the ship must be very great to set up a current density of a few milli-amperes at a distance of only a few yards from an electrode. Future research in this field should be directed toward finding methods of concentrating or confining the electric field to a limited volume of water between the electrodes in so far as may be possible. Laboratory experiments should also be carried out to determine the correct current densities for producing the conditions of electro-taxis and paralysis in various kinds of commercially valuable fishes, as well as the best waveform, pulse length, and pulse rate to use with these fishes. Having ascertained these factors it will be possible to estimate the electrical power required and proceed with the assembly of the apparatus needed for applying electrical methods of fishing to a particular fishery in a practical way.

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Holding Fresh Shrimp in Refrigerated Sea Water[1]

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During the past several years shrimp boats in the Gulf of Mexico have been making longer and longer trips. The greater length of time spent away from port has increased the difficulty of landing high quality fresh shrimp. In addition, present icing methods result in a condition known as "black spot" on the shrimp. (Figure 1.).

The need for more efficient methods of refrigeration and control of the black spot problem led the Marine Laboratory of the University of Miami to conduct a series of experiments, for the Florida State Board of Conservation, in which shrimp were held in refrigerated seawater instead of in crushed ice.

Preliminary tests were conducted in which the quality of iced shrimp was compared with that of shrimp held in sea-water, fresh water, and solutions of calcium chloride and sodium chloride. Pink grooved shrimp (*Penaeus duorarum*), caught by a commercial trawler off Key West, were held in the various solutions at temperatures which ranged between 37.9° and 41.7°F. The quality of these shrimp was tested seven times over a period of 24 days. A testing panel of ten staff members of the Marine Laboratory rated the shrimp as to firmness, black spot, odor and taste. (Table 1).

1 Contribution No. 94 from The Marine Labortaory, University of Miami.

TABLE 1

PALATABILITY SCORES OF SHRIMP HELD ON ICE AND IN VARIOUS SOLUTIONS

MAXIMUM SCORE: 4.0

Days Storage Time	ICED Taste	Odor	Black Spot	Firm ness	CALCIUM CHLORIDE Solution 33 °/oo Av. holding temp.: 38.3°F Taste	Odor	Black Spot	Firm ness
5	2.0	3.5	2.3	2.7	3.2	3.7	3.4	2.8
7	3.4	3.9	2.2	2.8	2.1	3.7	2.2	3.4
10	3.4	3.9	2.6	3.2	2.3	3.7	2.6	3.3
12	2.8	3.3	2.2	3.2	2.0	3.5	1.7	3.3
17	..	..	..	..	2.0	3.4	1.8	3.5
21	..	..	..	..	1.6	3.8	2.1	3.4
26	..	..	..	..	..	3.3	2.7	3.1
	FRESH WATER Av. holding temp.: 41.7°F				SEA WATER Av. holding temp.; 38.6°F			
5	3.1	3.9	3.9	3.1	3.8	3.5	3.1	3.9
7	3.4	4.0	4.0	3.2	3.7	3.6	3.3	3.5
10	3.1	3.9	3.6	3.2	3.2	4.0	3.3	3.7
12	3.1	1.8	4.0	2.6	3.5	3.2	3.6	4.0
17	1.7	2.4	4.0	2.9	2.7	3.1	3.9	3.3
21	2.7	1.7	4.0	3.3	3.0	3.2	3.7	3.5
26	..	2.3	4.0	2.9	..	3.3	2.7	3.1
	SODIUM CHLORIDE Solution 33 °/oo Av. holding temp.: 38.3°F							
5	3.9	3.7	3.0	3.6				
7	3.7	3.6	3.3	3.6				
10	3.2	4.0	3.3	3.5				
12	3.5	3.2	3.6	3.7				
17	2.7	3.1	3.9	3.8				
21	3.0	3.2	3.7	3.8				
26	..	3.3	2.7	3.7				

The palatability of the iced shrimp in this experiment declined rapidly, and moderate amounts of black spot developed. This sample was discarded after the 12th day. (Table 1).

Shrimp held in a solution of calcium chloride were objectionable on the 12th day. These shrimp became noticeably bitter, on the 7th day. Large amounts of black spot developed on these shrimp by the 12th day. (Table 1.).

Ratings of taste (1.7) and odor (2.4) made the fresh water-held shrimp objectionable by the 17th day. (Table 1). However, this sample showed little evidence of black spot. The quality of the shrimp held in seawater and sodium chloride solution remained acceptable until the end of the experiment. (Table 1.). There was no significant development of black spot in either of these latter samples.

These preliminary results indicate that fresh shrimp held in seawater or sodium chloride would be more acceptable to the consumer than shrimp held in crushed ice, calcium chloride or fresh water.

The encouraging results from the tests with sodium chloride and seawater-held shrimp warranted further experimentation. Therefore a more detailed study was made of the quality of shrimp held in refrigerated seawater.

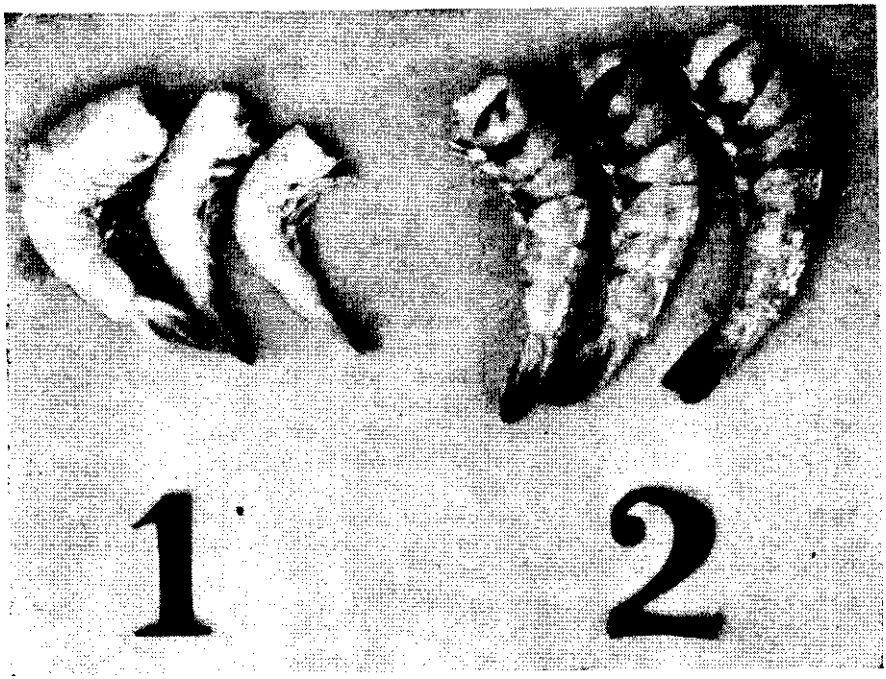

FIGURE 1. Sample No. 1 was held in refrigerated seawater for 16 days at 31.0°F. Sample No. 2 was held in crushed ice for 16 days. The blackened areas at the edge of the segments of the shell on sample No. 2 are typical of "black spot" (melanosis) which develops on ice-held shrimp. The unmarked appearance of sample No. 1 is typical of the condition of shrimp held in refrigerated seawater.

Samples of shrimp used in this experiment were taken from a single drag made by a commercial shrimp trawler operating on the Tortugas grounds.

TABLE 2

BLACK SPOT SCORES

MAXIMUM SCORE: 5.0.

Days Storage	Seawater 15% changed daily		Seawater Unchanged		Ice Held	
	Heads Off	Heads On	Heads Off	Heads On	Heads Off	Heads On
	Average holding temperature °F					
	34.8	34.7	30.7	32.4	32.0	32.0
2	4.9	5.0	4.9	4.8	5.0	4.8
4	5.0	5.0	5.0	4.0	4.8	4.0
6	5.0	4.8	4.8	5.0	4.0	4.0
8	5.0	5.0	5.0	4.9	4.0	4.0
10	5.0	5.0	5.0	5.0	5.0	3.4
12	5.0	5.0	5.0	4.8	3.8	3.8
13	5.0	5.0	5.0	5.0	3.4	4.2
15	5.0	4.6	5.0	5.0	3.6	3.8
17	5.0	5.0	5.0	5.0	4.0	4.2
19	5.0	..	5.0	..	4.0	3.8
22	5.0	..	4.8	..	3.4	..
24	5.0	..	5.0	..	..	..

These shrimp were placed in refrigerated seawater or crushed ice within one hour after being caught. Crushed ice samples were held at 32° F. throughout the experiment. The temperature of the seawater samples ranged from 30.7° to 34.8° F. (Table 2).

Eleven series of bacteriological tests were made on the seawater and the drip from the iced samples. Numbers of bacteria per cubic centimeter of seawater were determined by the dilution extinction method of Zobell (1948). No attempt was made to identify the bacteria.

Taste, odor and black spot were used as the criteria of quality. Values ranging from one to five were assigned to each quality tested. A rating of five denoted the highest quality shrimp, while a rating of one described inferior quality. In these tests an arbitrary score of 3.5 was established as the limit for "good" quality shrimp. This standard is higher than the quality of shrimp accepted by the consumer. Only boiled shrimp without condiments were served to the test panel. Had these shrimp been french-fried or served with sauce they would probably have remained acceptable for a longer period of time.

Six samples of shrimp were tested in this experiment. They were grouped in pairs, each pair consisting of a heads-on and a heads-off sample. One pair of samples was held in crushed ice, one pair in unchanged seawater, and the third pair in seawater. Fifteen per cent by volume of the seawater was changed daily on the third pair of samples.

Results of this experiment again indicate that a higher quality product may

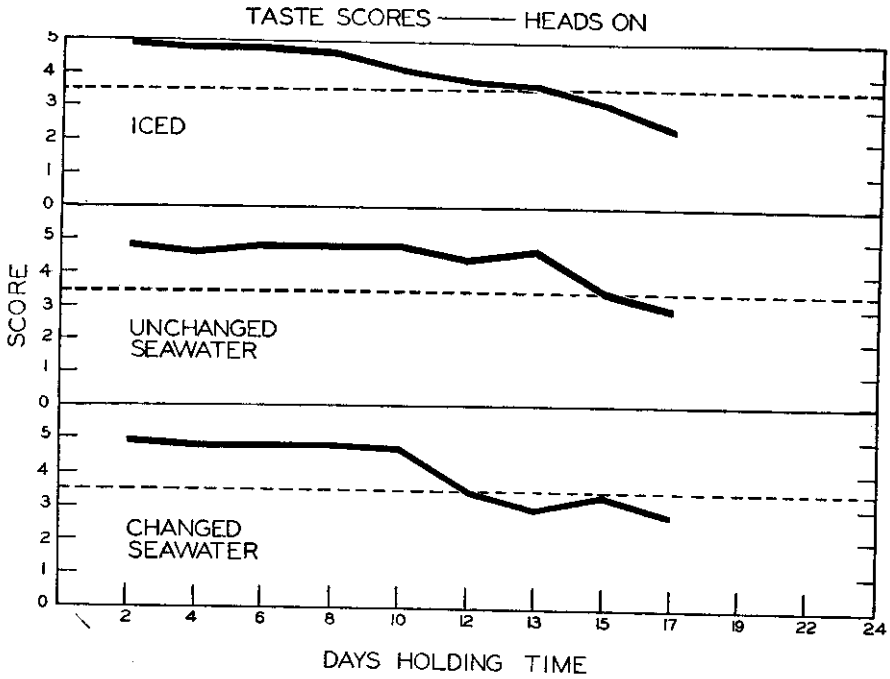

FIGURE 2. Taste scores of "heads-on" shrimp held on ice or in refrigerated seawater for 17 days. Broken lines indicate the arbitrary minimum level of acceptability (3.5).

be obtained by holding shrimp in refrigerated seawater than by the conventional icing method. (Figs. 2-5).

All samples of heads-on shrimp had a shorter storage life than heads-off samples of the same pair. This is shown by the lower heads-on scores for taste and odor. (Figs. 2-5).

The taste scores of the heads-on iced sample fell below the 3.5 level of acceptability on the 15th day of storage. The heads-off iced sample of the same paid did not fall below this level until the 17th day. (Figs. 2, 3). Taste scores of heads-on, changed and unchanged seawater samples fell below the level of acceptability on the 13th and 17th days respectively. (Fig. 2.) The corresponding heads-off samples were of "good" quality until the 19th and 24th days. (Fig. 3).

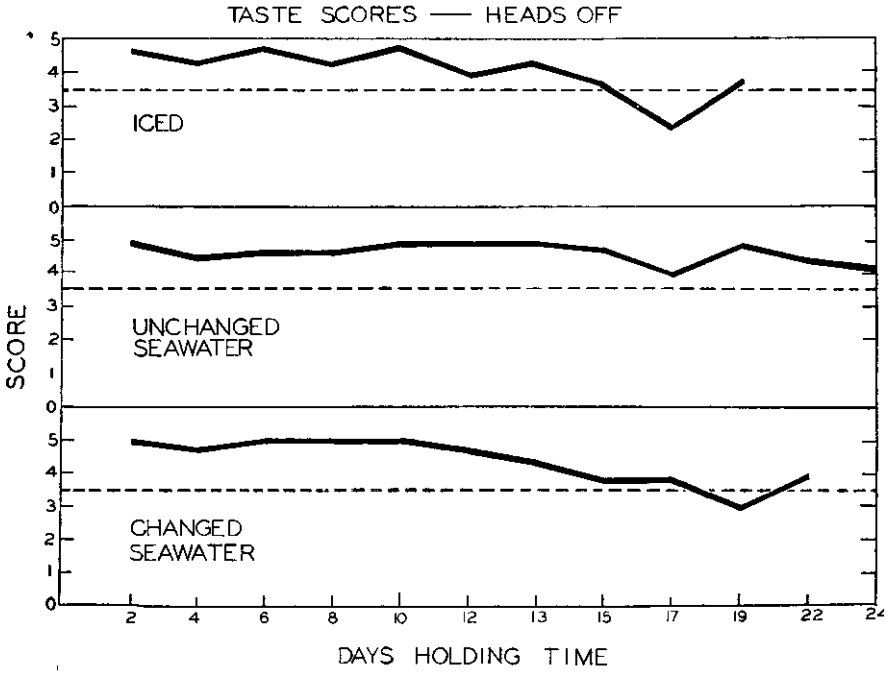

FIGURE 3. Taste scores of "heads-off" shrimp held on ice or in refrigerated seawater. Broken lines indicate the arbitrary minimum level of acceptability (3.5).

Odor scores of the heads-on iced sample fell below the level of acceptability on the 15th day of storage and continued this downward trend until the end of the experiment. (Fig. 4). The heads-off iced sample of this pair was rated 3.2 on the 12th day of storage. This however is an anomaly since the score on the following day was 4.2 and not until the 17th day did this sample fall below the 3.5 level of acceptability and continue its downward trend. (Fig. 5.). Odor scores rated the heads-on, changed and unchanged seawater samples objectionable on the 12th and 15th days respectively. (Fig. 4). The heads-off changed seawater sample was unacceptable on the 15th day, while the heads-off unchanged sample was not objectionable until the 24th and final day of the experiment. (Fig. 5).

There was no significant indication of black spot in any of the samples held in seawater. Black spot developed in a normal manner on the ice-held shrimp. In the heads-on sample black spot developed most rapidly in the heads of these shrimp. Since the heads were removed from this sample before being rated by the test panel this difference does not show in the rating scores. In comparing the scores of the black spot ratings on shrimp tails only, there seems to be no difference in the rate or amount of black spot developed on these two iced samples. (Table 2).

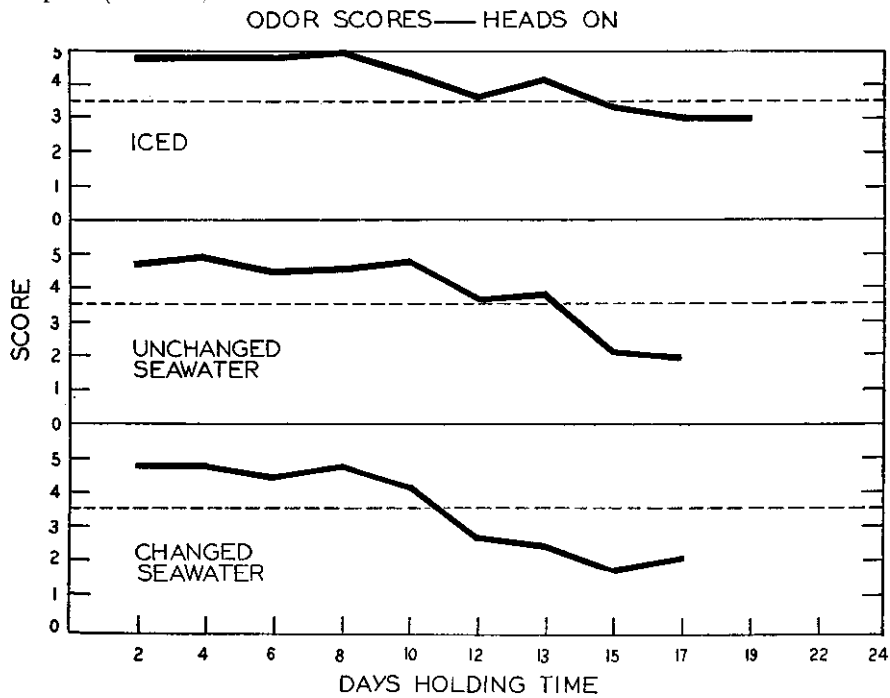

FIGURE 4. Odor scores of "heads-on" shrimp held on ice or in refrigerated seawater. Broken lines indicate the arbitrary minimum level of acceptability (3.5).

The headed sample held in unchanged seawater remained above the 3.5 level of acceptability in respect to taste, odor and black spot for 22 days. This was the best sample in the experiment. On the 24th day it fell below the acceptable level only in the quality of odor, which was rated 3.3 (Fig. 5). By contrast the iced samples fell below this level in one or more qualities by the 15th day. (Figs. 2-5).

Bacteriological tests were conducted on each day that organoleptic tests were made. It was anticipated that the numbers of bacteria in the seawater might increase with prolonged holding and that relative size of the bacterial population might give some clue as to the minimum holding period. Figure 6 shows the estimated numbers of bacteria per cubic centimeter of seawater, or drip from melting ice, at the various sampling days.

Bacterial counts on all samples showed either no increase throughout the experiment (Numbers 1, 4, 5, & 6) or slight increases (Numbers 2 & 3). The

fact that no large increases in bacterial counts occurred in the seawater would suggest that at the temperatures involved bacterial action is slight. Such a situation must necessarily prevail if shrimp are to retain their quality.

Shrimp held in the same seawater throughout the experiment kept better than those on which 15 per cent of the water was changed daily. The latter result was unexpected. It was anticipated that shrimp would keep better if part

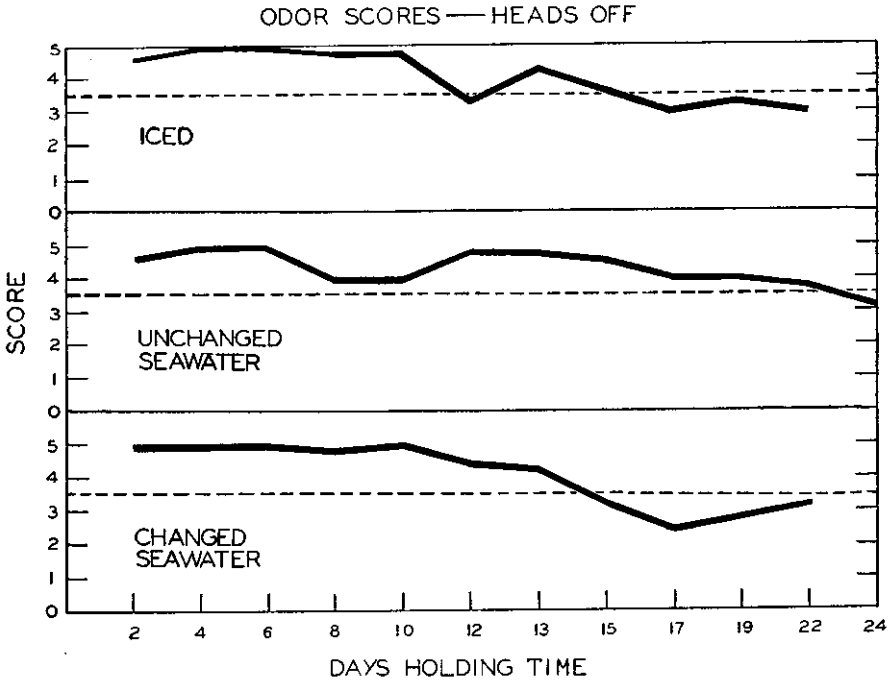

FIGURE 5. Odor scores of "heads-off" shrimp held on ice or in refrigerated seawater. Broken lines indicate the arbitrary minimum level of acceptability (3.5).

of the water containing fragments of shrimp, bacteria and dirt was replaced by clean water. Due to a temperature differential in the refrigeration unit the headed unchanged seawater sample was held 3.5°F. lower than the headed changed seawater sample. (Table 2). The comparison between these two samples was not considered conclusive inasmuch as the higher quality of the unchanged seawater sample could have been due to the lower holding temperatures.

To confirm these results, in later experiments the temperature was held constant while changed and unchanged seawater samples were compared. From this series of tests it would appear that nothing is to be gained, in terms of quality, by changing the seawater.

Following the first announcement of these results it was learned that several owners of shrimp boats had installed tanks for the purpose of holding shrimp in refrigerated seawater. Shrimp from the cargos of two of these vessels were rated by the test panel.. Although both samples were of marketable quality they were on the borderline of acceptability, according to Marine Laboratory standards. The lower quality was attributed to two factors. First, holding tem-

peratures of these shrimp ranged from 34° to 40° F., whereas recommended holding temperatures are between 28.5-30° F. In addition, both of these boats returned with shrimp, the oldest of which were 25 days. This is well beyond the recommended maximum holding period.

Insofar as could be determined these cargos of shrimp were marketed without difficulty. In judging their quality some buyers stated that their odor was objectionable.

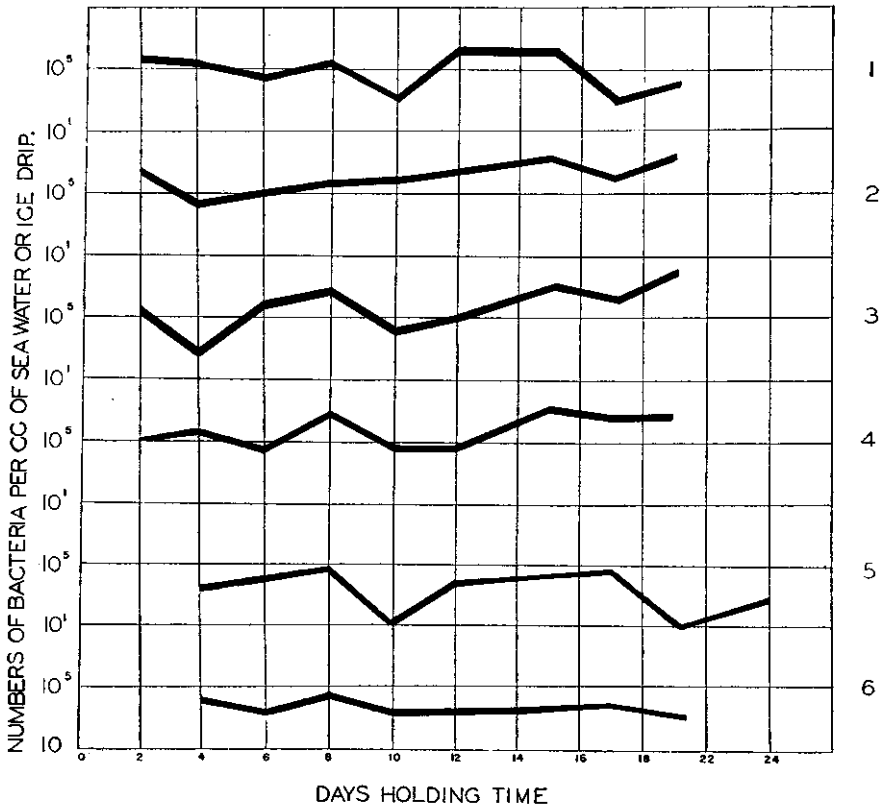

FIGURE 6. Graphical representation of the bacterial history of ice- and seawater-held shrimp. Sample No. 1, "heads-off" shrimp held in changed seawater; sample No. 2, "heads-on" shrimp held in changed seawater; sample No. 3, "heads-on" shrimp held in unchanged seawater; sample No. 4, "heads-off" shrimp held in unchanged seawater; sample No. 5, "heads-off" shrimp held in ice; sample No. 6, "heads-on" shrimp held in ice.

The odor ascribed to these shrimp had been noted in our experiments. Thorough washing partially eliminated it. Furthermore, there was no indication that the odor influenced the quality of the taste, according to ratings of the test panel. It was decided to investigate the odor question more fully.

The problem was first approached by further experimentation with the changing of various volumes of refrigerated sea water at regular intervals. Tables 3, 4 & 5 report the results of two separate experiments, each comparing

shrimp held in unchanged seawater with samples having part or all of the water changed at intervals. Ten percent of the seawater on one sample was changed daily; on another sample 100 percent of the seawater was changed every third day. Organoleptic tests were made comparing the quality of shrimp held in changed and unchanged seawater. There was no marked difference in odor and taste among the samples,(Tables 3,4) again confirming previous results. However, the changed seawater samples became sigificantly tougher upon holding for 21 days. (Table 5.).

Bacteriological tests were again made, in addition to organoleptic tests.

TABLE 3

TASTE SCORES—HEADS OFF

MAXIMUM SCORE: 5.0.

Days Storage	Seawater Unchanged	Seawater 10% changed daily	Seawater Unchanged	Seawater 100% changed each 3rd day
	Average holding temperature °F			
	31.1	31.1	31.1	31.1
4	5.0	5.0	5.0	5.0
7	5.0	5.0	4.6	4.8
9	4.8	5.0	..	..
11	4.8	5.0	4.8	4.8
14	4.4	4.2	4.8	4.4
16	4.6	4.6	..	..
18	4.6	4.4	4.2	4.0
21	4.8	4.4	4.0	3.6
23	4.2	3.6	..	..
25	3.2	3.6	4.0	3.0
28	4.0	3.6	..	..
30	3.0	3.4	..	..

TABLE 4

ODOR SCORES—HEADS OFF

MAXIMUM SCORE: 5.0.

Days Storage	Seawater Unchanged	Seawater 10% changed daily	Seawater Unchanged	Seawater 100% changed each 3rd day
	Average holding temperature °F			
	31.1	31.1	31.1	31.1
4	5.0	5.0	5.0	5.0
7	5.0	5.0	4.8	5.0
9	5.0	5.0	..	..
11	4.6	4.8	4.6	4.6
14	5.0	4.6	4.6	4.8
16	4.8	4.8	..	..
18	4.8	4.8	4.8	4.6
21	4.8	5.0	4.6	4.8
23	3.4	3.8	..	..
25	3.8	3.8	4.0	4.2
28	4.6	4.4	..	..
30	3.2	4.8	..	..

TABLE 5

TOUGHNESS SCORES—HEADS OFF

MAXIMUM SCORE: 5.0.

Days Storage	Seawater Unchanged	Seawater 10% changed daily	Seawater Unchanged	Seawater 100% changed each 3rd day
	Average holding temperature °F			
	31.1	31.1	31.1	31.1
4	5.0	5.0	5.0	5.0
7	4.6	4.8	4.2	4.4
9	4.4	4.2	..	..
11	4.0	4.4	4.2	4.2
14	3.2	3.4	4.2	3.8
16	3.8	3.8	..	..
18	3.8	3.8	4.0	3.8
21	3.8	3.0	3.8	3.2
23	3.8	2.8	..	..
25	3.0	3.0	3.4	2.2
28	2.8	2.6	..	..
30	2.8	3.0	..	..

Table 6 shows the number of bacteria per cc. of seawater after various periods of storage. As may be seen from Table 6 the beginning of the rise in bacterial numbers on the 25 day does not coincide with the acceptability ratings of the organoleptic tests. Tables 3,4 depicting scores for taste and odor indicate the maximum storage time for seawater held shrimp is about 21 to 23 days.

Since changing the seawater did not retard the development of the undesirable odor, attempts were made to eliminate this factor by adding to the seawater, chemicals which inhibit bacterial activity.

TABLE 6

THOUSANDS OF BACTERIA PER CUBIC CENTIMETER OF SEAWATER

Days Storage	Average holding temperature °F. 31.1 Seawater Unchanged	31.1 Seawater 10% changed daily
4	1000.0	100.0
7	0.1	1.0
9	1.0	0.1
11	0.1	1.0
14	0.1	0.1
16	1.0	1.0
18	1.0	0.1
21	0.1	0.1
23	1.0	0.1
25	1.0	1.0
28	10.0	100.0
30	1000.0	10,000.0

Tests were made of the quality of shrimp held in untreated seawater to which sodium hypochlorite had been added in concentrations of 5, 10 and 20 parts per million (p.p.m.). The scores for odor show that no advantage is

gained in suppressing odor by the addition of sodium hypochlorite in the concentrations tested. (Table 8). Taste and toughness scores indicate minor variations in quality, the advantage being with the unchanged seawater sample. (Tables 7-9). "Fram Kem" and "Perchloran" were also tried as bacteriostatic agents. "Fram Kem" (a mixture of sodium benzoate and fumaric acid) was used in concentrations of 500 p.p.m. and 1000 p.p.m.; Perchloran (70% calcium hyperchlorite) was tried in concentrations of 10 and 50 p.p.m.

The results indicate that no advantage is to be gained by the use of these concentrations of chemicals. (Tables 7-9).

TABLE 7

TASTE SCORES—HEADS OFF

MAXIMUM SCORE: 5.0

Days Storage	SEAWATER-HELD				SEAWATER-HELD				
	Unchanged	Plus 5ppm NaOCl	Plus 10ppm NaOCl	Plus 20ppm NaOCl	Unchanged	Plus 500 Fram Kem	Plus 1000 Fram Kem	Plus 10ppm $CaOCl_2$	Plus 50ppm $CaOCl_2$
	Average holding temperature °F								
	30.8	30.2	30.9	33.2	31.8	31.8	31.8	32.0	32.0
2	4.8	4.6	4.2	4.6	..	..	..	..	..
5	4.2	4.8	4.6	4.4	..	..	..	..	..
6	..	..	..	..	4.6	..	..	4.4	4.6
7	..	..	..	..	4.6	4.8	4.6	..	..
8	4.2	4.0	4.2	4.4	..	..	..	..	..
10	..	..	..	..	4.6	..	..	4.4	3.8
11	..	..	..	..	4.4	4.0	4.4	..	..
12	4.4	4.4	4.0	3.8	..	..	..	..	..
13	..	..	..	..	3.4	..	..	4.2	4.2
14	..	..	..	..	3.8	3.8	4.0	..	..
15	4.0	4.2	3.4	3.0	..	..	..	..	..
17	..	..	..	..	3.4	..	..	3.4	3.6
18	..	..	..	..	4.0	3.6	3.8	..	..
19	3.2	4.0	3.2	2.8	..	..	..	..	..
20	..	..	..	..	4.0	..	..	3.0	3.0
21	..	..	..	..	4.0	2.8	3.6	..	..
22	2.8	2.6	2.6	2.4	..	..	..	..	..
24	..	..	..	..	3.4	..	..	3.6	4.0
25	..	..	..	..	3.8	3.2	2.8	..	..

At the recommended holding temperature of 28.5-30°F. the method of holding shrimp in refrigerated seawater shows several advantages over the conventional icing method.

1. Iced shrimp are not of acceptable quality after 15 days while seawater held shrimp may be kept for 21 days.

2. No measurable amount of black spot develops on shrimp held in refrigerated seawater.

3. Changing the seawater does not improve the quality of shrimp. Indications are that it toughens them.

TABLE 8

ODOR SCORES—HEADS OFF

MAXIMUM SCORE: 5.0

Days Storage	SEAWATER-HELD				SEAWATER-HELD				
	Unchanged	Plus 5ppm NaOCl	Plus 10ppm NaOCl	Plus 20ppm NaOCl	Unchanged	Plus 500 Fram Kem	Plus 1000 Fram Kem	Plus 10ppm $CaOCl_2$	Plus 50ppm $CaOCl_2$
	Average holding temperature °F								
	30.8	30.2	30.9	33.2	31.8	31.8	31.8	32.0	32.0
2	5.0	4.0	4.8	4.6	..	..	..	..	..
5	5.0	4.6	4.4	4.2	..	..	..	..	..
6	..	..	..	..	4.6	..	..	4.8	5.0
7	..	..	..	..	5.0	4.6	4.8	..	..
8	4.6	5.0	5.0	4.4	..	..	..	..	..
10	..	..	..	..	5.0	..	..	4.6	4.4
11	..	..	..	..	4.6	4.6	5.0	..	..
12	4.2	5.0	3.8	4.4	..	..	..	..	..
13	..	..	..	..	4.6	..	..	4.6	4.6
14	..	..	..	..	4.4	4.8	4.4	..	..
15	4.2	4.6	3.6	3.8	..	..	..	..	..
17	..	..	..	..	4.6	..	..	4.2	4.6
18	..	..	..	..	4.4	4.2	4.4	..	..
19	3.4	3.2	3.2	2.6	..	..	..	..	..
20	..	..	..	..	4.4	..	..	4.6	4.4
21	..	..	..	..	4.2	4.2	4.2	..	..
22	3.4	3.2	3.6	2.2	..	..	..	..	..
24	..	..	..	..	3.8	..	..	3.8	2.8
25	..	..	..	..	3.8	3.6	2.8	..	..

4. The quality of shrimp kept in various chemical solutions show no improvement over shrimp held in plain seawater.

5. Temperature is the most important factor in determining the success of this method. An average temperature of 28.5-30°F. should be maintained if possible; every degree of temperature higher than this will lower the quality of the shrimp and shorten the storage time.

6. In all methods of holding, shrimp with the heads removed kept better than those with the heads left on.

TABLE 9

TOUGHNESS SCORES—HEADS OFF

MAXIMUM SCORE: 5.0

Days Storage	SEAWATER-HELD				SEAWATER-HELD				
	Unchanged	Plus 5ppm NaOCl	Plus 10ppm NaOCl	Plus 20ppm NaOCl	Unchanged	Plus 500 Fram Kem	Plus 1000 Fram Kem	Plus 10ppm $CaOCl_2$	Plus 50ppm $CaOCl_2$
	Average holding temperature °F								
	30.8	30.2	30.9	33.2	31.8	31.8	31.8	32.0	32.0
2	4.8	4.8	4.6	4.8	..	..	..	..	..
5	4.0	4.6	4.4	4.2	..	..	..	..	..
6	..	..	..	..	4.6	..	..	4.4	4.2
7	..	..	..	..	4.4	4.4	4.2	..	..
8	4.0	3.8	3.8	4.4	..	..	..	..	..
10	..	..	..	..	4.0	..	..	4.0	3.2
11	..	..	..	..	3.6	3.8	3.8	..	..
12	4.2	4.0	4.4	4.4	..	..	..	..	..
13	..	..	..	..	3.8	..	..	4.0	3.0
14	..	..	..	..	3.8	3.4	3.8	..	..
15	4.2	3.8	4.0	4.0	..	..	..	..	..
17	..	..	..	..	3.0	..	..	3.2	3.8
18	..	..	..	..	4.2	3.6	3.6	..	..
19	3.2	3.8	3.2	3.2	..	..	..	..	..
20	..	..	..	..	3.8	..	..	3.0	2.6
21	..	..	..	..	3.6	2.8	3.2	..	..
22	3.4	2.4	2.8	2.6	..	..	..	..	..
24	..	..	..	..	3.0	..	..	3.4	3.8
25	..	..	..	..	3.0	2.8	2.4	..	..