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Chilling and Freezing Guidelines to Maintain Onboard Quality and Safety of Albacore Tuna

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INTRODUCTION

This report was prepared for albacore fishermen and processors to support planning, design, and operation that will lead to improved quality of albacore tuna. The report provides information on how rapidly albacore can be chilled and frozen on board under a range of conditions. Many of the reported results will be predictions, but these predictions are based on temperature measurements made during several trips over the course of three seasons. The scale of the fishing operation, as well as the types of freezing systems used in calculations, were based on 22 questionnaires returned by members of the American Fishermen's Research Foundation (AFRF).

MATERIALS AND METHODS

To describe how fish temperature will respond to various conditions, it was necessary to first develop a way to simulate chilling and freezing rates of the fish. This was done using a computer model that allows us to investigate a range of "what-if" conditions on round (i.e., not dressed) albacore tuna. A paper by Zhao et al. (1998) describes how this was done. Although the details of this paper are not of direct interest here, we list it with other reports and articles in the References and Additional Reading section of this paper.

RESULTS AND DISCUSSION

Chill Rates

Effect of Various Parameters and Conditions

Chill rate is affected by landed fish temperature (commonly >80^{o}F at the core), fish size, ambient air temperature, or water temperature in a deck tank. The simulation model was developed using a range of onboard measurements. As shown in Figure 1, the calculations (lines) correlate well with the data (symbols). These cases represent three fish, first left on deck for less than an hour, then placed into a slush ice tank.

The simulation alone can be used to show the effects of various other parameters (Fig. 2). Although not shown, a set of cooling curves for ice alone would fall somewhere between those for immersion cooling (CSW, chilled sea water [slush ice]; or RSW, refrigerated sea water) and those for cold air. This is because the cold medium surrounding the iced fish will be a combination of melted water and cold air gaps.

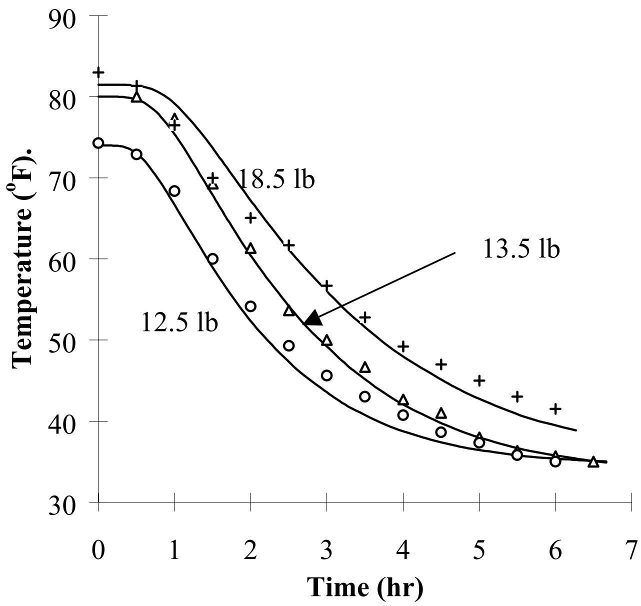


Figure 1*. Comparison of model (lines) and data (symbols) for three fish chilled in slush ice. All were on deck in 75°F air for about a half hour before placing in CSW tank.*

Sizing of a CSW Deck-tank System

The critical chill-rate for product safety is to lower fish core temperature to 50°F within 6 hours, then chill to 32°F within an additional 18 hours (FDA 1996). We consider maximum quality to result from chilling fish to 40°F as quickly as possible. Use of a deck tank with slush ice (or CSW) will produce a rapid chill rate to 40°F. A slush ice system is the most feasible system for short-range fishing vessels since all ice can be carried from shore.

The calculation procedure will be to assume that fish are chilled slightly in seawater or air to a core temperature of about 70°F. They are then put into the deck tank partially filled with ice and seawater. The rate of ice use is roughly calculated according to procedures described by Kolbe et al. (1985); results appear in Table 1. Note that this table assumes a uniform rate of catch. If the daily catch were landed all at once, the tank would naturally have to be larger to prevent warm fish from lying on deck for an excessive period.

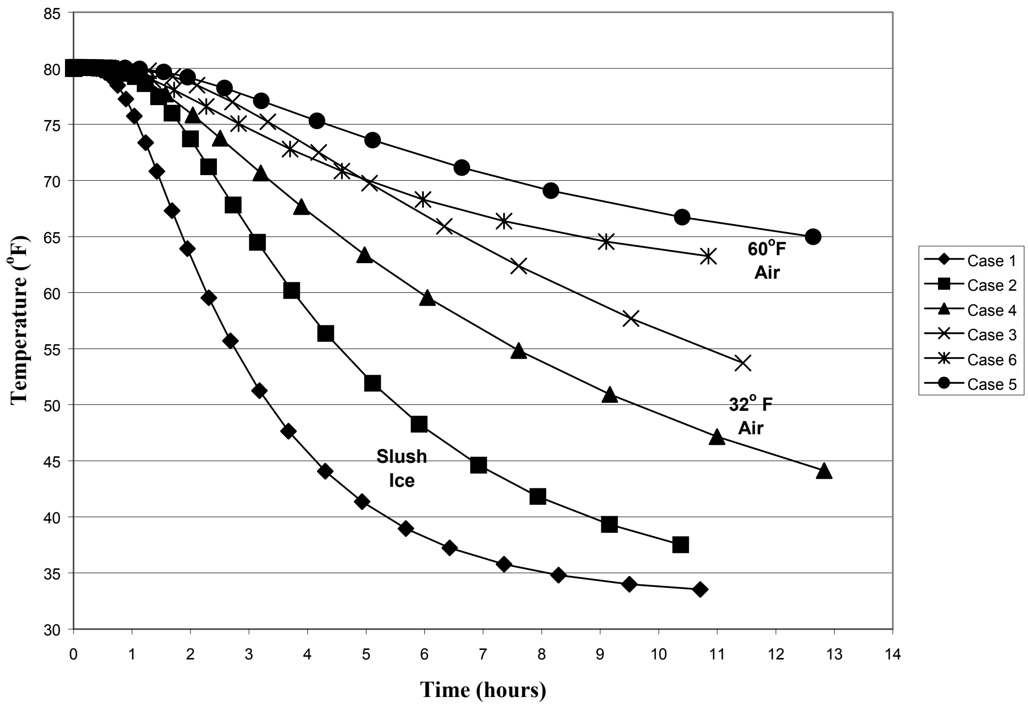


Figure 2. *Simulation showing effects of fish size and ambient conditions on chill rate.*

Case 1: 12-lb fish in CSW/slush ice tank
Case 2: 24-lb fish in CSW/slush ice tank
Case 3: 24-lb fish in still cold air
Case 4: 12-lb fish in still cold air
Case 5: 24-lb fish on deck, light breeze
Case 6: 12-lb fish on deck, light breeze

Sizing of an RSW Deck-Tank System

In many cases, a freezer boat would likely have a deck tank chilled by a separate RSW (refrigerated seawater) refrigeration unit and chiller. In this section, we make some estimates of the unit required for such a system. First, we assumed that a separate refrigeration unit is installed to maintain deck tank water at about 35°F. Results and assumptions appear in Table 2. As with Table 1, the assumption of uniform catch rate is made.

Table 1. *Chilling capacity of CSW (slush ice) deck tanks.*

Catch Rate of Fish (Fish/day)		Ice Required per Day (lb)	Deck Tank	
			Minimum Volume (ft^3)	Maximum Capacity (No. of fish)
100	12-lb fish	270	10	34
	24-lb fish	550	30	54
200	12-lb fish	510	20	67
	24-lb fish	1,050	60	108
300	12-lb fish	760	30	100
	24-lb fish	1,540	90	162

Assumptions:

1. *Initial average fish temperature = 70^{o}F;*
2. *Time to reach fish core temperature of 40^{o}F: for 12-lb fish: 5 hours, for 24-lb fish: 8 hours;*
3. *Maximum fish loading density = 42 lb/ft^3;*
4. *Fish caught at uniform rate;*
5. *Chilled fish are removed as warm fish are loaded;*
6. *On-deck covered tank is of insulated plastic construction;*
7. *Tank is drained and refilled once each day;*
8. *Fishing period is 15 hours/day.*

Freezing Rates

Data Collection and Simulation

In the 1996 season, Oregon State University project member Cormac Craven was invited aboard two freezer vessels that were chartered by AFRF and fishing off Oregon, Washington, and British Columbia. During the trips, Craven measured temperatures, recorded conditions, and brought controlled samples back for quality analyses. He collected 75 fish, handled under different conditions; 37 of these were instrumented with sensors to record the time-temperature histories of the freezing and storage events.

Table 2. *Size of RSW unit required for deck tank.*

Catch Rate of Fish (Fish/day)		Btu/hr Required (Refrigeration Tons)	Nominal Horsepower Needed to Drive Unit	Deck Tank: Minimum Volume (ft^3)	Deck Tank: Maximum Capacity (No. of fish)
100	12-lb size	2,330 (0.2)	1/3	10	34
	24-lb size	4,660 (0.4)	1/2	30	54
200	12-lb size	4,660 (0.4)	1/2	20	67
	24-lb size	9,310 (0.8)	1	60	108
300	12-lb size	6,980 (0.6)	3/4	30	100
	24-lb size	13,960 (1.2)	2	90	162

Assumptions:

Initial average fish temperature = 70ºF;
Time to reach fish core temperature of 40ºF:
for 12-lb fish: 5 hours,
for 24-lb fish: 8 hours;
Fish loading density ≤42 lb/ft^3*;*
Fish caught at uniform rate;
Chilled fish are removed as warm fish are loaded.

Assumptions:

Refrigerant is R-22;
Evaporator temperature is 25ºF;
RSW water temperature is 35ºF;
RSW water circulation is excellent;
Refer operating time = 15 hrs/day;
15% of refrigeration capacity is absorbed by heat leakage and pumping

One vessel was equipped with a spray brine system. The second vessel had a combination blast and plate-shelf freezer. Air velocities over the fish were relatively low, but freezing took place with some direct contact with the plates. Sixty fish were selected for quality samples, 33 of which had sensors that continually recorded core temperatures.

Temperature measurements also have been simulated effectively by the model of Zhao et al. (1998). Figure 3 shows representative results for measurements aboard the brine freezer; Figure 4, aboard the blast freezer. For the spray brine case, the 10-lb fish first lay on deck in 57^{o}F air for about 2 hours, the 20-lb fish about 1.5 hours in 68^{o}F air, before being placed in the freezer. From these measurements and comparison with the model, we estimated the surface-heat-transfer coefficient, one of the critical unknowns in conducting simulations of freezing rates. This number describes how effectively heat is removed from the fish surface in both an air-blast and a brine-spray refrigeration system. The air velocity shown in the blast freeze situation (0.6-1 m/sec in Fig. 4) is the value used in the model. However, it is higher than the actual velocity recorded on board, because we assumed it to be the air velocity that would characterize the air around the fish if the fish had not been placed on freezer plates.

Note that there is a second method of simulating freezing time of fish, which is an "analytical model" that calculates a single number (rather than a temperature-vs.-time curve) for the time needed to freeze to some final core temperature. It tends to be less accurate than the time-vs-temperature simulation shown in Figures 3 and 4, but it can be used more easily with a simpler computer program or spreadsheet. The procedure, developed by Cleland and Earle of New Zealand, is described by Kolbe (1991) who found these predicted times to be within roughly 25 percent of measurements in fish processing plants. This isn't too bad, given the variation of products tested and the difficulty of accurately measuring (or knowing) parameters in the plant like air velocity, fish thickness, etc.

If we define "freezing time" as that needed to reach a core temperature of 15°F, then the Cleland and Earle approach can be compared with the simulation (Figures 3 and 4) as shown in Table 3. The Cleland and Earle model generally assumes a fairly ideal situation. Unlike the more complex simulation, it does not account for time-on-deck in relatively warm air or for uneven air velocity over the bottom and top surfaces of the fish. But in fact, the calculated result is quite sensitive to these things that are often unknown. The prediction "success" that was indicated in the last column of Table 3 is slightly better than one could ordinarily expect with this method under these freezing conditions. For the blast-frozen fish, we got the best answers by choosing the menu option "vertical velocity over fish on a screened shelf," even though the real situation had horizontal velocity over fish on a freezer plate.

Table 3*. Comparison of three methods to determine albacore freezing times to 15°F core temperature.*

Fish[a]		Measured (hr)	Numerical Simulation (hr)	Analytical Model (Cleland and Earle) (hr)
Blast frozen	11 lb	11.4	11.5	9.2[b]
	16 lb	13.5	12.9	13[b]
	22 lb	15.8	16.2	16[b]
	38 lb	23.9	25	22.6[b]
Brine frozen	10 lb	11.7	11.1	10.1[c]
	20 lb	19	19.7	14[c]
	34 lb	≈24[d]	≈24	20[c]

Notes:

[a] *Initial fish temperatures are indicated in Figs. 3 and 4;*

[b] *Assume heat transfer coefficient with vertical air velocity through screened shelves;*

[c] *Assume brine velocity of 0.3 ft/sec;*

[d] *Last measurement taken at 22.8 hr, when core temperature = 20.2°F.*

All calculations of freezing time must assume a well-designed fish-hold insulation system, as installed by a professional contractor. Some additional information on this subject has been described by Kolbe and Wang (1989).

Because the dimensions of albacore (which have an elliptical cross section) are needed in any calculation of freezing time, these dimensions (i.e., height and thickness) have been measured for all fish sampled, correlated with fish weight, and presented in Figure 5.

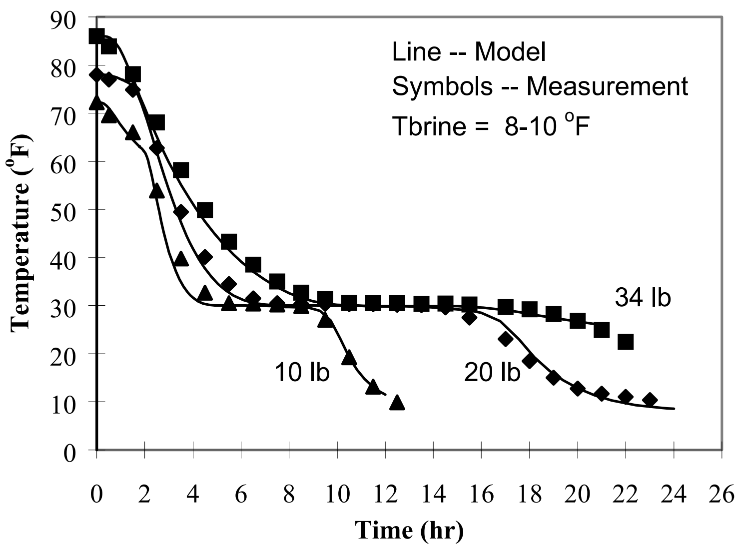


Figure 3. *Spray brine freezing of three sizes of fish.*

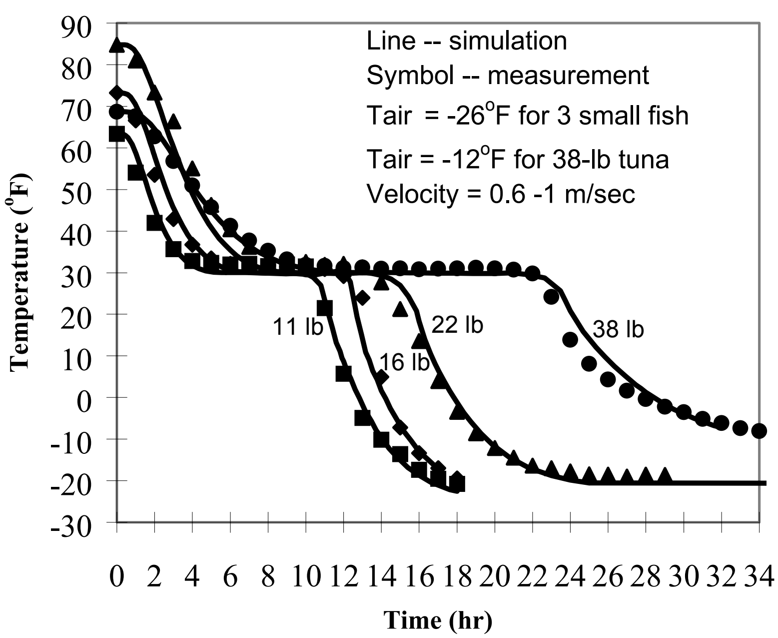


***Figure 4**. Blast freezing of four sizes of fish.*

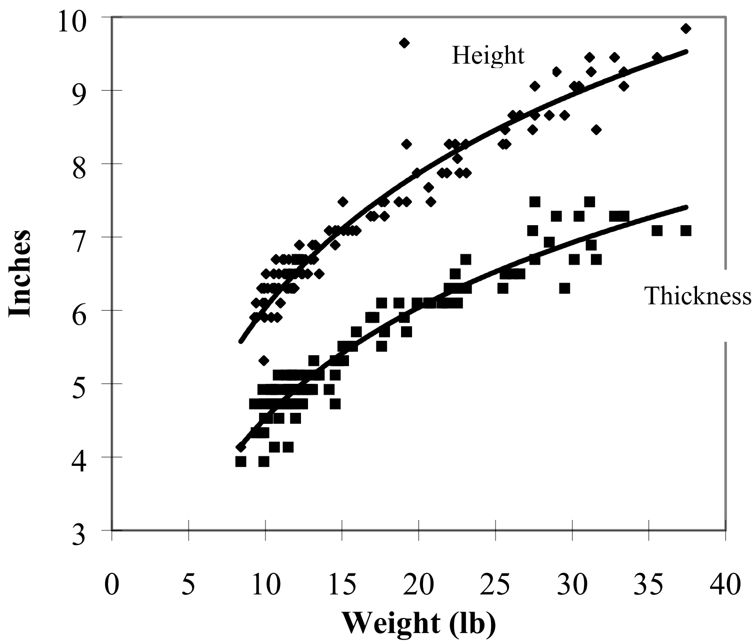


Figure 5. *Maximum height and thickness of albacore tuna. Symbols represent measurements.*

Effects of Variables on Freezing Time

Blast Freezers

Using the simulation program, we can see how different parameters will affect the time it takes a fish to freeze from an initial core temperature of 60^{o}F. Three major parameters for blast freezers are fish size, air temperature, and air velocity over the fish. Figures 6a-c show the effects of some representative ranges of these important factors.

Note that a well-designed commercial freezer will have air velocities of around 5 m/sec (11 mph), but in most ordinary rooms or spaces with fans, it is difficult to attain that velocity. The albacore observed on the test vessel were lying on solid shelves (made of freezer plates) behind screened enclosures. Measured air velocities over the top of these fish were on the order of 0.3 m/sec, but less than that in spaces between fish, closer to the plates. An ideal configuration for blast freezing of whole fish is to suspend them in a tunnel directly in the path of cold air leaving the evaporator coils, thus allowing equal velocities on all surfaces.

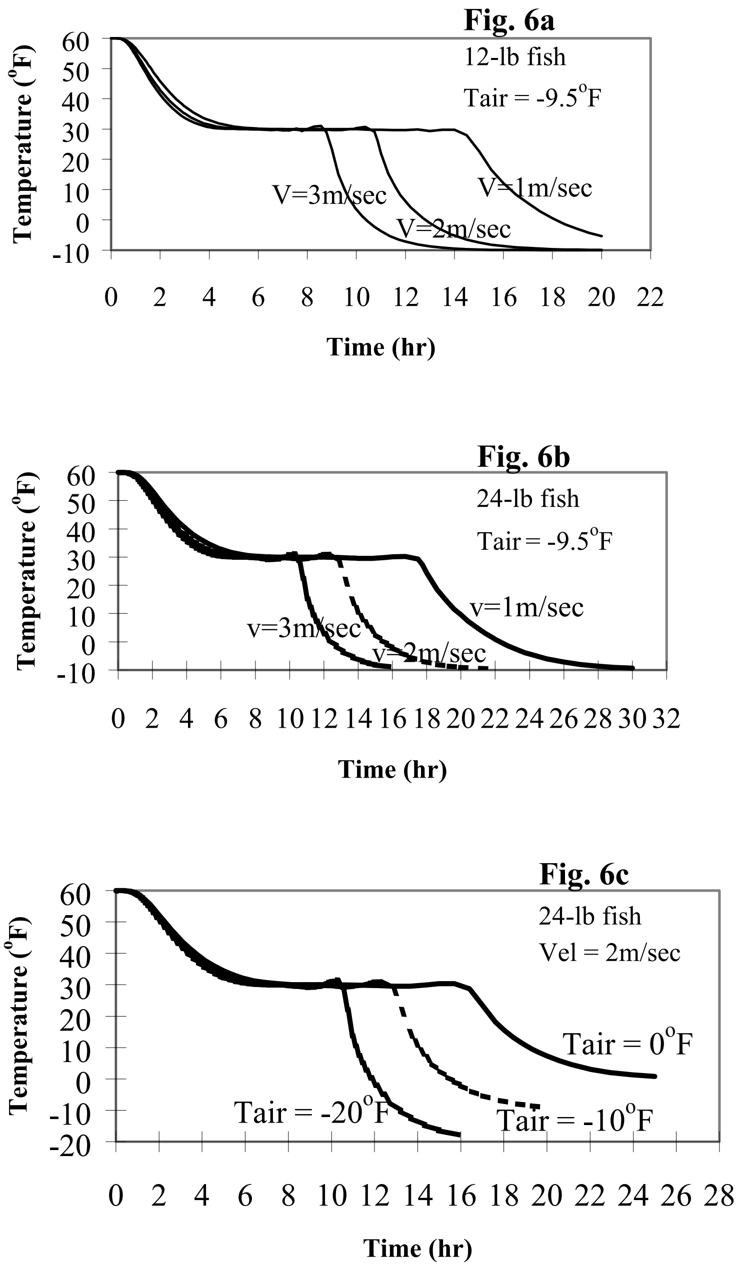


Figure 6. *How fish size, air temperature and velocity affect freezing in blast freezers.*

Spray-brine Freezers

The lowest brine temperature one can attain with sodium chloride salt is about -6°F (Hilderbrand 1989). The design temperature of the surrounding medium in a spray-brine freezer will be higher than that in a blast freezer. Because brine operates at a higher temperature, the refrigeration system will also be more energy efficient. In addition, the rate of heat removal from the fish will tend to be higher when the fish is hit with liquid brine than with air. So, given two well-designed systems, one should be able to freeze fish at roughly the same rate in either system, even though the blast air temperature is much lower than the temperature of the brine.

The simulation program was run on two sizes of fish placed in two well-designed freezers. Results appear in Figure 7.

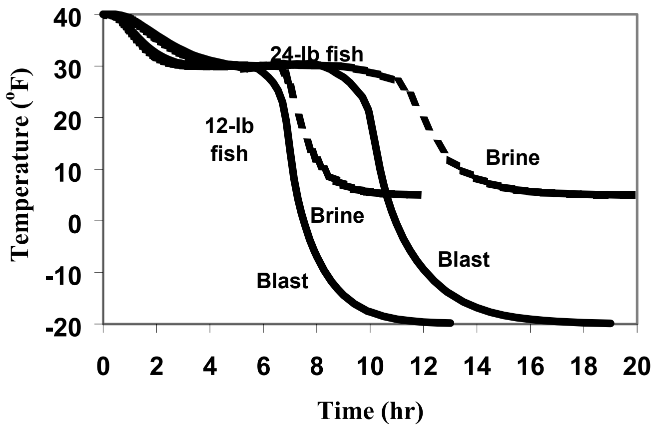
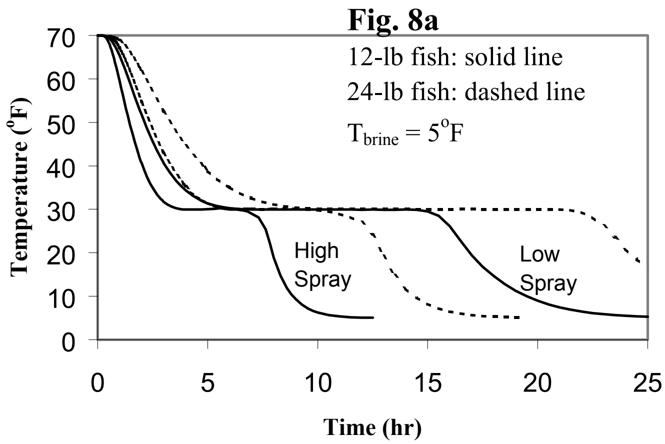


***Figure** 7. Compared performances of well-designed and operated blast and spray-brine freezers.*

Assumptions:
Fish is prechilled to a core temperature of 40°F;
For blast: air velocity = 3 m/sec, air temperature = -20°F;
For brine: strong spray coverage, brine temperature = 5°F.

The time-to-freeze is quite sensitive to the value of the heat transfer coefficient used to describe heat flow from the fish surface. For the spray-brine case, this coefficient was dependent on the spray pattern and intensity. Note that the expected freeze time of the 24 pounder in spray brine is about 12 or 13 hours in a well-designed system as shown in Figure 7. However, it was greater than 20 hours in the case measured on board (Figure 3). Thus sprayers have a very important influence on freezing time in a spray brine system.

It is difficult to ensure a high intensity, uniform spray density in a fish hold. Most spray heads tend to produce a non-uniform pattern; fish are at varying distances and angles from the sprayers or overhead ceiling where some of the spray is reflected. Some fish will be hit directly by brine spray, others by misty cold air (Kolbe 1980). Figures 8a and b show the effects of spray intensity, fish size, and brine temperature on freezing in a spray-brine freezer. The "high spray" implies spray is hitting fish directly; heat transfer characteristics are taken from ideal tests reported in the literature. "Low spray" corresponds to the lower rate of heat transfer found during on board measurements as shown in Figure 3.



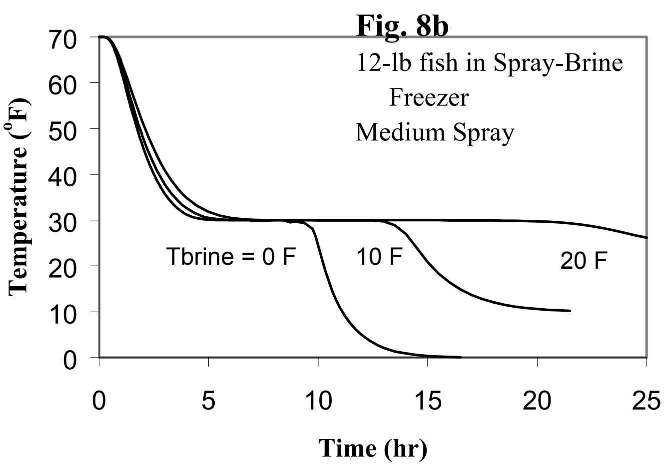


Figure 8. *How spray intensity, fish size, and brine temperature affects freezing in a spray-brine system.*

Effects of Prechilling

An earlier section described how on-deck tanks could be designed and operated to rapidly chill fish. What effect does that have on freezing time? Figure 9 shows that there is some advantage of prechilling to enable quicker freezing. Less time is required to reach final freezing/storage temperature with prechilled fish.

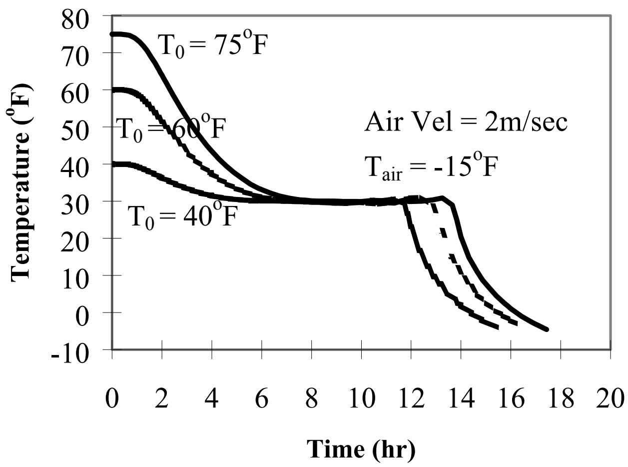


Figure 9. *Effects of pre-chilling on blast-freezing of a large (24-lb) fish.*

A second and perhaps more significant advantage of prechilling found in this study is its effect on albacore quality. Fish that are frozen rapidly soon after capture will have a higher quality than fish frozen over a longer time period.

A third possible advantage of prechilling is some improved energy efficiency. RSW systems used on deck to remove the initial heat (called "sensible heat") of the fish prior to blast freezing will operate more efficiently than the low-temperature blast freezer (Kolbe 1990).

Finally, the fluctuation of fish hold temperature will be significantly lower if fish are prechilled. Although the exact quality effects of this could not be measured in this study, we know from frozen storage studies of other seafoods that storage temperature fluctuation is detrimental to quality (Kolbe and Kramer 1993). Consider Figure 10: approximately 128 BTU of heat was removed from 1 pound of albacore as it was first chilled from 80°F, then frozen to -10°F.

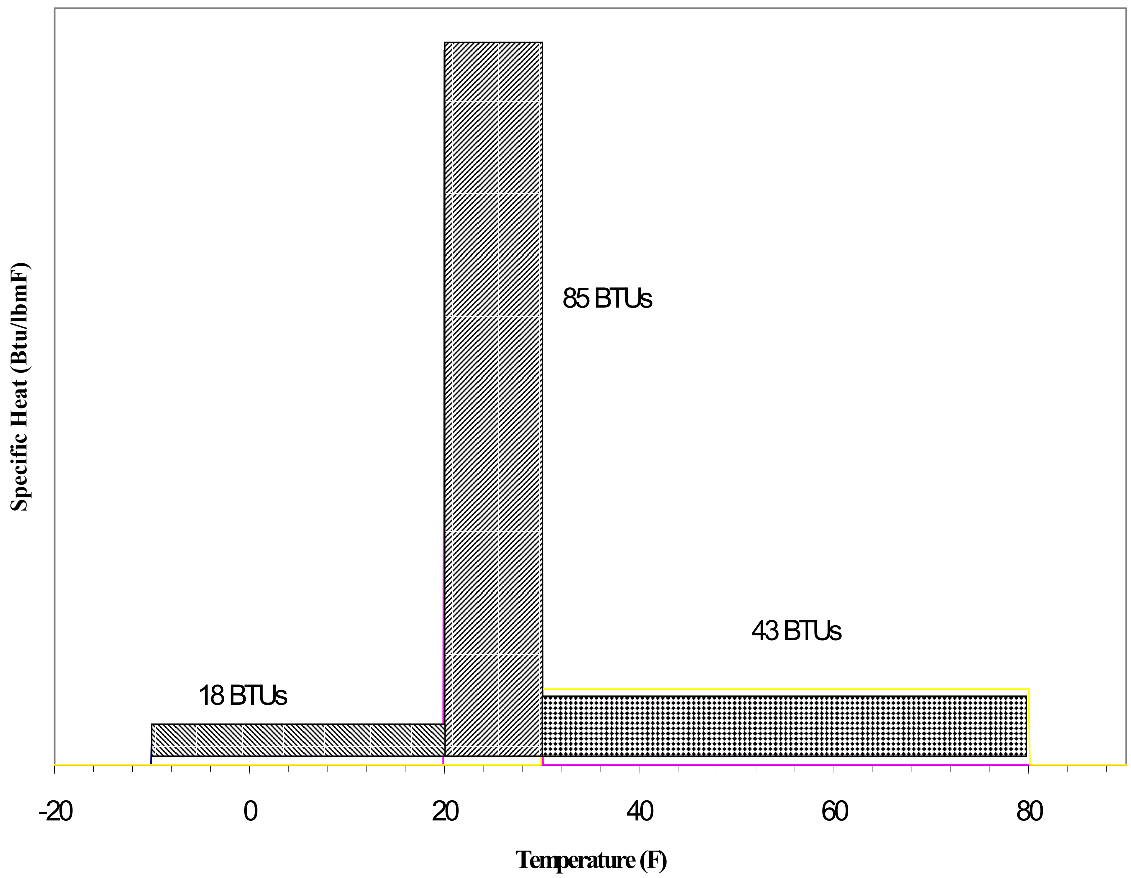


Figure 10. *Areas show the heat removed (in BTU) from 1 pound of albacore as it chills and freezes.*

Of the 128 BTU removed, 43 BTU represents the sensible heat, the amount of heat that must be removed from the fish before it begins to freeze. The 85-BTU block in the center is the "latent heat"–about 58 percent of the total–that is the heat removed in the freezer as moisture in the fish changes to ice. Finally, the 18-BTU block–about 12 percent of the total–is the sensible heat removed as the mostly-frozen fish is cooled down to its final storage temperature.

If the right-hand block of sensible heat were removed in a deck tank prior to loading fish in the freezer, two payoffs would result. One is that the refrigeration load on the freezer would be cut by 30 percent. The second is that the sudden increase in freezer temperature that often occurs when unfrozen fish are loaded would be minimized. Less temperature fluctuation of stowed fish will translate into better quality.

How rapidly will frozen fish warm up when hit with warm air? The left-hand block in Figure 10 gives one clue. The frozen fish does not need to absorb much heat before its temperature begins to rise. This small heat capacity is coupled with the fact that "thermal conductivity"–a number that measures how readily heat conducts from the center of the fish to its outer boundary–is about four times greater in frozen fish than in unfrozen. Figure 11 gives a heat transfer simulation of a 12-lb fish suddenly hit with 40°F air. As a "bad-case scenario," an air velocity of 2 m/sec is assumed. So the situation would correspond to one in which a blast freezer is loaded up with warm fish; fans continue to blow relatively warm air over previously frozen fish.

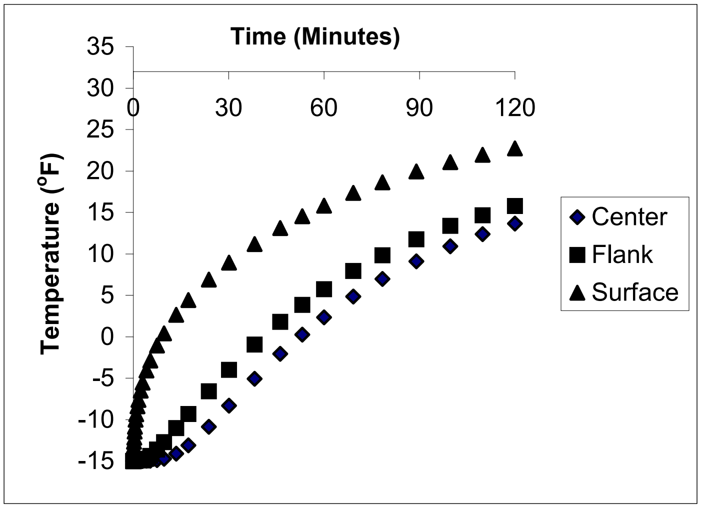


Figure 11. *Rapid internal temperature change of a frozen fish exposed to warmer air.*

Assumptions:
12-lb fish;
Initial fish temperature = -15°F;
Air velocity = 2 m/sec;
Air temperature = 40°F.

General Guidelines on Freezing Capacity

In this section, we will estimate the refrigeration system capacity required for various catch rates of fish. Some assumptions will be based on capability and practice of boats in the fleet. We received 22 completed questionnaires from AFRF fishermen; about a third used blast freezing. Common refrigerants were R-502 or R-22. They reported typical air-blast temperatures to be on the order of -15°F, although the reported range was -32 to 0°F.

About two-thirds of the respondents used spray brine. The dominant refrigerant was R-22 and typical reported brine temperatures while freezing were about 5°F. The range reported was -6 to +22°F.

Results of the fish quality study indicated little effect of freezing time (or rate) on quality, within the range measured. This has an impact on system design: we are less concerned about whether the fish will be frozen in, say, 8 hours versus 16 hours, than we are about the freezing rate keeping pace with catch rate. So required refrigeration capacity is estimated under the following assumptions:

- Freezing rate will match a daily, continuous catch rate. Thus, all fish caught one day will be frozen by the next;

- Fish will be loaded into the freezer continuously, so freezer conditions are relatively uniform (i.e., constant low temperature);
- The refrigeration system will be well designed, with adequately sized major components: evaporator (with appropriate fans or pumps), compressor, condenser, power source, and fish-hold insulation;
- Fishing period will be 15 hours per day; refrigeration will be operated 20 hours per day, with appropriate defrost periods. This implies that when catching large fish late in the day, the equipment would have to operate throughout the night to freeze them in time for the next day's fishing (e.g., Figure 7).

The "capacity" of a refrigeration unit is often given in terms of "refrigeration tons." This is a rate of heat removal equal to 12,000 BTU/hour. One refrigeration ton is a rate equivalent to the amount of heat absorbed by 1 ton of ice melting in 24 hours.

But the actual capacity of a system will depend upon the temperature at which it is operating. A "10-ton unit" might be rated for a saturated (refrigerant) suction temperature of 5^{o}F and saturated discharge temperature of 86^{o}F. But if you were to use this same system to blast-freeze albacore, it must operate at a far lower suction temperature (-30 to -20^{o}F). Its capacity to remove heat at that low temperature will be less than half of what it was at 5^{o}F. Thus, data in the "capacity required" columns listed in Tables 4a and 5a are capacities that the equipment must deliver at the low suction temperatures noted.

Blast Freezers

The calculations in Table 4 were made under the additional assumption that the total heat load will be composed of the following components:

Fans	25%
Leakage through fish-hold boundaries (assumed to be well insulated)	10%
Moisture/defrost heat	5%
Personnel, lights	5%
Fish chilling/freezing	55%

Table 4a. *Required blast freezer capacity.*

Catch rate of fish (Fish/day)		Blast freezer system requirements			
		Prechill to 60^0F		Prechill to 40^0F	
		Capacity required (BTU/hr)	Equivalent "refrigeration tons" at -25^{o}F	Capacity required (BTU/hr)	Equivalent "refrigeration tons" at -25^{o}F
100	12 lb	14,180	1.2	12,220	1.0
	24 lb	28,360	2.4	24,440	2.0
200	12 lb	28,360	2.4	24,440	2.0
	24 lb	56,720	4.7	48,880	4.1
300	12 lb	42,540	3.5	36,660	3.1
	24 lb	85,080	7.1	73,320	6.1

Assumptions:
Final temperature of the fish = -10^{o}F;
Blast air temperature = -15^{o}F.

The "capacity required" in Table 4a includes all parts of the heat load. We've used a saturated suction temperature of -25^{o}F and assume that blast air temperature will be on the order of -15 to -20^{o}F. In Table 4b, we included a column showing "Horsepower required at 20^{o}F." This indicates the system load under relatively warm conditions (i.e., at startup). Refrigeration capacity ("Refrigeration tons at 20^{o}F") of the equipment would be much higher, but so is the "Horsepower required" to drive it.

Table 4b. *Selected ratings.*

A representative compressor model*	Compressor displacement (cfm)	Refrigeration tons at -25^{o}F	Horsepower required at -25^{o}F	Horsepower required at 20^{o}F
5F20	19	1.7	4.5	8.2
5F40	39.8	3.5	9.1	18.5
5F60	59.6	5.2	13.3	27.5
5H40	92.4	8.5	20.5	41.4

* From: Carrier Corp. Form 5F, H-8P.

Assumptions:
Refrigerant = R-502;
Compressor speed = 1750 RPM;
Sat. Suction Temp. = -25^{o}F;
Sat. Discharge Temp. = 100^{o}F;
15^{o}F Subcooling;
Gas to compressor = 65^{o}F.

Brine Freezer

Calculations of heat load on a brine system are assumed to be made up of the following components:

Circulating/spray pump heat	10%
Leakage through hold boundaries (assumed to be well insulated)	10%
Fish chilling/freezing	80%

The "Capacity required" given in Table 5a will include the losses as well as the heat removed from freezing fish. We assumed a brine temperature of 5°F, a temperature drop across the chiller of 10°F, and a saturated suction temperature of -5°F

Table 5a. *Required brine freezer capacity.*

Catch rate of fish (Fish/day)		Brine Freezer System Requirements: Prechill to 60°F: Capacity required (BTU/hr)	Prechill to 60°F: Equivalent "refrigeration tons" at -5°F	Prechill to 40°F: Capacity required (BTU/hr)	Prechill to 40°F: Equivalent "refrigeration tons" at -5°F
100	12 lb	9,230	0.8	7,880	0.7
	24 lb	18,460	1.5	15,760	1.3
200	12 lb	18,460	1.5	15,760	1.3
	24 lb	36,920	3.1	31,520	2.6
300	12 lb	27,690	2.3	23,640	2.0
	24 lb	55,380	4.6	47,280	3.9

Assumptions:
Final fish temperature = 8°F;
Brine temperature = 5°F.

Table 5b. *Selected ratings.*

A representative compressor model*	Compressor displacement (cfm)	Refrigeration tons at -5°F	Required horsepower at -5°F	Required horsepower at 30°F
5F20	19.0	2.9	5.8	8.1
5F30	29.8	4.4	8.6	12.0
5F40	39.8	6.0	11.4	15.9

** From Carrier Corp. Form 5F, H-8P.*

Assumptions:
Refrigerant = R-22;
Compressor speed = 1750 RPM;
Sat. Suction Temp. = -5°F;
Sat. Discharge Temp. = 100°F
Subcooling = 15°F;
Gas to compressor = 65°F.

RECOMMENDATIONS

1. Use a deck tank to:
    a) Improve quality with faster initial chill;
    b) Reduce energy load on the freezer;
    c) Minimize temperature fluctuation in the hold.

2. Prevent overloading the system (either the deck tank or freezer) by matching catch rate with refrigeration capacity.

3. The heat transfer coefficient, a measure of the ease with which heat is removed from the side of a chilling or freezing fish, is a significant factor influencing the freezing time and thus the ability of the freezer to keep pace with the catch rate. To ensure that this important quantity will have a sufficiently high value, place fish in blast and brine freezers to ensure maximum air velocity or spray intensity.

4. Use onboard temperature monitors to check and record freezer and hold temperatures. One should also be able to estimate freezing rates and system performance using the information provided in this report.

REFERENCES AND ADDITIONAL READING

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Summary Guidelines for the Handling and Freezing of Albacore Tuna

Changes in the quality of albacore tuna impacted by onboard handling and chilling techniques were observed in research conducted during the 1996 fishing season. These changes appear to be related to handling of the fish onboard the vessel during the first several hours after capture. Albacore tuna are warm-bodied fish that have body temperatures above the water environment in which they are caught. This temperature increases during capture and continues to increase during its death throes onboard the vessel. These higher temperatures will accelerate the autolytic breakdown in the fish and cause a decrease in quality. Minimizing this autolytic degradation will maximize the quality of the fish that are landed.

There is concern about histamine formation in scombroid species such as tuna. The FDA's Fish & Fisheries Products Hazards and Control Guide, published as a guideline for "Hazard Analysis and Critical Control Point" (HACCP) implementation, states that the best way to control scombroid toxin formation is rapid chilling after harvest: "The internal temperature of the fish should be brought to 50°F (10°C) or below within 6 hours of death ..." and "... Chilling from 50°F (10°C) to the freezing point can take as long as an additional 18 hours, without jeopardizing the safety of the product." Although there is debate whether this time-temperature schedule is too restrictive for albacore given recent scientific information (Begona et al., 1998), the HACCP safety guidelines can be readily achieved. The models developed in this study show that this can be accomplished using a slush ice tank onboard the vessel (Figure 2). The use of slush ice reduced the temperature of larger albacore to less than 50°F (10°C) within 6 hours and smaller fish in less than 4 hours. Rapid chilling also had a significant effect on flesh quality. As the albacore tuna industry develops alternative markets, quality control through good handling and refrigeration will become paramount.

The approach, which minimizes degradation, enhances quality, and assures safety, is immediate chilling and freezing of fish after landing. The first section of this report focuses on the mechanics of achieving this goal while the second section describes the relationship of handling and refrigeration on quality.

Five general guidelines derived from this study are as follows:

The tuna fishing and processing industry should discuss promoting the use of a deck tank. This will achieve several benefits including the rapid lowering of temperature, improving flesh quality, reducing freezer energy load, and minimizing temperature fluctuation in the hold. Given the characteristics of an individual vessel including freezer efficiency and freezer capacity, fishing power and expected peak catch rates, deck tanks may not only improve the safety and consistency of product quality but also may be economically efficient.

Prevent overloading the system. This is important for both the deck tank and the freezer. The catch rate for the vessel should match the chilling rate or freezing rate of each individual vessel. This can be of concern if peak catching rates exceed the fisherman's ability to rapidly chill the catch, particularly if fish are lying on deck for more than 6 hours. Catch rates are variable and impossible to predict; however, fishermen should recognize the quality and possible safety trade-offs associated with overloading their freezing system.

Fish should be placed in the blast and brine freezers to ensure maximum air velocity or spray intensity. The heat transfer coefficient is a significant factor influencing freezing time. The proper placement of fish in the freezer compartments will guarantee the fastest freezing time.

The use of onboard temperature monitors is strongly recommended. The quality of tuna (and most seafood) is directly impacted by time and temperature. The use of temperature monitors allows accurate estimates of freezing rates and helps fishermen better understand their refrigeration system's performance. Temperature monitoring equipment is not expensive and provides records for quality and safety assessment. They also can be used as a tool in contracts between fishermen, processors, and marketers.

Methods such as spiking albacore when fish are landed should be further investigated. This method holds promise for controlling the thrashing of the fish on deck thereby minimizing post-harvest increases in temperature, bruising, and quality defects.

Albacore fishermen are the first link in the distribution and marketing of a valuable food resource. Many factors affect the quality of the fish during harvesting and distribution to the consumer. The guidelines presented above are intended to give fishermen a better idea of the range of time, temperature, and on-deck handling factors critical for maintaining a high-quality product. Guidelines may also provide a certain quality and safety "buffer" if there is temperature abuse or poor product handling further down the distribution chain. Although our data and discussion focus on minimizing the rejection of product at the first buying station, they also lay a general plan for improving quality of landed albacore. With increased attention to time and temperature parameters, quality will improve, thereby supporting increased opportunities to diversify markets.