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Fish Smoking Procedures for Forced Convection Smokehouses

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The Extension Sea Grant Program, a component of the OSU Extension Service, provides education, training, and technical assistance to people with ocean-related needs and interests.

Fish Smoking Procedures for Forced Convection Smokehouses

by

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Disclaimer:

Most of the experimental work referred to in this publication was conducted using an AFOS Mini Kiln of British origin. 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 chose 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.

Since the early 1970's, the U.S. Food and Drug Administration and other regulatory agencies have recommended that "hot-process" smoked fish be processed in a manner which meets certain minimum standards for salt content, process time/temperature, and storage/transport conditions. This report is written at a time when experts anticipate that these recommendations will soon be codified into law (Good Manufacturing Practice). Commercial smoked fish processors should check with Federal, State, and local authorities to determine what current minimum processing standards will apply to their production and marketing.

Smoke 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 spoilage bacteria or render them harmless by altering the chemistry of the food 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.

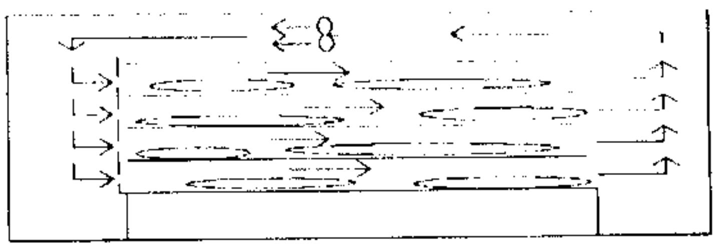
Smoked food is prepared with two basic procedures. One cooks the product (hot smoking) and the other does not (cold smoking). Cold smoking devices have one basic function: to apply smoke to the product. Hot smoking devices have the added function of applying heat. And because preservation of fish usually requires moisture removal, systems designed for hot or cold smoking fish 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 must be designed to have adequate air flow 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). 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.

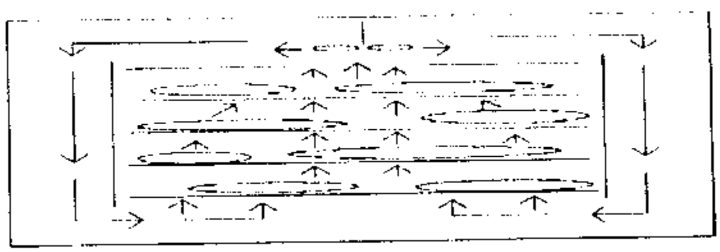
Figure 1 shows air flow patterns in forced convection systems. True horizontal and vertical flow designs give relatively even smoking and drying throughout the smokehouse. Modified systems may have uneven patterns when operated at full capacity because more air is forced through the top racks than through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

FIGURE 1 AIR FLOW PATTERNS IN FORCED CONVECTION SMOKEHOUSES

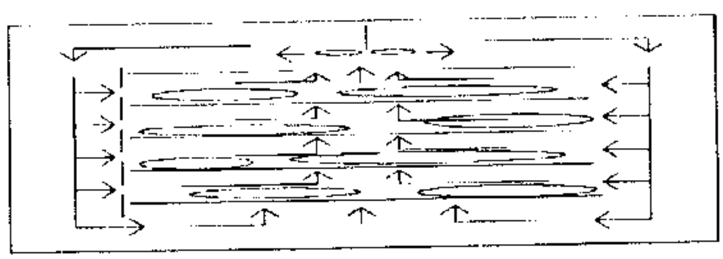
HORIZONTAL FLOW



VERTICAL FLOW



MODIFIED VERTICAL FLOW



Government Smoked Fish Regulations

The U.S. Food and Drug Administration's general Current Good Manufacturing Practice (GMP) [1] is currently the only major law regulating production of smoked fish. A specific GMP for hot smoked fish [2] 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 continuing research program has produced sufficient data to allow reissue of that GMP in the near future. If passed into law, this GMP will have significant impact on smoked fish producers. It will set minimum standards for time/temperature smoking cycles, salt and moisture content, manufacturing, holding and shipping temperatures, process monitoring and record keeping, and packaging.

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[3] which is similar (but not identical) to the GMP being developed by the FDA. Although neither of these GMPs presently are in force, they are based on recognized hazards of smoking fish and will become law at some point. 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.

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 (about 95^{o}F), while the "hot smoke" process cooks the fish to the center (about 140^{o}F). Between those two extremes are temperatures that can create an environment favorable to growth of food poisoning bacteria.

Both hot and cold smoked fish are preserved primarily by control of salt and moisture content (Water Phase Salt). 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.

Hot Smoke

Safe hot smoked fish must contain at least 3.5% water phase salt (WPS) and must have reached a center temperature of at least 145^{o}F for at least 30 minutes[4]. The potential for growth of harmful bacteria (e.g. *Staphylococcus aureus* or *Clostridium botulinum*) is high if these conditions are not met[5].

Elevating the fish temperature above 95^{o}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 fish can harbor harmful bacteria which may grow and produce toxins without competition from normal spoilage bacteria. Food poisoning bacteria can produce these toxins without appearing to be spoiled. Serious illness or even death can result from eating such spoiled fish.

As an additional safety margin, hot smoked fish should always be cooled to less than 38°F immediately after smoking and held at that temperature until consumed to prevent growth of food poisoning bacteria.

Cold Smoke

Safe cold smoked fish must contain at least 3.5% WPS and must not have reached temperatures greater than 95°F. These conditions do not completely eliminate normally harmless food spoilage bacteria. These bacteria can then grow in competition with food poisoning bacteria and indicate visually or by odor that the fish has been mishandled, is spoiled, and should not be eaten. Cold smoked fish is not a fully preserved product and, for the same safety reasons as with hot smoked fish, must be chilled to 38°F 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[6]. Special attention to sanitation and quality control is therefore essential for these products. The National Marine Fisheries Service is investigating chlorine dips for thawing fish to eliminate Listeria from the surface of fish prior to smoking.

Cooked fish loses the distinctive flavor and texture that defines cold smoked products. It is therefore essential that cold smoked seafood products do not exceed a maximum of about 95°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 fish be used as a raw material. This is particularly true of salmonid species from coastal streams in the Pacific Northwest.[7]

Cold smoked fish is produced in many different styles and is 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. [8]

"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 the products.

Salt

Neither smoke nor heat by themselves are effective in preserving fish. Bacteria growth is retarded (but not stopped) only by salt levels which reduce water activity (AW) of the flesh to about .97 or less (pure water is AW 1.0). Fish with salt contents greater than 3.5% in the water phase 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.

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 laboratory procedures. In addition, because sugars may aid in growth of some food poisoning organisms, salt level is a better indicator of preservation.

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 percent moisture would have about 4.8% WPS (3%/[60%+3%] = 3/63 = .047619 x 100 = 4.8%).

WPS is a function of both 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 to 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 dangerous, 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. 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 4x4cm (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% by weight), it took about 45 minutes for a 4x4cm block of yellowfin tuna to absorb enough salt to give it a final WPS when the final product reached 60% moisture.

For kingfish the brining time was over 100 minutes. Large salmon take about the same time and brine strength. Small salmon take much less time, perhaps only 15 to 20 minutes. In general, salt absorption is affected by brine strength, brining time, thickness of the piece, temperature of the brine, texture of the fish, fat content of the fish, species, and fish quality. Although mathematical models have been developed to predict salt absorption rates, practical considerations in manufacturing dictate that procedures are best developed by testing.

FIGURE 2 SALT ABSORPTION IN YELLOWFIN TUNA
Time vs Percent Salt in 60 Degree Salometer Brine
(4 cm x 4 cm blocks)

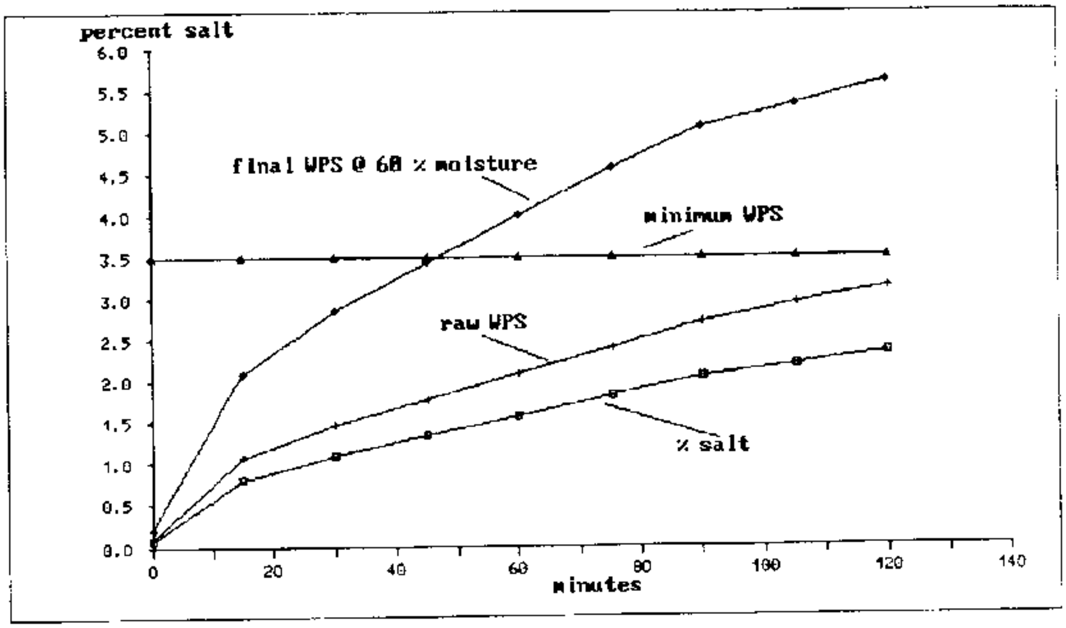
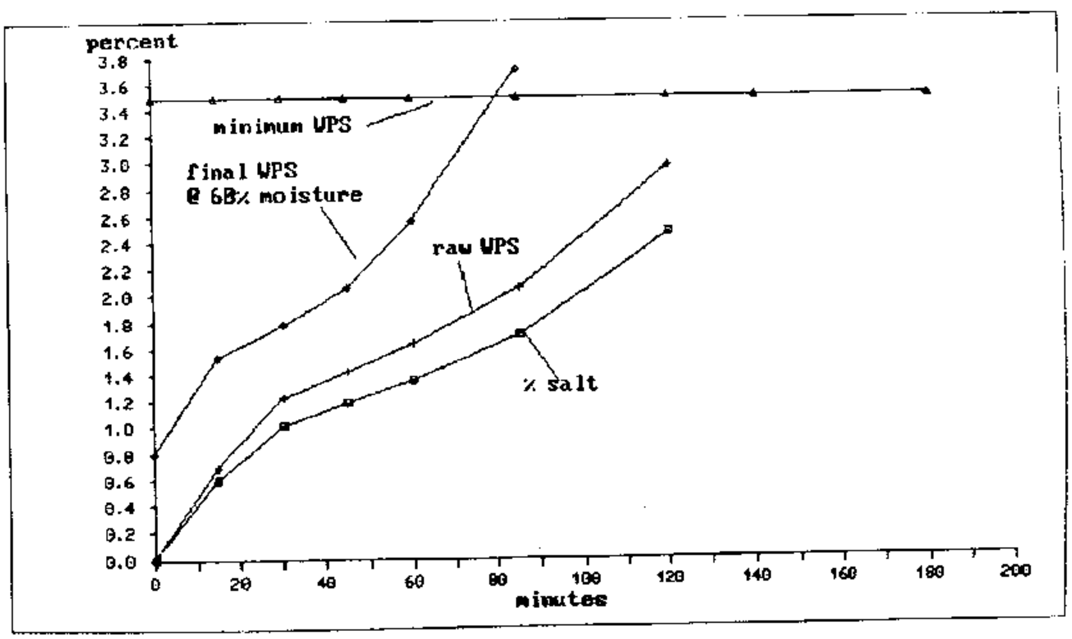


FIGURE 3 SALT ABSORPTION IN KINGFISH
Time vs Percent Salt in 60 Degree Salometer Brine
(4 cm x 4 cm blocks)



Brine Strength

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 uneven salt absorption. Dry salting is a technique which covers fish with a thin layer of salt (.25 in to .5 in) between layers of fish.

Brining Time

Fish will continue to absorb salt over time only up to a point. The rate of salt absorption slows as salt is absorbed into the outer surface and tries to penetrate into 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" stage. 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.

Thickness of Piece

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 not take twice as long (2 x 30 = 60 min), but may take 90 minutes or 3 times as long. The exact relationship between time and thickness may depend on the other factors which also affect salt penetration.

Temperature

In general, fish absorbs salt faster as the brining temperature increases. However, it is best to standardize brining at a cool temperature (34 to 35°F) to achieve consistent and predictable results and to discourage bacteria growth. 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)[9].

Texture

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

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.

Species

Different species of fish have different flesh characteristics and may absorb salt at different rates. Salting times should be specific for each species.

Fish Quality.

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 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. After smokehouse size and product thickness is set, the other critical factors are drying, heating, and smoking.

Drying

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. Factors which affect the rate of drying are heat, humidity, air velocity, air exchange, flesh characteristics, and flesh thickness.

Heat

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 part 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 must be avoided.

Humidity

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 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. Dryers must expel air to get rid of moisture, thereby allowing new, lower humidity air to enter the system.

Air Velocity

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

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.

Fish Flesh Characteristics

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

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.[10]

Heating

Common heat sources in 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

Increasing air velocity produces higher product heating rates.

Air Temperature

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°F, increased air temperature increases smoke deposition.

Relative Humidity

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

The rate that smoke deposits on fish depends on smoke density, air circulation, humidity, temperature and nature of the surface. A brief drying period to form a coating of protein on the surface of the fish (pellicle) will prevent surface moisture accumulation and assist in even smoke deposition. 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.

There is some evidence that a relative humidity of 60% at a temperature of 160°F will produce maximum smoke deposition in some species [11]. 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 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.

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 size. Producing mixed loads with different species and size will be more complex if not impossible in some cases. A combination of two systems, one set for smoking/drying and one set for cooking, may be necessary for simultaneous production of widely variant products. And only experience, experimentation, and good record keeping will produce optimum cycles for specific situations.

Time\Temperature Smoking Cycles

The hot smoking of fish requires five steps, 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.

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 the five fish smoking steps may overlap somewhat, they can be summarized as surface drying, smoking, drying, heating/cooking, and cooling:

1. Surface Drying

Removing surface moisture leaving a protein coating (pellicle) on each piece of fish so it will accept an even smoke deposit.

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

TABLE 1 SMOKED FISH DATA SHEETS

SAMPNO: __________ DATE: __________ SPECIES: __________________________.
BRINING: _______ min ________ deg. salometer THICKNESS:____ inches
BEGINNING WT: __________ ENDING WT: _______________________ net/gross

TOTAL HOURS	TIME	OVEN SETTING	OVEN TEMP (X)	FISH CENTER (O)	ROOM TEMP. (*)	OUTSIDE TEMP (.)	SMOKE TRAY (-)	DRAFT SETTING	FINAL READINGS
0	_____	_____	_____	_____	_____	_____	___	____.	salt ____.
..	_____	_____	_____	_____	_____	_____	___	____.	%M _____.
..	_____	_____	_____	_____	_____	_____	___	____.	%wps ____.
..	_____	_____	_____	_____	_____	_____	___	____.	% yield
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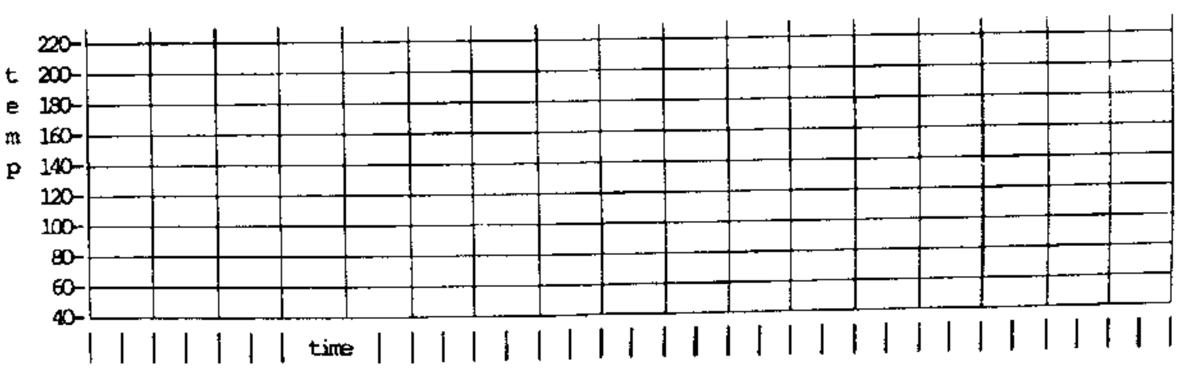


preservation. Often color will not develop until after the surface of the fish reaches 130 to 140°F during the cooking step.

3. Drying

Evenly drying the fish to reduce moisture, raise the WPS, and establish final texture. This is a critical step in producing safe products.

4. Heating/Cooking

Heating each piece of fish to at least 145°F and holding that temperature for at least 30 minutes. This is also a critical step in safe smoked fish production.

5. Cooling

Cooling the fish below cooking temperature (120 to 140°F internal temperature of largest piece) in the smokehouse as quickly as possible. Further cooling to less than 38°F to reduce growth of food poisoning bacteria is recommended, but not necessarily in the smokehouse. A suitable sanitary refrigerated room is usually more practical and cost effective than a refrigerated smokehouse. Future smoked fish regulations may specify minimum cooling temperatures and rates. Cold smoking procedures do not use step 4 (heating/cooking).

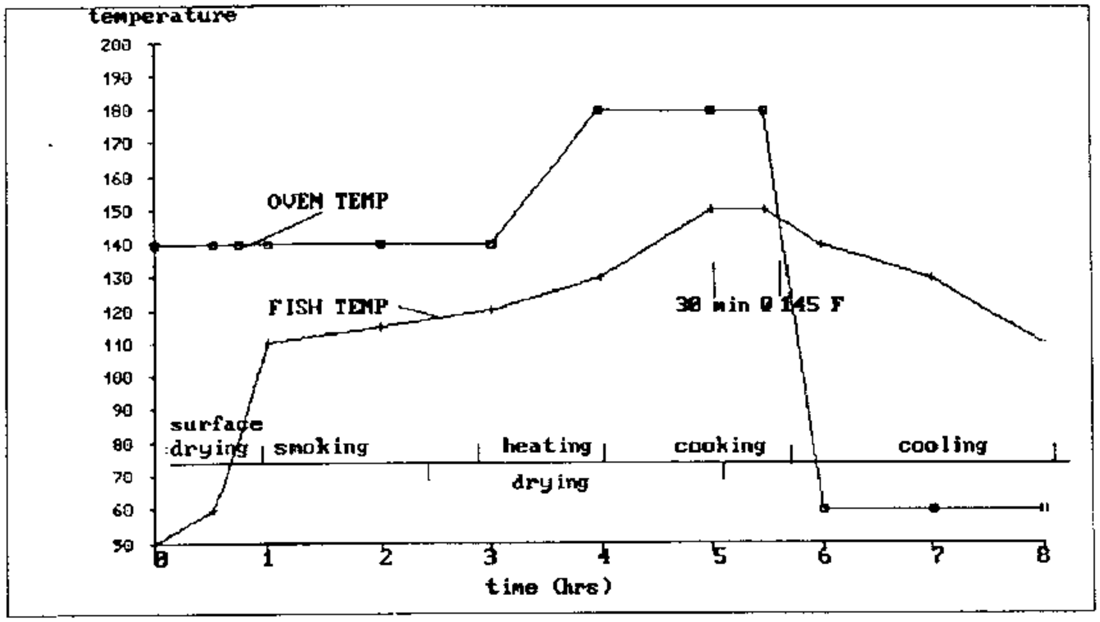
Examples Of Smoked Fish Time\Temperature Cycles.

Smoked fish producers are obligated by law 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 only by establishing a regime of time and temperature (a cycle) which produces the desired result and by reproducing that cycle accurately. 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 would look something like Figure 4. The oven and internal fish temperatures would rise togethe,r allowing for a quick surface drying period of 15 to 20 minutes, a smoke deposition period of one or two hours, a drying period of a few hours, a cooking stage as required by law or good practice, and a cooling off period. If this could all take place in less than 12 hours, then two cycles per day would 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 products.

FIGURE 4 SMOKED FISH CYCLE - THEORETICAL



Modern smokehouse time/temperature programming systems are capable of producing the "ideal" cycle because they can be set to maintain a constant temperature difference between oven temperature and internal fish temperature, and then elevate both to cooking temperature at any desired point of temperature or time.

During the drying period the exhaust damper should be open to allow maximum surface 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; and during the cooking period they should again be closed. The exact damper settings during drying, smoking, and cooking depend on 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.

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. It must not lose excessive moisture (yield = $), and it must not sour (spoil) or become toxic (e.g. *Staphylococcus* bacteria) in the smokehouse. <u>And It Must Meet The Requirements Of The Law.</u> For example, it must meet minimum time/temperature exposure and final water phase salt content.

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.

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

Figure 5 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 7 hours to bring the product to 145^{O}F with another 3 to 4 hours to cool the product, totaling 10 or 11 hours. The temperature of the air conditioned process room was about 64^{O}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 86^{O}F after one hour and remained there until the oven temperature was increased from 122^{O}F to 158^{O}F after 4 hours. The oven temperature was later increased to 212^{O}F to achieve 167^{O}F internal temperature (145^{O}F minimum recommended by NMFS). Two trays of wood were smoked in the first two hours of the cycle.

Figure 6 has a similar cycle for kingfish which resulted in overcooked fish, loss of yield, and considerable oil being baked out of the fish. Notice that the internal fish temperature peaked at 185^{O}F after about 11 hours. The oven temperature was elevated to 248^{O}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 air flows (exhaust) and initial oven temperature.

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 5.

Butchering, Brining, and Loading

The fish were loined (about 50% yield) and cut into 3 to 4 cm (1 in to 2 in)

FIGURE 5   SMOKING CYCLE FOR YELLOWFIN TUNA

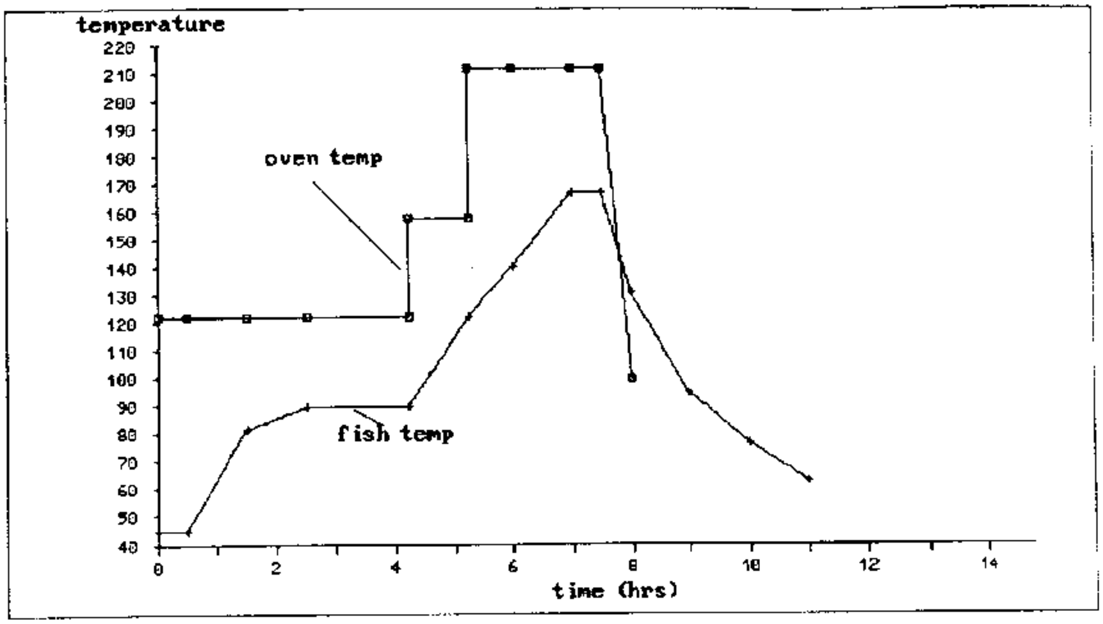
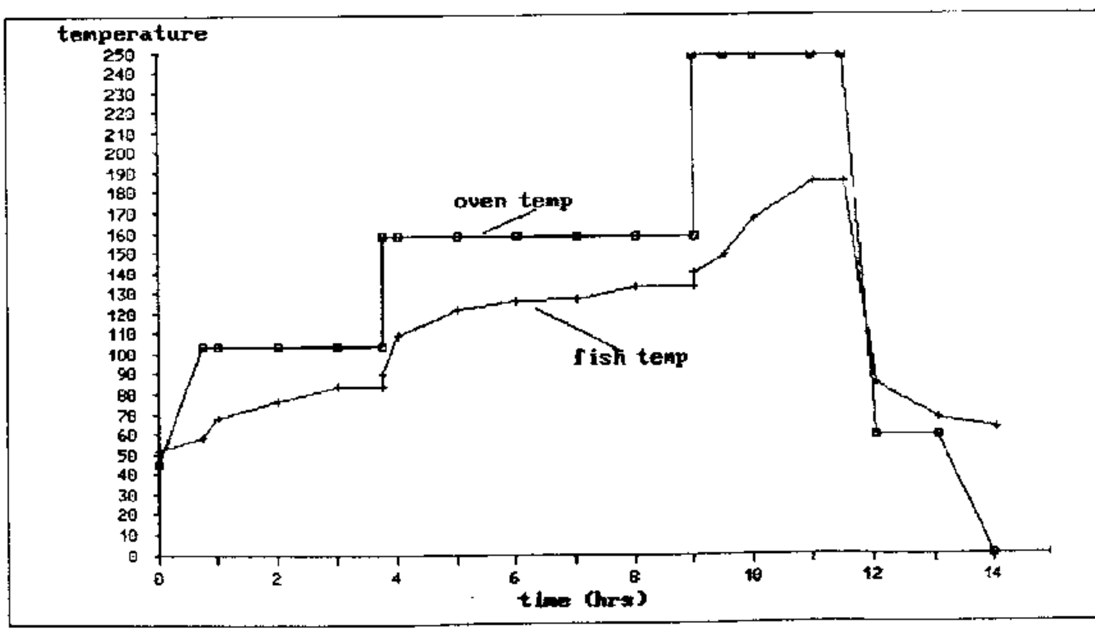


FIGURE 6   SMOKING CYCLE FOR KINGFISH (resulting in overcook)



thick pieces about 4 inches to 5 inches square. They were immersed for 60 min in chilled 60° 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°F to 122°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 well 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 drum. 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 reverse the direction of air flow). It is usually sufficient in hot smoking 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 2nd tray of wood. Rotating racks while the second 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 95°F.

Drying

With the exhaust damper at 1/4 open, a 1/2 maximum load[12], and a 122°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 setpoint 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 212^{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 unwanted in most smoked fish markets.

Heating (cooking)

The heating (cooking) step began as soon as the drying step was completed to the point where the temperature rise in the flesh indicated that the drying rate was slowing. Because the oven setpoint was already sufficient to cook the fish (212^{o}F), all that was necessary to begin cooking was to raise the humidity by closing the exhaust damper. Although some heating took place in the drying step, evaporative cooling kept the temperature down to about the wet bulb temperature, which was a function of the humidity. Some drying took place in the heating step even though the exhaust draft was closed.

If the flesh temperature was elevated too fast, curd formation might have been a problem (see previous section). This would have reduced the visual appearance of the fish. At the same time, the fish would take on an undesirable flavor similar to baked fish.

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^{o}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 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 *Clostridium botulinum* toxin production.

New recommendations by the Association of Food and Drug Officials suggest that all smoked products be cooled to 50°F or less within 3 hours of cooking and further cooled to 38°F or below within 12 hours of cooking.

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 6 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 (i.e. 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 7 and 8 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 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° salometer brine, then rinsed briefly in fresh water. The chunks were allowed to dry for about an hour in a 104°F oven with open damper. Figure 7 shows oven settings (oven temperature followed closely) over a 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 8.

Figure 8 follows the loss of weight (moisture) from the fish over time. Yield is, of course, 100% minus % 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

FIGURE 7 SMOKING CYCLE FOR CHINOOK SALMON, APRIL 30, 1990

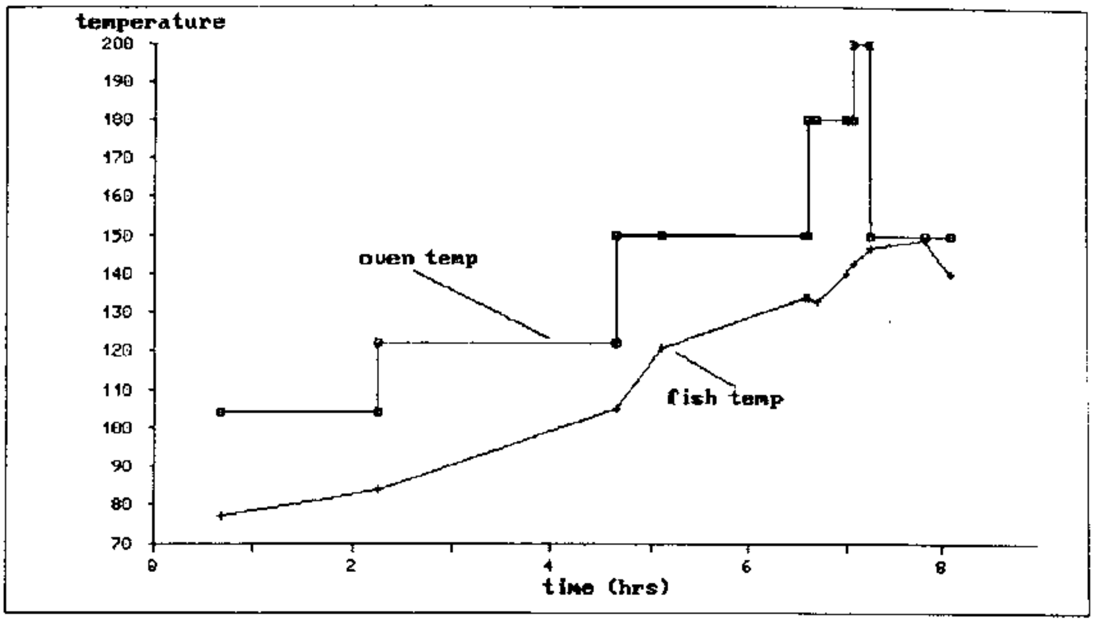


FIGURE 8 YIELD FOR CHINOOK SALMON, April 30, 1990

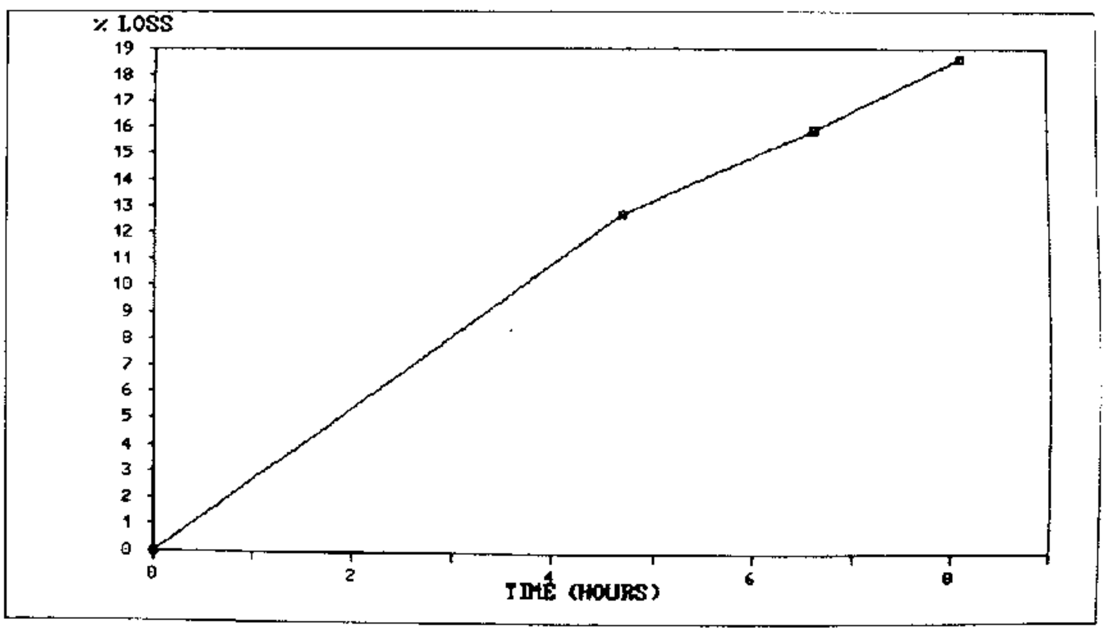


TABLE 2 SPRING CHINOOK SALMON PROCESS
11 LBS OF 2 INCH THICK FILLETS
2.89 LBS/SQ FT LOADING
April 30

clock time	oven temp	fish temp	draft setting	comment	process time	test weight	% loss
12:15				in 60 SAL salt, 1 fish	-1.33		
13:30				out salt, rinse	-0.08		
13:35	104		open	dry	0.00	11.00	0.00
14:15		77	1/4	smoke on	0.67		
15:50	104	84	1/2		2.25		
15:50	122	84	1/2		2.25		
18:15	122	105			4.67	9.600	12.7
18:15	150	105			4.67		
18:43		121			5.13		
20:10		134			6.58	9.250	15.9
20:12	150		close		6.62		
20:12	180		close		6.62		
20:17		133			6.70		
20:35		140			7.00		
20:41	180	143			7.10		
20:41	200	143			7.10		
20:51	200	147			7.27		
20:51	150	147			7.27		
21:25		149	open	off	7.83		
21:40		140			8.08	8.950	18.6

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.

A second chinook (fresh) was smoked on May 1st in an attempt to reduce smoking time. Figures 9 and 10 and Table 3 record the details. It can be seen that drying and smoking temperatures were elevated to 140°F from the lower initial temperatures on 4/30. The oven temperature was elevated to 180°F on about process hour 3 and the damper left at 1/2 open. The target 145°F internal fish temperature was reached by hour 4 and the oven reduced to 150°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 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°F and left until about hour 7 where the weight loss was about 20%.

A comparison of these two tests with their tables and figures shows that the higher initial temperature of the 5/1 trial (fresh) produced a higher

FIGURE 9 CHINOOK SALMON SMOKING CYCLE, MAY 1, 1990

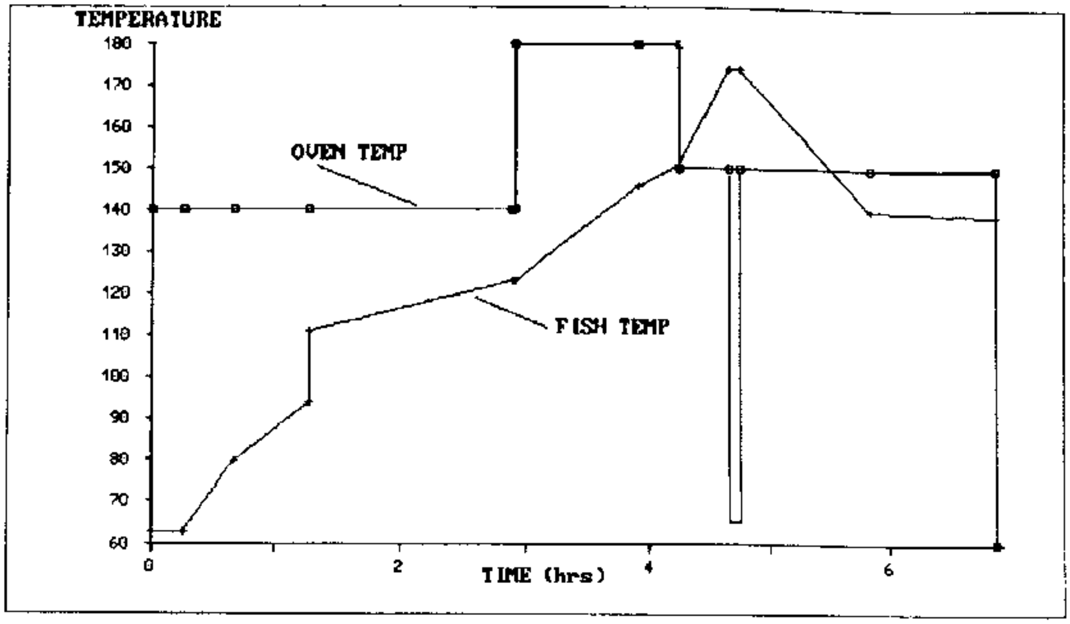


FIGURE 10 CHINOOK SALMON SMOKING YIELD, MAY 1, 1990

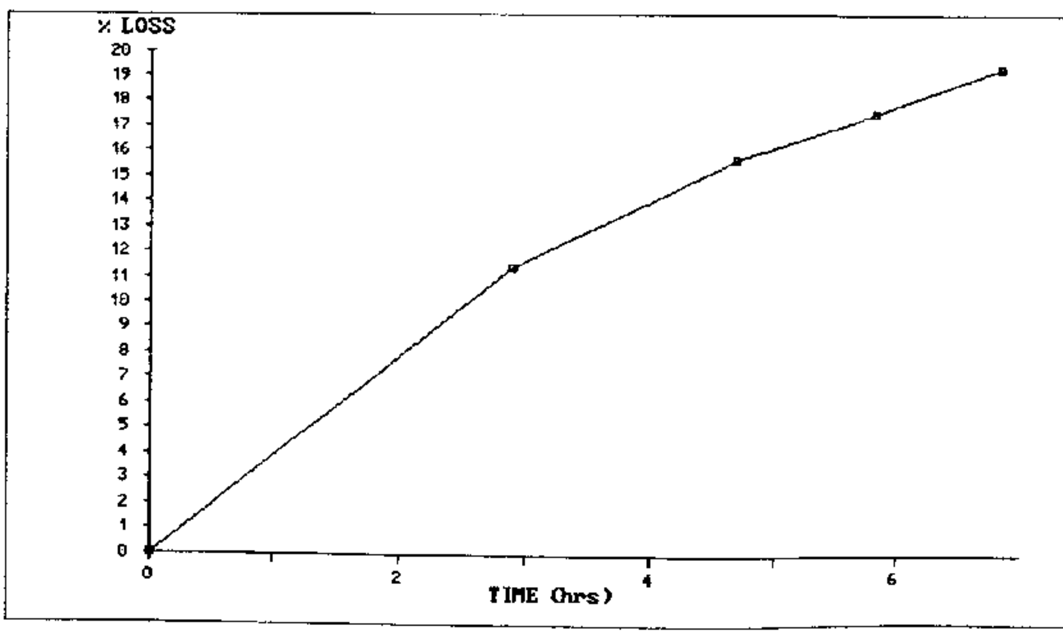


TABLE 3 CHINOOK SALMON PROCESS, MAY 1, 1990

ONE FRESH SPRING CHINOOK SALMON. 8.15 LBS OF 1 1/2 INCH THICK FILLETS.

clock time	oven temp	fish temp	draft setting	comment	process time	test weight	% loss
8:50				into 60 SAL brine, 2 fish	-1.17		
9:55				rinse	-0.08		
10:00	140		open		0.00	8.300	0.00
10:15		63			0.25		
10:40		80			0.67		
11:15		94	1/2		1.25		
11:15		111			1.25		
12:53		123			2.88	7.350	11.4
12:55	140				2.92		
12:55	180				2.92		
13:55		146			3.92		
14:15	180				4.25		
14:15	150	151			4.25		
14:40	150				4.67	7.000	15.7
14:40	60	174	open		4.67		
14:45	60				4.75		
14:45	150			drying	4.75		
15:50		140			5.83	6.850	17.5
16:50	150	139			6.83	6.700	19.3
16:50	60			oven off	6.83		

dehydration rate than the 4/30 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 third chinook run was made on 5/30 (see Figures 11 and 12 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 7th 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

FIGURE 11 CHINOOK SALMON SMOKING CYCLE, MAY 30, 1990

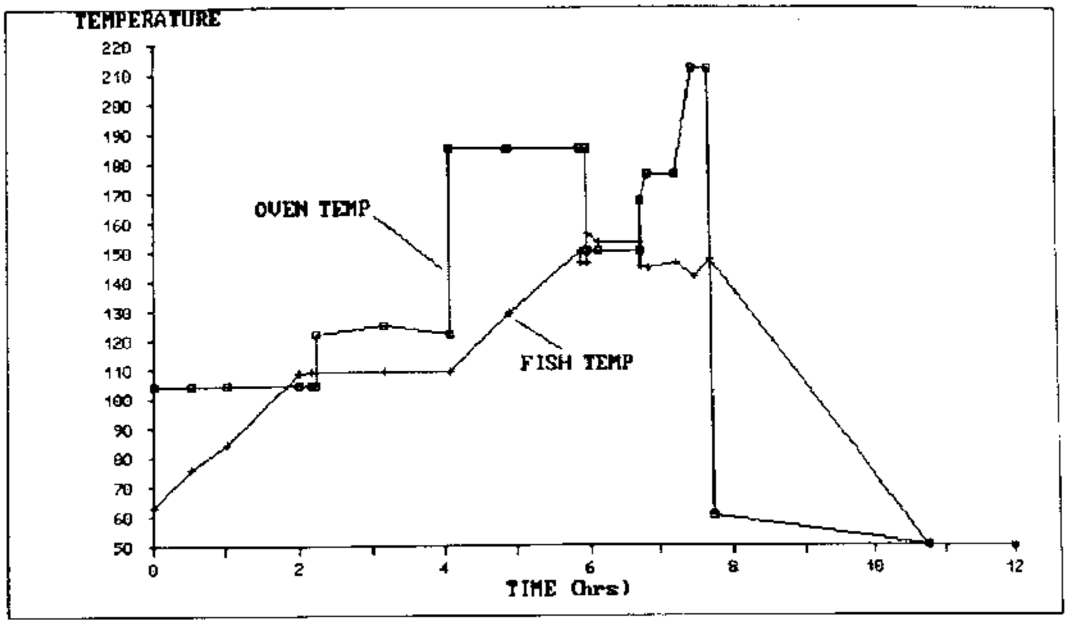


FIGURE 12 CHINOOK SALMON SMOKING YIELD, MAY 30, 1990

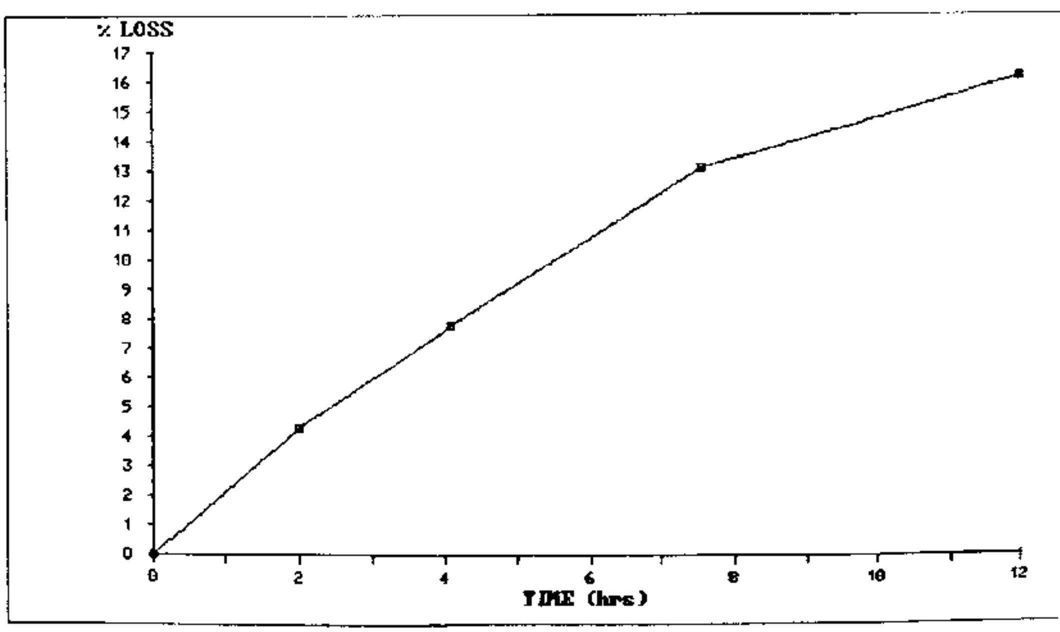


TABLE 4 FROZEN SPRING CHINOOK SALMON PROCESS, MAY 30, 1990
75 LBS, 1 3/4 INCH FILLETS (15 LB FISH)

clock time	oven temp	fish temp	draft setting	comment	process time	test weight	% loss
9:00	104	63	open	brined 1.25 hr 5/29, full load	0.00	75.55	0.00
9:30		76	1/2	lite #1	0.50		
10:00		84			1.00		
11:00		108			2.00	72.30	4.30
11:10		109			2.17		
11:15	104				2.25		
11:15	122				2.25		
12:10	125				3.17		
13:05	122		open		4.08		
13:05	185		open		4.08	69.70	7.74
13:55		129			4.92		
14:55		150			5.92		
14:55		146			5.92		
15:00	185				6.00		
15:00	150	156			6.00		
15:10		153			6.17		
15:45	150				6.75		
15:45	167	145			6.75		
15:52	176	144			6.87		
16:15	176	146			7.25		
16:30	212	141			7.50	65.65	13.1
16:45	212	147			7.75		
16:45	60	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

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.

The three chinook processes described above 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 13 and 14 and Table 5 show time temperature cycles for dark chum salmon which were being smoked for a canning project on 5/21. 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°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.

Smoking Chum Salmon For Canning

A special smoking cycle for chum salmon intended for canning was tested, but not show here, as it was 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 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 13 CHUM SALMON SMOKING CYCLE, MAY 21 1991

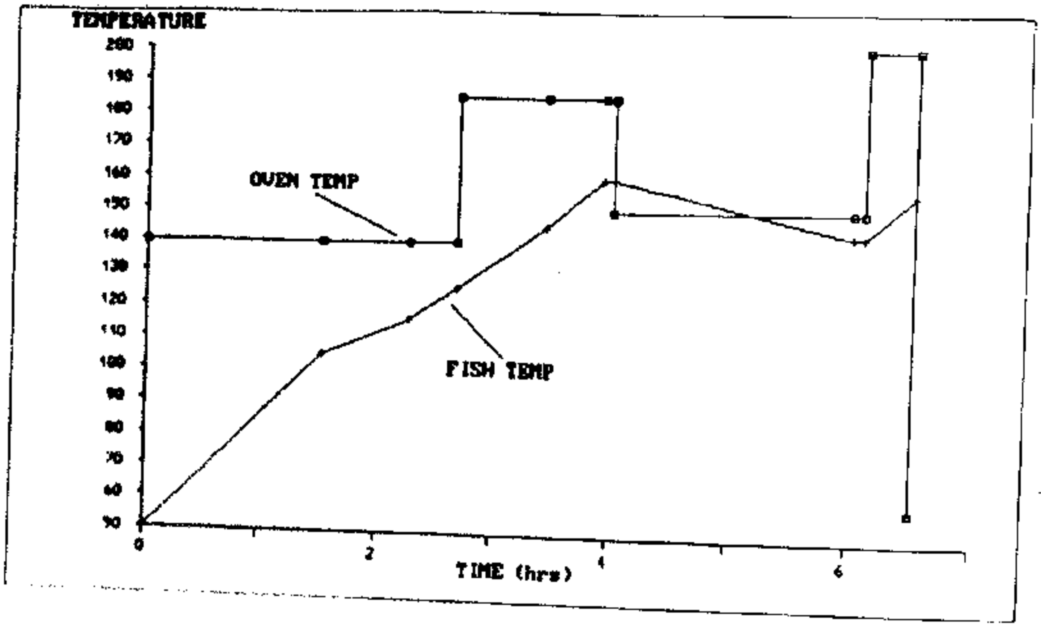


FIGURE 14 CHUM SALMON YIELD, MAY 21, 1991

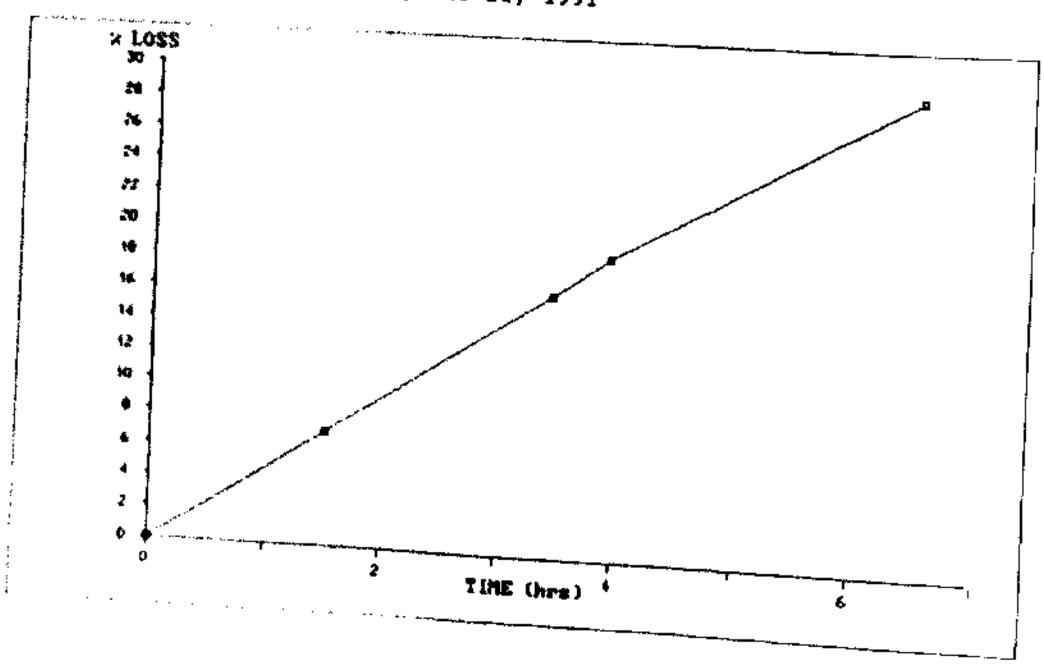


TABLE 5 CHUM SALMON PROCESS, MAY 5, 1991

DARK CHUM. 75 LBS FILLET

clock time	oven temp	fish temp	draft setting	comment	process time	test weight	% loss
13:19	140	50	open	75# total, 45.15 (30% loss)	0.00	45.15	0.00
14:50		105			1.52	41.90	7.20
15:35		116		fire #2	2.27		
16:00	140				2.68		
16:00	185	126	close	douse fire for smoke control	2.68		
16:45		145			3.43	37.80	16.3
17:15		160			3.93	36.65	18.8
17:20	185				4.02		
17:20	150		open	change thermocouple to #6	4.02		
19:20		143			6.02		
19:25	150				6.10		
19:25	200				6.10		
19:50		156			6.52	31.90	29.3
19:50	60			30% out, 1% loss in cooler	6.52		

Quality And Food Safety

Past problems with botulism poisoning from smoked fish has made industry and 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.

The GMP for "Hot Process Smoked Fish" from the 1970's has been revised by the FDA based on research by the National Marine Fisheries Service Utilization Research Division and will be proposed for adoption soon. Producers should be advised that past recommended practices may soon become law and that requirements for technical skills necessary in the production of smoked fish are likely to increase.

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.

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[13]. 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°F will keep fish quality less than half as long as ice at 32°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.[14]

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 a 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 not been 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.[15]

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 knowledgable 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.

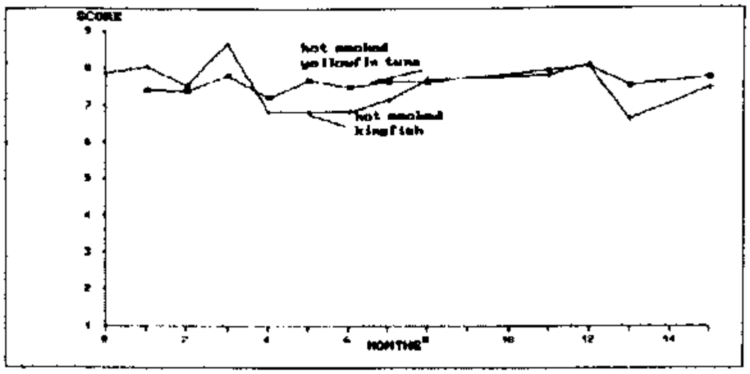
Without use of mold inhibiting chemicals, contaminated smoked fish will show visible signs of mold growth within two or three weeks when stored in a high humidity atmosphere. Plastic bags, waxed or plastic lined cartons, and damp coolers or refrigerators all produce the high humidity conditions favorable 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 storage in vacuum packages will provide good quality shelf life of 12 months or longer.

Figure 15 shows organoleptic evaluations of smoked fish held in frozen storage over a 15 month period. Nine is the highest rating (like extremely) and 1 is the lowest (dislike extremely). This fish was not specially packaged for frozen storage and showed visible freezer burn and surface discoloration after 6 months. However, the data does not show a marked deterioration in flavor as judged by a novice taste panel.

FIGURE 15 STORAGE OF FROZEN SMOKED FISH

Months Storage vs. Average Taste Panel Scores



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 inter-relationships 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. A materials balance shows that kingfish (65% moisture) and hamour (grouper, 80% moisture), if dried to the same 60% final moisture, would have 87.5% and 50% smokehouse yield respectively.

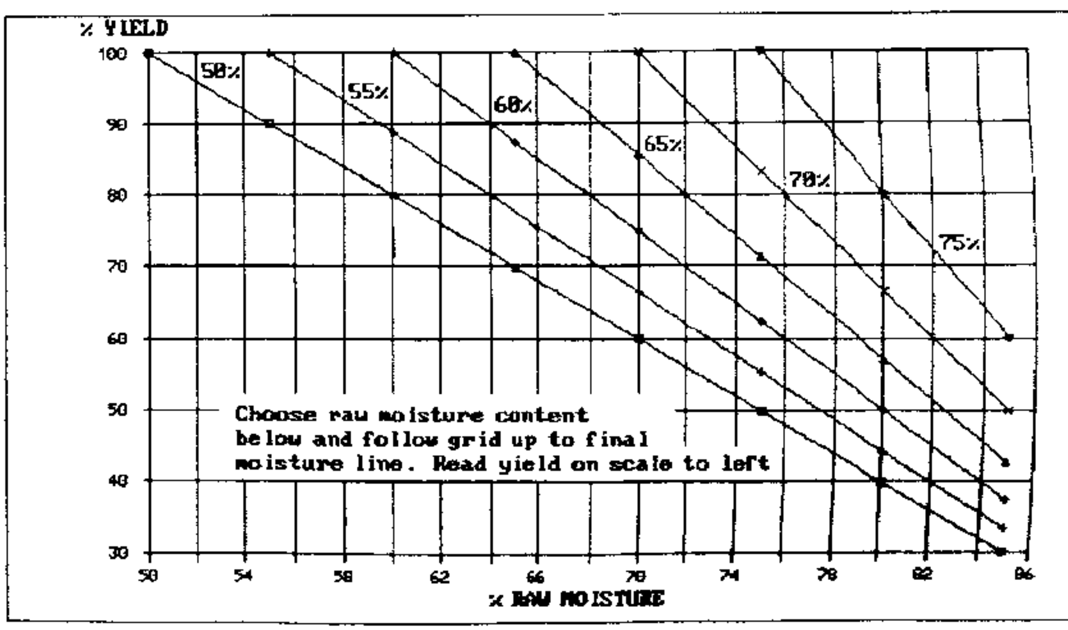
Figure 16 shows the theoretical yield of smoked fish at various final moisture contents. Yield (%Y) can be calculated by:

$$\%Y = [(100-\%RM)/(100-\%FM)] \times 100$$

where %RM = percent raw moisture and %FM = percent final moisture.

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). Estimates of raw fish moisture can be made using techniques described in the section on "Moisture Analysis" in this document.

FIGURE 16 THEORETICAL YIELD OF SMOKED FISH
Raw Moisture vs. Yield at 50 to 75% Final Moisture



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 such as the one illustrated in Table 6. 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, this and other spreadsheets are no better that the data and assumptions that go in them.

A copy of this spreadsheet which runs on IBM Lotus or compatible software products can be obtained from the author [16]. The example shown in Table 9 compares cold smoked yellowfin tuna (A), hot smoked albacore tuna from frozen loins (B), and hot smoked albacore from whole fish (C). The smokehouse size is that of an AFOS Maxi Kiln which has double the capacity of the Mini Kiln used in this study. The analysis assumes one smoker in a small building with minimum equipment. The resulting profit/loss numbers reflect only limited data for assumptions on capital costs. The comparison <u>between</u> products (A, B, & C) is more accurate. Notice that raw material cost represents 70% to 75% of total production cost. This implies that control of yield is a very important factor.

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 analyses can be made if accurate input data is available.

TABLE 6 SMOKED FISH COST ANALYSIS

INPUTS: days/mon	22		
SMOKEHOUSE SIZE			
rack width (26.77)	26.77 inches		
depth (21.26)	21.26 inches		
# racks (7)	7	27.67 sq ft	
# cells (1)	2		
loading (3.53)	3.5 lbs/sft/inch		
MAX #/IN	193.7		
UNITS 1	193.7 TOTAL		
PRODUCTION GOAL			
8000 LBS/MON	364 LBS/DAY		
PERCENT EFFICIENCY	90%	90%	90%
	A	B	C
SPECIES	COLD YF	HOT ALOI	NHOT AWHO
MEAT THICK (in)	2	1.5	1.5
max loading	387	290	290
SMOKING YIELD	75%	80%	80%
LOADS/DAY	1	2	2
daily output (lbs)	261	418	418
monthly output	5752	9203	9203
percent goal	72	115	115
CUTTING YIELD	100%	100%	45%
daily input	349	523	1162
monthly input	7669	11504	25563
VARIABLE COSTS			
fish ($/lb)	$4.35	$3.35	$1.25
cash need ($/mon)	33360	38537	31954
OTHER $/lb			
salt	$0.01	$0.01	$0.01
power	$0.01	$0.01	$0.01
water	$0.01	$0.01	$0.01
packaging	$0.10	$0.10	$0.10
transportation	$0.00	$0.00	$0.00
sum	$0.13	$0.13	$0.13
FIXED COST			
overhead($/mon)			
mgmt $5,000			
admin $800	FULL TIME		
water $100			
power $300			
total $6,200			
LABOR hours	8	8	8
crew size	3	4	5
$/hr/man	$7.50	$7.50	$7.50
$/day	$180.00	$240.00	$300.00
PRODUCTION COST/LB	$7.70	$5.56	$4.99

SALES MARKUP	45%	45%	45%
sales price	$11.16	$8.07	$7.24
daily revenue	$2,918	$3,375	$3,029
monthly revenue	$64,189	$74,259	$66,628
wholesale markup	35%	35%	35%
wholesale price	$15.07	$10.89	$9.77
retail markup	35%	35%	35%
retail price	$20.34	$14.71	$13.19

TABLE 6 (continued) SMOKED FISH COST ANALYSIS

INVESTMENT ASSUMPTIONS

	#	DESCRIP	VALUE	VALUE		DEP/
LEASE/MON	0	smoker	500	0		AMORT
EQUIP(PLNT)			X1000	X1000	LIFE	X1000
TOTAL	1	BUILDING	$150	$150	20	$8
AFOS	1	SMOKER	$15	$15	10	$2
XXX	1	MISC	$30	$30	5	$6
XXX	1	WALKIN COOLER	$20	$20	10	$2
XXX	1	WALKIN FREEZER	$20	$20	10	$2
XXX	0	XXX	$0	$0	1	$0
XXX	0	XXX	$0	$0	1	$0
XXX	0	XXX	$0	$0	1	$0
XXX	0	XXX	$0	$0	1	$0
XXX	0	XXX	$0	$0	1	$0
XXX	0	XXX	$0	$0	1	$0
XXX	0	XXX	$0	$0	1	$0
XXX	0	XXX	$0	$0	1	$0
XXX	0	XXX	$0	$0	1	$0
XXX	0	XXX	$0	$0	1	$0
XXX	0	XXX	$0	$0	1	$0
XXX	0	XXX	$0	$0	1	$0
		TOTAL		$235		$19
EQUIP(office)						
XXX	1	MISC	$10	$10	1	$10
PACKAGING						
XXX	1	BAGS	$5	$5	1	$5
XXX	1	vaccum packager	$5	$5	5	$1
		TOTAL		$20		$16
		G TOTAL		$255		$35
% INTEREST	15%	CAPITAL COST		$38,250		
	0%	FISH PURCHASE	A	B	C	
			$0	$0		$0

EXPENDABLE SUPPLIES/MON

SALT	$77
PACKAGING	$575
WOOD CHIPS	$75
XXX	$0
XXX	$0
TOTAL	$726

ANNUAL PROFIT/LOSS STATEMENT

	A	B	C
	COLD YF	HOT ALOIN	HOT AWHO
REVENUE	$770,263	$891,110	$799,541
PRODUCTION COST	$531,216	$614,559	$551,408
LOAN COST	$38,250	$38,250	$38,250
DEPRECIATION	$35,000	$35,000	$35,000
LEASE	$0	$0	$0
GROSS PROFIT	$165,797	$203,302	$174,884
ROI	71%	87%	74%
ROS	22%	23%	22%

COST BREAKDOWN	COLD YF	HOT ALOIN	HOT AWHO
cost/lb	$7.70	$5.56	$4.99
raw material	75.4%	75.2%	69.5%
other variable	1.7%	2.3%	2.6%
fixed overhead	14.0%	12.1%	13.5%
labor	8.9%	10.3%	14.4%
total	100.0%	100.0%	100.0%
SALES VALUE BREAKDOWN			
plant price	$11.16	$8.07	$7.24
wholesale price	$15.07	$10.89	$9.77
retail price	$20.34	$14.71	$13.19

Salt And Moisture Analysis Procedures

Each lot (load) of smoked fish should be checked for water phase salt (WPS). 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. Pending State and/or Federal regulations may mandate a sampling schedule.

Salt and moisture analysis is not difficult and can be learned by careful attention to instructions. The equipment and supplies needed are:

Equipment Needed[17]

1) A balance capable of 1/100 gram accuracy
2) A household blender
3) A small electric oven capable of maintaining 100°C (plus or minus 10 degrees)
4) Several glass jars or beakers of 300 to 400 ml capacity
5) Quantab[18] Chloride Titrators (50 tests per bottle)
6) Small disposable aluminum dishes or a roll of heavy aluminum foil
7) A pocket calculator
8) An assortment of small knives and spoons
9) A wood or plastic cutting board
10) Small coffee filters or a roll of paper towels
11) Distilled water

The procedure for moisture analysis is outlined in the AOAC[19], a copy of which is located in many university libraries. The procedure for salt analysis is also included with each bottle of Quantab Titrators. In brief, the procedures is as follows:[20]

Sample Preparation

1. Select a piece of fish which is most likely to have the lowest WPS. This will usually be the largest and thickest piece located in the center of the smoking oven. Often it will be the same piece that was chosen for monitoring internal temperature.

2. Cut a slice about two inches wide from the center of the piece big enough to blend evenly (1 lb to 1.5 lbs). Avoid bones.

3. Blend the sample until it is evenly ground into a fine particle size.

Salt Analysis

1. Weigh out exactly 10 grams of ground sample into a widemouth jar or beaker of about 150 to 200 ml capacity.

2. Add exactly 90 grams of hot distilled water (or measure exactly 90 mls). Using an electronic balance with the ability to set tare (zero the weight) will facilitate these measurements.

3. Stir for several minutes to extract salt from the sample.

4. Place the Quantab titrator strip (folded into a circle of filter paper or paper towel) into the sample solution. Read the value from the titrator scale after waiting several minutes as per directions included with each bottle of strips. Read the percent salt from the calibration table included with each bottle of titrators and multiply by 10 (dilution factor).

Moisture Analysis[21]

1. Record the weight of a small (3 inch to 4 inch) dry aluminum tray capable of holding 30 or 40 grams of sample. Make a suitable tray with .25 inch high sides from aluminum foil if nothing else is available.

2. Weigh out 8 to 12 grams of sample onto the tray. Record weight of tray and sample together. Record sample weight (wts) as total weight less weight of tray.

3. Place the sample in $100^{o}C$ ($212^{o}F$) preheated oven for 8 to 10 hours then begin recording weight every 2 or 3 hours until the weight is constant (no more weight is lost). Record total weight lost (wtl).

4. Compute percent moisture (%m) as weight lost (wtl) divided by sample weight (wts) multiplied by 100.

$$\%m = (wtl/wts) \times 100$$

Water Phase Salt

Calculate WPS as percent salt (%S) divided by percent salt + percent moisture (%M) multiplied by 100.

$$WPS = [\%S/(\%M + \%S)] \times 100$$

Water phase salt should be at least 3.5 percent[22]. If it is not, the product is perishable and should not be sold. If it has 2 to 3 percent WPS, it will probably be safe for personal consumption if refrigerated and consumed within a few days, although there are no assurances that it has not already spoiled in the smokehouse. Do not eat any smoked fish which has "off" (unusual, bad, unpleasant, or odd) flavor, odor, or visual appearance.

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 per 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).

By 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 = 20 gm). That is the same as saying (What = 20gm/.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.

Footnotes

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[1]Current Good Manufacturing Practice in Manufacturing, Processing, Packing or Holding Human Food. Part 110 of Title 21 of CODE OF FEDERAL REGULATIONS.

[2]Good Manufacturing Practice for Hot Process Smoked Fish and Smoke-Flavored Fish Products. Part 122 of Title 21 of the CODE OF FEDERAL REGULATIONS.

[3]Cured, Salted, and Smoked Fish Establishments Good Manufacturing Practices. An Association of Food and Drug Officials Model Code Adopted June 1991.

[4]National Marine Fisheries Service recommendations as of July 1991.

[5]For more detailed information on microbiology of fish smoking see "Hazard Analysis and Critical Control Point Applications to the Seafood Processing Industry." Jong. S. Lee with Kenneth S. Hilderbrand. Oregon state University Sea Grant Program. ORESU-H-92-001. January 1992.

[6]See Listeria section of "Food Safety Fact Sheet for Seafood Processors". Oregon State University Extension Service.

[7]Olson, Robert E. Marine Fish Parasites of Public Health Importance. Oregon State University Sea Grant Program. ORESU-R-86-040. 1986.

[8]It is recommended that cold smoked fish products be made only from previously frozen raw materials. See "Parasites in Marine Fishes - Questions and Answers for Seafood Retailers". Oregon State University Extension Service. SG79. September 1984.

[9]For more information on salt brines see "Preparation of Salt Brines in the Fishing Industry". Kenneth S. Hilderbrand Jr. Oregon State University Extension Service. SG22. January 1979.

[10]See Figures 8,10,12, and 14 for examples of dehydration rates for salmon in an AFOS Mini Kiln.

[11]Chan, W.S., R. Toledo and J. Deng. 1975. Effect of Smokehouse temperature, humidity and air flow on smoke penetration into fish muscle. Journal of Food Science, Volume 40, p. 240.

[12]The AFOS Mini Kiln will hold about 95 lbs of one inch thick fish or about 190 lbs maximum (about 3.5 lbs/ft sq/inch thick).

[13]Why Seafood Spoils. Robert J. Price. University of California Fact Sheet UCSGEP 89-3. August 1989.

[14]For more information on microbiology of fish smoking see "Hazard Analysis and Critical Control Point Applications to the Seafood Processing Industry". Jong. S. Lee with Kenneth S. Hilderbrand. Oregon state University. ORESU-H-92-001. January 1992.

[15]See "Life Begins at 40 F: How to Use a Seafood-Handler's Thermometer". William D. Davidson. Oregon State University Extension Service. SG32. October 1980.

[16]This spreadsheet runs on Lotus or Symphony products. To obtain a copy send a 5 1/4 inch MS-DOS formatted disk in a suitable stamped return shipping envelope to Ken Hilderbrand, OSU Marine Science Center, 2030 South Marine Science Drive, Newport, Oregon 97365. Ask for "SMOKED FISH COST ANALYSIS SPREADSHEET.

[17]See "Quick Determination of Water Phase Salt Content of Smoked Fish." Kenneth S. Hilderbrand Jr. Oregon State University Extension Sea Grant Special Report 883. August 1991.

[18]Quantab Chloride Titrator # 1176 (.05 to .6% range). Environmental Test Systems, Inc. PO BOX 4659, Elkhart, Indiana 46514, USA.

[19]Official Methods of Analysis. 1984. Association of Official Analytical Chemists, Arlington, Virginia. 24.001

[20]see 17 above.

[21]see 17 above for details on equipment, costs, and procedures for this and alternative micro-oven techniques.

[22]National Marine Fisheries Service recommendations suggest that smoked fish should have at least 3.5% WPS and be stored and shipped at 38°F (3°C) or less. Hot smoked fish should be cooked to an internal temperature of at least 145°F (62.8 C) for at least 30 minutes. Experts believe the FDA will soon codify this into law.

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