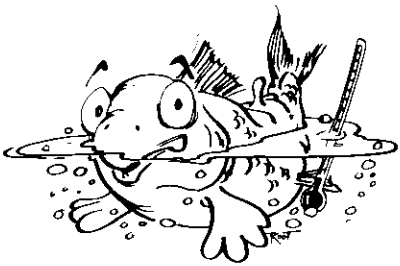
Salmon Quality: The Effects of Elevated Refrigerated Seawater Chilling Temperatures



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INTRODUCTION

Refrigerated seawater (RSW) is a type of chilling system popular in Alaska's salmon fisheries. Properly operated, it provides rapid and uniform cooling of large catches. The system functions best around $31^{o}F$, but reaching this temperature may require chilling the seawater several hours before fish are added. In large systems with minimal equipment, the chilling process may take as long as 30 hours. During peak fishing periods, the ability to properly chill and maintain a RSW system can be difficult or impossible. Frequently, a vessel or tender arrives at the fishing grounds and adds fish immediately, before the seawater reaches $31^{o}F$, so proper chilling is never achieved. In some cases, temperatures may remain as high as $40^{o}F$. How does this affect the quality of salmon and what are the storage limits for these systems? How are fresh and frozen shelf life affected? This publication reports on an investigation of quality changes in salmon held in RSW systems at temperatures above $31^{o}F$.

THE EXPERIMENT

Freshly caught pink salmon were placed in small-scale $31^{o}F$, $34^{o}F$ and $37^{o}F$ RSW systems at initial packing densities of 45 lb per cu ft, approximating a fully loaded system. At intervals of two, four, six, eight and ten days, salmon were removed from the systems and evaluated for visual changes, microbiological growth, weight changes and salt uptake. Fish were held ten days in the $31^{o}F$ and $34^{o}F$ seawater and eight days in the $37^{o}F$ system.

After examination, fish were dressed, plate-frozen at $-40^{o}F$, water-glazed and held in $0^{o}F$ storage for frozen shelf life tests. After one, eight and fourteen months of frozen storage, the salmon were thawed and evaluated for taste panel acceptance and rancidity development.

RESULTS AND DISCUSSION

VISUAL CHANGES

Every two days, ten salmon from each system were graded excellent, good, fair or poor according to specific criteria (Appendix A). As expected, there were significant changes during the storage periods (Table 1).

Table 1. Visual Condition of Salmon Held in RSW

Storage time (days)	Storage Temperatures		
	31°F	34°F	37°F
		Fish Condition*	
2	Excellent (80%) Good (20%)	Excellent (70%) Good (30%)	Good (70%) Fair (30%)
4	Excellent (20%) Good (80%)	Good (90%) Fair (10%)	Fair (100%)
6	Good (70%) Fair (30%)	Good (50%) Fair (50%)	Fair (80%) Poor (20%)
8	Fair (100%)	Fair (70%) Poor (30%)	Fair (40%) Poor (60%)
10	Fair (70%) Poor (30%)	Fair (60%) Poor (40%)	

* See Appendix A descriptions of grading criteria

After two days, fish held at 37°F were graded good or fair, with slight belly discoloration and neutral odor. On day four, moderately soft flesh, strong odor, red eyes and noticeable bellyburn indicated fair condition. All fish were judged to be in fair to poor condition at day eight, with significant decomposition, very soft flesh and distinct off-odor in 40 percent of the fish.

After two days in 34°F seawater, the salmon were in excellent to good condition, although some slight softness was present in 30 percent of the samples. After four days, 90 percent of the salmon remained in good condition with neutral odor and slight bellyburn. The remainder were fair. By the end of ten days in RSW storage, all fish were in fair to poor condition with 40 percent of the fish showing decomposition, very soft flesh and distinct off-odors.

Fish held in 31°F RSW fared slightly better than those at 34°F. At two days, all fish were in excellent to good condition. After four days, some fish (20 percent) were still in excellent condition, but most were in good condition with neutral odor, slight softness and belly discoloration. The salmon were in fair condition with slight decomposition and noticeable flesh softness at day eight. After ten days of storage, all fish exhibited some degree of bellyburn and moderately soft flesh. The majority were in fair condition, but 30 percent were rated poor.

Visual examination proved the best method of evaluating salmon quality because of the conspicuous changes that occurred during RSW storage.

MICROBIOLOGICAL CHANGES

Bacterial levels in seawater and salmon were monitored in each system (Table 2). Every two days, water and flesh samples were taken for total plate counts. Bacterial levels in seawater increased substantially during storage periods, especially at elevated temperatures. In the 31°F system, bacteria increased from an initial count of 36,750 per g to 3.5 million per g in 10 days. In the 34°F system, the tally rose from 14,600 bacteria per g to 10 million per g in 10 days. And in the 37°F system, the count rose from 30,500 bacteria per g to 45 million per g in eight days.

Bacterial numbers in 31°F seawater increased about a hundredfold during the storage period. The 34°F seawater, however, exhibited a bacterial growth rate more than six times greater

Table 2. Bacterial Levels in Salmon and Seawater

Treatment	Storage Time (days) 0	2	4	6	8	10
			Bacteria per g			
Salmon:						
31°F	<500	<500	<500	--	<1,500	--
34°F	<500	<500	<500	--	<1,500	--
37°F	<500	--	4,612	--	2,882	--
Seawater:						
31°F	36,750	59,600	167,200	759,600	2,022,300	3,573,500
34°F	14,600	63,700	414,900	921,722	4,058,800	10,032,300
37°F	30,500	77,800	1,100,000	1,648,200	45,898,600	

than the 31°F system, and bacteria in the 37°F system grew at almost 15 times the rate of those in 31°F seawater. The rapid increase in bacteria in 34°F and 37°F RSW demonstrated the temperature-dependent nature of microbiological growth and the need to maintain low temperatures to keep bacteria at manageable levels. The data indicate a RSW temperature of 31°F is necessary for proper control.

Salmon flesh showed remarkably low bacteria counts during storage, with less than 500 per g after two days in each system. By the end of the experiment, salmon held in 31°F and 34°F RSW had counts of less than 1,500 per g. The 37°F system had counts of 2,900 per g.

Bacterial levels in the flesh rose slowly, an indication that there was little or no contamination by the seawater. Even with low counts and microbiologically good quality after eight and ten days of storage, the visual condition of the fish was only fair to poor. This can be attributed to exposure of the skin to high bacterial levels in the seawater; the bacteria produced the distinctive off-odors associated with old and spoiling fish.

WEIGHT CHANGES

One of the disadvantages of RSW is the weight gain sometimes experienced during long-term storage. Ten salmon in each system were tagged and weighed every two days to determine the extent of the changes (Figure 1). Weight gains occurred in all systems, with salmon in the 31°F RSW showing a gain of 6 percent over the ten-day storage period. Fish in the 34°F and 37°F seawater showed smaller gains of 5 and 4 percent, respectively. Weight gain usually is due to an increase in water content, which can result in excessive processing losses and drip loss in frozen salmon.

SALT UPTAKE

Another concern with RSW during extended storage is increased salt content in flesh. Levels in excess of 1 percent are undesirable since salt accelerates rancidity and may affect the flavor of frozen salmon. Fish in all systems appeared to absorb salt at similar rates, resulting in a twofold to threefold increase during the storage period (Table 3). Although these amounts approached detectable levels, all were within normal ranges experienced in RSW operation. Fish held for eight and ten days in the systems, however, had salt levels that affected the flavor of the frozen product.

Table 3. Salt Content of Fish Held in RSW

RSW System	Storage Time (days)				
	2	4	6	8	10
	Salt Content (%)				
31°F	0.54	0.62	0.69	0.97	1.06
34°F	0.33	0.50	0.62	0.72	0.82
37°F	0.40	0.65	0.87	1.07	–

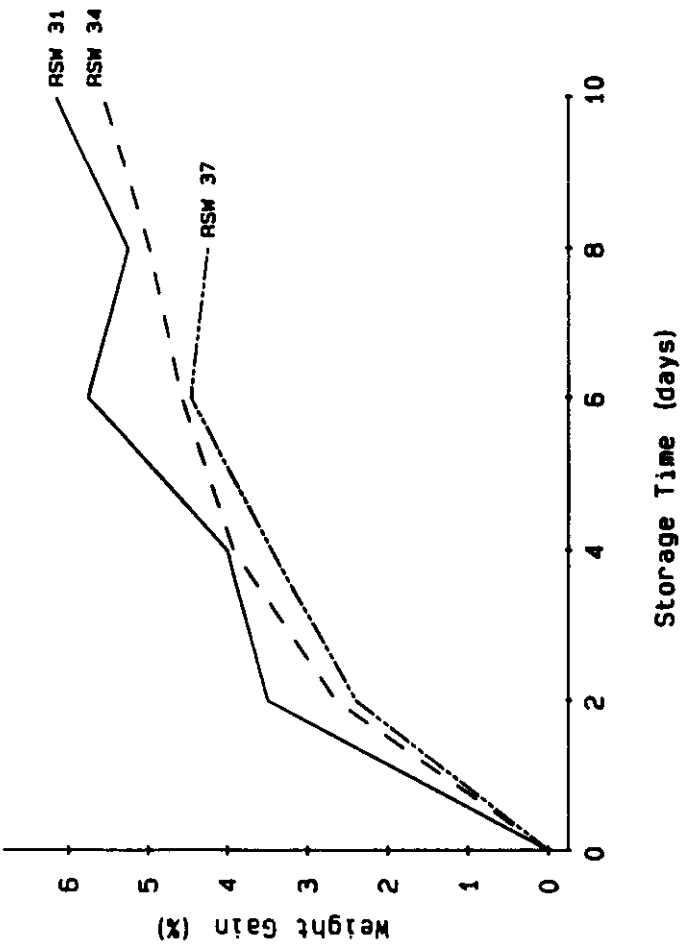

Figure 1. Weight Gain of Salmon Held in RSW.

FROZEN SHELF LIFE

The objective of the storage trials was to determine practical shelf life for the frozen product. Salmon were processed, frozen and held at $0^{o}F$ for one, eight and fourteen months. At the end of each storage period, fish were thawed and evaluated for taste panel acceptance and rancidity development. Taste panels evaluated samples for off-odor, off-flavor, saltiness, moistness, tenderness and overall desirability using a nine-point scale (one = none, nine = extreme). Rancidity was determined using the thiobarbituric acid (TBA) method to measure the rate of fat oxidation.

TASTE PANEL RESULTS

After one month of frozen storage, the salmon held in $31^{o}F$ and $34^{o}F$ RSW were all acceptable. Saltiness was noted in the eight- and ten-day treatments. Salmon held at $37^{o}F$ had lower desirability scores; six- and eight-day fish exhibited off-odors and flavors (Table 4). After eight months of storage, off-flavors were noted in fish held six and eight days at $31^{o}F$, in those held four days at $34^{o}F$ and in salmon kept two days in the $37^{o}F$ treatment (Table 5). Taste panel scores for fish held eight months indicated a significant drop in acceptability when compared to the one-month scores. Fish stored in $37^{o}F$ RSW for six and eight days and in $34^{o}F$ for ten days were considered of poor quality. All fish that received other treatments were still acceptable.

Table 4. Desirability Scores for Salmon Held One Month in Frozen Storage

RSW System	Storage Times (days)				
	2	4	6	8	10
$31^{o}F$	5.6	5.9	6.0	5.8	5.9
$34^{o}F$	5.6	6.1	6.2	6.5	6.3
$37^{o}F$	6.2	5.9	4.8	4.3	-

Higher scores indicate better overall desirability.

Table 5. Off-Flavor Scores for Salmon Held Eight Months in Frozen Storage

RSW System	Storage Times (days)				
	2	4	6	8	10
31°F	3.4	3.4	4.7	4.7	4.2
34°F	4.3	4.3	4.7	4.7	4.7
37°F	4.0	5.5	5.2	5.3	--

Higher scores indicate more intense off-flavors.

After fourteen months in frozen storage, all salmon had significant off-flavors, so the taste panels evaluated only odor. Those fish held at 37°F and 34°F were of very poor quality. The fish held two days at 31°F were only slightly better (Table 6).

Table 6. Off-Odor Scores For Salmon Held Fourteen Months in Frozen Storage

RSW System	Storage Times (days)				
	2	4	6	8	10
31°F	4.4	4.1	4.2	5.2	5.5
34°F	4.1	4.6	4.9	5.4	4.9
37°F	3.8	4.9	5.2	5.1	--

Higher scores indicate more intense off-odors.

RANCIDITY DEVELOPMENT

Fish held in 31°F and 34°F systems developed rancidity at about the same rate. Values of TBA, the measurement of fat oxidation, were slightly higher for salmon held in 37°F seawater. In frozen storage, rancidity in salmon held at 37°F reached noticeable levels after one month. Fish kept at 31°F and 34°F developed detectable rancidity after eight months (Table 7).

Table 7. TBA Values of Frozen Salmon

Treatment	Storage Period (months) 1	8	14
	(mg/100 g fish)		
RSW 31°F			
2 Days	2.86	3.06	2.46
4 "	3.13	3.62	4.11
6 "	3.49	4.25	4.04
8 "	2.82	4.01	4.25
10 "	3.19	4.83	3.77
RSW 34°F			
2 Days	3.52	2.48	3.71
4 "	3.46	3.71	2.75
6 "	3.67	3.94	3.50
8 "	3.35	5.57	2.50
10 "	3.31	2.77	5.83
RSW 37°F			
2 Days	2.30	3.58	3.04
4 "	4.50	4.26	3.36
6 "	3.66	5.51	4.76
8 "	5.62	7.82	2.60

* Generally, values above 4.0 indicate noticeable rancidity.

Taste panel data from the frozen storage trials indicated salmon held six and eight days at 37°F changed noticeably after one month of frozen storage and fish held two days at 31°F could be stored frozen fourteen months and be marginally acceptable. Most samples had acceptable quality after up to eight months in the freezer and then deteriorated rapidly.

CONCLUSION

This experiment demonstrated that refrigerated seawater systems operating at 31°F produced better quality fresh and frozen fish than systems operating at higher temperatures. Quality differences between fish held in 31°F and 34°F seawater were no-

ticeable. The fish held at 31°F maintained better quality during both the RSW and frozen storage periods. Operating RSW systems at 37°F was detrimental, as evidenced by rapid bacterial growth, poor quality fish and shortened frozen shelf life. As little as two days in 37°F seawater had an adverse effect on the quality of the frozen product.

The fresh shelf life data indicated that salmon should be held no longer than four days at 31°F. This is in general agreement with Tomlinson (1974), who found that chill storage of pink salmon should not exceed three days in ice or 31°F RSW. At higher temperatures, pink salmon held between two and four days at 34°F and less than two days at 37°F remained acceptable, but quality was lower. After these periods, the fish deteriorated quickly. Frozen shelf life data indicated that the best quality was found in fish frozen less than eight months, although fish held at 31°F were marginally acceptable after 14 months.

The explosive bacterial growth in seawater indicated another potential problem area. Rapid bacterial increases in both 34°F and 37°F RSW systems demonstrated that temperature is an important factor in controlling bacterial levels. Uncontrolled bacterial growth was detrimental to quality due to the development of off-odors usually associated with old and spoiling fish.

The recommendation resulting from this investigation is to chill seawater to 31°F or below for the best quality. When RSW systems are unable to achieve proper temperatures, better scheduling of tenders, adding ice to the fish hold or upgrading equipment is necessary to achieve quick chilling of the system. Temperatures higher than 31°F result in rapid quality loss and reduced frozen shelf life. To obtain maximum frozen storage life for high-quality pink salmon, fish should never be held in 31°F water for more than four days.

REFERENCES

Tomlinson, N., S.E. Gieger, J.W. Boyd, B.A. Southcott, G.A. Gibbard and S.W. Roach. 1974. Comparison between refrigerated seawater (with and without added carbon dioxide) and ice as storage media for fish to be subsequently frozen in *Cooling and Freezing Aboard Fishing Vessels.* International Institute of Refrigeration, Paris, France.

APPENDIX A
SALMON GRADING CRITERIA

Condition	Excellent	Good	Fair	Poor
Odor	Fresh, seaweedy	No odor, neutral	Strong slime odor	Decomposing, acid odor
Eyes	Bright, clear	Flat, slightly opaque	Opaque, slight reddening	Opaque, red, sunken
Skin	Bright, no bleaching	Slightly dull, wavy	Dull, some bleaching	Dull, bleached
Gills	Bright red	Pink	Green-brown	Dull brown, bleached
Flesh	Firm	Slightly soft	Moderately soft	Severely soft
Gut/ Roe	Firm, no decomposition, bright	Softening, no decomposition, slight discoloration	Slight liquid, slight decomposition, darkening	Liquid, decomposition, dark