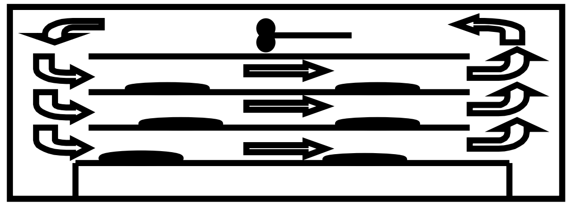


Fish Smoking Procedures

for

Forced Convection Smokehouses

revised
May 23, 2001

by

Kenneth S. Hilderbrand, Jr.
Seafood Processing Specialist

Oregon State University
Extension Sea Grant Program
Hatfield Marine Science Center
Newport, Oregon 97365

Oregon State University Extension Service
Sea Grant ORESU-I-01-001

This publication can be downloaded from:
http://seagrant.orst.edu/sgpubs/onlinepubs/i01001.pdf

Table of Contents

Table of Figures

List of Tables

For information on seafood safety go to University of California's Website SeafoodNIC at: http://seafood.ucdavis.edu/

DISCLAIMER: TRADE NAMES

Most of the experimental work referred to in this publication was conducted using an AFOS Mini Kiln. Although this smoker quite effectively demonstrates the operating characteristics of a modern horizontal flow smoker designed for fish, it is not the only good equipment option available to smoked fish processors. One primary advantage of the AFOS Mini Kiln is that it is small enough to be used in experimental laboratories. However, commercial smoked fish processors should explore all equipment options available to them and choose that which best suits their needs. Use of the AFOS kiln or mention of trade names in this publication does not imply endorsement of any brand of equipment.

REGULATIONS AND TERMINOLOGY

Since the early 1970s, the U.S. Food and Drug Administration (FDA) and other regulatory agencies have recommended that smoked fish be processed in a manner which meets certain minimum standards for salt content, process time/temperature, and storage/transport conditions. The primary purpose of these recommendations is to prevent safety hazards associated with *Clostridium botulinum* and other foodborne pathogens.

The U.S. Food and Drug Administration's general GMP (Current Good Manufacturing Practice) for "Hot Process Smoked Fish" issued by the FDA in 1977 was held invalid by the courts (also in 1977). The GMP is now used only for a guideline. However, a subsequent research program has produced sufficient data to set minimum standards for time and temperature of smoking cycles and final product water activity (or water phase salt) for both hot and cold smoked seafood. These standards are contained in guidelines published in the FDA's Hazard and Controls guide, which provides guidance for meeting the requirements of new regulations which were effective on December 18, 1997 (21 CFR 123, "Procedures for the Safe and Sanitary Processing and Importing of Fish and Fishery Products"). These regulations also contain requirements for sanitation monitoring and record keeping, employee training, and hazard analysis.

If a hazard is identified, then a HACCP (Hazard Analysis Critical Control Point) plan must be developed and implemented. Sec 123.16 of these regulations requires processors of "smoked and smoke-flavored" fishery products to include in their HACCP plans how they are controlling the safety hazard associated with the formation of *Clostridium botulinum* toxin "for at least as long as the shelf life of the product under normal and moderate abuse conditions."

Various state and local government agencies have also established regulations or recommendations for production of smoked fish. In 1991 the Association of Food and Drug Officials developed recommended practices in the form of a GMP which is similar (but not identical) to the FDA guidance document. It is in the best interest of all smoked fish producers to become familiar with these laws and recommended practices. This is especially true of producers who are considering modification in products, processing facilities, or equipment. Many of these regulations can be found in Chapter 7 of the

"Compendium of Fish and Fishery Product Processes, Hazards, and Controls" at: http://seafood.ucdavis.edu/haccp/compendium/compend.htm.

Because FDA regulations require a **Hazard Analysis** for all seafood production, and because a **Hazard Analysis** for smoked fish processes will almost always identify at least one **significant hazard reasonable likely to occur**, it can be assumed that **all smoked fish processors will be required to write and implement a HACCP plan**.

For this reason this operations manual will point out some of the operations that may be affected by HACCP implementation. Important HACCP terms used in the text are based on the seven principles of HACCP:

SEVEN PRINCIPLES OF HACCP

1. Conduct hazard analysis. Prepare a list of steps in the process where significant hazards occur and describe the preventive measures.
2. Identify Critical Control Points (CCP) in the process.
3. Establish Critical Limits (CL) for preventive measures associated with each CCP identified.
4. Establish CCP monitoring requirements. Establish procedures for using monitoring results to adjust the process and maintain control.
5. Establish corrective actions to be taken when monitoring indicates that there is a deviation from an established critical limit.
6. Establish effective record-keeping procedures that document the HACCP system.
7. Establish procedures for verification that the HACCP system is working correctly.

Hazard = A biological, chemical, or physical property that may cause a food to be unsafe for consumption.

CCP = Critical Control Point. A point, step, or procedure at which control can be applied and a food-safety hazard can be prevented, eliminated, or reduced to acceptable levels.

CL = Critical Limit. a criterion that must be met for each preventive measure associated with a critical control point.

HACCP Plan = Hazard Analysis Critical Control Point. The written document based on principles of HACCP that delineates the procedures to be followed to ensure the control of a specific process or procedure.

This fish smoking procedures manual does not offer prescriptive information on CCPs or CLs. Each fish smoker will need to determine , as required by the FDA regulations, CCPs and CLs based on their individual practices.

INFORMATION SOURCES

For information on purchasing a copy of the training curriculum used by FDA to judge the "equivalence" of adequate training, write or call North Carolina Sea Grant, Box 8605, N.C. State University, Raleigh NC 27695-8605. Telephone (919-515-2454). Ask for the most current edition of the HACCP Training Curriculum developed by the National Seafood HACCP Alliance for Training and Education. Advance payment of US $25 is required.

For information on obtaining a free copy of the FDA's Fish and Fisheries Products Hazards and Controls Guide, contact U.S. Food and Drug Administration, Office of Seafood, 200 C St. S.W., Washington DC 20204. Fax (202-418-3196). Fax your request, phone requests are not accepted. Call FDA for additional information (202-418-3133).

A copy of the FDA regulation 21 CFR parts 123 and 1240, "Procedures for the Safe and Sanitary Processing and Importing of Fish and Fishery Products; Final Rule," December 18, 1995 can be found in each of the two documents listed above. It can also be downloaded from the internet at http://seafood.ucdavis.edu/, under the heading of "USA Guidelines and Regulations."

The Seafood HACCP Alliance sanitation training manual "Sanitation Control Procedures for Processing Fish and Fishery Products," First Edition 2000, Florida Sea Grant Report 119, is available for $25 from Florida Sea Grant - PO Box 110409, Gainesville, FL 32611-0409 or call 352-392-2801. It may also be available online at: http://seafood.ucdavis.edu/sanitation/scpmanual.htm.

The HACCP Encore course training manual is available using Adobe Acrobat (free download) online at:
http://www.fda.gov/ora/training/Satellite/Announcements/manual2.pdf

Examples of generic smoked fish SSOPs or HACCP plans are available on the internet Web site http://seafood.ucdavis.edu/ under the heading of "Seafood HACCP".

SMOKED FOOD PRESERVATION AND CHANGING PRACTICES

A combination of smoke, salt, and drying is one of the earliest recorded methods of food preservation. These procedures, loosely known as "Smoking" or "Smoke Preservation," are successful because they kill food poisoning and spoilage bacteria or render them harmless by altering the chemistry of the environment these spoilage organisms need to grow.

Traditional methods of smoked food preservation typically produced high salt and low moisture content products that are not desirable to most modern consumers. Commercial processors have therefore adjusted processing conditions to produce the lower salt and moister products that will sell in today's markets. One result of these changes in processing practices is that processing conditions must be standardized, controlled, monitored, and documented so the potential for producing toxic, or even lethal, food products is eliminated. This is especially true for seafood products which may contain food poisoning organisms of marine origin that are more difficult to control than those from land sources. *Clostridium botulinum* Type E is the most notorious of these marine organisms and most smoked seafood procedures are designed to eliminate the potential of toxin production from this bacteria species.

Smoked seafood is prepared with two basic procedures. **Hot smoking** cooks the product; **cold smoking** does not. Cold smoking devices have one basic function: to apply smoke to the product. Hot smoking devices have the added function of applying heat. And because preservation of fish usually requires moisture removal, systems designed for hot or cold smoking fish may have the added function of dehydration. Modern fish smoking equipment is usually designed to produce either hot or cold smoked products, but in either case they are usually designed to have adequate airflow and exchange to remove large quantities of water from the product (and eject it from the system).

Air movement in a smokehouse is essential to the application of smoke and heat and the removal of water from the product. Traditional smokehouses used natural (gravity) convection to circulate air. Modern equipment uses forced (mechanically produced) convection. Forced air can be applied to the product either horizontally or vertically (or both in some modified vertical flow designs). Horizontal flow air movement works best for products which must be placed in the smokehouse on screened trays (e.g., fish fillets and jerky strips). Vertical flow air movement works well for products which can be conveniently hung from rails in the smokehouse (e.g., hams, sausage links, and large whole fish or fish sides). The best design for fish smokehouses is therefore (with some exceptions) horizontal flow forced convection. The AFOS Mini Kiln used in preparation of data for this report is such a system. There are other excellent examples.

Figure 1 shows airflow patterns in forced convection systems. True horizontal and vertical flow designs give relatively even smoking and drying throughout the smokehouse. Modified systems may have uneven patterns when operated at full capacity because more air is forced through the top racks than through those at the bottom.

SMOKED FISH PRESERVATION

The "hot smoke" process for smoking fish differs from the "cold smoke" process in a fundamental way. The "cold smoke" process requires that the fish never reach an internal cooking temperature (less than about 90^{o}F), while the "hot smoke" process cooks the fish to the center (about 145^{o}F or higher). Between those two temperature extremes are conditions that can create an environment favorable to the growth of food poisoning bacteria. Both products must be refrigerated.

Both hot and cold smoked fish are preserved primarily by controlling water activity (Aw) and temperature during storage and shipment. Measurement of salt and moisture content (Water Phase Salt) is a typical way of inferring Aw. Smoke deposition is effective only in controlling surface spoilage. However, due to potential problems associated with parasites in many species, cold smoked fish should be prepared only from previously frozen fish or fish known to be parasite free. Whether hot or cold smoked, fish jerky must have an Aw of .85 or less to be shelf stable. An Aw of .75 or less is necessary to inhibit mold growth.

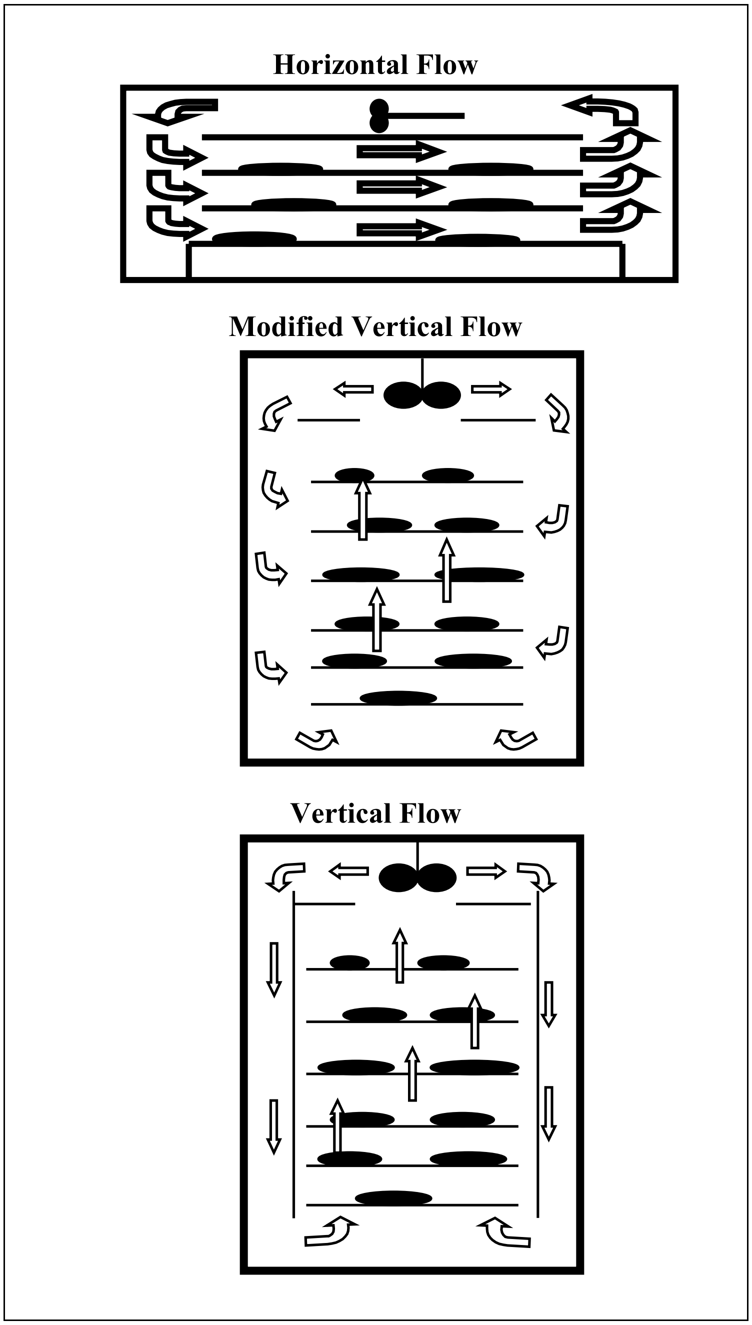


Figure 1: AIRFLOW PATTERNS IN FORCED CONVECTION SMOKEHOUSES

FDA guidelines suggest that safe vacuum or modified atmosphere packaged (MAP) hot smoked fish contain at least 3.5% water phase salt (WPS) and must have reached a center temperature of at least 145°F for at least 30 minutes. Products containing at least 100 ppm nitrite (200 ppm maximum) need only 3.0% WPS. Air packaged (no vacuum or MAP) smoked fish must contain at least 2.5% WPS. The potential for growth of harmful bacteria (*Clostridium botulinum*) from temperature abuse is increased if these conditions are not met. Serious illness or even death can result from eating such spoiled fish. Nitrites are allowed in only a few species of fish used for smoking. Check with FDA for those species. The guidelines also list food and color additives and metal fragments as potential hazards.

As an additional safety margin to prevent growth of food poisoning bacteria, hot smoked fish should **always** be cooled immediately after smoking and eventually to about 40°F or less (or frozen) and held at that temperature until consumed. Each processor's FDA-mandated hazard analysis will need to address the issues of time and temperature abuse, and each processor should keep up to date on the latest FDA requirements for smoking and cooling temperatures.

Elevating the fish temperature above 90°F begins to kill "indicator" spoilage bacteria which would normally indicate by sight or odor that smoked fish has been improperly handled and is not fit for consumption. Such partly cooked fish can harbor harmful bacteria which may grow and produce toxins without competition from normal spoilage bacteria. Some food poisoning bacteria can produce these toxins without appearing to be spoiled. Serious illness or even death can result from eating such spoiled fish. Cold smoked fish is not a fully preserved product and, for the same safety reasons as with hot smoked fish, must be chilled to about 38°F or less and held there until consumed.

Unfortunately, in recent years it has become evident that at least one food spoilage bacteria (*Listeria monocytogenes*) will survive the cold smoking process and continue to grow at refrigeration temperatures. Special attention to sanitation and quality control is therefore essential for these products. The National Marine Fisheries Service has investigated chlorine dips for thawing fish to eliminate *Listeria* from the surface of fish prior to smoking. There is some evidence that thawing fish in 50 ppm flowing chlorinated water is effective in reducing the numbers of *Listeria* from the surface of the fish. **Processors should check FDA guidelines on application of chlorine directly to seafood.**

Cooked fish loses the distinctive flavor and texture that defines cold smoked products. It is therefore also essential for quality reasons that cold smoked seafood products do not exceed a maximum of about 90 °F. Because some fish parasites that are of concern to human health can survive the cold smoking process, it is recommended that only previously frozen or parasite free fish be used as a raw material. This is particularly true of salmonid species from coastal streams in the Pacific Northwest or any freshwater species. Some farm raised fish may be free of parasites.

Cold smoked fish is produced in many different styles and sold under many different names. Lox, for instance, is traditionally produced from mild cured (salt) salmon and is only lightly smoked. Nova lox is usually made from freshly cured frozen salmon and special spices.

"Hard smoked," "Lox smoked," "Lochs," and "Traditional" are also terms used in industry for cold smoked seafoods. Sugars, spices, and method of cure help define the character of these products.

Salt Affects Smoked Fish Preservation

Neither smoke nor heat by itself is effective in preserving fish. Bacterial growth is retarded (but not stopped) by salt levels which reduce water activity (Aw) of the flesh to about .97 or less (pure water is Aw 1.0). Smoked fish with salt contents greater than 3.5% **in the water phase** (WPS) will usually have such an Aw, although many factors can cause variation. A water activity of less than .85 is necessary to make products stable at room temperature (as in fish jerky) and an Aw of about .75 or less is needed to inhibit mold growth. Check the latest edition of The FDA's Fish and Fishery Products Hazards and Controls Guide for the latest guidelines.

Water activity is also influenced by inclusion of sugars in the cure. However, WPS can easily be monitored with inexpensive laboratory equipment while Aw measurement needs sophisticated equipment. In addition, because sugars may aid in growth of some food poisoning organisms, salt level is a better indicator of preservation. See "Quick Determination of Water Phase Salt in Smoked Fish" (References) for details of WPS analysis http://seagrant.orst.edu/sgpubs/onlinepubs/QuickSalt.pdf.

Water Phase Salt (WPS) is a term which means the amount of salt compared to the amount of moisture (water) in the fish. For example, fish with 3% salt and 60 % moisture would have about 4.8% WPS (3% salt divided by [60% moisture + 3% salt]).

.

$$\frac{3\%}{60\% + 3\%} = \frac{3}{63} = .047619x100 = 4.8\%WPS$$

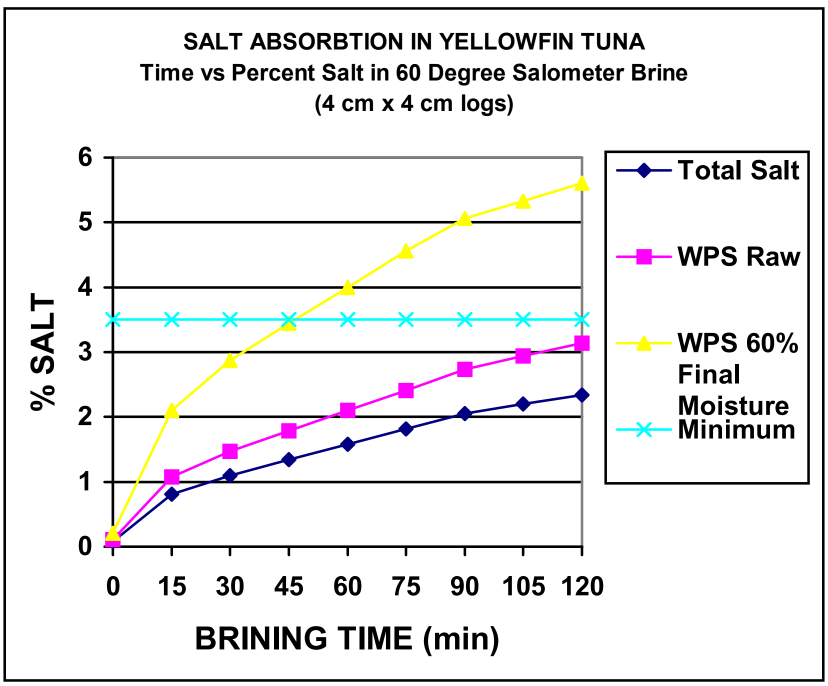
WPS is a function of both the level of added salt and the final moisture content. The fish in the above example, if dried to 50% moisture, would have about 6% WPS (3/53 x 100 = 5.7%). Trying to balance these two factors to achieve a safe and high-quality product requires experience and some knowledge of how fast salt is absorbed by various kinds of fish and what final moisture content is suitable for the consumer (market). Moist fish products require more salt than dryer fish products and will therefore taste saltier even if the WPS is the same.

Sodium nitrate salts are sometimes used to fix color and act as a preservative in certain fish. There are varying opinions among experts as to the best method of application and effectiveness of this preservative. Nitrites can be dangerously toxic, are difficult to apply in legal amounts, and are covered in specific state and federal regulations. In addition, nitrites are not allowed in all species of fish used for smoking . The FDA currently allows nitrites to be used in salmon, sablefish, shad, chubs, and tuna. Smoked fish processors should seek advice from regulatory agencies and suppliers before using nitrites in their process.

Figures 2 and 3, show the results of salt penetration studies on 4 x 4 cm (about 1.5 in x 1.5 in) blocks of yellowfin tuna and kingfish (an oily tropical mackerel). Notice that with 60 degree salometer brine (about 16% salt by weight), it took about 45 minutes for the block of yellowfin tuna to absorb enough salt to give it a final 3.5% WPS when the final product reached 60% moisture.

For kingfish the brining time was over 100 minutes to reach 3.5% WPS. Large salmon take about the same time and brine strength. Small fish take much less time, perhaps only 15 to 20 minutes. In general, salt absorption is affected by many factors. Although mathematical models have been developed to predict salt absorption rates, practical considerations in manufacturing dictate that procedures are best developed by testing.

These data are estimates for illustration purpose only - actual brine absorption time variables include, **brine strength**, **brining time**, **product thickness**, **brine to fish ratio**, **brine temperature**, **texture**, **fat content**, **species**, and **fish quality**.



Note: Actual brining times depend on many variables.

Figure 2: SALT ABSORPTION IN YELLOWFIN TUNA

Brine Strength Affects Salt in Smoked Fish

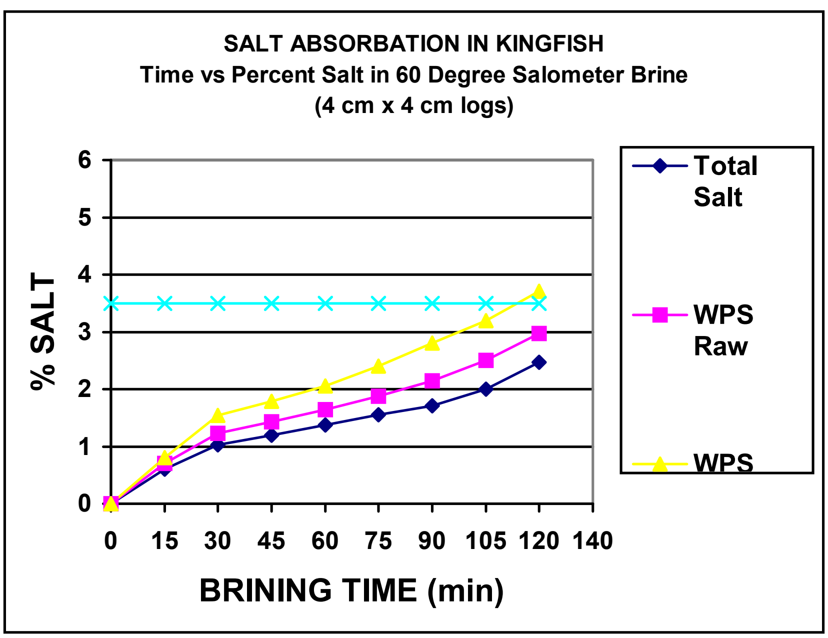
Fish flesh absorbs salt faster from higher salt brine concentrations. Brines greater that 60 degrees salometer (15.8% by wt) tend to remove moisture from the fish, which can be an advantage in some products. However, strong brines and short times may not allow even distribution of salt into the center of the piece of fish prior to smoking. Dry salting has the advantage of removing moisture, but has the disadvantage of less even salt penetration. Dry salting is a technique which covers fish with a thin layer of salt (.25 in to .5 in) between layers of fish. Brine strength is usually a critical control point in a HACCP plan.

Brining Time Affects Salt in Smoked Fish

Fish will continue to absorb salt over time only to a point. The rate of salt absorption slows as salt is absorbed into the outer surface and begins to penetrate the center. Fully salt cured ("struck") fish has been allowed to reach an equilibrium (about 17%) with a saturated brine and is firm to the touch in the "wet" state. Some smoking procedures use this type of salt cured fish after it has been soaked ("freshened") for several hours or days in fresh water to remove excess salt. Long brining times of fish (like overnight or longer) provide time for harmful bacteria to grow and therefore must be refrigerated. Brining time is usually a critical control point in a HACCP plan.

Thickness of Piece Affects Salt in Smoked Fish

Thicker pieces of fish need more time to absorb salt and distribute it evenly throughout. This is an exponential function of thickness, not a linear function. In other words, if a 3/4 inch thick piece of fish takes 30 minutes to absorb enough salt, a 1 1/2 inch piece may take 90 minutes or 3 times as long, not twice as long (2 x 30 = 60 min). The exact relationship between time and thickness may depend on other factors which also affect salt penetration. Thickness of each piece of fish may be a CCP in a HACCP plan, but if testing shows that brining conditions are sufficient to adequately salt the largest pieces reasonably likely to occur, then the tedious task of measuring the largest pieces in each batch can be eliminated.



Note: Actual brining times depend on many variables.

Figure 3: SALT ABSORPTION IN KINGFISH

Ratio of Brine to Fish Affects Salt in Smoked Fish

There must be enough brine to adequately salt any batch of fish. This can be insured by creating a CCP in a HACCP plan which measures the weight or volume of both brine and fish which testing shows will adequately salt the product. For practical reasons, fish placed in a container of 60 degree salometer brine will float level with the surface of the brine until too much fish is placed in the container. This usually occurs at a one/one volumetric ratio. For instance, one five gallon bucket of 60 degree Salometer brine can be mixed and evenly divided with a second five gallon bucket. A five gallon bucket of fish chunks can usually then be divided equally between the two half full buckets of brine (one to one by volume) and be adequately brined. Often a clean pan or weight must be placed on the surface of the fish to make sure the top layer is beneath the surface.

Temperature Affects Salt in Smoked Fish

Fish absorbs salt faster as the brining temperature increases. However, it is best to standardize brining at a cool temperature (40^{o}F or less) to achieve consistent and predictable results and to discourage bacteria growth and/or histamine formation. Using ice in the brine make up water is a good way to accomplish this, but caution must be used to make sure no ice remains in the finished brine. Brining in a cold room is also a good way to keep brines cool and is advisable for long brining times. Although preparing brine mixed by weight can be convenient and accurate, brine strength should always be checked with a salt hydrometer (salometer). Brining temperature may be a critical control point in a HACCP plan if brining times are over 3 to 4 hours.

Texture Affects Salt in Smoked Fish

Soft-textured fish tend to absorb salt faster than tough or firm-textured fish. Frozen flesh will not absorb salt until it thaws. Mishandled fish with gaping (separated flesh fibers) may have decreased brining times.

Fat Content Affects Salt in Smoked Fish

High fat content fish absorb salt slower than low fat fish. However, they may need less salt to obtain adequate final WPS content. Fat content in the flesh can vary at different locations on the body of the fish. Salmon, for example, tend to have less fat at the tail. Fat content can very dramatically within a species because of feeding conditions and life history.

Species Affects Salt in Smoked Fish

Different species of fish have different flesh characteristics and may absorb salt at different rates. Salting times should be specific for each species unless testing shows they have the same rate of salt uptake.

Fish Quality Affects Salt in Smoked Fish

Previously frozen (and thawed) fish or low quality fish have flesh characteristics which may affect (usually increase) the rate of salt absorption. The rate of freezing affects flesh cell structure and therefore the subsequent rate of salt absorption.

SMOKEHOUSE PERFORMANCE

The product quality and throughput of any smokehouse are determined by its loading capacity and by how fast it can dry, cook, and deposit smoke on the product. The physical size of a smokehouse it not important. Its throughput is determined by how much rack surface area it has and how long it takes to finish a cycle. Average loading rates for horizontal flow smokehouses is about 3.5 lbs of fish for each 1 inch of flesh thickness with 5 to 8 hour cycles possible in 1/2 to 2 inch thick pieces respectively. A limiting factor in most cases is the rate at which moisture can move from the center of the product to the surface where it can then evaporate and be ejected from the smokehouse. After smokehouse size and product thickness are set, the other critical factors are **drying**, **heating**, and **smoking**.

Drying Step

Most fish smoking processes require that moisture be removed from the flesh. A smokehouse is simply a drying oven with the ability to apply smoke. Weight (moisture) loss in the smokehouse may or may not be a useful HACCP safety CCP but is always a vital quality and economic control point. Factors which affect the rate of drying are **heat**, **humidity**, **air velocity**, **air exchange**, **flesh characteristics**, and **flesh thickness**.

Heat Affects Drying Step

Removing moisture from fish flesh is a process of surface evaporation and therefore requires energy (heat). In general, the hotter the fish, the faster moisture will be evaporated. This rate decreases as the surface becomes dryer than the interior of the piece, causing the movement of moisture to the surface to become a limiting factor.

Heating the surface too fast can produce a hard crust (mostly dried soluble protein), which retards movement of moisture. This phenomenon (case hardening) can severely reduce the rate of drying and should be avoided.

Relative Humidity Affects Drying Step

Dry air will pick up moisture from the surface of fish faster than wet (humid) air. The relative humidity (a measure of "dryness") of a dryer (smokehouse) is determined by the humidity of incoming air, temperature rise of incoming air, and rate of air exchange. Relative humidity is the ratio of water in air to the maximum amount of water the air can hold at any given temperature and pressure. Relative humidity is lowered when air temperature is raised. It is raised when moisture is added by evaporation from the surface of fish. Most dryers must expel air to get rid of moisture, thereby allowing new, lower-humidity air to enter the system. In zero emission smokers, dehumidifiers (refrigeration heat pumps) are used to condense moisture from recirculated air.

Air Velocity Affects Drying Step

Rate of surface evaporation from fish is proportional to the velocity of air passing over it. In general, the higher the velocity, the higher the rate of evaporation. Increased air velocity also increases the heating rate of the fish, further increasing evaporation.

Air Exchange Affects Drying Step

The rate that air is exhausted from a drying oven affects the entrance of new air and, therefore, affects the relative humidity and the rate of drying. This expelled air is the primary way moisture gets out of the drying oven after it has evaporated from the fish. Fully loaded smoking ovens need more air exchange than those partly loaded if relative humidity is to be consistent from batch to batch.

Fish Flesh Characteristics Affects Drying Step

Factors such as flesh texture, fat content, and species differences will affect migration of moisture from the center to the outside of the piece being dried and, therefore, will affect the drying rate. In general, firm, high oil content flesh dries slower than soft, low fat flesh. However, high oil content flesh has less moisture to begin with and may require less drying.

Flesh Thickness Affects Drying Step

Moisture must migrate from the center to the surface of a piece of fish before it can leave by evaporation. Increased thickness, therefore, increases drying time. Brining procedures must insure that all pieces of fish receive adequate salt regardless of thickness. Thickness may be a HACCP CCP if thickness variation is large.

Heating Step

Common heat sources in forced convection smoking devices are direct gas flame, indirect steam heaters, and electric resistance coils. Direct gas flame heat needs combustion air and produces some moisture from that combustion. However, regardless of the advantages or disadvantages of each type, the rate that heat is transferred from air to the fish for cooking or drying is directly related to **air velocity, air temperature, and relative humidity**.

Air Velocity Affects Heating Step

Increasing air velocity produces higher product heating rates. In some situations air velocity can be too high leading to unwanted surface drying. Some smoking ovens are equipped with air velocity controls such as variable speed blower motors.

Air Temperature Affects Heating Step

Increasing air temperature will of course increase the product heating rate. Higher final cooking temperatures will tend to produce more intense flavor and darker color. Up to about 160^{o}F, increased air temperature increases smoke deposition.

Relative Humidity Affects Heating Step

Low relative humidity will indirectly lower temperature or rate of temperature rise of a piece of fish because it will increase evaporation, thereby removing energy (cooling). The. relative humidity should be high, approaching 100% for fast heating. This is usually accomplished by closing the exhaust vent damper, thereby allowing the humidity to rise due to evaporation. Some smokehouses use steam injection to accomplish the same purpose and provide automated humidity controls.

Smoking Step

The rate that smoke deposits on fish surfaces depends on smoke density, air circulation, humidity, temperature, and nature of the surface (texture and oil content). A brief drying period to form a coating of protein (pellicle) on the surface of the fish will prevent the accumulation of surface moisture and assist in the even deposition of smoke. Most modern smokehouses have more than adequate circulation, and humidity is not critical. Many problems of smoke deposition in smoked fish processing involve the relationship between smoke density and air exchange.

Natural smoke has both water soluble and oil soluble components. These components will selectively deposit on wet or dry surfaces, giving different colors and flavors. Avoiding wet spots on an otherwise dry surface will help avoid color spotting and inconsistent flavor intensity.

There is some evidence that a relative humidity of 60% at a temperature of 160^{o}F will produce maximum smoke deposition in some species. However, other factors require that drying and heating rates be controlled to other temperatures and humidities at various stages of the smoking cycle.

While smoke density can be increased by reducing air ejection from the system (closing dampers), the same action will raise relative humidity and, therefore, also reduce the drying rate. It is useful to be able to generate high smoke density even at high ejection rates. Modern automatic hotplate-auger smoke generators are capable of producing large quantities of smoke if properly operated. Manufacturer's instructions usually specify damper settings as well as moisture content and particle size of the sawdust. In addition, **manufacturer's recommendations for cleaning and use of fire protection devices should be strictly followed**.

Combustion chamber type smoke generators (either internal or external to the oven) may create higher smoke densities than the hot-plate type, but may have the disadvantage of not being automated. Manufacturer's instructions should be followed carefully with these devices also for they, too, are a fire hazard. Particular attention should be paid to loading rates, cleaning, and damp sawdust capping techniques.

Species of wood will affect smoke deposition and flavor. Most producers have their own preference based on their markets. However, moisture content of the wood, time of cutting (seasoning and sap content), and presence of bark will also affect smoke flavor and density within a species of wood. Consistent smoke flavor and density is easier to achieve if consistent wood character is maintained.

Liquid smoke flavors can be applied by dipping the product or by spray injection into the smoking oven. With either natural or liquid smoke the smoke should be applied at least during the first few hours of the process. This is important to the smoke's ability to destroy pathogenic organisms such as *Listeria*, especially with hot smoked fish. The color produced by liquid or natural smoke is intensified when the surface is heated and dried. It is more difficult to get dark smoke colors with cold smoke processes than with hot smoke processes.

FISH SMOKING PROCEDURES

Fish smoking procedures may be unique to each producer's products, equipment, and environment, but they all should meet certain minimum requirements. This publication gives examples of some fish smoking cycles and discusses basic principles. The examples are of single specie loads of relatively uniform product size and configuration. Producing mixed loads with different species and size will be more complex if not impossible in some cases. And **only experience, experimentation, and good record keeping will produce optimum cycles for specific situations**. Table 1 is an example of a data recording sheet that can help in developing, monitoring, (**and therefore repeating**) smoking cycles.

Time\Temperature Smoking Cycles

The hot smoking of fish requires five steps (cold smoking has four leaving out heating/cooking), each with different goals and operating conditions. It is vital that the internal temperature be monitored in several of the largest pieces of fish in the coldest part of the oven (thermocouple placement can be difficult as well as critical). Observing the internal temperature of the fish, along with its weight loss, is the only way to effectively monitor the entire smoking cycle and consistently produce desired results. Finding the coldest spot in the smoking oven will require some experimentation. Time and temperature of cooking in a smoking cycle is likely to be a CCP (critical control point) in a HACCP plan and once smoking cycles are determined with confidence, oven time and temperature programs can be used as a CL (Critical Limit) for proper cooking and drying. Weight loss during the process and WPS (Water Phase Salt) or Aw (Water Activity) can be used to as Verification Procedures in the HACCP plan.

Table 1: SMOKED FISH DATA SHEETS

<table>
<tr><td colspan="4">Date:</td><td colspan="4">SampleNo: LotNo:</td><td colspan="2">Species:</td></tr>
<tr><td colspan="4">Brining Time min</td><td colspan="4">deg sal</td><td colspan="2">Thickness:</td></tr>
<tr><td colspan="4">Beg Wt: ____________</td><td colspan="4"></td><td colspan="2"></td></tr>
<tr><td>Total Hrs</td><td>Clock Time</td><td>Oven Temp Setting</td><td>Actual Oven Temp.</td><td>Fish Center Temp</td><td>Smoke Generator Setting</td><td>Draft Setting</td><td>Sample Weight</td><td>% Weight Loss</td><td>Comment</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Every commercial fish smoking facility should be equipped with recorders to monitor and record both oven and internal fish temperatures. Table 1 is an example of how important information can be recorded manually for each batch of fish.

Although some of the five fish hot smoking steps may overlap, they can be summarized **as surface drying, smoking, drying, heating/cooking, and cooling.**

Step 1. Surface Drying

Removing surface moisture leaving a protein coating (pellicle) on each piece of fish so it will accept an even smoke deposit. Excessive surface drying can produce a hard coating that prevents moisture from migrating to the surface for proper drying. This phenomena is know as "case hardening".

Step 2. Smoking

Producing a dense smoke atmosphere and conditions where smoke will be deposited evenly on the surface of each piece to insure good flavor, color, and surface preservation. Often color will not develop until after the surface of the fish reaches 130 to 140^{o}F during the cooking step. Cold smoking ovens sometimes are operated below ambient room temperatures by refrigerating the forced air stream. This refrigeration can also be used to dehumidify air in zero emission smokers.

Step 3. Product Drying

Evenly drying the fish to reduce moisture, raise the WPS content (lower Aw), and establish final texture. This is a vital step in controlling costs and quality and may be a critical step in producing safe products. Monitoring drying rate by weight loss is a good verification step in a HACCP plan.

Step 4. Heating/Cooking (hot smoke only)

Heating each piece of fish to at least 145^{o}F and holding that temperature for at least 30 minutes. This is also a critical step (HACCP CCP) in safe smoked fish production. Check with recent FDA recommendations for minimum hot smoking and maximum cold smoking times and temperatures.

Step 5. Cooling

Cooling the fish from cooking temperature to about 140^{o}F internal temperature in the smokehouse as quickly as possible helps to maintain consistent results. Further cooling to 40^{o}F or less to reduce potential for growth of food poisoning bacteria is recommended (and may be a HACCP plan CCP), but does not necessarily have to be done in the smokehouse. A suitable, sanitary, refrigerated room is usually more practical and cost effective than a refrigerated smokehouse. State and federal smoked fish regulations may specify maximum cooling temperatures and minimum cooling rates. Cold smoking procedures do not use step 4 (heating/cooking) but monitoring fish temperature may be a HACCP plan CCP to insure a maximum temperature is not exceeded.

EXAMPLES OF SMOKED FISH TIME - TEMPERATURE CYCLES.

Smoked fish producers are obligated by regulations to produce products which meet certain requirements. In addition, markets demand various product characteristics and consistency in those characteristics. These various requirements can be met best by establishing a regime of smoke deposition, drying conditions, and time and temperature (a cycle) which consistently produces the desired result. Matching the cycle with the desired result requires an understanding of the basic physics of the smoking steps.

Smoking Cycles in Theory

In theory, the "ideal" smoked fish cycle might look something like Figure 4. The oven and internal fish temperatures would rise together, allowing for a quick surface drying period of 15 to 20 minutes, a smoke deposition period of 1 or 2 hours, a drying period of a few hours, a cooking stage as required by law or good practice, and a cooling off period after the oven heaters are shut off. If this could all take place in 12 hours or less then at least two cycles per day could double the daily capacity of the system. A cycle of less than 8 hours would triple the daily capacity and so on. Cycles of 4 hours or less are possible with thin, lightly-smoked or precooked products such as oysters.

Some modern smokehouse time/temperature programming systems are capable of producing the "ideal" hot smoking cycle because they can be set to maintain a constant temperature difference between oven temperature and internal fish temperature, and then increase both to cooking temperature at any desired point (temperature or time). In actual practice however, programming oven temperature alone is more reliable and avoids the problems inherent with thermocouple placement in the center portion of a piece of fish.

Smoking Cycles In Practice

The reality of fish smoking using automated equipment is that the equipment is expensive and must be programmed by processors who have first established the parameters for each product they produce. The end product must finish with proper texture, flavor, and color.

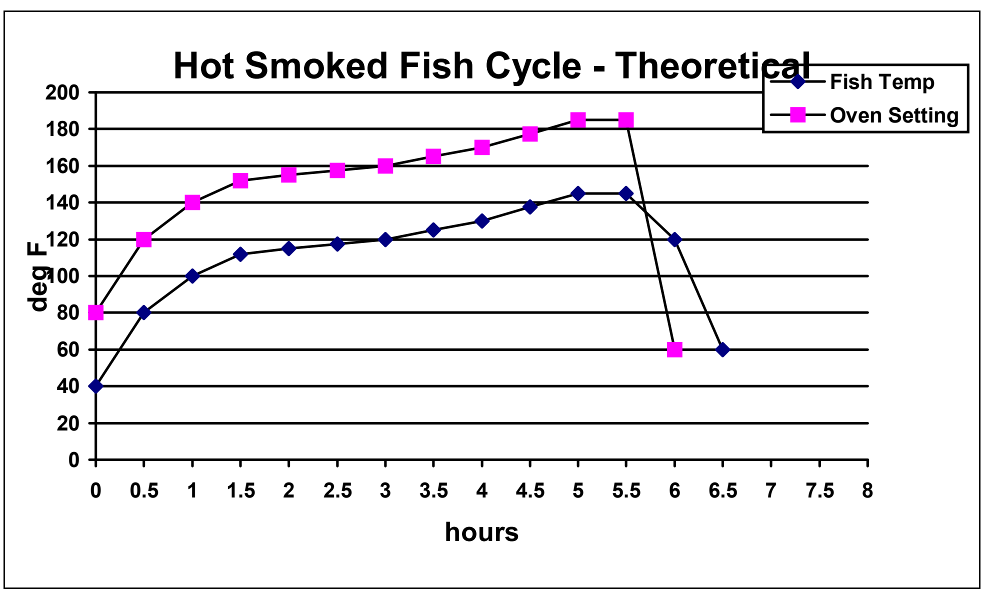


Figure 4: SMOKED FISH CYCLE - THEORETICAL

It must not lose excessive moisture (yield = $), and it must not sour (spoil) or become toxic in the smokehouse. **And it must meet the requirements of the law**, which is the basis for HACCP plans. For example, it must meet minimum time/temperature exposure and final water phase salt content which are likely to influence CCPs and CLs in smoked fish HACCP plans.

Smoked fish producers must have a basic understanding of the principles of fish smoking processes and fish smoking equipment if they are to avoid product losses and production mistakes while maintaining quality products. Once they have this understanding, equipment operators will find automated programming equipment useful in repeating successful results with satisfying consistency.

Figure 5 illustrates a typical fish hot smoking cycle. During the initial surface drying step, the exhaust damper should be open to allow maximum drying and moisture ejection from the system. During the smoke deposition period, the damper should be restricted to increase smoke density. During the drying, period the dampers should again be open to the optimum point while avoiding case hardening; and during the cooking period they should again be closed. And finally, for initial cooling the dampers should be open to maximize cool air input. The various steps in fish smoking overlap in actual practice. The exact damper settings during drying, smoking, and cooking depend on many factors such as smoke generator capacity and humidity in the oven. Humidity in the oven depends on atmospheric humidity, oven heater and exhaust fan capacity, and the size and characteristics of the load. Again, modern smokehouse programming devices can automate the control settings needed to maintain these parameters once they have been established by testing.

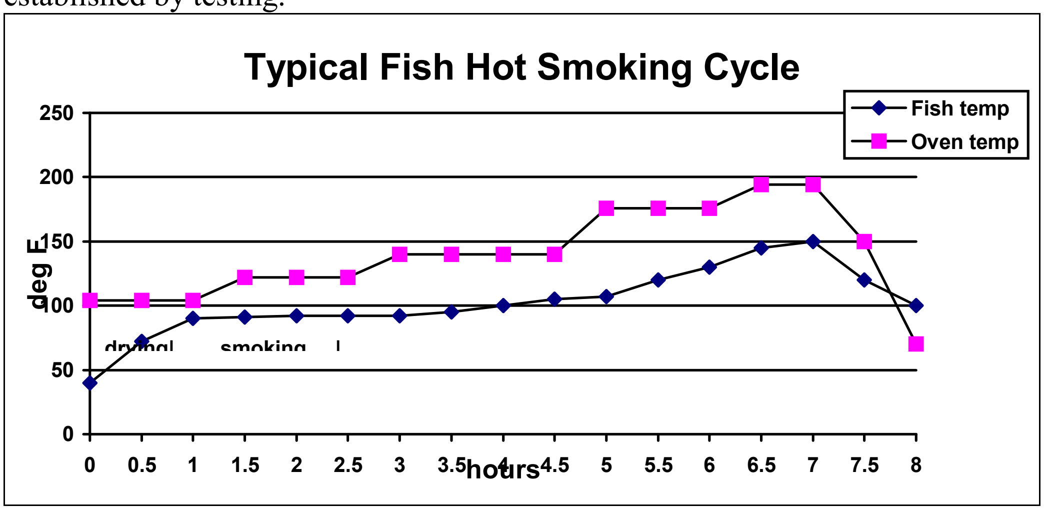


Figure 5: TYPICAL FISH HOT SMOKING CYCLE

The following descriptions of actual smoking cycles, along with the figures and tables, will help provide a starting point for developing product specific fish smoking cycles. **They are not optimum cycles and are presented here only for purpose of illustration.**

Figure 6 contains a typical smoking cycle for 21 KG (46.2 lbs or about 1/3 full load) of yellowfin tuna in an AFOS Mini Kiln. It took about 7 hours to bring the product to 165°F with another 3 to 4 hours to cool the product, totaling 10 or 11 hours. The temperature of

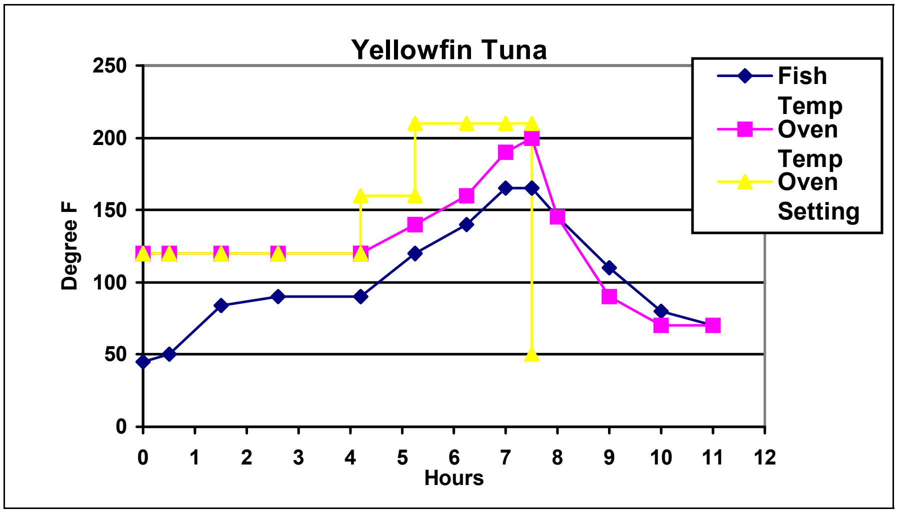


Figure 6: EXAMPLE FISH HOT SMOKING CYCLE - YELLOWFIN TUNA

the air-conditioned process room was about 64°F. The product yield in this case was 71.5% with a final moisture content of 66 to 70 percent. The same cycle has been used successfully on albacore tuna.

Notice that the fish temperature reached about 84°F after one hour and remained around 90°F until the oven temperature setting was increased from 120°F to 160°F after about 4 hours. The oven temperature setting was later increased to 210°F to achieve 165°F internal temperature (145°F minimum recommended by NMFS and FDA guidelines) with actual oven temperature eventually reaching 190°F. Two trays of wood were burned in the first two hours of the cycle.

Curd formation is a common visual defect in hot smoked fish. It is caused by soluble protein boiling to the surface when the fish is cooked prior to sufficient drying. This defect is most pronounced in previously frozen fish.

Figure 7 has a similar cycle for kingfish *which resulted in overcooked fish* (in the opinion of most observers), loss of yield, and considerable oil being baked out of the fish. Notice that the internal fish temperature peaked at 185°F after about 11 hours. The oven temperature was elevated to 248°F (maximum for the AFOS equipment) in an effort to finish the cycle in less than 12 hours (and test the upper limit of heating for kingfish). Production of fish with cycles over 12 hours cuts equipment output by 50% because 2 loads per day are not possible. With experience, smokehouse operators produced kingfish with cycles similar to those of yellowfin tuna, after consideration was given to higher airflows (exhaust) and initial oven temperature.

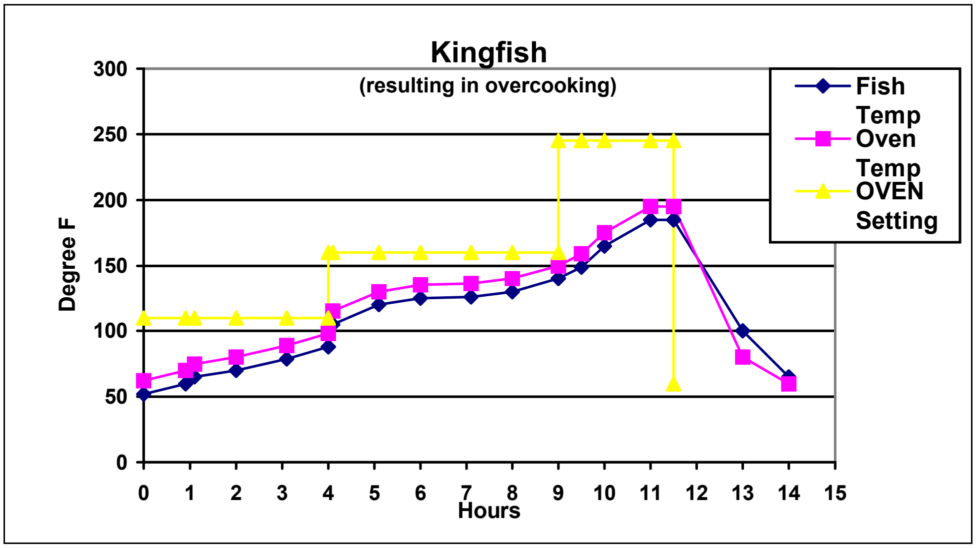


Figure 7: EXAMPLE FISH HOT SMOKING CYCLE - KINGFISH

DETAILED DESCRIPTIONS OF PROCEDURES

The procedures described in this publication are not perfected "optimum" smoking cycles. They are presented to illustrate the effect of various time and temperature regimes and to give the reader a basis for developing procedures that best suit their own needs.

Yellowfin Tuna

The smoking cycle used on this trial for yellowfin tuna is illustrated in Figure 6.

Butchering, Brining, and Loading

The fish were loined (about 50% yield) and cut into 3 to 4 cm (1 in to 2 in) thick pieces about 4 inches to 5 inches square. They were immersed for 60 min in chilled 60 degree salometer brine, rinsed quickly in fresh water, stored overnight in ice (bagged) to allow salt level to equilibrate, then loaded onto 4 racks so that no two pieces touched. This loading density was about 50% of maximum.

Surface Drying

The product surface dried for about 1/2 hour with the oven at 113^{o}F to 122^{o}F, the circulating fan on, and the exhaust damper full open. This step is necessary to give the product a dry surface on which smoke can deposit. Smoke will not deposit evenly on a wet surface. The surface should develop a sticky coating ("pellicle") which gives a smooth, attractive color to the finished product. This surface drying can be accomplished in a dry room with circulating fans prior to loading the racks into the smokehouse. Care should be taken to protect the fish from contamination from insects or dust.

Smoking

Two trays of hard wood sawdust were ignited in sequence for a total time of about 2 hours. During this time the exhaust damper was set at 1/4 open, just enough to keep smoke from backfiring into the process area and to provide some additional surface drying. Because this was a load of only about 1/2 capacity, the 1/4 draft was adequate. Medium size dry sawdust was layered about 2 inches to 3 inches deep in each tray and topped with 1/4 inch of damp, fine sawdust which was prepared ahead of time and stored in a waterproof plastic container. A small quantity of dry wood shavings was placed near the combustion air drafts to promote ignition. Combustion air was controlled by drafts to keep a minimum burn rate without extinguishing the fire.

It is sometimes necessary to rotate racks of thick fish sometime during the smoking step so that the fish is more evenly exposed to the incoming smoke. Otherwise there may be a color difference from left to right across the racks of fish because the air circulation is from that direction (some modern systems periodically reverse the direction of airflow). It is usually sufficient in hot smoking with an AFOS Mini Kiln to use two trays of chips. If necessary, the racks can be rotated just before igniting the second tray of sawdust. Three trays of sawdust give a better color to cold smoked fish, so rotating the racks can be done before or after the second tray of wood. Rotating racks while the second wood chip tray is actively burning will release a large quantity of smoke into the process area.

During cold smoking, the combustion air draft on each tray must be adjusted to support combustion yet minimize heat to maintain the oven temperature below about 95^{o}F.

Drying

With the exhaust damper at 1/4 open, a 1/2 maximum load, and a 122^{o}F oven, significant drying was taking place simultaneously with smoking. Heat from the burning sawdust added appreciable heat to the system. At hour 4, the oven set point was increased to about 150^{o}F and again to about 210^{o}F at hour 5. Drying continued until about hour 6 when the exhaust damper was closed to increase the relative humidity for cooking. The weight of a single rack was monitored during the drying to estimate yield (see section on mathematics of fish drying).

From hour 1.5 to hour 4 the fish center temperature remained about the same. This confirmed that the fish was drying and cooling itself through evaporation. A subsequent rise in the fish temperature indicated that the drying rate was slowing. At that time, the oven temperature was increased to begin cooking. In this trial run the exhaust damper was open to 1/2 at the same time that the oven setting was raised to about 210^{o}F. This was to provide additional drying and prevent "curd formation." Curd formation is the coagulation of soluble protein boiling out of fish heated too much before it is sufficiently dry. Fish which is heated too much before it is sufficiently dry will also take on a characteristic "baked fish" flavor which, is undesirable.

Internal fish temperature was monitored by placing a thermocouple in a large piece of fish which would heat slower than small pieces. It is not desirable to cook mixed species because their drying rate (and therefore evaporative cooling rate) may be different, affecting how quickly the temperature will rise. If two different species are cooked at the same time, the center temperature of each species should be determined separately. It will sometimes be necessary to rotate the racks of fish during the cooking cycle to even out exposure to the hottest and driest incoming air.

Cooling

The cooling portion of the smoking cycle was in two steps, either of which could have been completed outside the smokehouse. First, the temperature was lowered quickly (1 hour or less) to less than 122°F to stop the cooking. This was easily done in the smokehouse by shutting off the heat, opening the exhaust damper, and allowing the circulating fan to draw cool room air over the product and expel hot air. Second, within another 2 or 3 hours, the temperature was further lowered to less than 45°F to stop the growth of food poisoning bacteria. This was also done in the smokehouse, which was in a refrigerated room. This fish was eventually cooled in a refrigerator to the storage temperature of 38°F or less to eliminate any chance of the production of *Clostridium botulinum* toxin.

Cooling should be done in a sanitary environment free of dust, mold spores, and insects. Cooling in plastic bags or any air tight container is not advisable because moisture from the fish will deposit on the inner surface of the container, creating a good environment for mold growth.

Kingfish

Figure 7 shows a smoking cycle used for kingfish (*Somberomorus commerson*), a large oily fish. The fish was prepared and salted in a manner similar to the yellowfin tuna above. However, the oven was maintained much longer (to hour 9) at about 160°F to provide a much longer drying period. A higher cooking temperature was used in an attempt to accelerate the process, but oil began boiling from the fish at an internal temperature of about 165°F. An internal temperature of about 185°F was finally reached at about hour 11.5, at which time the oven was turned off.

Cooking oil out of the flesh of some species is desirable in some markets (e.g., black cod), but in this species the product was judged to have been overcooked at an internal temperature of around 165°F.

Chinook Salmon

Figures 8 and 9 along with Table 2 give a detailed description of the smoking of one large, previously frozen chinook salmon on April 30, 1991. Sides were taken from the fish, which had been thawed in air over night. They were cut into two, 2 1/2 to 3-inch wide by
6 to 8 inch-long chunks along the vertical axis. Many of the chunks were 2 inches thick in the center.

The chunks were brined about 90 minutes in cold 60 degree salometer brine, then rinsed briefly in fresh water. The chunks were allowed to dry for about an hour in a 104°F oven with an open damper. Figure 8 shows oven settings (oven temperature followed closely) over an 8 hour period. Table 2 shows that cooking began at hour 6.6 by closing the exhaust dampers in a 180°F oven. A 30 minute final cook at 145°F was achieved by hour eight.

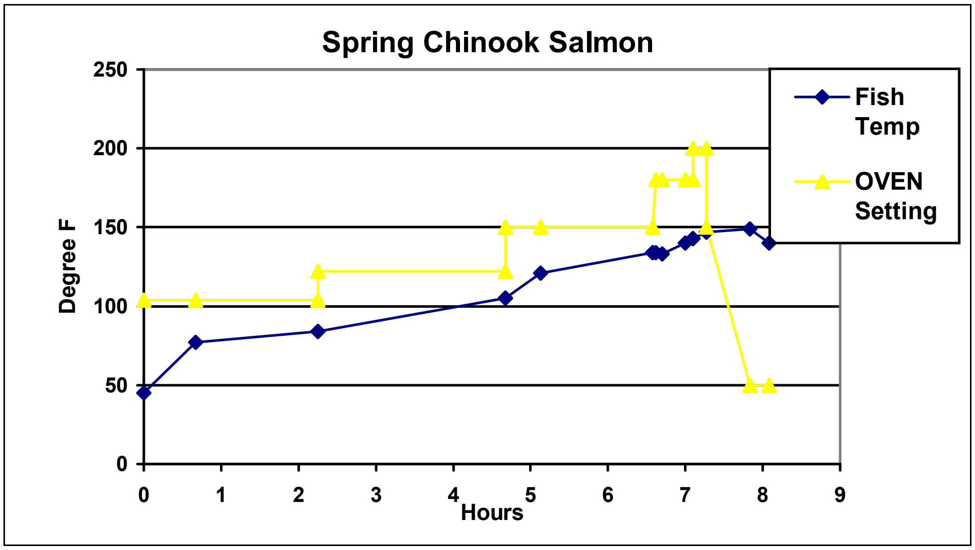


Figure 8: SMOKING CYCLE FOR CHINOOK SALMON, APRIL 30, 1991

Figure 9 follows the loss of weight (moisture) from the fish over time. Yield is, of course, 100% minus percent loss of weight. Notice that rate of moisture loss was relatively constant at about 2 1/2% per hour until hour 5 when the drying rate decreased slightly. The dampers were then closed for cooking. The total weight loss in this 8 hour cycle was about 20%, giving an 80% smokehouse yield. The texture was moist to the taste due to the high oil content. The final water phase salt was about 3.5 %. The quality was excellent.

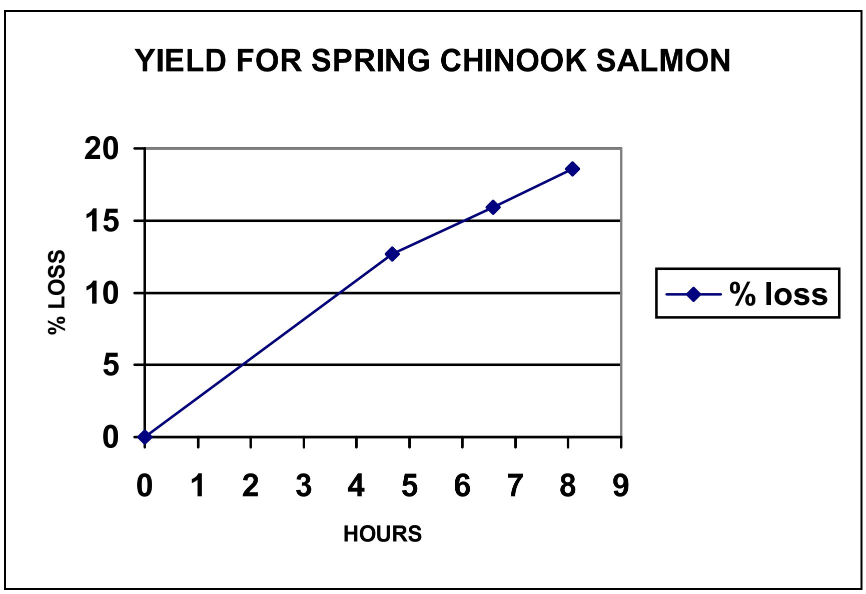


Figure 9: YIELD FOR CHINOOK SALMON, APRIL 30, 1991

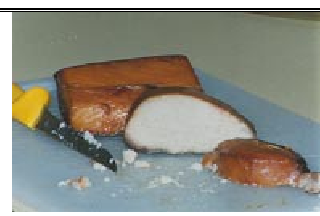
Table 2: SPRING CHINOOK SALMON PROCESS April 30, 1991

Clock Time	Oven Temp Setting	Fish Temp	Draft Setting	Comment	Process Time	Test Weight lbs	% Weight Loss
12:15				Brined in 60SAL	-1.33		
13:30				Fish out, rinse	-0.08		
13:35	104		open	surface drying	0.00	11.00	0.00
14:15	104	77	1/4 open	smoke on	0.67		
15:50	104	84	1/2 open		2.25		
same	122			increase oven			
18:15	122	105			4.67	9.60	12.7
same	150	105		increase oven	4.67		
18:43	150	121			5.13		
20:10	150	134			6.58	9.250	15.9
20:12	150				6.62		
same	180		close	begin cooking	6.62		
20:17	180	133			6.70		
20:35	180	140			7.00		
20:41	180	143			7.10		
same	200	143		increase oven	7.10		
20:51	200	147			7.27		
same	150	147		decrease oven	7.27		
21:25		149	open	oven off	7.83		
21:40		140			8.08	8.950	18.6

11 lbs of 2 inch thick fillets, 2.89 lbs/sq ft loading

A second chinook (fresh) was smoked on May 1st in an attempt to reduce smoking time. Figures 10 and 11 and Table 3 record the details. It can be seen that drying and smoking temperatures began at 140^{o}F compared to the lower initial temperatures on the April 30 test. The oven temperature was elevated to 180^{o}F on about process hour 3 and the damper left at 1/2 open. The target 145^{o}F internal fish temperature was reached by hour 4 and the oven reduced to 150^{o}F for 30 minutes, then shut off. The test seemed successful in reducing total process time from 8 hours to just about 4 1/2. However, the weight loss

Good quality fish will produce good quality finished product only when good smoking procedures are followed
.



at hour 4.5 was only about 15% rather than the 20% seen in the earlier test, so the oven was quickly reset to 150^{o}F and left until about hour 7 where the weight loss was about 20%. The fish internal temperature spike to 174 was probably an anomaly caused by the thermometer probe protruding from the piece of fish. Oven temperatures were not recorded during this trial. Actual oven temperatures produced by an oven temperature setting will vary depending on several factors such as damper setting, ambient air temperature, and oven loading.

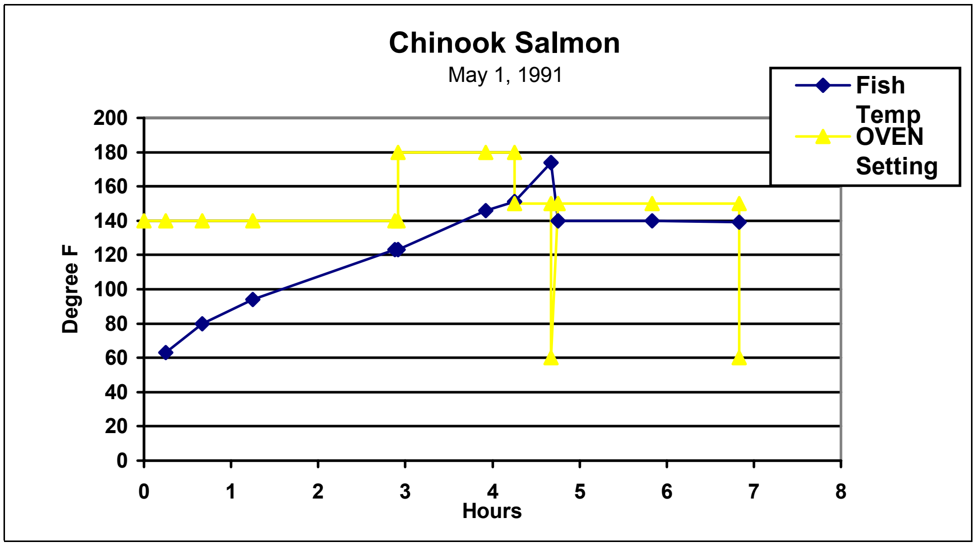


Figure 10: CHINOOK SALMON SMOKING CYCLE, MAY 1, 1991

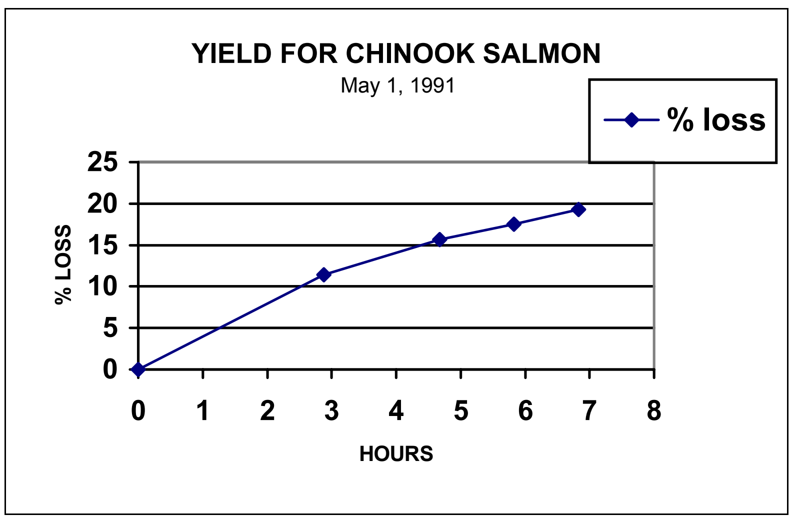


Figure 11: CHINOOK SALMON SMOKING YIELD, MAY 1, 1991

A comparison of these two tests with their tables and figures shows that the higher initial temperature of the May 1 trial (fresh) produced a higher dehydration rate than the April 30 run (frozen) and might have been even higher if it had also been a previously frozen fish. However, in both cases the loading was light (a single fish).

A previous chinook run was made on May 30, 1990 (see Figures 12 and 13 and Table 4) using 75 lbs of previously frozen chinook fillets plus frames. The fillets accounted for 6 of 7 racks (86%) with the frames using the seventh rack (14%). After 50 minutes drying with an open damper at 104°F, the damper was closed to 1/2 for smoking. At hour 2.25 the oven temperature was elevated about 20 degrees. The damper was fully opened at hour 4 and the oven was set to 185°F for drying. Notice that the internal temperature reached 145°F by hour 6 when the oven was reduced to 150°F and weight loss was only about 10 percent. The oven temperature was increased to hold about 145°F internal fish temperature, and by process hour 7.75 (13% to 14% weight loss) the oven was turned off and cooling begun. At hour 12, the total weight loss was only 16.2%, indicating that oven drying capacity was a limiting factor compared to previous lightly loaded runs.

Table 3: CHINOOK SALMON PROCESS, MAY 1, 1991

Clock Time	Oven Temp Setting	Fish Temp	Draft Setting	Comment	Process Time	Test Weight lbs	% Weight Loss
8:50				into 60SAL	-1.17		
9:55				rinse	-0.08		
10:00	140		open	surface drying	0.00	8.3	0.00
10:15	140	63			0.25		
10:40	140	80			0.67		
11:15	140	94	1/2 open	smoking	1.25		
12:53	140	123			2.88	7.350	11.4
12:55	140		close	cooking	2.92		
same	180				2.92		
13:55	180	146			3.92		
14:15	180	151			4.25		
14:15	150			decrease oven	4.25		
14:40	150				4.67	7.00	15.7
same	off	174	open	cooling			
14:45	off				4.75		
same	150			drying	4.75		
15:50	150	140			5.83	6.850	17.5
16:50	150	139			6.83	6.700	19.3
same	off			oven off	6.83		

One Fresh Spring Chinook Salmon. 8.15 Lbs Of 1 1/2 Inch Thick Fillets.

The three chinook processes described in this section are obviously not optimum in terms of speed, but all had good flavor, color, and texture. No objectionable curd formation was observed in any of the three. One important observation might be that the internal fish temperature of the full load (5/30) increased more rapidly than that of the partial load with the same initial oven temperature (4/30) and damper setting (1/2). This is a good indication that the 1/2 open damper setting on a full load did not allow enough air to be exhausted, which resulted in increased humidity. If smoke density can be maintained with a fully open damper in the smoking stage, higher initial temperatures might result in faster drying and a shorter total process time without causing curd formation. If not, it seems likely that a process time of more than 8 hours will be required for this product if weight loss is to be more than 15% (less than 85% yield).

Chum Salmon

Figures 14 and 15 and Table 5 show time temperature cycles for dark chum salmon which were being smoked for a canning project on 5/21/91. It is typical of what to expect from this fish even though about 1/2 the load was removed from the oven (for the canning project) at a point where 20% weight loss was experienced. The adjustments of oven temperature made in the later stages were an attempt to control internal fish temperature after it had reached 145 to 150^{o}F. An interesting comparison of these chum cycles to the

Chinook is that 30% to 40% weight losses were achieved in 7 to 8 process hours, while the Chinook lost only 15 to 20 % in the same time. The most likely explanation for this is simply the differences in flesh thickness and moisture content. A rough estimate of moisture content can be obtained by the following formula:

protein + ash + fat + moisture = 100%
protein + ash = 20%
fat + moisture = 80%
therefore: 80% - % fat = % moisture

A 10% fat content chinook would therefore be about 70% moisture. A 5% fat content chum would be about 75% moisture. This difference is significant when dehydration time (and therefore cycle time) is important.

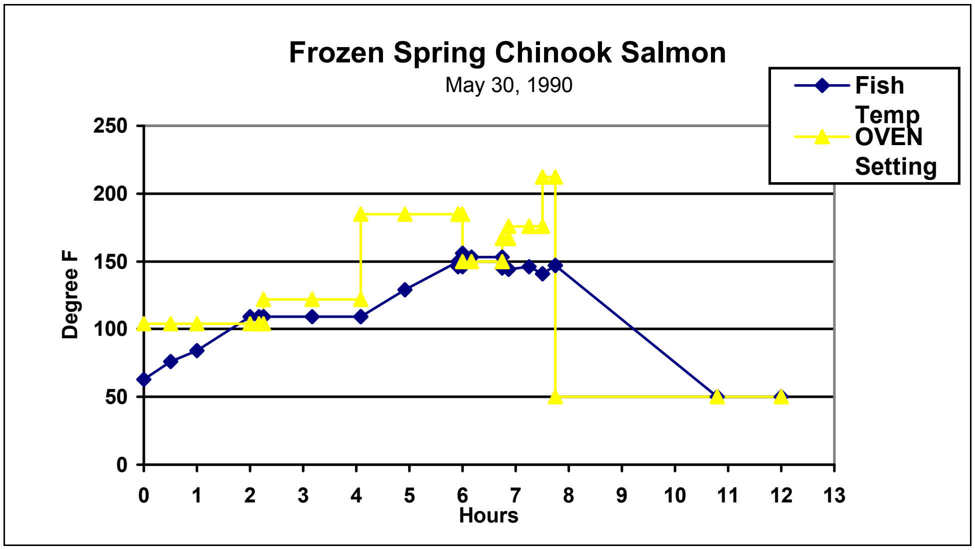


Figure 12: FROZEN SPRING CHINOOK SALMON SMOKING CYCLE, MAY 30, 1990

Soft, mushy, honey-comb, or crumbly texture may indicate decomposition in smoked fish. With scombrotoxin forming species it may indicate presence of histamine.

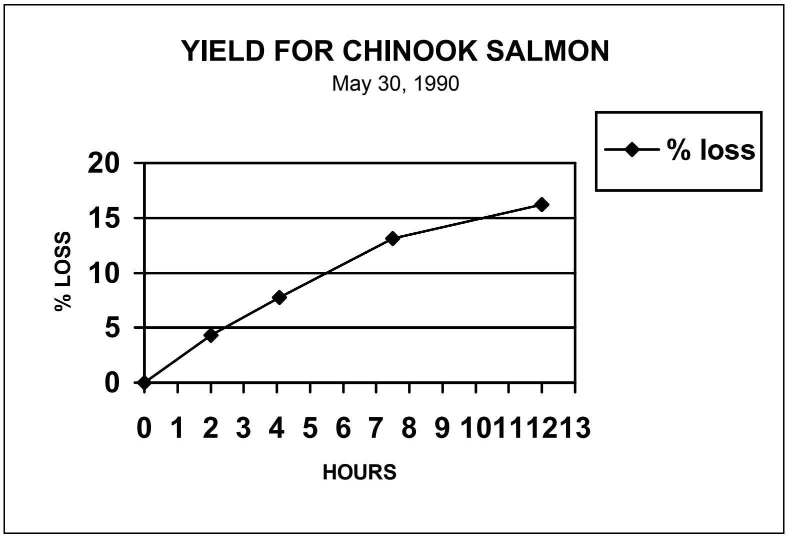


Figure 13: FROZEN SPRING CHINOOK SALMON SMOKING YIELD, MAY 30, 1990

Table 4: FROZEN SPRING CHINOOK SALMON PROCESS, MAY 30, 1990

Clock Time	Oven Temp Setting	Fish Temp	Draft Setting	Comment	Process Time	Test Weight lbs	% Weight Loss
9:00	104	63	open	brined 1.25 hr 5/29 - full load	0.00	75.55	0.00
9:30	104	76	1/2 open	light #1	0.50		
10:00	104	84			1.00		
11:00	104	109			2.00	72.30	4.30
11:10	104	109			2.17		
11:15	104	109			2.25		
11:15	122	109			2.25		
12:10	122	109			3.17		
13:05	122	109	open		4.08		
13:05	185	109	open		4.08	69.70	7.74
13:55	185	129			4.92		
14:55	185	150			5.92		
14:55	185	146		door open	5.92		
15:00	185	146			6.00		
15:00	150	156			6.00		
15:10	150	153			6.17		
15:45	150	153			6.75		
15:45	167	145		fish too cold	6.75		
15:52	167	144		fish too cold	6.87		
15:52	176	144			6.87		
16:15	176	146			7.25		
16:30	176	141			7.50	65.65	13.1
16:30	212	141			7.50		
16:45	212	147			7.75		
16:45	50	147		oven off, fan on	7.75		
19.45	50	50			10.8		
21:00	50	50		after cooling	12.0	63.30	16.2

75 lbs, 1 3/4 inch fillets (15 lb dressed weight fish)

Smoking Chum Salmon For Canning

A special smoking cycle for chum salmon intended for canning was tested, but not shown here, as it was very similar to the first 2 hours of the chum cycle already discussed. It was a brief low temperature smoke with a drying time sufficient to achieve a 10% weight loss. The end product was very moist and would not have been considered ready-to-eat. For canning, this cycle will produce the lighter-colored, more moist end product preferred by many markets and the yield will be much higher than ready-to-eat products. The high temperatures of canning darken smoked fish and intensify its flavor almost to the bitter point. This short cycle will help compensate for those changes.

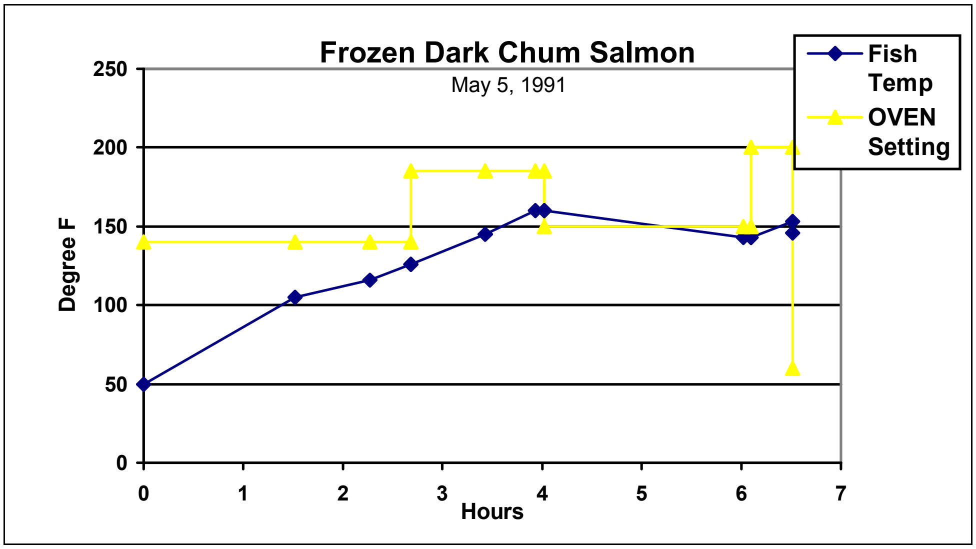


Figure 14: CHUM SALMON SMOKING CYCLE, MAY 21 1991

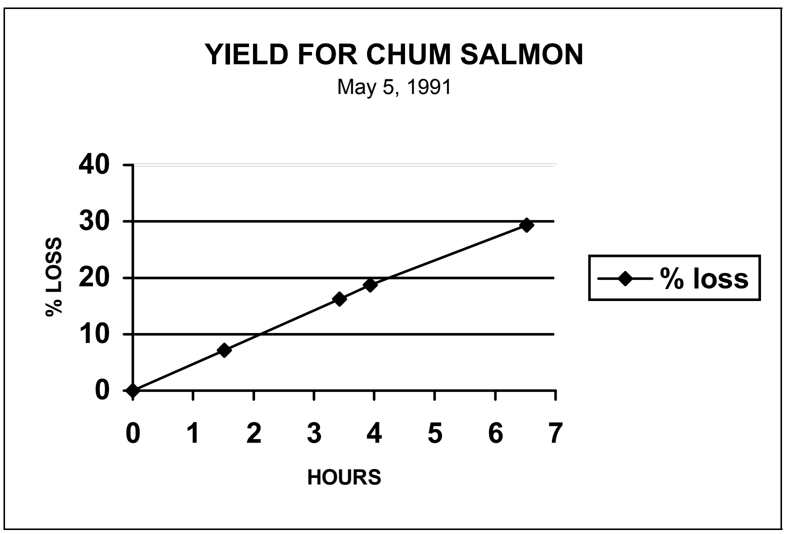


Figure 15: CHUM SALMON YIELD, MAY 21, 1991

> Smoke generators need to be cleaned. Follow manufacturers directions to prevent fire hazard.

Table 5: CHUM SALMON PROCESS, MAY 5, 1991

Clock Time	Oven Temp Setting	Fish Temp	Draft Setting	Comment	Process Time	Test Weight lbs	% Weight Loss
13:19	140	50	open	from 75lbs fish	0.00	45.15	0.00
14.50	140	105			1.52	41.90	7.2
15:35	140	116		fire #2	2.27		
16:00	140	126		close	2.68		
16:00	185	126		douse fire	2.68		
16:45	185	145			3.43	37.80	16.3
17:15	185	160			3.93	36.65	18.8
17:20	185	160			4.02		
17:20	150	160	open	change temp probe	4.02		
19:20	150	143			6.02		
19:25	150	143			6.10		
19:25	200	143			6.10		
19:50	200	156			6.52	31.90	29.3
19:50	60			to cooler	6.52		
				30% loss final			

Dark Chum. 45 Lbs Fillet

Smoking Coho Salmon Belly Flaps

- an illustration of oven temperature setting vs. actual oven temperatures.

Figure 16 and accompanying Table 6 illustrate how actual oven temperature may compare to oven temperature setting. This was a closely packed full load of coho salmon belly flaps, which have a lot of surface area and a high evaporation rate (drying). Notice that

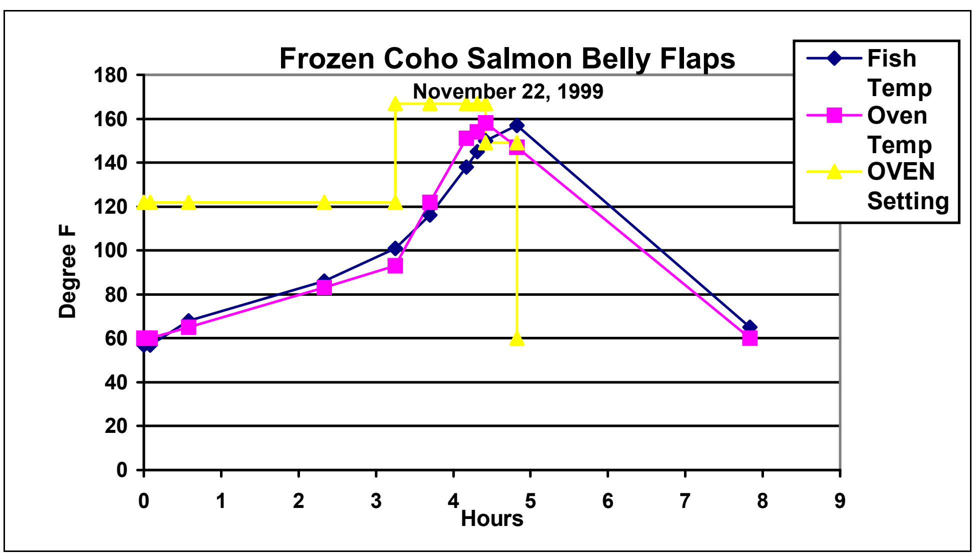


Figure 16: COHO SALMON BELLY FLAPS, NOVEMBER 22, 1999

until about 3 1/2 hours into the process the actual oven temperature was below the fish temperature. Several factors could account for this apparent anomaly (including inaccurate thermometers). However, in this case the fish probe was placed in a piece of fish on the left side of a left-to-right horizontal flow oven whereas the oven temperature gauge is located to right of the fish in the return air duct. The fan blows air over the electric heaters, then it is ducted onto the fish from the left side. As a consequence the air is cooled by the somewhat by the time it gets to the oven temperature probe on the right side of the oven. The first fish (with the fish probe) is therefore exposed to the hottest air. This is confirmed by uneven cooking of the fish and is the reason that some horizontal smoking ovens have alternating airflow from left to right then right to left.

Table 6: COHO SALMON BELLY FLAPS, NOVEMBER 22, 1999

Clock Time	Oven Temp Setting	Oven Temp	Fish Temp	Draft Setting	Comment	Process Time	Test Weight lbs	% Weight Loss
11:35	122	60	57	open		0		
11:46	122	60	57			.18		
12:10	122	65	68			.58		
1:55	122	83	86*			2.33		
2:50	122	93	101			3.25		
2:50	167	93	101	1/4		3.25		
3:17	167	122	116	1/8		3.70		
3:45	167	151	138			4.17		
3:54	167	154	145			4.31		
4:00	167	158	150			4.42		
4:00	149	158	150		overheating	4.42		
4:24	149	147	157			4.82		
4:24	60	147	157	open	cooling	4.82		
7:25	60	60	65		remove	7.83		

* Oven temperatures and fish temperatures may not be consistent for several reasons. Oven temperature gauge may be less sensitive than fish probe. Oven probe in this case reads return air temperature after it passes over fish.

Notice that the fish internal temperature continues to rise even after the oven controller is turned off. This is not an unusual occurrence and may be caused by thermocouple placement in the center of the fish where it continues to register temperature increase even while the surface is beginning to cool. In any case, both temperature probes (internal and oven) should show cooling at a consistent rate as illustrated in Figure 16 starting at hour 2.24 when the oven was turned off.

SMOKING SHELLFISH

Shellfish smoking procedures are different from finfish in that they are usually precooked or blanched (short cook) to set shape and color. Raw molluscan shellfish are often steamed to open the shell and remove the meat prior to brining. Crustaceans are usually fully cooked prior to shell removal. The smoking temperature is usually cool and the time usually is short. Adding edible oil to the brine or marinade helps smoke deposition. But in either case, the shellfish must meat the same WPS levels (3.5%) and the same time and temperature cooking (at least 145^0F for at least 30 min) requirements as finfish.

OVEN TEMPERATURE CONTROLLER OVERSHOOT

Figure 17 illustrates another phenomenon affecting oven temperature. Oven temperature controllers have a range of temperature for heat-on and heat-off at any given temperature setting. When heating capacity of the oven element is not well matched to the heat load, and depending on oven design and controller sensitivity, actual oven temperature may over shoot the desired operating (set point) temperature by several degrees. For this reason, the AFOS oven used in these experiments has three power settings (low, medium, and high) to active one, two, or three individual 1000-watt heating elements. Figure 17 shows the hypothetical effect of heating capacity on overshoot. The smoking cycle illustrated in Figure 16 used the 3000-watt high setting which was adequate only after about hour 3.5 when oven temperature became higher than fish temperature.

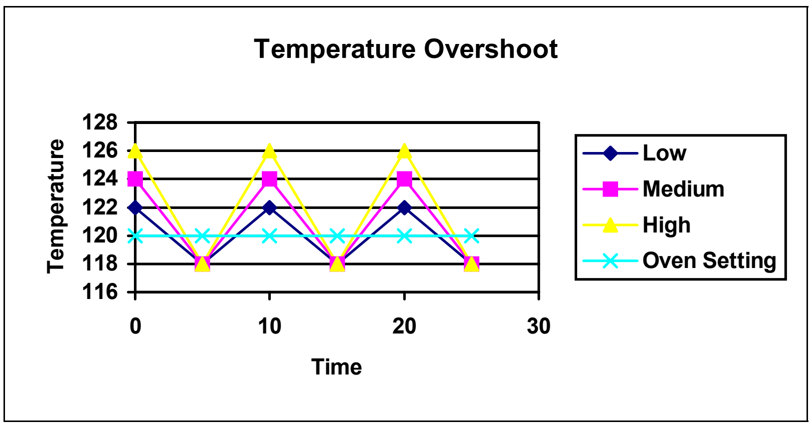


Figure 17: OVEN TEMPERATURE SETTING VS. ACTUAL OVEN TEMPERATURES

An Example of Oven Controller Overshoot

COLD SMOKED YELLOWFIN TUNA

Figure 18 and accompanying Table 7 show a typical cold smoking cycles. The AFOS Mini Kiln smoker used in this test produced too much heat for cold smoking in normal ambient temperatures, so the test was conducted in an air conditioned room at about 63 to 66^{0}F. Notice that the fish temperature stayed below oven temperature because of the cooling effect of drying. After 4.75 hours the moisture loss in the smoker was 9.6% which was judged to be insufficient. After 12.75 hours it increased to 21.5% which produced an excellent product. Leaving the oven on all night produced a weight loss of 28.5% after a total of 22.75 hours smoking time. Final moisture contents varied from 62 % to 67%, with WPS (Water Phase Salt) contents of 5.6% and 2.0%, respectively. This variation was from small to large pieces emphasizing that uniform size is desirable. Subsequent tests using tuna loins trimmed to 4 cm (about 1.5 inches) thickness produced more uniform brining and drying, and therefore more uniform WPS.

Current USFDA guidelines suggest that cold smoked fish should never be allowed to reach temperatures above 90^{0}F in order to avoid reducing spoilage bacteria loads that compete with *Clostridium botulinum* Type E in reduced oxygen packaging. This guidance is being reviewed by the FDA along with recommendations on cumulative temperature exposure about 40^{0}F for scombrotoxin (histamine) forming species. For a list of these species, refer to The FDA's most recent version of *Fish & Fisheries Products Hazards & Controls Guide*.

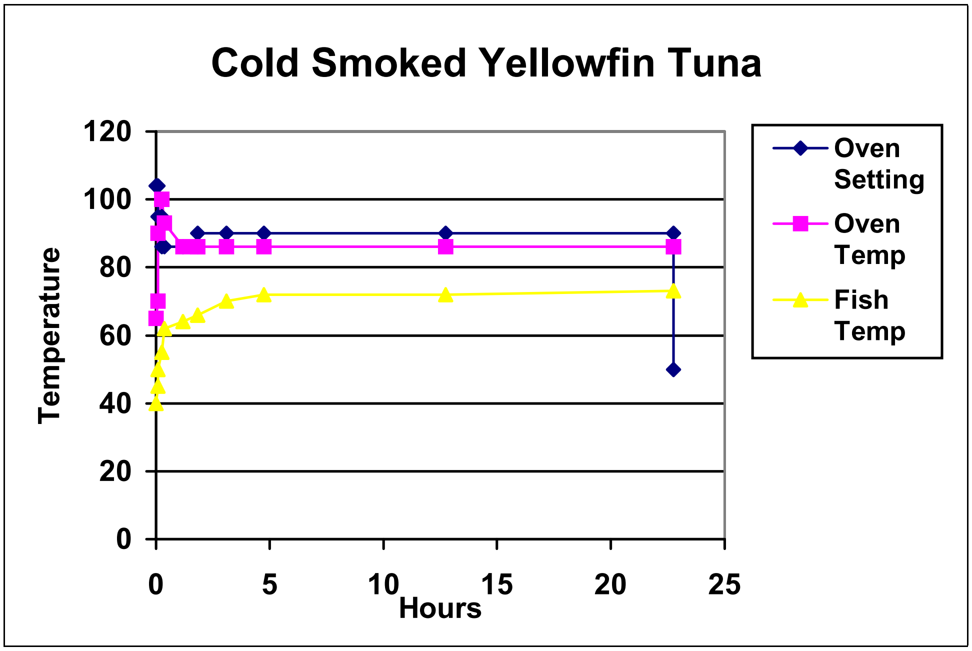


Figure 18: COLD SMOKED YELLOWFIN TUNA

Table 7:COLD SMOKED YELLOWFIN TUNA, May 12, 1988

Clock Time	Oven Temp Setting	Oven Temp	Fish Temp	Draft Setting	Comment	Process Time	Test Weight lbs	% Weight Loss
9:15am	104	65	40	open*		0.0		
9:20	104	70	45			.08		
9:20	95	90	50			.08		
9:30	95	100	55		excess heat**	.25		
9:30	86	100	55	1/4		.25		
9:37	86	93	62	3/8		.37		
10:25	86	86	64	1/4		1.17		
11:05	86	86	66			1.83		
11:05	90	86	66			1.83		
12:20	90	86	70		rotate racks	3.08		
2:00	90	86	72			4.75	NA	9.6
10:00pm	90	86	72			12.75	NA	21.5
8:00am	90	86	73		next day	22.75	NA	28.5
8:00am	50	86	73			22.75		

13 lbs brined 60 min in 60 SAL salt brine, * 63 to 66 degree F ambient temperature
** excess heat from smoke source

QUALITY AND FOOD SAFETY

Past problems with botulism poisoning from smoked fish has made regulatory agencies consider laws ("Good Manufacturing Practices") to protect consumers (and industry's reputation) from hazards of improperly processed and handled smoked fish products. More recently, detection of *Listeria* bacteria in cold smoked products has caused further concern. At this time issuer concerning the safety of smoked fish are covered by The FDA's "Safe and Sanitary Seafood" regulation (21 CFR 123, *Procedures for the Safe and Sanitary Processing and Importing of Fish and Fishery Products)*.

Recent information on fish parasites suggests that only previously frozen fish be used for cold smoking. Some fish parasites of public health importance are known to survive the cold smoking process. This is especially true of salmonid species from Pacific Northwest coastal streams. FDA feels that some farm raised salmon are parasite free.

REFRIGERATION AND SANITATION

Smoked fish is produced at temperatures and conditions which are favorable to the growth of spoilage and food poisoning bacteria. It is, therefore, important that the growth of these bacteria be retarded as much as possible. Starting with good quality raw material is a must (see next section), and refrigeration and good sanitation are necessary to maintain that quality. Each five-degree elevation of fish temperature will almost double the rate of chemical deterioration and bacteria growth. Fish should be held on ice (or kept frozen) until time of processing. This holding time should be kept to a minimum, certainly less than 2 or 3 days. Refrigerated rooms at 45^{o}F will keep fish quality less than half as long as ice at 32^{o}F. Fish which is held on ice or in refrigeration might have quality good enough for fresh sale, but may not withstand the time and temperatures of a smoking process. High quality fish (with low bacteria count) can become contaminated with bacteria from handling and processing. These bacteria will grow and spoil the fish or contaminate it with food poisoning bacteria and toxins. Some bacteria found in dirty processing plants will grow well at refrigeration and ice temperatures. Dirty tools, containers, working surfaces, and workers are the main source of contamination. If good sanitation practices are not used, the resulting smoked fish production will be low quality and develop a bad reputation in the market. In some countries of the world it might be seized and destroyed because of high bacteria counts.

It is of particular importance that finished products (smoked fish) not be contaminated with material from raw fish. The smoked fish will be relatively free of bacteria, but may become recontaminated with bacteria from the raw fish. Even smokehouse surfaces, refrigerated rooms, and salt brining containers are not free of bacteria. Some can grow at high temperature (smokehouse), some can grow at low temperature (refrigerated rooms), and some can grow in high salt concentrations (brining containers). Every portion of the fish processing plant with which the fish or workers will come into contact **must be kept clean and free of bacteria.**

RAW MATERIAL QUALITY

Fish from warm tropical waters should be gutted, washed, and iced as soon as they die. Often this is immediately upon capture, but some fishing techniques land dead fish. Gillnets and longlines, for instance, may leave the fish in the water for hours or days prior to landing. Tropical fish which are dead for long periods before landing should not be used for fish smoking. Even in cold water fisheries, fish should be cleaned or iced as soon as possible. Fish should not be used for smoking if they exhibit any characteristic signs of spoilage.

Fish which have been iced immediately after capture will probably be of good smoking quality for several days. However, fish which have been gilled and gutted before icing may be good for up to a week. Fish which have been neither gilled and gutted nor iced will probably be spoiled in a few hours if left in the sun on a warm day. In tropical areas, the temperature can be so hot that a fish will spoil within minutes of being laid on a hot surface.

Low quality fish can not be successfully smoked. The smoking procedure will subject them to several hours of temperatures favorable to bacteria growth and chemical decomposition. Products made from low quality fish will, at best, have a soft texture, taste bad, look bad, and smell bad. At worst, they can cause a serious outbreak of food poisoning or even death. Producers who cause food poisoning through careless handling or use of low quality materials can be held legally responsible for damages or criminal actions.

Fish displayed for sale in a retail case should **never be used for smoking**. In some states such a practice would be a violation of Good Manufacturing Practice regulations.

PACKAGING AND STORAGE

Smoked fish is a perishable product and must be stored below 38^{o}F, the temperature above which *Clostridium botulinum* Type E can grow and produce toxin. Ideally, for retail sales, the fish should be also be vacuum packaged to prevent contamination, preserve moisture, and prevent mold growth. However, vacuum packaging is expensive and not necessary for institutional sales where handling and storage are controlled by knowledgeable professionals. The biggest problem faced by producers seems to be growth of mold. Producers should be aware however, that mishandled vacuum packaged smoked fish can become toxic and may therefore be regulated in future federal or state GMPs with special time/temperature, labeling, or WPS requirements.

Without use of mold-inhibiting chemicals, contaminated smoked fish will show visible signs of mold growth within two or three weeks when stored in a high humidity atmosphere. Plastic bags, waxed or plastic lined cartons, and damp coolers or refrigerators all produce the high humidity conditions favorable to mold. Smoked fish is best protected from mold by preventing initial contamination. Good sanitation and handling practices are the ways to accomplish this. However, weather conditions in certain climates, along with necessary air conditioning, make it difficult to completely eliminate mold spoors from the air. Under these conditions the best remedies seem to be drying out the storage area (lower humidity), quick handling and marketing, preservatives, **or short term frozen storage.**

Smoked fish does not suffer extensive tissue damage from freezing and thawing because the protein is already cooked (hot smoke) or cured in salt (cold smoke). Reasonably quick freezing times (1 to 2 hours) accompanied with short term frozen storage (4 to 6 weeks) in a reasonably good vapor barrier package or container at constant -15 to -20^{o}F will not seriously lower fish quality. Cold smoked yellowfin tuna may suffer some loss of color (bloom), but the quality is generally good. Long-term frozen storage in vacuum packages will provide good-quality shelf life of 12 months or longer.

For information on seafood safety go to University of California's Website SeafoodNIC at: http://seafood.ucdavis.edu

SMOKEHOUSE ECONOMICS AND FINANCIAL ANALYSIS

The most important factor in the profitability of smoked fish production (aside from selling price) is usually the yield of finished product. This is because raw material costs represent the largest percentage of total costs. Producers should understand how smoking procedures affect the interrelationships between yield, throughput, and final profitability.

Yield and Economics

The smokehouse yield of various species depends almost entirely on the amount of moisture that must be removed. Other losses from fat or protein are negligible unless high fat fish (like kingfish, chinook salmon, or black cod) are cooked long enough and hot enough (above about 160^{o}F) to melt oil from the flesh. The economic consequences of a lower than necessary yield (excess drying) can be seen in the following illustration:

cost of fish = $2.90/lb
cutting yield = 40%
cost of raw material = $2.90/.4 = $7.25/lb
Case 1 - 80% smokehouse yield
cost of smoked fish = $7.25/.8 = $9.06 finished product cost
Case 2 - 70% smokehouse yield
cost of smoked fish = $7.25/.7 = $10.36
difference ($10.36 - $9.06)/$9.06 = 14.3% increase in cost/lb

This loss might best be illustrated by comparing the sales value of 1000 lbs of fish loins (worth $15/lb after smoking) smoked at 80% yield (1000 lbs x .8 = 800 lbs @ $15/lb = $12,000) to the same quantity of fish smoked at 70% yield (1000 lbs x .7 = 700 lbs @ $15/lb = $10,500), a loss of $1,500.

Smokehouse yields of 75% to 80% are typical of fish which is smoked to a final moisture content of 60%, where it is reasonable to expect good texture, a 3.5% WPS level, and good flavor (not too salty). High fat fish, having less initial moisture, will have better smokehouse yield.

Periodic weighing of a rack or single piece of fish will assist in monitoring drying rate and yield. For example, a 72% theoretical yield means that a 40 lb rack of fish (net weight) will weigh 28.8 lb when finished (.72 x 40 lb = 28.8 lb).

Production, Cost, and Financial Analysis

Good production and cost analyses are dependent on knowledge of cutting and smoking yields. With adequate data, the analyses can be reduced to a computer spreadsheet. This type of spreadsheet is simply computations of smokehouse loading and costs modified by cutting and smoking yields. They are especially useful in making comparisons between alternative product choices. With the addition of data on capital investment, the spreadsheets can also be useful in a rough financial analyses. But remember, spreadsheets are no better that the data and assumptions that go in them.

Computer spreadsheets are most valuable because of their speed. They can instantly compute comparisons based on different assumptions. For instance, the impact of raw material costs, worker skill in butchering fish (cutting yield), and smokehouse performance (smoking yield) on costs and production can be made immediately obvious. More detailed financial analysis can be made if accurate input data is available.

> The USFDA will continue to promulgate new regulations and guidelines for smoked seafood. Be sure to check federal and state agencies for the latest information.

SALT AND MOISTURE ANALYSIS PROCEDURES

Each lot (load) of smoked fish should be checked for water phase salt (WPS) until enough data is gathered to insure that brining procedures are adequate to satisfy WPS requirements. With this data, then HACCP Critical Limits can be set for brining (time and brine strength). This means salt and moisture content must be determined separately for each group which might have a different salt content. This might be a different species, a different size, or fish that were brined at a different time. At the minimum, a lot would be each smokehouse load consisting of the same species and the same size pieces which were
brined at the same time. State and or federal regulations mandate a that a HACCP plan be prepared for all smoked fish.

Salt and moisture analysis is not difficult and can be learned by careful attention to instructions. The equipment and supplies needed can be found in the publication *Quick Determination of Water Phase Salt Content of Smoked Fish* available on-line at:
http://seagrant.orst.edu/sgpubs/onlinepubs/QuickSalt.pdf

Summary of Equipment Needed

* Balance capable of 1/10 gram accuracy (1/100 gram accuracy is better)
* Household blender with 1/2 pint blender jars & several extra cutting blades
* Small microwave oven with a digital minute/second timer
* Glass fiber filter pads
* Chloride titrators
* Pocket calculator
* Assortment of small knives and spoons
* Wood or plastic cutting board
* Small coffee filters or a roll of paper towels
* Distilled water

FISH SMOKING MATHEMATICS

Calculations for yield and final moisture content of smoked (dried) fish assume that nothing is lost except moisture. Of course, this would not be the case in any fish which was overheated enough to melt out the fat. However, making this assumption (no solids loss) is a useful device in materials balance calculations. By following the solids content and use of simple algebra, the following example calculates an estimate of the final moisture content of fish which had a raw moisture content of 80% and a yield of 70%:

Start	Final (end)
80% moisture	X (unknown)
20% solids	20 gm (original solids/100 grams)
100 gm total	70 gm (ending weight)

If the ending weight is 70 gm (70% yield x 100 gm start) and the solids were not lost (20 gm), then the moisture left must be 50 gms (70 - 20 = 50). That means that the moisture content would be 71.4% (50/70 x 100).

The OSU Extension Service and Experiment Stations have seafood and fisheries publications site at:
http://eesc.orst.edu/agcomwebfile/EdMat/default.html

Using the same logic, if **starting** and **ending** moisture content are known, an estimate can be made of the yield.

for example:
80% (starting moisture)
20% (starting solids)
20 gm original solids per 100 (100 - 80 = 20 gms)
65% (ending moisture)
35% (ending solids (100- 65))
X gm final total (unknown)
X% yield (unknown)

The final total must be 57.1 gm (20/.35 = 57.1) because the 20 gms of solids represents 35 percent of the total. Another way to say it algebraically is 35% of what weight is equal to 20 gm (.35 x what weight = 20 gm). That is the same as saying (What = 20 gm/.35). The yield then must be 57.1% (57.1/100 x 100 = 57.1%), which is the final weight divided by the beginning 100 grams in the raw fish.

REFERENCES

Compendium of Fish and Fishery Product Processes, Hazards, and Controls", Chapter 7 at: http://seafood.ucdavis.edu/haccp/compendium/compend.htm.

Fish & Fisheries Products Hazards & Controls Guide: Second Edition. Food and Drug Administration, Center for Food Safety and Applied Nutrition, Office of Seafood, Jan 1998. http://vm.cfsan.fda.gov/~dms/haccp-2.html.

Hazard Analysis and Critical Control Point Applications to the Seafood Industry. Jong S. Lee, with Kenneth S. Hilderbrand, Jr. Oregon Sea Grant. ORESU-H-92-001. 1992. 29 pp. http://nsgl.gso.uri.edu/oresu/oresuh92001.pdf.

Procedures for the Safe and Sanitary Processing and Importing of Fish and Fishery Products, 21 CFR 123 http://vm.cfsan.fda.gov/~dms/haccp-2z.html.

Quick Determination of Water Phase Salt Content of Smoked Fish. Hilderbrand, Kenneth. S Jr. ORESU-I-00-003 (was Special Report 883) Revised November 21, 2000 http://seagrant.orst.edu/sgpubs/onlinepubs/QuickSalt.pdf.

Seafood Haccp Alliance Seafood Haccp Encore Course, http://www.fda.gov/ora/training/Satellite/Announcements/manual2.pdf

FURTHER READING

"Hot Smoked Fish Company HACCP Plan", Hilderbrand, Kenneth S. Jr. Oregon State University Extension Sea Grant Program. Publication No. ORESU-I-97-001. Revised 6/20/97. http://www-seafood.ucdavis.edu/haccp/plans/hotsmk.htm.

Preparation of Salt Brines for the Fishing Industry. Hilderbrand, K.S. Sea Grant Publication ORESU-H-99-002. OSU Sea Grant Extension Service, Corvallis, OR., 4 pp. (Revised in 1999 from SG 22 1973.). http://seagrant.orst.edu/sgpubs/onlinepubs/h99002.pdf.

Understanding and Controlling Histamine Formation in Troll-Caught Albacore Tuna: A Review and Update of Preliminary Findings from the 1994 Season. Cormac Craven, Ken Hilderbrand et. al. Bulletin. Oregon Sea Grant ORESU-T-01-001. Revision of SG 74. 4 pages.
http://seagrant.orst.edu/sgpubs/onlinepubs/t01001.pdf.

The Author is: Kenneth S. Hilderbrand, Jr. Seafood Processing Specialist, OSU Extension Sea Grant Program, Hatfield Marine Science Center, 2030 Marine Science Drive, Newport, OR 97365, phone 541 867-0242 http://seagrant.orst.edu/extension/seafood.html
email <ken.hilderbrand@hmsc.orst.edu>

This special report was funded by the National Sea Grant College Program of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration under NOAA grant NA76RG0476 (project number A\ESG-4), and by appropriations made by the Oregon State legislature. The views expressed herein do not necessarily reflect the views of any of those organizations.

Sea Grant is a unique partnership with public and private sectors, combining research, education, and technology transfer for public service. This national network of universities meets the changing environmental and economic needs of people in our coastal, ocean, and Great Lakes regions.