Defrosting Shrimp With Microwaves

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INTRODUCTION

The fishing industry has paid a great deal of attention to rapid freezing in order to reduce quality losses and increase efficiency, and many innovations concerning cryogenic freezing have been developed. Conversely, very little has been done on defrosting applications, and the industry is still using procedures developed many years ago. Much of the U.S. seafood production is dependent on reprocessing, where bulk frozen products are defrosted and processed into consumer items. Fish portion and fish stick processors are required to temper fish blocks up to 20F for cutting operations. Layer-packed fillets must be partially defrosted for proper separation prior to processing, and scallops and shrimp must be completely defrosted for peeling and breading operations. These operations are usually carried out using tempering rooms, water defrosting systems, warm air systems and ambient air. In general, all of these require a large amount of labor and a great deal of time and space, creating problems in production scheduling and leading to quality losses and bacterial contamination problems.

In the shrimp industry, the most common defrosting procedure used is water defrosting. The frozen shrimp in 5-pound boxes are immersed in continuously overflowing tanks with 80F water for periods of 1 to 3 hours. This system often leads to product losses, high labor costs and sanitation problems.

In recent years, technologists have been researching new methods of defrosting and tempering for the fishing industry in an attempt to eliminate the warm air or warm water procedures.

When heat is applied to frozen fish, either by warm air or water or by radiant heat, the surface thaws first. The remaining frozen fish is then surrounded by thawed material having only about one-third the thermal conductivity of the frozen material; consequently the time necessary to thaw fish completely is much greater than that necessary to freeze it under similar conditions of surface heat transfer. Unfortunately thawing time cannot be shortened by subjecting the surface to high temperatures, for this could produce cooking, drying or deleterious effects upon quality.

For these reasons, much research has been carried out on electronic methods of defrosting such as dielectric and microwave heating. The basic principle of these procedures is similar. The frozen mass of material is placed in an alternating electrical energy field which causes individual molecules within the frozen

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material to oscillate with the alternating current. This results in molecular friction within the material generating heat. Since the heat is uniform throughout, great precision in heating can be achieved, and since thermal conductivity is not a factor the time of defrosting can be greatly reduced.

Researchers at Torry Research in Aberdeen (Jason and Sanders, 1962) have carried out extensive testing with fish at 35 mHz and Bengtsson (1963) has demonstrated the defrosting of both meat and fish at 35 and 2450 mHz. The results of these experiments indicated marked advantages over common defrosting procedures and some disadvantages concerning runaway heating and high capital cost for equipment. In general, the lower frequencies indicate a slower heating rate, and "arcing" problems occur, producing spot burning of the product. At the higher frequency, the depth penetration is limited, restricting product thickness. In 1969 the National Marine Fisheries Service (NMFS) with the cooperation of Raytheon Company carried out a series of defrosting and tempering experiments using 915 mHz (Learson and Stone, 1969). Results of these tests indicated that this intermediate frequency eliminated many of the problems previously reported for electronic defrosting. Using a 5 kw conveyorized microwave tunnel, blocks of clam meats, scallops, flounder and shrimp were uniformly heated to internal temperatures of 28-34F, allowing separation of the block for further processing. The most promising applications for the microwave system appeared to be the tempering of fish blocks for cutting applications and the defrosting of shrimp. Fish blocks could be heated from 0F to 15F very rapidly with a temperature differential of less than 3 degrees within the block. Five-pound blocks of frozen raw, headless shrimp were heated to 31 ± 2F at a rate of 50 lbs per hour per kw at which point semi-thawed shrimp were surrounded by the ice glaze. The block could then be broken easily by impact, releasing the shrimp for processing after removing the ice glaze with a water spray.

The following describes the continued research carried out on shrimp defrosting using microwave energy.

OBJECTIVES

In 1971 it is estimated that over 60 million pounds of raw, headless shrimp were defrosted for further processing in the United States, primarily in breading plants. For this reason, these experiments were conducted with raw, headless shrimp of the intermediate sizes used for breading. During this time, water-defrosting was the prevailing method used by industry. The purpose of this research was to compare quality and sanitation aspects of microwave versus typical industry water-defrosting procedures.

Laboratory tests and production-scale tests in a shrimp breading plant were conducted. Data were obtained on sanitation, quality and economic considerations for both water and microwave-defrosting. The following sets forth the procedures used and results obtained from these experiments.

LABORATORY TEST PROCEDURES

Water-defrosting experiments were carried out at the NMFS Atlantic Fishery Products Technological Center in Gloucester, Massachusetts. Corresponding studies on microwave-defrosting were conducted at the Raytheon Company Microwave and Power Tube Division, New Products Center in Waltham, Massachusetts. Raw, headless brown shrimp *(Penaeus aztecus)* of known history were used for the laboratory experiments. These shrimp were shipped in ice to the Gloucester Laboratory where they were then frozen and glazed in 5-pound cartons. They were held at 0F for 30 days prior to defrosting.

A stainless steel tank holding approximately 50 pounds of 65F water was used to defrost 10-pound batches of shrimp. Water was added periodically to maintain approximately 65F throughout the defrosting process.

The microwave defrosting was carried out in a 915 mHz conveyorized multimode applicator (Fig. 1). Duplicate samples were defrosted by both methods and were analyzed in comparison with a frozen control sample. Determinations of bacterial load and composition were carried out, and organoleptic comparisons were made using an experienced laboratory taste panel.

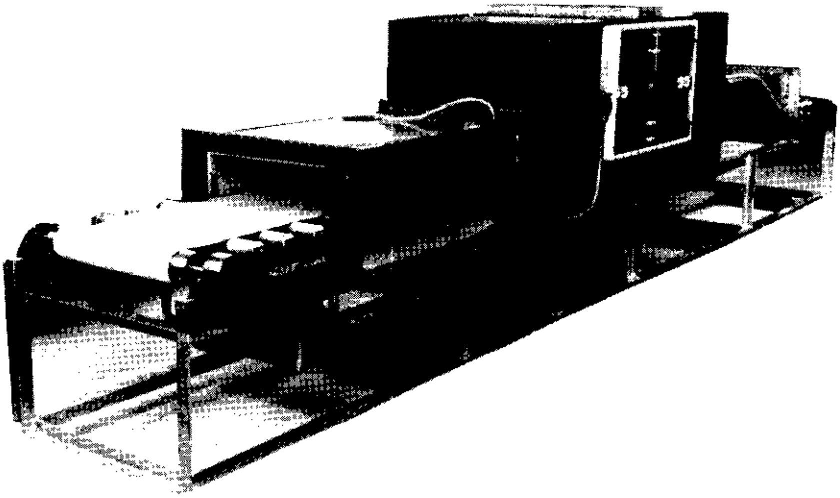

Fig. 1. Photograph of 5 kw microwave defrosting system.

LABORATORY TEST RESULTS

Bacteriological samples taken from the frozen control indicated a total plate count of 1.8×10^5. At the conclusion of microwave-defrosting and at the conclusion of a 2-hour water-defrost, the counts were identical to that of the control. A rapid spray wash with tap water reduced the count by one log cycle to 1.7×10^4 on the microwave-defrosted shrimp. Total plate counts on peeled meats defrosted by the two methods did not differ significantly. These data are summarized in Table 1.

Proximate analyses were carried out on the samples (Table 2). The microwave-defrosted sample did not vary significantly from the frozen control. However, the water-defrosted shrimp contained an average of 16.30% protein compared with 18.70% in the frozen control. The moisture/protein ratio of the

Table 1. Laboratory test – Bacteriological results for microwave vs water defrosted raw, headless shrimp (31-35 per lb)

Sample	Total Plate Count (number per gram)
Frozen control	1.8×10^5
Microwave-defrosted, no wash	1.8×10^5
Microwave-defrosted, spray wash	1.7×10^4
Water-thawed for one hour	7.7×10^4
Water-thawed for two hours	1.8×10^5
Water-thawed, peeled	7.2×10^4
Microwave-thawed, peeled	5.7×10^4

water-defrosted samples averaged 5.05 versus 4.32 for the frozen control and 4.34 for the microwave-defrosted.

Batches of shrimp defrosted by both methods were hand peeled, then cooked for a yield determination. These data are summarized in Table 3. Peeled yield of water-defrosted shrimp was 1.7% greater than the microwave-defrosted samples. However, the cooked yield was 4.5% greater for the microwave-defrosted shrimp. This result is attributed to the improved protein retention associated with microwave-defrosting.

Table 2. Laboratory test – Proximate composition of microwave vs water defrosted raw, headless shrimp (31-35 per lb*)

	Frozen control	Microwave-defrosted	Water-defrosted 1 hour	Water-defrosted 2 hours
% protein	18.70	18.60	16.05	16.55
% moisture	80.68	80.72	81.91	82.35
% fat	.134	.217	.220	.178
% ash	1.05	1.01	1.00	.80
Moisture/ protein ratio	4.32	4.34	5.10	4.97

*For analysis purposes the compositions are based on peeled meats

Table 3. Laboratory test – Peeled and cooked yield from microwave vs water defrosted raw, headless shrimp (31-35 per lb)

	Water-defrosted	Microwave-defrosted
Frozen raw, headless weight (g)	2267	2267
Peeled weight (g)	1828	1788
Peeled yield (%)	80.6	78.9
Cooked weight (g)	1468	1517
Cooked/peeled yield (%)	80.2	84.7
Cooked/frozen yield (%)	64.8	67.0

Taste panel evaluations using a triangle test format indicated that no significant difference could be attributed to either defrosting method.

PRODUCTION TESTS

The 5 kw microwave system used in the laboratory tests and illustrated in Figure 1 was installed in a shrimp breading plant and operated for 11 days. During this time 16,010 pounds of raw, headless shrimp of various sizes were microwave-defrosted (Table 4).

The optimum flow condition was found to be 350 pounds per hour at 5 kw. Typical shrimp temperatures at the tunnel exit ranged from 28.5F to 30F, while input temperatures ranged from 5F to 17F. It was possible to achieve separation of individual shrimp at flow rates up to 450 pounds per hour (26F) but those shrimp required considerable additional heat input before they became suitable for peeling.

Conversely, flow rates as low as 250 pounds per hour were tested in order to try to raise the temperature of the shrimp above 30F. However this resulted in

Table 4. Production test – Type and quantity of raw, headless shrimp defrosted with 5 kw microwave tunnel

Size	Type	Origin		Quantity (lb)
26-30	White	Texas		1,800
31-35	White	Colombia		1,210
36-40	White	Colombia		2,950
41-50	White	Colombia		2,400
40-50	Brown	Louisiana		1,200
51-60	Pink	Mexico		6,450
			TOTAL	16,010

some spot overheating of shrimp. This condition was attributed to three factors: (a) defrosted shrimp absorbs microwave energy faster than frozen shrimp, (b) substantial temperature gradients existed in shrimp blocks entering the tunnel and (c) the tunnel used in the tests was subsequently found to have an energy gradient, so that more energy was applied to the sides of the shrimp blocks than to the center portion.

It was found that the microwave energy had little effect on the glaze ice. At all flow rates, a matrix of ice surrounded the partially-defrosted shrimp upon exit from the tunnel. This ice matrix could be easily broken into small fragments by impacting the carton once on a flat solid object. Careful inspection to determine whether this impact had any adverse effect upon the shrimp, such as broken tails, indicated no damage to the shrimp. Shrimp that were lightly glazed (Colombian, poly-lined cartons) could be separated without impacting. Shrimp mixed with as much as 2-pounds of glaze ice (Mexican, pan-frozen) could be separated effectively after impacting the carton on its large side.

Bacteriological samples were not obtained during the production tests, but some general observations relative to water-defrosting were made. First, it was not possible to completely remove the carton from frozen shrimp, so the exterior packaging material normally accompanied the shrimp into the defrosting tank. This could lead to cross-contamination of the entire contents of the defrosting tank. Second, the temperature of the tap water was approximately 80F and this

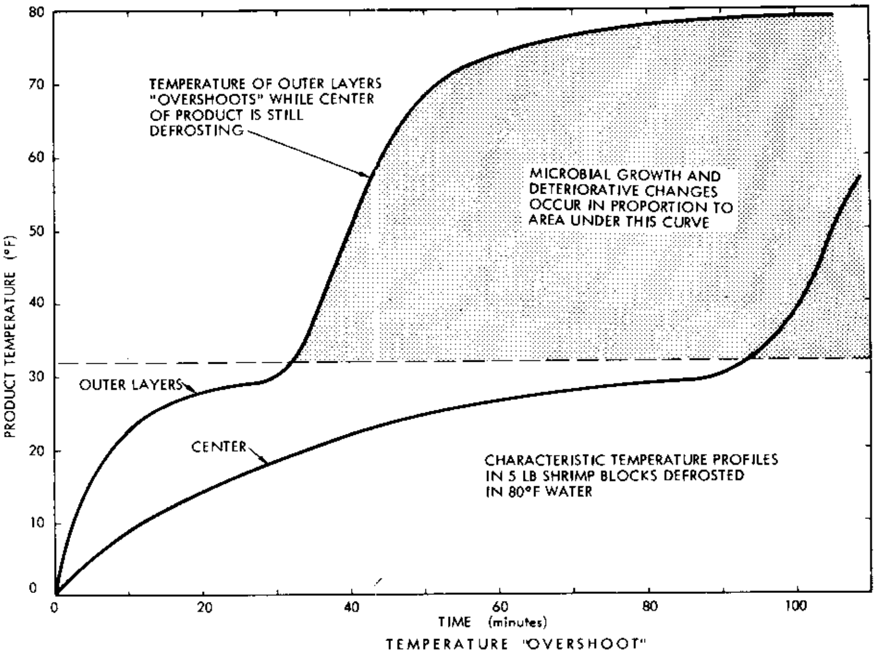

Fig. 2. Temperature overshoot curve.

temperature was maintained during most of the defrosting process. Typical time-temperature profiles in the water-defrosted shrimp are shown in Figure 2.

Proximate analyses were carried out on samples defrosted under production conditions by both methods. These results are set forth in Table 5. As reported in the laboratory tests, the water-defrosted shrimp consistently contained less protein than the microwave-defrosted. Moisture/protein ratios were also higher in the water-defrosted samples.

Loss of protein during water-defrosting was further investigated by sampling the defrosting water. Figure 3 shows this protein-leaching effect. Soluble protein in the water was found to increase steadily throughout the 4-hour test.

Shrimp defrosted by both methods were subjected to informal taste tests at the plant. For both boiled and fried breaded samples, the panelists indicated a preference for the microwave-defrosted shrimp. A "sweet" flavor was attributed to microwave-defrosted samples versus a "bland" flavor for water-defrosted shrimp.

During the production tests, a number of attempts were made to obtain comparative yield data for the two defrosting methods. Based on composition difference, one might expect that microwave-defrosting would improve yield at least 1% over water-defrosting. The value of a 1% gain in yield could exceed $150,000 per year in a large shrimp breading plant. Conclusive data were not obtained, however, because of excessive variables and difficulties encountered in making accurate measurements under production conditions. For example, suc-

Table 5. Production test – Proximate composition of microwave vs water defrosted raw, headless shrimp*

	Louisiana brown 40-50 count	Louisiana brown 40-50 count	Colombia white 41-50 count	Colombia white 36-40 count
% protein (water defrosted)	16.57	17.13	16.68	15.54
% protein (microwave-defrosted)	18.66	17.80	17.49	16.36
Protein difference (% of total weight)	2.09	.67	.81	.82
Moisture/protein ratio (water-defrosted)	4.97	4.76	4.93	–
Moisture/protein ratio (microwave-defrosted)	4.28	4.53	4.65	–

*For analysis purposes the compositions were determined from peeled meats

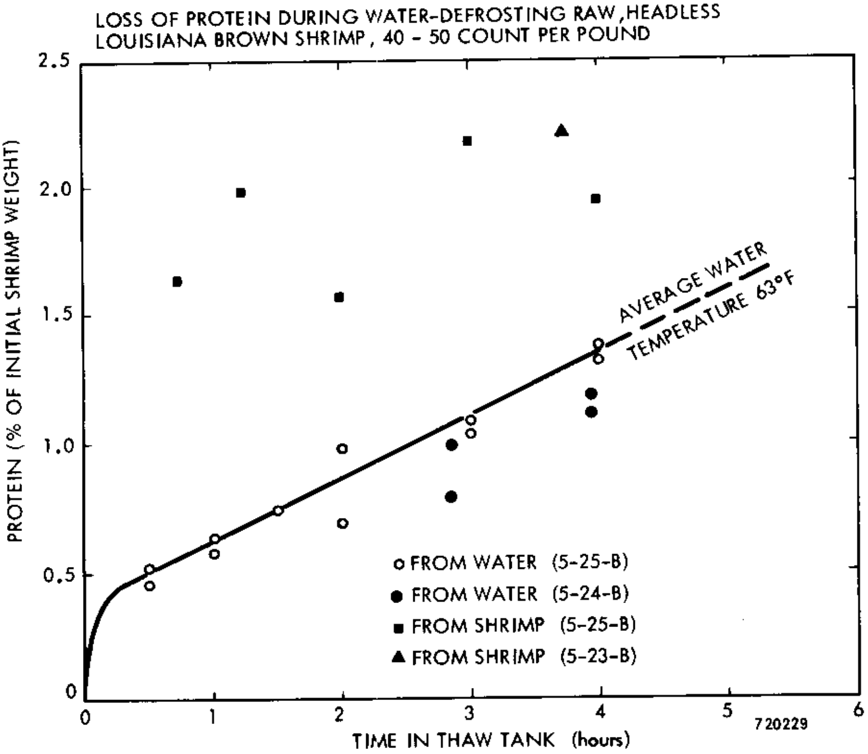

Fig. 3. Loss of protein vs time.

cessive tests on shrimp from the same lot, defrosted and handled under identical conditions, showed production yield differences of 3%.

The only significant measure of yield that is relevant for this analysis would compare the weight of the frozen raw, headless shrimp versus peeled or breaded weight. However, frozen weight is indeterminate because all frozen raw, headless shrimp contain glaze. Therefore, label weights must be used. Accordingly, an experiment was conducted to determine true frozen weights in one lot of Mexican, pan-frozen shrimp. Individual 5-pound boxes were microwave-defrosted, drained and weighed under uniform conditions. The standard deviation in the individual weights was ± 3.3%, and distribution was not normal in the sample measured (28 boxes). Therefore, a large number of comparative tests would be required to establish statistical validity.

Drained weight of raw, headless shrimp is also of little significance since it was shown that defrosted shrimp lose weight continuously with time. Also, since water-defrosting significantly alters the composition, there may be differences in the physical properties of water and microwave-defrosted shrimp. This could affect the subsequent peeled yield, especially when machine peeling is employed. In similar studies on herring defrosting, Jason and Sanders (1962) reported yields, after subsequent processing, of 88% for electronic-defrosted herring versus 68% for water-defrosted samples.

It proved to be very difficult to follow individual lots of shrimp through the peeling stage and obtain accurate weight measurements under commercial conditions. Mechanical adjustments of the peeling machine and variable residence time of peeled shrimp in water were two variables contributing to differences in peeled yield. If an attempt had been made to measure yield differences on the basis of breaded weights, even more variables, such as breading percentage, would be introduced. When these factors became apparent, no further attempts were made to measure comparative production yields.

Table 6. Comparison of defrosting and drip loss costs[1] for processing frozen shrimp[2]

	Air	Water	Microwave
		OPERATING COSTS	
Initial investment	1.00	.18	3.12
Operation & maintenance	1.00	1.00	1.50
Space cost	1.50	.12	.20
Inventory cost	1.00	–	–
Labor cost	6.00	4.00	4.00
Icing cost	2.00	4.00	–
Water cost	–	.30	.02
Water disposal cost	.15	.45	.03
Subtotal of Operating Costs	12.65	10.05	8.87
		EFFECT OF YIELD	
Drip loss (estimated)	4%	3%	2%
Cost of drip loss	60.00	45.00	30.00
Total Operating & Effect of Yield Costs	72.65	55.05	38.87
Cost Difference	33.78	16.18	–
Annual Savings from Microwave ($)	101,340	48,540	–

[1] Costs in $ per 1,000 lbs. of shrimp

[2] Based on 3 million pounds annual production

ECONOMICS: AIR, WATER AND MICROWAVE-DEFROSTING

Ambient air and forced warm air defrosting are commonly used at the present time, especially for block-frozen peeled shrimp. The great advantage of this method is that little or no investment is required. However, the resultant time-temperature profiles in shrimp defrosted by this method contribute to high drip loss and unsatisfactory sanitary conditions. The Food and Drug Administration's Good Manufacturing Practice (GMP) guideline for raw breaded shrimp indicates that air defrosting should not be carried out above 45F. Defrosting in chilled air is common in the meat industry where procedures are closely regulated. However, this is a very expensive method from the standpoint of operating costs. If the material to be defrosted is left on pallets, a week or more may be required to defrost the interior cases. This is not a desirable practice from the standpoint of quality and sanitation. Furthermore, the value of the product tied up in inventory and the space required generate high operating costs.

Normally, the product to be defrosted in chilled air is set out on racks to permit circulation. The time required is dependent on spacing and air flow, but typically may be 2 days for shrimp. This method is also attended by high operating costs for space and inventory. In addition, there is a significant labor factor in setting out shrimp cartons on racks and cleaning racks before they are reused. Although the outer layers of shrimp are held under 45F, they are likely to undergo considerable drip loss during the time required for the center portion to defrost. In Table 6, an estimate of $12.65 per 1,000 pounds is given as the cost of defrosting by this method. The writers estimate that this method would result in an average drip loss of 4% which would add approximately $60 per 1,000 pounds to the defrosting cost. Table 6 also contains an analysis of operating cost for a water-defrosting system. This method is less costly ($10.05 per

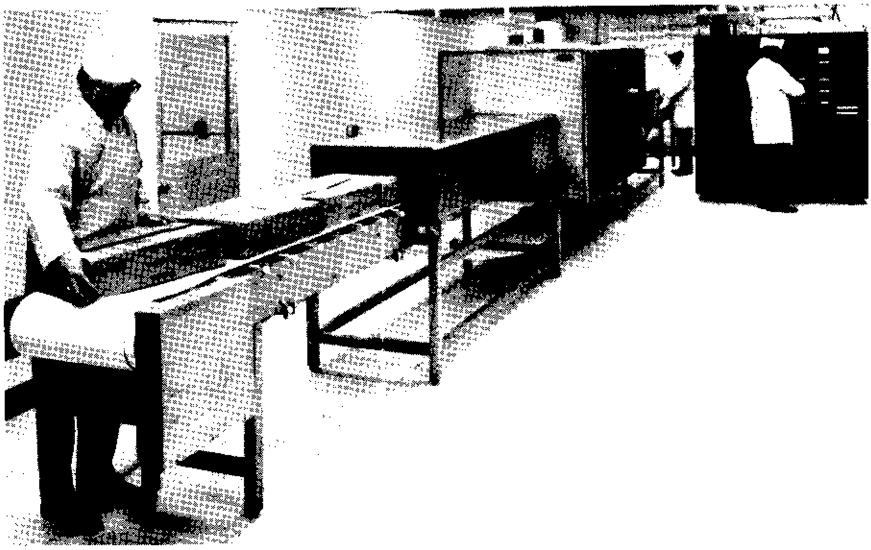

Fig. 4. Photograph of 25 kw microwave defrosting system.

1,000 pounds) than air-defrosting. Water-defrosting results in higher product temperatures, as shown in the "temperature overshoot" condition illustrated in Figure 2. This in turn generates a requirement for careful icing. The cost of this ice, and the labor of applying and later removing it, make a substantial contribution to overall operating cost. Also, the pressure created by this ice may induce shrinkage. Drip loss varies among types of shrimp, method of freezing, conditions of storage, etc., but the writers estimate 3% as an average for water-defrosting. This would add about $45 per 1,000 pounds to the total defrosting cost.

An analysis is also presented in Table 6 for microwave-defrosting with a production model 25 kw conveyorized system.[4] A typical system used in the meat industry is illustrated in Figure 4. This equipment has a higher initial cost than air or water systems, equivalent to $3.12 per 1,000 pounds defrosted, when amortized over 8 years at 3 million pounds per year. However, the total operat-

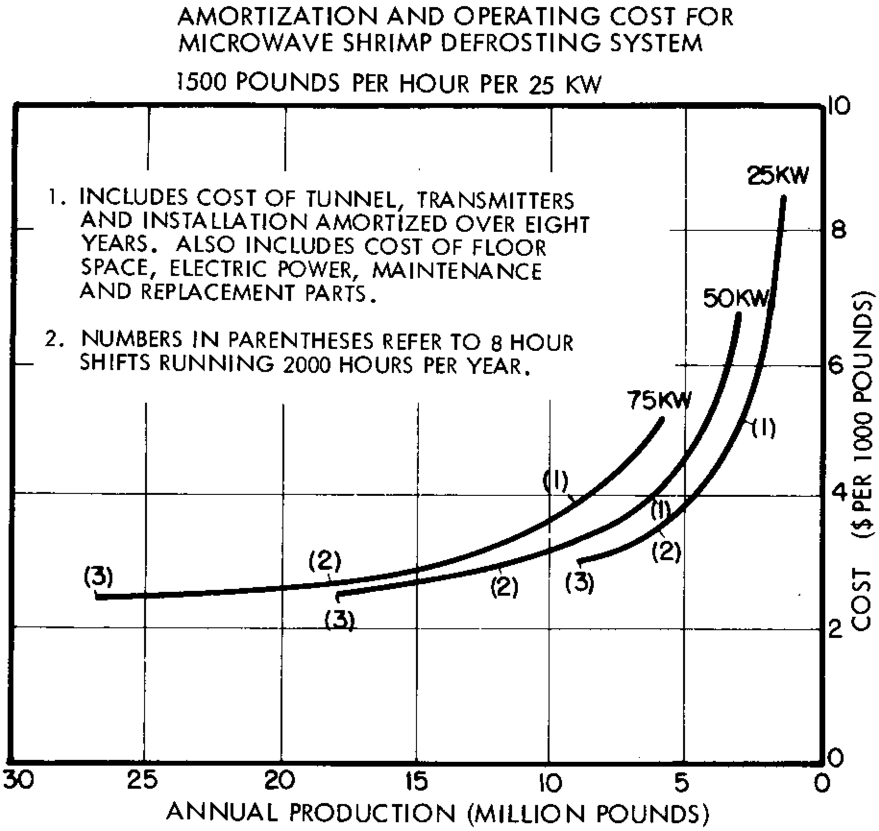

Fig. 5. Operating cost of microwave system.

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[4] Continuous flow tempering tunnel Model QMP 1679, Raytheon Company, Microwave and Power Tube Division, Foundry Ave., Waltham, Massachusetts 02154

ing cost is $8.87 per 1,000 pounds, which is less than either air-or water-defrosting. The writers' estimate of drip loss for a microwave system is 2% or $30 per 1,000 pounds. Additional operating cost data are shown in Figure 5. For a 3 million-pound-per-year plant, it is estimated that a microwave system would save $48,540 per year compared with a water-defrosting system and $101,340 per year compared with a chilled air-defrosting system.

CONCLUSIONS

It is concluded that microwave defrosting is particularly suited to the defrosting of raw, headless shrimp for the following reasons: (1) Microwave defrosting would allow compliance with the present GMP guideline for raw, headless shrimp regarding the requirements of temperature and packaging removal. (2) There is improved production control resulting from rapid in-line processing. (3) Water usage is reduced substantially alleviating waste disposal problems. (4) Defrosting takes place within the carton eliminating the need to remove the carton and increasing handling efficiency after thawing. (5) Ice requirements are reduced because there is no "temperature overshoot." (6) Bacteriological control and quality control are improved. (7) Wholesomeness, as evidenced by moisture/protein ratio, is retained. (8) Total defrosting cost is reduced compared with air or water defrosting.

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