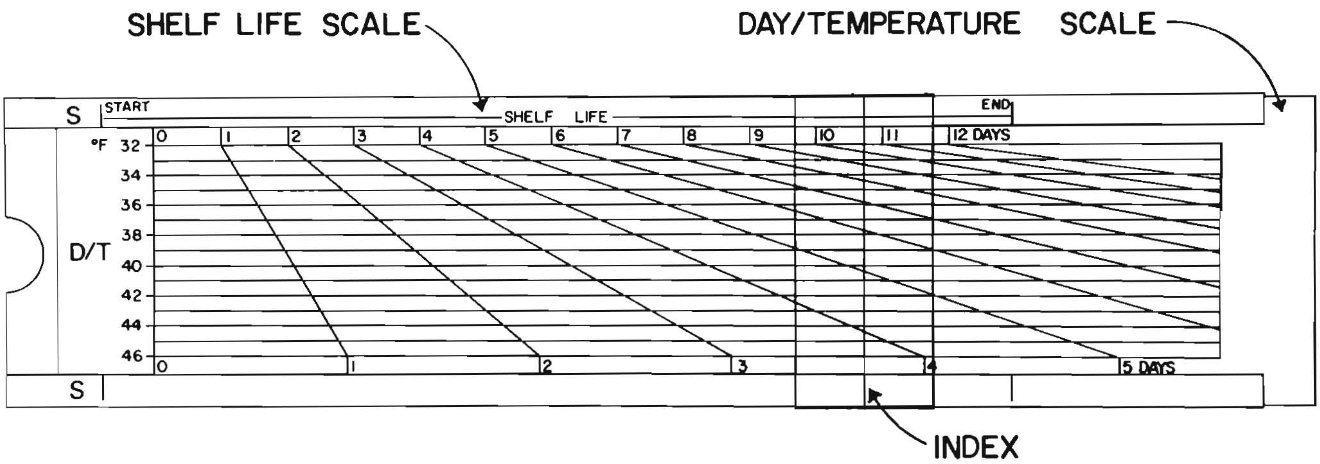

Figure 1.—The shelf life prediction slide rule, or predictor.

aerobes (Licciardello et al. 1967; Sinskey et al. 1967). Obviously, since spoilage bacteria require oxygen to metabolize, the spoilage rate in fish, due to their enzymes, is a function of the oxygen availability in the substrate. It should be pointed out that a second role of oxygen, in which it enters into adverse chemical reactions that result in rancidity or discoloration, is not of significance at the storage temperatures cited here. Also, it should be pointed out that only the enzymes of specific bacteria are responsible for the common spoilage of fish. Flesh enzymes and enzymes of other bacteria are relatively insignificant.

Even when oxygen is removed from packaged fish, the gas permeability of the container is important to the survival or inactivation of bacteria. When containers are impermeable to gases, not only do they prevent the entrance of oxygen, but they might also prevent the release of bacteriostatic or bactericidal gases resulting from bacterial metabolism.

At least one other factor that affects the reaction rate is the amount of substrate surface exposed to bacteria. Thus, one would expect that when the surface to volume ratio is small as in whole large fish, the spoilage rate of the whole mass will be relatively slow and when the surface to volume ratio is large as in fillets of small flat fish, the spoilage rate of the entire fillets will be relatively fast. Practical experience supports this. In the case of minced fish, which is becoming popular, the surface to volume ratio is very large and, very likely, it will have a short shelf life unless it is kept frozen or spoilage is controlled by some other means.

This discussion of oxygen, gas permeability of packaging, and surface to volume ratio of substrate is made only to call attention to these factors. In fact, there may be other factors in addition to those cited above that affect the spoilage of fish as well as the rate at which they spoil. None of these factors were considered in any of the research cited above or reported herein because refrigerated fish are not, as a rule, packaged in gas-impermeable containers—nor are they comminuted except when they are to be made into frozen blocks. Thus, while bacteria and storage temperature are the decisive factors in the spoilage of refrigerated fish, we must remain alert to recognize other possible factors that may be involved.

SHELF LIFE PREDICTION

Although the spoilage of seafood undoubtedly involves a number of interactions among many of a variety of reactants that may be present in them, a significant amount of data in the literature appears to support the thesis that one of the reactions must be limiting with the consequence that it controls the spoilage rate. While it is generally accepted that the spoilage rate is dependent of the activity of the spoilage bacteria (the activity of bacteria is generally expressed as a function of the integral of the area under the bacterial growth curve), our work suggests that this is true only up to a point. That is, the spoilage rate depends on the number of spoilage bacteria until a level of activity has been reached such that the spoilage rate is no longer affected by an increase in the bacterial numbers.

Mathematical and Graphical Methods

It has been demonstrated in the literature cited above (Spencer and Baines 1964; James and Olley 1971; Charm et al. 1972) that the shelf life of fish held at temperatures within limits may be predicted with the use of the Arrhenius equation:

$$K = Ae^{-H/RT}$$

where: K = rate of spoilage,
A = orientation factor,
e = mathematical constant,
H = energy of activation,
R = gas constant, and
T = temperature (absolute).

Since spoilage can be defined as the limit of quality, the rate can be used to predict the time required for the limit to be reached.

In addition to the mathematical methods for predicting the shelf life of fish products, graphical prediction methods have been proposed by James and Olley (1971) and Charm et al. (1972).

Olley and Ratkowsky (1973) discussed the use of an electronic universal integrator for determining the shelf life of fish and possibly other foods. The device, a temperature function integrator and multipoint telemeter, was developed by Nixon (1971).

A Simple Prediction Device

Although the prediction methods cited thus far are suitable for the purpose, it appeared that a simple, inexpensive integrator that could be used by the layman should be possible (Fig. 1). The graph described by Charm et al. (1972) was used as the basis for a shelf life predictor (Ronsivalli et al. 1973) that was manufactured from plastic relatively inexpensively, is simple in operation, and permits the prediction of the shelf life of fish irrespective of the variety of temperatures (in the range 32°-46°F) to which fish might be exposed and irrespective of the sequence of the exposures.

The predictor consists of three parts: 1) an index, 2) a shelf life scale, and 3) a temperature scale. By a series of simple operations that accumulates the shelf life that has been used up, the remaining shelf life at any temperature can be predicted. The predictor is especially useful for buyers and distributors of fish products who need the kind of information that the predictor can supply quickly and relatively accurately. One of the observations that is noted through the use of this device is the implied economic benefit to be realized by keeping seafoods at as low a temperature as possible. For example, the shelf life at 32°F is seen to be about twice that at 42°F.

As with any other prediction method, the accuracy of the predictor requires that the quality of the fish is either known at some point or that its history (the temperature(s) and the time at each temperature at which the fish has been kept from the moment it was landed on board the vessel) is known.

Operation of the device is demonstrated by Ronsivalli et al. (1973).

DISCUSSION

Our study included storage temperatures in the range 32°-46°F. In that range, the rates at which fish spoiled appeared to be linearly related to the temperature at which they were stored. Our reasons for selecting that temperature range were: 1) we felt that temperatures below 32°F would be difficult to maintain, and we might run the risk that the possible crystallization of some water might affect our results, and 2) our experience had shown that 46°F is about the upper limit of the temperature range of domestic refrigerators and of commercial display refrigerators. In addition, we did not believe that the effort at higher temperatures could be justified in terms of practical application because of the short shelf life of the product at higher temperatures. Although studies by others indicated a linear relationship between spoilage rates and temperatures over a wide range, Olley and Ratkowsky (1973) stated that this relationship is not linear at temperatures above 46°F. We believe that from an academic point of view, this discrepancy might deserve more study. However, from a practical point of view, there is little to be gained. The effort would be better spent towards establishing the case for low temperature holding. In our view, the temperature at which fish are held should be strictly controlled up to the point when the products are purchased by the consumer.

We must reiterate that the use of packaging may introduce new variables depending on the size (bulk) of the package and the gas permeability of the container.

Finally, it should be emphasized that the predictor was based on data obtained from cod. Although experiments were not conducted to test it for other fish, we have good reason to believe that the difference in the shelf lives among other lean species of fish is relatively small and certainly within the inherent error of the device. The bulk of the pertinent literature supports this thesis.

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MFR Paper 1138. From Marine Fisheries Review, *Vol. 37, No. 4, April 1975. Copies of this paper, in limited numbers, are available from D83, Technical Information Division, Environmental Science Information Center, NOAA, Washington, DC 20235.*