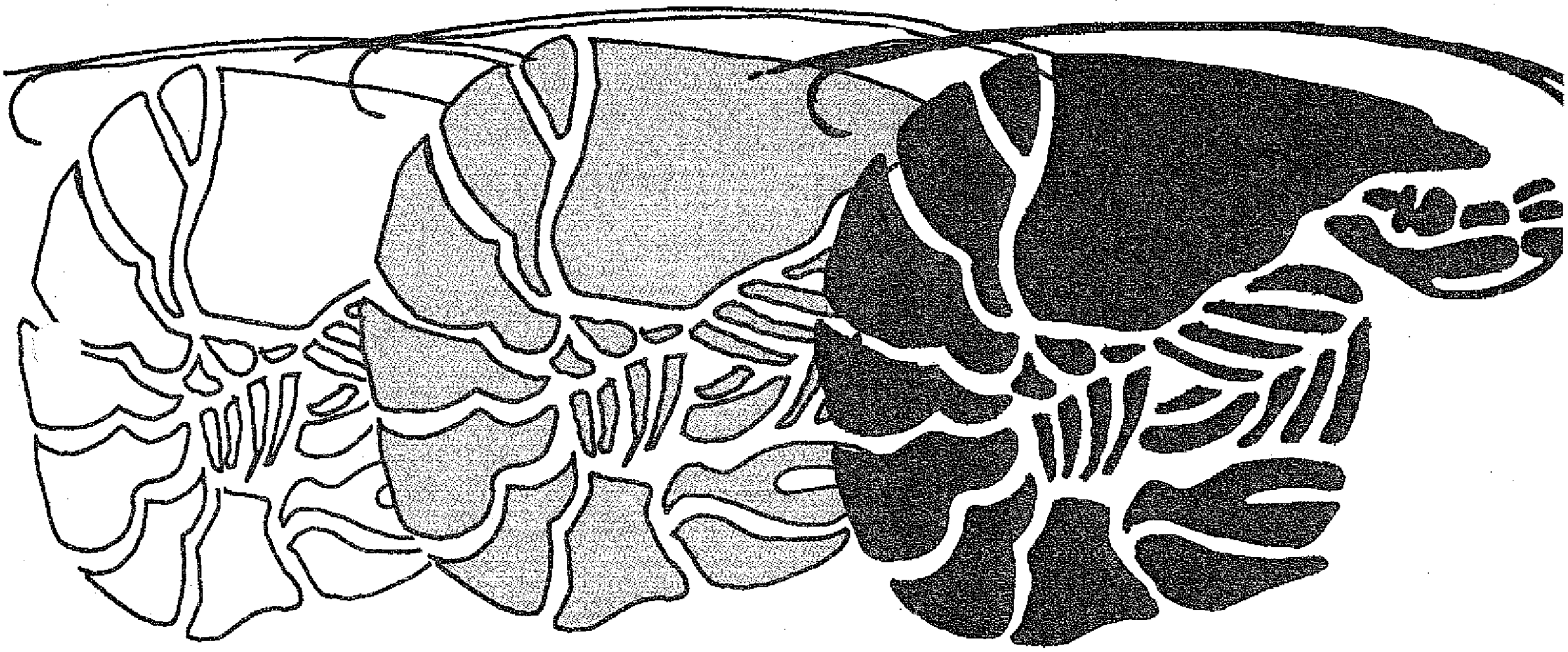
Brine Freezing



LOUISIANA COOPERATIVE EXTENSION SERVICE
LOUISIANA STATE UNIVERSITY AGRICULTURAL CENTER

LOUISIANA SEA GRANT College Program
Center for Wetland Resources
Louisiana State University

ENERGY DIVISION
Expanding Louisiana's Energy Potential
Louisiana Department
of Natural Resources

Brine Freezing

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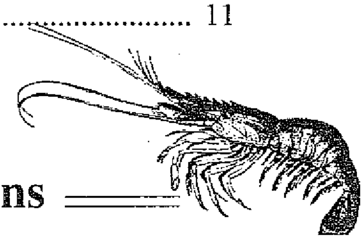


Processing Considerations

Brine freezing offers an effective and relatively economical method for freezing shrimp. Since rapid freezing in brine does not require extremely low temperatures, it is also an inherently energy-efficient method of quick freezing. Because of rapid ice crystal formation within the shrimp, a superior end product is the result. Shrimpers receive an additional benefit, because the need for icing is eliminated. There is more space for shrimp, and because refrigeration is always available, the shrimper does not have to guess how much ice is needed for a trip.

Wrong guesses result in either wasted ice or the necessity of cutting productive trips short, resulting in less efficient operation. This results in more cost for each pound of shrimp caught. The cost results from more fuel burned because of heavier loads (more ice than necessary) or more trips in and out (not enough ice). It also shows up in less catch because the boat cannot stay on the productive ground, and the shrimp may be gone when the boat returns. Time on the water does not become a limiting factor if shrimp are brine frozen. When shrimp are iced, time is the most important factor.

Brine freezing is an exacting procedure that must be followed carefully. To guess, or to use procedures not recommended, will result in a poor or unacceptable product. The following comments should be useful in producing good results:

1. Use brine freezing for shell-on headless or head-on shrimp. Brine freezing can also be used for other whole shellfish such as live crabs and crawfish. Do not use brine freezing for fish fillets or other exposed flesh type of seafoods. Because of the harsh salt solution, fish fillets will absorb excessive salt and lose moisture.

2. To minimize the absorption of salt by the product, always pre-chill the shrimp before dipping them in the brine tank. It is also important to use the exact amount of salt and use the lowest possible temperatures with adequate brine circulation. Results have shown that, even with these precautions, a 0.7% NaCl absorption can be expected.

3. The use of sodium bisulfite is especially crucial since the upper levels are highly regulated. By law, there can be no more than 100 p.p.m. It is not recommended to add sulfite to the brine tank. Always dip in a 1.25% aqueous solution for one minute followed by a 15-second rinse in clean water. This ensures even dispersal of the sulfite and will not exceed the limitations. When sulfite is added to the brine tank, poor distribution is usually the result. When using any sulfiting solution, always use a well-ventilated area since toxic fumes may be given off.

4. Foaming can create considerable problems when using a brine tank. Foaming can be controlled for the most part by using an anti-foaming agent. A list of agents and companies is included.

Like all frozen products, shrimp, fish and other seafoods will lose weight during freezer storage. To mimimize the weight loss, sugar or syrup is added to the brine tank. Sugar or syrup will freeze on the product and form a protective glaze. This will help to prevent dehydration and, consequently, weight loss. In addition, this glaze will help to prevent the product from sticking together. One type of sugar that you can use is corn sugar.

As a general rule add corn syrup and dip in the following amounts:

1. Corn syrup (liquid) 0.12 gallons per gallon of brine.

2 Corn syrup (powder) 1.19 pounds per gallon of brine.

Anti-foaming Agents

1. Distilled Monoglycerides
2. Mono & Di-glycerides
3. Silicon-based Additives
4. Sugar Esters
5. Combined Products

ABCO Laboratories (1-5)
2377 Stanwell Drive
Concord, CA 94520
(415) 685-1212

Bentley Chemical Corp. (2)
190 North Cannon Drive
Box 5581
Beverly Hills, CA 90210
(213) 272-9946

Breddo, Incorporated (2)
18th & Kansas Avenue
Kansas City, KS 66105
(913) 321-5300

C-Corp (1,2,4)
2770 Vail Avenue
Los Angeles, CA 90040
(213) 722-4800

Dairyland Food Labs, Inc., (3)
620 Progress Avenue, Box 406
Waukesha, WI 58316
(414) 547-5531

Dederich Corp. (3)
Box 218
Germantown, WI 53022
(414) 251-6171

Dow Corning Corporation (3)
Box 0994
Midland, MI 48686-0994
(517) 496-4000

Accurate Ingredients, Inc. (2)
135 Eileen Way
Syosset, NY 11791
(516) 496-2500

Biocon (US), Inc. (3)
2348 Palumbo Drive
Lexington, KY 40509
(606) 269-6351

Capital City Products Co. (2)
P. O. Box 569
Columbus, OH 43216
(614) 299-3131

Continental Flavors &
Fragrances (2)
2951 E. Enterprise Street
Brea, CA 92621
(714) 524-8320

Dari-Tech Industries (2)
3582 McCall Place, NE
Atlanta, GA 30340
(404) 455-3603

Degussa Corporation (3)
Rt. 46 & Hollister Rd.
Teterboro, NJ 07608
(201) 288-6500

Durkee Industrial Food,
SCM Corp (2)
925 Euclid Avenue
Cleveland, OH 44115
(216) 344-8317

Dynamit Nobel of America,
Inc. (2)
Kay-Fries Chemical Division
10 Link Drive
Rockleigh, NJ 07647
(201)784-0200

Fellek Chemical Corp. (1,4)
21-25 Center Avenue
Fort Lee, NJ 07024
(201) 592-8100

Germantown Mfg. Co. (2)
505 Parkway
P. O. Box 405
Broomall, PA 19008
(215) 544-8400

Grindsted Products, Inc. (1,2)
201 Industrial Pkwy., Box 26
Industrial Airport, KS 66031
(913) 764-8100

ITT Paniplus (2,5)
100 Paniplus Rdwy.
Olathe, KS 66061
(913) 782-8800

Kraft, Inc. (2)
Industrial Foods Group
Box 398
Memphis, TN 38101
(901) 766-2100

Patco Products Div. (1,3,5)
C. J. Patterson Company
3947 Broadway
Kansas City, MO 64111
(800) 821-2250

Seafood Preservatives, Inc. (5)
Box 1844
Bellevue, WA 98009
(206) 454-4551

Thompson Hayward Chemical
Company (3)
P. O. Box 2383
5200 Speaker Rd.
Kansas City, KS 66110
(913) 321-3131

Witco Chemical Company (1,2)
520 Madison Avenue
New York, NY 10022
(212) 605-3673

Eastman Chemical Products,
Inc.(1,5)
Health & Nutrition Products
Box 431
Kingsport, TN 37662
(615) 229-2000

General Electric Company (3)
Silicon Products Division
Section E92
Waterford, NY 12188
(518) 237-3330

Glyco, Inc. (2)
488 Main Avenue Rt. 7
Norwalk, CT 06856-5100
(203) 847-1191

Hodeg Chemical Corp. (2,3,5)
7247 N. Central Park Ave.
Skokie, IL 60076
(312) 675-3950

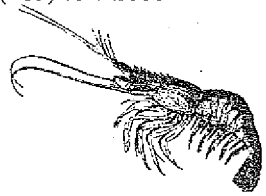
Kraft Chemical Company (1,2)
1975 N. Hawthorne Ave.
Melrose Park, IL 60160
(312) 345-8210

Mazer Chemicals, Inc. (1,3,5)
3938 Parett Drive
Gurnee, IL 60031

PVO International, Inc. (2)
416 Division Street
Boonton, NJ 07005
(201) 334-2900

Stauffer Chemical Company (5)
Milk Proteins Group
1000 Crooks Road
Clawson, MI 48017
(800) 521-7194

Union Carbide Corporation (3)
32 Old Ridgebury Road
Danbury, CT 06817-0111
(203) 794-2666



Economic Aspects

Even given that brine freezing is the most energy efficient and least energy cost method of quick freezing seafood, there are other factors which need to be considered in an economic analysis when considering the installation of a brine freezer in a retail or wholesale seafood business. Proper use of the system, once installed, is essential for quality products, energy efficiency and profits to result. A seafood retailer, in particular, needs to consider a few things before installing a brine freezer. If the following points are not considered before purchasing a freezer, proper operating procedures alone will not make the freezer a profitable addition to the business.

a. Is there adequate space to permit efficient operation? Most retail seafood businesses occupy buildings not designed specifically for seafood handling. A brine freezer will require space for equipment, work area and holding freezers.

b. Determine whether or not your existing holding freezer has sufficient unused space to accommodate the product from the brine freezer. Will the brine system addition be your only additional cost?

c. For which seafood will you use the brine freezer? Determine the role these items play in the business's profitability. If their contribution is small, then sales must increase to cover the additional investment.

d. The frequency of using the system may play a role in its location. Infrequent use for a few seasonal items may indicate location in a low-cost structure outside the existing store.

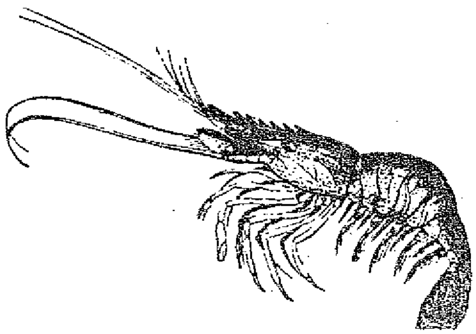
e. Storage of additional product when prices are low to sell when the off-season allows higher prices will require cash to establish the inventory. Does the business have sufficient cash to purchase enough seafood to use the brine freezer effectively? If not, the cost of borrowed money must be added to the total cost of using the brine freezer.

Investment in a brine freezer will more likely be profitable when a retailer considers these points. When combined with your product mark-up, this information can provide insight to profit potential. The two easiest costs to identify are the equipment cost (associated repairs) and utilities. Other real costs are difficult to specify. Among the other costs are labor, ingredients, additional holding freezer operation, and perhaps weight loss. Weight gain occurs initially because of the glaze. However, when the product is thawed for sale in the display case, this and other weight loss may occur.

Example: Prestige Seafood, a retail/wholesale operation, purchased a brine freezing system for $4,000. The owner used company reserves from the bank account to purchase the system. The account was paying the company 8% interest. The sales company recommends a depreciable life of seven years with an average of 5% of cost allowed for annual repairs. Prestige's owner estimates 20,000 pounds of product frozen annually, but wants to know the cost per pound so product price can be estimated accurately.

1. To pay back the $4,000 of company funds formerly earning 8% amounts to $768.28 per year:	$768.28
2. Annual repairs at 5% of equipment cost:	200.00
Sub-total	$968.28
3. Utilities @ $.015 per pound for 20,000 lbs.: (Includes holding freezer)	$300.00
Total	$1,268.28
Cost of initial brine freezing:	$.063 per lb.

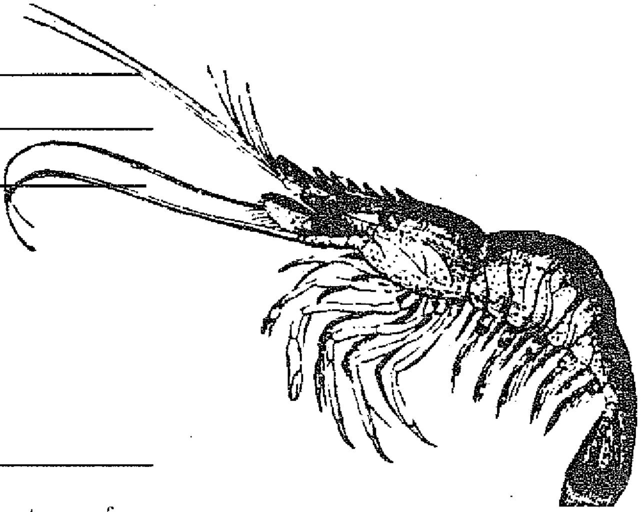
Many additional complicating factors can be important. The use of 20,000 pounds may reflect a volume the typical retailer cannot achieve. A reduction of volume to 15,000 pounds increases the cost per pound to $.085 per pound. Do not forget to include your own estimates of other costs such as labor, packaging and interest from money borrowed to store seafood. With interest at only 8%, a $2 product you are freezing will add another $.04 per pound per quarter to the cost of the frozen product.



The annual amount which a brine system must pay back per $1,000 invested over a certain period at various interest rates is available from the table. For the example, the $768.28 charge was obtained by: 4 x $192.07 where 4 is the number of thousands of dollars for freezer purchase.

Annual Amount to be repaid per $1,000

Interest rate	Recapture Period of Investment		
	5 years	7 years	10 years
8%	$250.46	$192.07	$149.03
10%	263.80	205.41	162.75
12%	277.41	219.12	176.98
14%	291.28	233.19	191.71



The initial cost of a brine freezer is usually less than for other types of IQF freezers as is the energy usage and utility cost. Based on these costs, the brine freezer is the most economical one to use. However, keep in mind that you are limited as to which products are compatible with this freezing method.

Technical Aspects

Quick Freezing

Quick frozen product requires that heat be rapidly removed from the product. For this reason, the emphasis could be placed on the word quick.

How rapidly heat is removed from the product can be described by the equation:

$$\dot{Q} = h \cdot A \cdot \Delta T$$

This is the equation used by engineers in discussing transfer of heat from a solid to a fluid such as to air or water.

“$\dot{Q}$” is the heat transfer rate usually expressed as British thermal unit/hour. Btu/hr. is a measure of the amount of heat transferred. For rapid freezing $\dot{Q}$ should be large.

“ΔT” is the temperature difference between the product and the fluid medium surrounding the product. If the temperature difference is increased, the heat transfer rate is increased.

“A” is the surface area for heat transfer. Increasing the surface area increases the heat transfer rate.

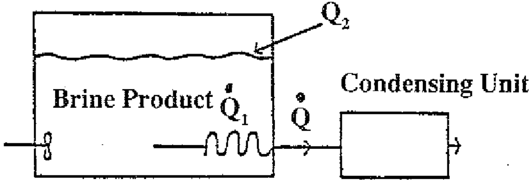
“h” is the convective heat transfer coefficient. It is used to relate two easily measured quantities, A and ΔT, to the heat transfer rate. It depends on the fluid, fluid movement and the physical arrangement. It is difficult to determine exactly, but you already know how to increase its value. Have you ever blown on a spoonful of soup or gumbo to cool it? Have you ever dropped a hot object in water to cool it? In both cases you were increasing the heat transfer rate by increasing h. Liquids have higher convective heat transfer coefficients than do gases. Rapidly moving fluids have higher coefficients than do slowly moving or still fluids. Increasing h increases the heat transfer rate.

The high convective heat transfer coefficient of fluids is one reason a brine freezer is so energy efficient. The high heat transfer coefficient means that the brine temperature does not have to be as low as with air or cryogenics. It is harder to produce lower temperatures and requires more energy and bigger compressors. Another advantage of the brine freezer is that no defrosting is required. This means that all the energy that is put into a defrost cycle, and the energy used to remove the heat put in by the defrost cycle, is saved. These two factors combine to make the brine freezer about 40% more efficient than freezing with air.

Brine Freezers

One way of obtaining rapid freezing is with brine freezers. Brine, a mixture of salt and water, is a good heat transfer medium. The convective heat transfer coefficient tends to be high, the brine is nontoxic, inexpensive and the right concentration is liquid down to -6°F.

A brine freezing system is illustrated in the following schematic:



Heat from the product, at a rate of $\dot{Q}_1$, enters the brine. As heat is removed, the product freezes. If the brine is cold (below 10°F) and is well circulated, typical freezing time for shrimp or crawfish is 5 to 10 minutes. To preserve the quality, the product should not be in the brine any longer than necessary, and certainly no more than 15 minutes. At the same time heat, Q_2 from the surroundings also enters the brine. If the heat is not removed from the brine at the same rate it is put into the brine, the brine temperature will rise. If brine temperatures are over 10°F, freezing time increases and product quality declines. To keep the temperature of the brine constant, the rate of heat removal must equal the rate of heat input. In equation form,

$$\dot{Q}_3 = \dot{Q}_1 + \dot{Q}_2$$

The rate of heat removal depends on the refrigeration equipment and determines the long-term capacity of the brine freezer.

The Product

Brine freezing is frequently used for shrimp. Shrimp should not fill the basket, container or sacks used to hold them while freezing since they can pack together and block the flow of the brine.

The amount of product that can be frozen depends on how much heat has to be removed. Table 1 shows the amount of heat that must be removed from one pound of shrimp to freeze it to 10°F and 20°F.

Table 1: Btu Per Pound

Initial Temperature	32°	40°	50°	60°	70°
Final Temperature					
10°F	132	138	147	156	164
20°F	128	134	143	151	160

The required amount of heat removed from most seafood would be about the same.

If we wanted to freeze 100 pounds of shrimp (from 40°F to 20°F) an hour and keep the brine temperature constant, we would need to remove 134 X 100 or 13,400 Btu/hour of heat. In addition, we would need to remove any heat gain from the surroundings. Since the heat from the surroundings should be considerably smaller than the heat removed from the product, the refrigeration capacity needed is largely determined by how much product we want to freeze and the time period over which we freeze it.

To obtain minimum salt penetration and highest quality, shrimp should be prechilled before freezing.

Brine:

A mixture of NaCl (ordinary table salt) and water makes a suitable brine for freezing food. It is cheap, nontoxic and correct mixtures do not freeze down to -6°F. It also has considerable heat capacity and thus can store some cooling capacity. Table 2 lists pure NaCl brine solutions and their properties.

As you may note, the freezing point depends on the salt concentration. The lowest freezing point of -6°F is obtained at 23.31% salt. At only one percentage point more salt, the freezing point rises to about 5°F, a difference of 11°F. Because of this sensitivity, it is extremely important to use and maintain the proper proportions of salt to water. Failure to maintain proper proportions can result in coils icing, reduced capacity and a loss of energy efficiency. In addition, if brine temperature is allowed to rise, product quality may suffer.

Table 2 can be used as a guide.The density of the brine depends on how much salt it contains. As more salt is added, the density increases and each gallon of brine weighs more. The density can be measured with a hydrometer. A hydrometer is a calibrated tube weighted at the bottom. The height at which it floats depends on the density of the liquid it is floating in. As the density increases, the hydrometer floats higher. The hydrometer can be marked corresponding to the density of the liquid. However, since the density also depends on temperature, these markings are accurate at only one temperature. In most cases hydrometers are calibrated at a temperature of 60°F.

Table 2

Strength of Brine			Salt		Water	Freezing Point	
			Pound Salt Per				
Salometer Degree	Spec. Gravity	% Salt By Wgt.	Gallon Water	Gallon Brine	Gallon Water Per Gallon Brine	F°	C°
0.	1.000	0.0000	0.0000	.0000	1.0000	+32.0	0.0
2.	1.004	0.5279	0.0442	.0441	.9985	+31.5	-0.3
4.	1.008	1.0558	0.0889	.0886	.9970	+31.1	-0.5
6.	1.011	1.5837	0.1340	.1334	.9954	+30.5	-0.8
8.	1.015	2.1116	0.1797	.1785	.9938	+30.0	-1.1
10.	1.019	2.6395	0.2258	.2240	.9921	+29.3	-1.5
12.	1.023	3.1674	0.2724	.2698	.9905	+28.8	-1.8
14.	1.027	3.6953	0.3196	.3160	.9887	+28.2	-2.1
16.	1.031	4.2232	0.3672	.3625	.9870	+27.6	-2.4
18.	1.034	4.7511	0.4154	.4093	.9852	+27.0	-2.8
20.	1.038	5.2790	0.4624	.4565	.9834	+26.4	-3.1
22.	1.042	5.8069	0.5134	.5040	.9816	+25.7	-3.5
24.	1.046	6.3348	0.5633	.5519	.9797	+25.1	-3.8
26.	1.050	6.8627	0.6137	.6001	.9779	+24.4	-4.2
28.	1.054	7.3906	0.6646	.6448	.9759	+23.7	-4.8
30.	1.058	7.9185	0.7162	.6975	.9740	+23.0	-5.0
32.	1.062	8.4464	0.7683	.7468	.9720	+22.3	-5.4
34.	1.066	8.9743	0.8211	.7964	.9700	+21.6	-5.8
36.	1.070	9.5022	0.8745	.8464	.9679	+20.9	-6.2
38.	1.074	10.0301	0.9285	.8968	.9658	+20.2	-6.6
40.	1.078	10.5580	0.9831	.9474	.9637	+19.4	-7.0
42.	1.082	11,0859	1.0384	.9985	.9616	+18.7	-7.4
44.	1.086	11.6138	1.0493	1.0499	.9594	+17.9	-7.8
46.	1.090	12.1417	1.1509	1.1017	.9572	+17.1	-8.3
48.	1.094	12.6696	1.2082	1.1538	.9550	+16.2	-8.8
50.	1.098	13.1975	1.2662	1.2063	.9527	+15.4	-9.2
52.	1.102	13.7254	1.3249	1.2592	.9504	+14.5	-9.7
54.	1.106	14.2533	1.3844	1.3124	.9480	+13.7	-10.2
56.	1.110	14.7812	1.4445	1.3660	.9457	+12.8	-10.7
58.	1.114	15.3091	1.5055	1.4200	.9433	+11.4	-11.4
60.	1.118	15.8370	1.5671	1.4744	.9408	+10.9	-11.7
62.	1.122	16.3649	1.6296	1.5292	.9384	+9.9	-12.3
64.	1.126	16.8928	1.6928	1.5843	.9359	+8.9	-12.8
66.	1.130	17.4207	1.7569	1.6399	.9334	+7.9	-13.4
68.	1.134	17.9486	1.8218	1.6958	.9308	+6.8	-14.0
70.	1.139	18.4765	1.8875	1.7521	.9283	+5.7	-14.6
72.	1.143	19.0044	1.9541	1.8089	.9257	+4.6	-15.2
74.	1.147	19.5323	2.0216	1.8661	.9231	+3.4	-15.9
76.	1.151	20.0602	2.0899	1.9236	.9204	+2.2	-16.5
78.	1.156	20.5881	2.1592	1.9816	.9178	+1.0	-17.2
80.	1.160	21.1160	2.2293	2.0400	.9151	-.4	-18.0
82.	1.164	21.6439	2.3005	2.0988	.9123	-1.6	-18.7
84.	1.169	22.1718	2.3726	2.1580	.9096	-3.0	-19.4
86.	1.173	22.6997	2.4456	2.2176	.9067	-4.4	-20.2
88.	1.177	23.2276	2.5197	2.2776	.9039	-5.8	-21.0
88.3	1.178	23.3100	2.5314	2.2870	.9034	-6.0	-21.1
90.	1.182	23.7555	2.5948	2.3380	.9010	-1.1	-18.4
92.	1.186	24.2834	2.6710	2.3988	.8981	+4.8	-15.1
94.	1.190	32.9987	2.7482	2.4600	.8951	+11.1	-11.6
96.	1.195	25.3392	2.8265	2.5217	.8921	+18.0	-7.8
97.	1.197	25.6032	2.8661	2.5526	.8906	+21.6	-5.8
98.	1.199	25.8671	2.9060	2.5837	.8891	+25.5	-3.6
99	1.202	26.1311	2.9462	2.6150	.8876	+29.8	-1.2
99.6	1.203	26.2850	2.9686	2.6323	.8867	+32.3	+0.2
100	1.204	26.3950	2.9865	2.6469	.8863	+60.0	+15.56

The scale on the hydrometer could be any convenient range of numbers. A salometer is a hydrometer with a scale particularly useful for working with brines. With a salometer, we will be working with whole numbers or whole numbers with one decimal place. This scale is the first column in Table 2. Although salometers are convenient to work with, they are not as readily available as standard hydrometers. For this reason, the second column contains standard hydrometer readings. Both scales, as well as the entire Table 2, are for brines at 60^{0}F.

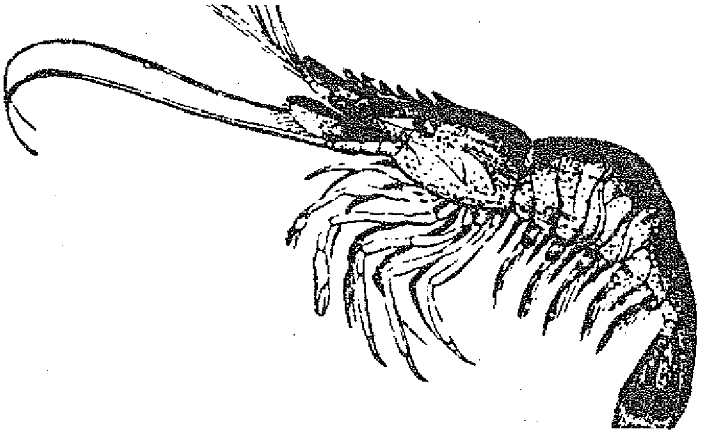
Table 3 can be used to correct readings taken at temperatures other than 60^{0}F.

Table 3

Observed Salometer Reading	**Approximate Correction in Salometer Degrees**	
	Subtract per degree below 60 F	**Add per degree above 60 F**
0 to 10..........	0.049	0.060
11 to 20..........	0.064	0.082
21 to 30..........	0.077	0.094
31 to 40..........	0.087	0.103
41 to 50..........	0.095	0.112
51 to 60..........	0.102	0.118
61 to 70..........	0.107	0.123
71 to 80..........	0.112	0.128
81 to 90..........	0.116	0.131
91 to 100..........	0.120	0.134

Once the correct reading is obtained, we can use the information in the remaining columns of Table 2 to determine what we need to add to the brine. This use of the table is best illustrated by an example:

Note: When adding salt, add slowly so that it will have a chance to dissolve. Some operators have found it helpful to have a separate mixing tank to dissolve the salt.



Example 1

Method:

1. Take hydrometer and temperature reading.

2. If temperature is not 60^{0}F, use Table 3 to obtain correct salometer reading. If a standard hydrometer is used, you must first use Table 2 to convert to salometer degrees.

3. If the salt content is too low:
   a. Determine how much salt is needed
   b. Determine how much salt is in solution
   c. Subtract b from a; add this much salt

   Repeat steps 1 - 3 until reading is correct.

4. If the salt content is too high:
   Add water gradually to get correct reading or
   a. Determine how much salt is in solution
   b. Determine how much water is in the solution
   c. Determine correct amount of water for the amount of salt
   d. Subtract b from c, and add this much water

Procedure:

Initial filling of a tank 30 inches wide by 48 inches long to depth of 36 inches.

$$\text{Volume} = L \times H \times W = 48 \times 36 \times 30 = 51{,}840 \text{ cubic inches}$$

there are 231 cubic inches in one gallon

$$\#\text{ gallons} = \frac{51{,}890}{231} = 224 \text{ gallons}$$

The volume taken up by the tubing and other equipment is estimated at 1 cubic foot. There are 7.5 gallons per cubic foot. Net amount of liquid 224 - 7.5 = 216.5 gallons. Since tubing and equipment volume were estimated, we will allow a margin of error and use a value of 200 gallons of liquid.

At 88.3 salometer degrees on Table 2, we have 2.287 pounds of salt per gallon of brine. We need 2.287 X 200 = 457.4 pounds of salt.

After filling the tank and mixing the salt with the water, we test the brine. A specific gravity reading of 1.16 at 70^{0}F is obtained. This corresponds to 80 salometer degrees. Since we are not at 60^{0}F, we correct for temperature by adding 0.128 X 10 = 1.28. Our actual salometer reading is 81.28 degrees. The brine has a freezing point of about -1^{0}F. This is not too bad, but we need more salt - some error must have been made - we actually have 220 gallons of brine. If we add salt, we increase the amount of brine, not water. We have 2.3 pounds of salt per gallon of water now or 457.4/2.3 = 198.9 gallons of water. At 88.3 we would have 2.53 pounds of salt per gallon of water or (2.53)(198.9) = 503 pounds of salt. We need to add 503 - 457.4 = 45.6 pounds of salt.

Brine can absorb about 7 1/2 Btu per gallon with a temperature rise of 1^{0}F. This means that the brine may allow a higher rate of product freezing for short periods than the refrigeration unit alone could handle. For example, 200 gallons of brine by going from 0^{0}F to 5^{0}F could absorb (7.5)(200)(5) = 7,500 Btu of heat from the product. This would be sufficient to freeze about 50 pounds of shrimp. Thus, if we had a steady freezing capacity of 100 pounds/hour, we could freeze 150 pounds in one hour if we allow the temperature to rise. To lower the temperature of the brine we would need to freeze less than 100 pounds/hour. This capacity allows some flexibility in scheduling product freezing but also requires time to cool the brine initially. In addition, this capacity means that the compressor will not be subjected to frequent cycling. Frequent cycling increases energy consumption and reduces compressor lifetime.

One potential problem with brine is corrosion. Brine can be very corrosive if the pH is not correct. pH refers to how acid or basic a solution is; a pH less than 7.0 is acidic, a pH greater than 7.0 is basic and a pH of 7.0 is neutral. To inhibit corrosive action, the pH of the brine solution should be slightly above 7.0 -- about 7.5. The pH can change, most commonly by absorbing carbon dioxide from the air and becoming acidic. For this reason, check the solution at least daily and avoid any unnecessary splashing. Adding sodium hydroxide will increase the pH.

The presence of dissimilar metals can lead to rapid corrosion of the more active metal. This process is known as electrolysis. It can occur even when only one metal is used if that metal has non-uniformity. The best practice to avoid electrolytic corrosion is to avoid the use of dissimilar metal. If this cannot be done, use of a sacrificial anode such as aluminum is recommended. In addition, disodium phosphate in an amount of 1 1/3 pound to 100 gallons of water can be used in the initial charge to inhibit corrosion by forming a protective metal film.

In some situations, such as the freezing of shrimp for long-term storage, adding corn syrup in the ratio of 1 to 1 1/2 gallons of syrup to 10 gallons of brine is helpful. The syrup will help form a glaze and can reduce salt penetration. However, the addition of syrup increases the density of the brine. If you decide to add syrup to the brine, you will need to make adjustments in the way you determine how much salt is needed. One way is to mix your first batch by the numbers and then record the hydrometer reading obtained at various temperatures. During operation, salt should be added to obtain a hydrometer reading somewhere between those listed in Table 2 and those you obtained. Another way is to use a general rule for how much to add. For every 1,000 pounds of product, add 28.8 pounds of salt and 2 1/2 gallons of syrup.

You may also combine these two methods and add salt and sugar in a ratio of 28.8 pounds salt to 2 1/2 gallons syrup until the initial hydrometer reading is obtained.

The brine will remain useable for an indefinite period if it is kept below 20 ^{0}F. At temperatures above 20 ^{0}F, the lifetime of the brine will be reduced. It is recommended that the solution be discarded and the tank thoroughly cleaned and flushed every 30 days or when 40 to 50 tons of product have been processed. At a minimum, clean the tank and flush with clean, fresh water at the end of each processing season.

Refrigeration Coils:

Refrigeration coils are the link between the brine and the condenser unit. They affect the (hA) part of the $\dot{Q} = h A \Delta T$ equation. A is the surface area of the coil, and h depends on both the coil and the flow of brine around it. A variety of types of coils, either inside or outside the tank, could be used.* The simplest to construct is the coil composed of bare tubing inside the tank. A bare tube should be able to obtain convective heat transfer coefficients of 50 to 150 Btu/hour per square foot per degree Fahrenheit. The amount of coil used is a compromise, but as a general rule, use 8 to 10 square feet of coil surface per 12,000 Btu/hour (ton) of capacity. The surface area of a tube is equal to:

$$A = \frac{\pi D}{12} \times \text{length}$$

where D, the outside diameter, is measured in inches, the length in feet and the area given in square feet. To find the length needed use:

$$\text{length (feet)} = \frac{12 \times A}{\pi \times D}$$

π is approximately equal to 3.14

A surface area of eight square feet with h of 100 would provide 12,000 Btu/hour of capacity with a 15^{0}F temperature difference between the refrigerant and the brine. The temperature difference should be small because the capacity of the refrigeration unit decreases as the temperature it sees decreases. We don't want to be extremely large in coil area (very low Δ T) since it would require a much larger refrigerant charge and result in greater chance of slugging the compressor. Slugging can destroy a compressor and should be avoided.

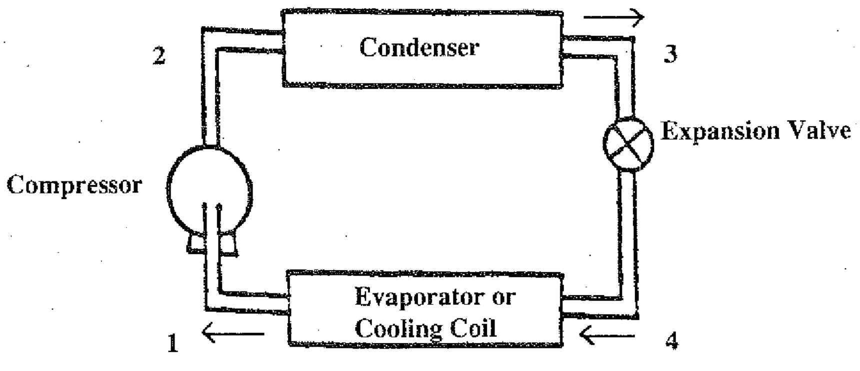
The diameter of the coil should be such that a high refrigerant velocity is maintained so that oil separation and lack of lubrication and compressor failure won't occur. A conflicting requirement that the pressure drop through the coil not be too great may require multiple coils. Too great a pressure drop in the coil will severely decrease the capacity and increase the operating cost. You should use experienced and qualified refrigeration personnel in putting your system together.

Ideally, seamless cupro-nickel or stainless steel tubing should be used because of their resistance to corrosion. This material is very expensive. For this reason copper tubing, both seamless and jointed, has been used, and with considerable success.

Arrange the tubing in the tank so that a good flow of brine around the coil is obtained. If a good flow is not obtained, the coil will freeze, resulting in a loss of capacity, and will require more energy to freeze each pound of product. The coil should also be physically accessible so that it can be cleaned when the tank is drained. Failure to do this could result in a buildup of deposits and greatly reduced heat transfer. This results in less capacity and more expensive operation.

The Condensing Unit:

The condensing unit is the heart of the refrigeration system. It consists of a compressor, a condenser and control and associated equipment such as receivers. The function of the unit can best be understood by first referring to a simple refrigeration system illustrated below.



*There are commercially available coils and plates which are made for applications such as brine freezing. The commercial coils should come with recommendations on capacity.

The compressor receives low pressure refrigerant vapor from the evaporator and discharges it at a high temperature and pressure. It is basically a constant volume pump. The amount of work input increases as the pressure output increases. The pressure output depends on outside temperatures and the condenser. This high temperature vapor is condensed to liquid refrigerant in the condenser. The pressure at which this occurs depends on the condensing temperature. Lower condensing temperatures mean lower condensing pressures. This is similar to what happens in a pressure cooker. At atmospheric pressure water boils at 212^0F, but at higher pressures, water must be at higher temperatures to boil.

The high pressure liquid from the condenser passes through an expansion valve and experiences a sudden drop in pressure. When the pressure drops, a portion of the liquid refrigerant boils and the temperature of the refrigerant is dropped. (This is similar to what happens when pressure is let off a pressure cooker. Part of the water flashes into steam and the remaining water drops to 212^0F.) The cold mixture of liquid and gas then enters the evaporator where the liquid absorbs heat and vaporizes.

Lower temperatures require lower pressures, which means that more refrigerant will be boiled in going through the expansion valve. Since a smaller portion of the refrigerant entering the evaporator is liquid, the refrigerant absorbs less heat because there is not as much liquid to boil. Lower evaporator temperature means less refrigeration from each pound of refrigerant circulated and less capacity from the system since fewer pounds of refrigerant are circulated (low pressure vapor weighs less and the volume the compressor doesn't change). As the evaporator temperature decreases, the capacity of the system is reduced and energy usage is increased.

Since the capacity of the system depends strongly on the evaporating temperature, condensing units must be chosen to match the load requirements at a particular evaporating temperature. Manufacturers have tables giving the capacity over the range of temperatures for which the unit is suitable. The evaporator temperature depends on the temperature of the brine and the temperature difference between the brine and the refrigerant. The equation of heat transfer yields this relationship:

$$\text{capacity} = \dot{Q} = h \bullet A \bullet \Delta T$$

The capacity and Δ T will change until the equation holds. If $h \bullet A$ is small, then Δ T will be large and the capacity of the unit will decrease. However, very large values of $h \bullet A$ are expensive to achieve and can lead to other problems. A good compromise is a ΔT of 12 to 15^0F.

Condensing units have ranges of evaporator temperatures over which they can operate. Temperatures lower than the low temperature limit could lead to failure because of insufficient cooling. The refrigerant vapor supplies the cooling, and at low pressures there may not be enough vapor to cool the compressor. At high evaporator temperatures (high pressure), this vapor is much denser and requires more power to pump. This could cause the compressor motor to overheat.

Choose an efficient condenser unit to obtain lower operating cost. The condenser unit must also be maintained properly if it is to achieve its rated capacity and efficiency. This means primarily to keep it clean. Failure to do so will result in higher energy usage and operating cost, reduced capacity and shorter life for the equipment.

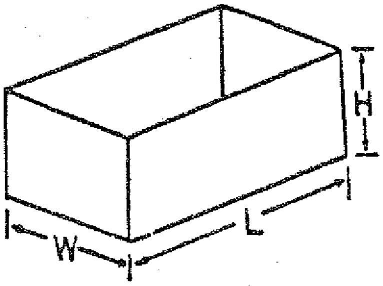
Tank:

The tank serves the dual purpose of holding the brine and insulating it from the surroundings. It should be large enough so that the product can be easily worked. Large volumes also give large storage capacity to the brine. In addition, there should be adequate room for any equipment such as evaporator coils that will be in the tank. Remember to allow for product displacing the brine. It should also incorporate some means of agitating the brine. Various devices such as propellers and pumps have been used successfully. Perhaps the most efficient is a boat propeller. It will be used in the sample system discussed later. Insulation should be equivalent to minimum of 2 inches of urethane (R-16). An insulated top should be part of the tank, and used at least during periods when no product is being frozen.

Finally, the tank should be constructed in such a manner and of materials so that it is easily cleaned and resistant to the corrosive effects of the brine.

The volume of a tank may be determined by:

Rectangular Tank



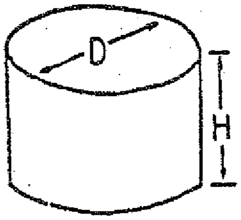
Volume = L X H X W
(H is depth of water)

Gallons = $\frac{\text{L X H X W (in inches)}}{231}$

or

Gallons = L X H X W (in feet) X 7.5

Circular Tank



$$\text{Volume} = .78 \times D \times D \times H$$

$$\text{Gallons} = \frac{.78 \times D \times D \times H(\text{in inches})}{231}$$

or

$$\text{Gallons} = .78 \times D \times D \times H(\text{in ft.}) \times 7.5$$

General Rules:

Because of the many variables involved, it is not possible to have precise design values. However, some general rules, along with the items already covered, should give a good starting point for your systems.

1. 1 1/4 to 1 1/2 tons of refrigeration capacity at evaporator temperature (-15 to -20^{0}F) for each 100 pounds/hour of product handled.

2. Eight to 10 square feet of evaporator surface area (tube type) for each ton of refrigeration capacity.

3. Four hundred gallons of brine for each 100 pounds/hour of product throughout. (If the product load is evenly spaced throughout the hour, for example 25 pounds every 15 minutes, 100 gallons for each 100 pounds/hour capacity may be used.)

4. Pump down control with receiver.

5. Use professionally competent refrigeration personnel.

Example:

Freezer Requirements:

1,000 pounds/day, 8-hour day,
sometimes 250 pounds/hour for an hour or two,
50 pounds in tank at a time in two 25-pound batches

Design:

1 1/4 to 1 1/2 tons of refrigeration per 100 pounds/hour. Since we don't know initial temperature of shrimp or exact heat gain from surroundings, use 1 1/2 ton

steady load = 125 pounds/hour

$$\frac{1.5 \times 125}{100} = 1.875 \text{ tons or } 22{,}500 \text{ Btu/hr.}$$

evaporator temperature -15 to -20^{0}F (assuming h = 100)

Looking over a manufacturer's capacity table, several units are noted:

One uses R-502 refrigerant, has a capacity of 29,900 Btu/hr. at -15^{0}F, an operating range of 0 to -40^{0}F and requires 3-phase power.

One uses R-22 refrigerant, has a capacity of 25,200 Btu/hour at -15^{0}F, an operating range of 0 to -40^{0}F and can use single-phase power.

One uses R-12 refrigerant, has a capacity of 22,800 Btu/hour at -15^{0}F, an operating range of -5 to -40^{0}F and can use single phase power.

Choose R-22 unit since 3-phase power is not available, and it has greater range of operating temperature. R-22 is also less harmful to the environment.

2.1 tons @ -15^{0}F and 8 to 10 square feet of coil per ton would give:

$8 \times 2.1 = 16.8$ ft.^{2}

$10 \times 2.1 = 21$ ft.^{2}

use about 20 ft^2 of tubing

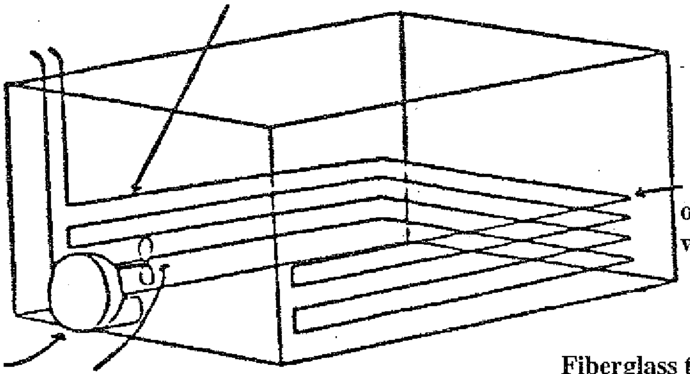
Since the suction line valve is 1 3/8 inches, this diameter tubing will be tried. This size of tubing requires 2.78 feet for each square foot of surface area.

$$L = \frac{A \times 12}{D} = \frac{(1)(12)}{(3.14)(1.375)} = 2.78 \text{ feet}$$

Total length needed is (20)(2.78) = 55.6 feet of tubing. A check with manufacturer's specifications says this is acceptable from both a velocity and pressure drop standpoint.

Gallons of Brine: Try (400)(1.25) = 500 gallons = 66.7 ft.^{3} Tank: 4' X 4' X 6' = inside dimensions; allow 1 foot freeboard. Gross interior volume = 4 X 3 X 6 = 72 ft.^{3}; about right

Tentative Design:



1 3/8" Dia. tubing on 6" centers first run 9" above tank bottom

Center line of tubing 4" from wall

Powered by 1/2 " HP motor. drive belt is shielded and propeller is enclosed by a guard

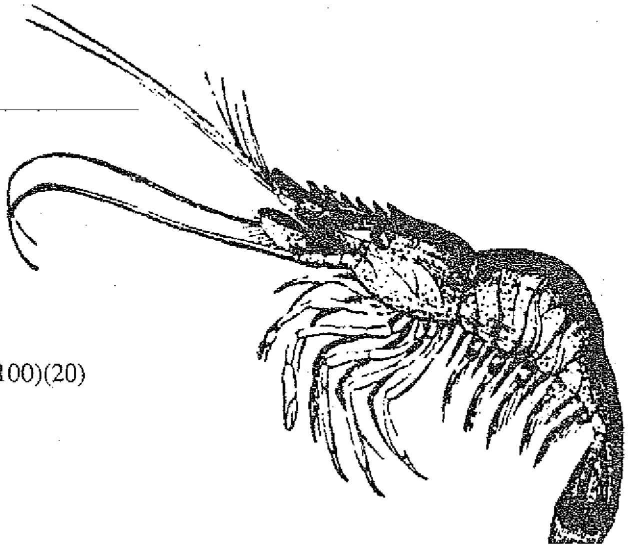
9" propeller turning 300 rpm at 1/2' from bottom

Fiberglass tank 2" polyurethane foam insulation

Expected Performance:

Compressor Data

Evaporating Temperature(F^0)	Capacity(Btu/hour)
- 5	31,600
-10	28,600 (estimated)
-13	28,600 (estimated)
-15	25,200
-20	22,400 (estimated)
-25	19,600



A. $h = 100$ Btu/hour-ft.^{2} - ^{0}F

using: capacity = $\dot{Q} = h \bullet A \Delta T$
and trial and error process as follows:

Brine temperature = 0^0F

Assume $\dot{Q} = 25{,}200$ $\Delta T = \dot{Q}/ha$ $ha = (100)(20)$

Then $\Delta T = \frac{25{,}200}{2{,}000}$ $\Delta T = 12.6^0$F

evaporator temperature would be -12.6^0F
capacity is larger than 25,200 - use 26,600

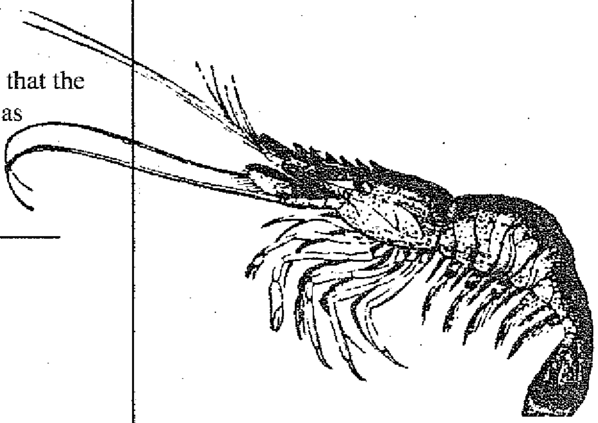
$\Delta T = \frac{26{,}600}{2{,}000} = 13.3$, evaporator temperature = -13.3

-13.3 is close enough. At 0°F brine temperature, the capacity of the unit is 26,600 Btu/hour. Following this procedure a chart of brine temperature vs. capacity is developed as follows:

Brine Temperature (F)	Capacity of unit (Btu/hr.)
0	26,600
5	28,600
10	31,000

500 gallons of brine means 1°F temperature change corresponds to 3,750 Btu.

We don't know the exact schedule of operation but will assume that the brine temperature is maintained between 0 and 5°F and the loading is as follows:



Hour	Quantity(lb.)
1	200
2	250
3	150
4	100
5	100
6	100
7	100
8	0

Heat transfer through the tank should be about 500 Btu/hour. If we allow an additional 1,500 Btu/hour of heat for loading (baskets, gain from open top, etc.), we have a steady load of 2,000 Btu/hour from the surroundings. Assuming the initial brine temperature is 5°F (worst case), the following table can be generated (product load is taken as 150 Btu/pound):

Hour	**Quantity) (lbs.)**	**Heat Load (Btu/hour)**	**Brine (F)**	**Refrigeration Effect (Btu/hour)**	**Temperature (F) Change of Brine**
1	200	32,000	5	28,600	+0.9
2	250	39,500	5.9	29,000	+2.8
3	150	24,500	8.7	30,500	-1.6
4	100	17,000	7.1	29,500	-3.3
5	100	17,000	3.8	28,000	-2.9
6	100	17,000	.9	27,000*	-0.9
7	100	17,000	0	-	+4.5
8	-	2,000	4.5	-	+0.5

Heat load = 150 X Quantity + 2,000

Refrigeration effect = Capacity at brine temperature while compressor running

$$\text{Temperature Change of Brine} = \frac{(\text{Heat load - Refrigeration effect})}{3{,}750}$$

* Compressor kicks off at brine temperature of 0°F

B. h = 50 Btu/hour-ft^{2}-^{0}F

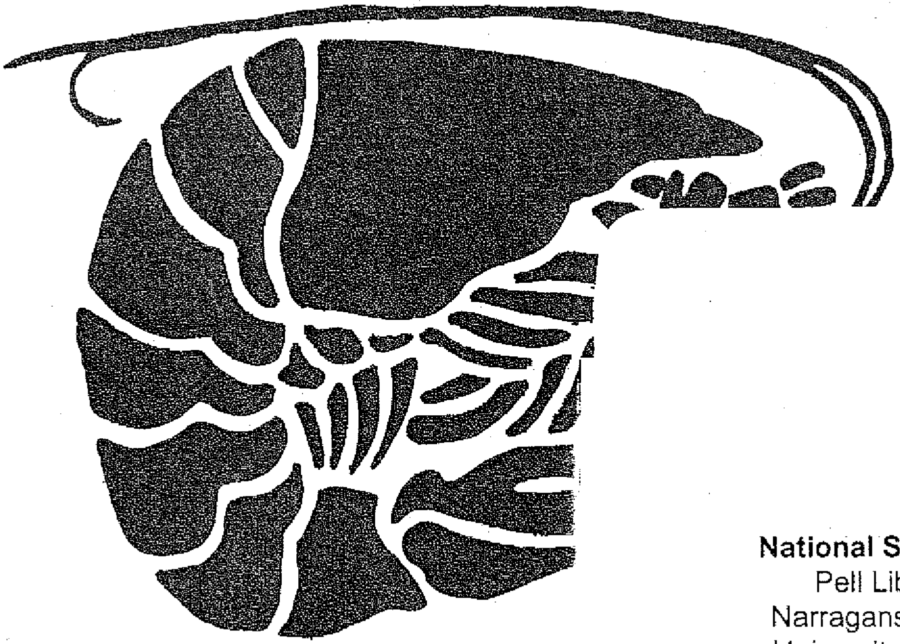
Using the same method results in

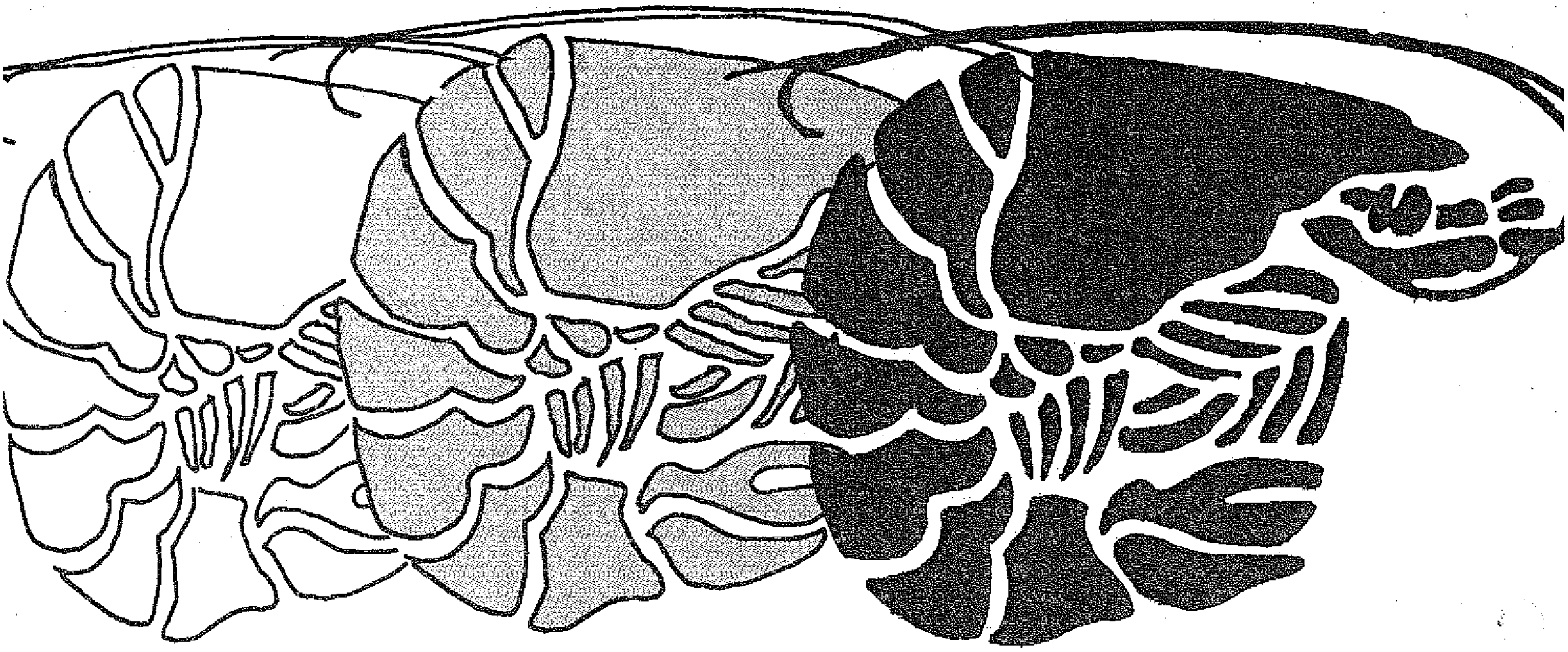
Brine Temperature (F)	**Capacity of Unit (Btu/hour)**
0	21,700
5	23,000
10	25,200

Hour	**Quantity lbs.**	**Heat Load (Btu/hr.)**	**Brine Temp. (F)**	**Refrigeration Effect(Btu/hr)**	**Temperature (F) Change of Brine**
1	200	32,000	5	23,000	2.4
2	250	39,500	7.4	24,000	4.1
3	150	24,500	11.5*	25,500	-.25
4	100	17,000	11.25	25,500	-2.25
5	100	17,000	9	24,500	-2
6	100	17,000	7	24,000	-2
7	100	17,000	5	24,000	-2
8	-	2,000	3	23,000	-3

*Slightly above desired temperature range of 0 to 10 °F

Conclusion: Unit is suitable since even with low h and severe loading unit keeps temperature within reason.





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