Fishing for maximum profit, of course, carries with it the connotation of no culling of the catch. All shrimp caught should be brought in and sold.

This question, I believe, can be answered by carrying out my third recommendation.

REFERENCES

BEVERTON, R. J. H., AND S. J. HOLT
1957. On the dynamics of exploited fish populations. Min. Agric., Fish. Food. Fish. Invest. Ser. II, Vol. XIX, 533p. Her Majesty's Stationery Office, London.

INGLE, ROBERT M., BONNIE ELDRED, HAZEL JONES, AND ROBERT F. HUTTON
1959. Preliminary analysis of Tortugas shrimp sampling data 1957-58. Fla. State Bd. Conserv., Tech. Ser. 32, Mar. Lab., St. Petersburg, Fla., 45 p.

IVERSEN, EDWIN S., ANDREW E. JONES, AND C. P. IDYLL
1960. Size distribution of pink shrimp, *Penaeus duorarum*, and fleet concentrations on the Tortugas fishing grounds. U. S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 356, 62 p.

REGAN, JAMES, C. P. IDYLL, AND EDWIN S. IVERSEN
1957. Mesh size regulations as a possible method of managing the Tortugas shrimp fishery. Proc. Gulf Carib. Fish. Inst., 9th Ann. Sess., Nov. 1956, p. 18-22.

THOMPSON, W. F. AND F. H. BELL
1934. Biological statistics of the Pacific halibut fishery. (2) Effect of changes in intensity upon total yield and yield per unit of gear. Rept. Int. Fish. [Pacific Halibut] Comm., No. 8, 49 p.

The Use of Liquid Nitrogen in the Shrimp Industry

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Abstract

The manufacture and properties of liquid and gaseous nitrogen are briefly described. The present and future uses of liquid nitrogen (LIN) for freezing and glazing peeled and deveined (P&D) individually quick frozen (IQF) shrimp are described for complete freezing and crust freezing. The advantages of liquid nitrogen freezing over conventional blast room or blast tunnel freezing are discussed. Also discussed is the application of liquid nitrogen to catch preservation at incipient freezing to extend fishing and running times with attendant improved quality of green headless shrimp. A possible application of liquid nitrogen is discussed in which the gas is generated at the fishing grounds by large ship-board generators for use in freezing. Other attendant uses for nitrogen are treated such

as inert packaging of products, auxiliary uses of the low-level refrigeration values in spent nitrogen gas, and in-transit refrigeration of frozen product to market, storage or further processing.

INTRODUCTION

The use in food processing and storage of nitrogen is not new. For years, gaseous nitrogen has been used in the storage of fruits and vegetables, in the blanketing of tanks of edible oils, in the deaeration of wines and juices, and in similar ways to protect these foods from the oxidative deterioration. Much work is in progress to extend the usefulness of these techniques. The foods of the future will be of better quality as the inert properties of nitrogen are increasingly put to work to reduce deteriorative processes and to permit more of the natural flavor of foods to reach the table.

A relatively new use in the food industry for nitrogen is that involving the supercold of liquid nitrogen to freeze foods. The freezing of foods with liquid nitrogen is done so rapidly that the quality of the food, as it comes to the freezing process, is encapsulated and preserved. It may be postulated that the combination of fast freezing with liquid nitrogen, followed by inert packaging in gaseous nitrogen, will permit most foods to be delivered to the point of consumption as near the state of natural freshness and quality as is possible to achieve. In all other preservation techniques, something foreign is added or something inherent is lost.

The use of these techniques has found its way to the shrimp industry. Today, peeled and deveined (P&D), individually quick frozen (IQF) shrimp and other shrimp products are being frozen with liquid nitrogen. Shrimp is being packaged in inert gaseous nitrogen. Gaseous nitrogen is being used for vacuum-breaking in the freeze-drying of quality shrimp. And shrimp are experimentally being irradiated at cryogenic temperatures for pasteurization and sterilization. The applicable techniques discussed above are being examined with regard to the processing and preservation of shrimp to ascertain their economic and technical feasibility. These applications can commence as soon as the shrimp have been brought out of the water.

THE PROPERTIES AND MANUFACTURE OF LIQUID NITROGEN

Before proceeding further with specific details of the application of nitrogen to the shrimp industry, it might be well to look at the properties of liquid nitrogen which permit it to be so admirably suited to applications in the shrimp industry and at the manufacture of liquid nitrogen to gain some insight as to its cost and factors which influence its cost.

Nitrogen is a gas at normal conditions of temperature and pressure. It is, for all practical purposes, completely inert with regard to foods. When reduced in temperature at atmospheric pressure, it condenses to a liquid at –320F. At significantly lower temperatures, like water it freezes to a colorless "ice." However, as normally encountered, it is a boiling liquid, contained in a highly insulated vessel, maintained liquid by refrigerating itself by evaporating a very small part of itself. When contacted by a warmer article or surface, heat is rapidly extracted from the article, causing the boiling liquid to vaporize to a gas, much like the result of sticking a red-hot iron into a pot of boiling water.

In being vaporized from a liquid at –320F to a gas at –320F, each pound of liquid nitrogen absorbs 86 Btu. (A Btu is a unit of heat energy equal to

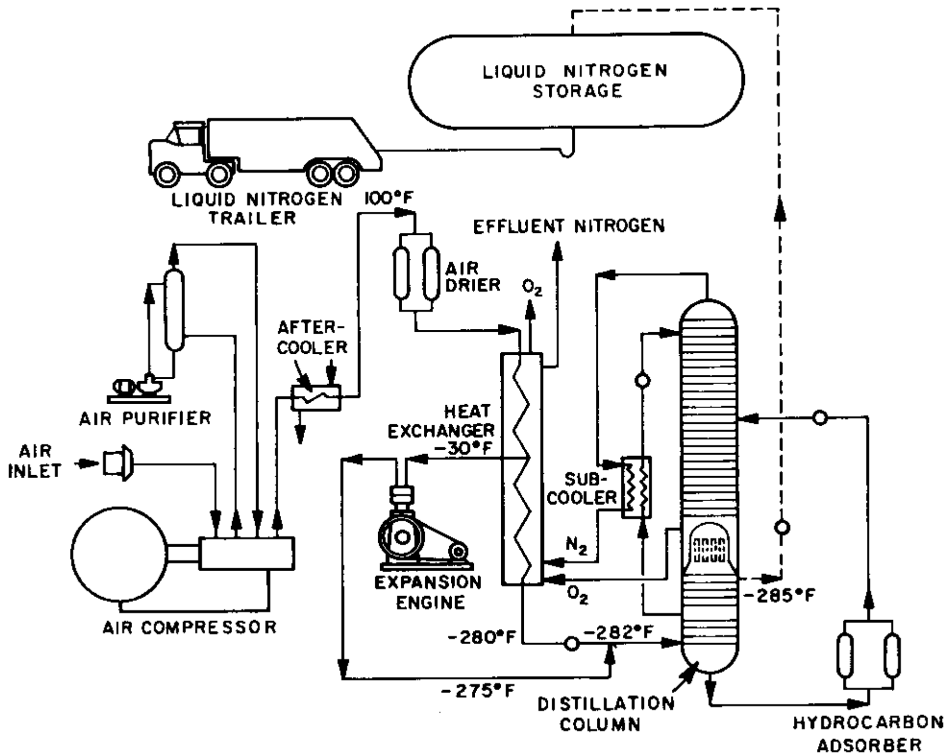

FIG. 1. Schematic diagram of equipment used to produce liquid nitrogen and liquid oxygen. Courtesy of Air Products and Chemicals, Inc.

that amount of heat required to raise one pound of water 1F.) Each pound of gas at –320F absorbs another 90 Btu in being heated to 40F. Thus, one pound of liquid nitrogen (LIN) absorbs 176 Btu in being heated to 40F, enough to freeze from one pound to two pounds of food, depending upon the properties of the food itself. It is important, in the economics of application of liquid nitrogen, that the nitrogen be raised to as high a temperature as possible, closely approaching that of the incoming food, to permit each pound of nitrogen to do as much cooling of the food as possible. Temperatures as high as 40F less than that of the incoming food are economically desirable and attainable commercially in properly designed equipment.

Liquid nitrogen is manufactured in a complex array of refrigerated hardware and separation equipment, nearly all contained within a well insulated chamber called a cold box. Fig. 1 shows in simple detail the principal features and equipment required. In essence, the processing is as follows. Air is compressed to 85 psig by reciprocating or centrifugal compressors and the heat of compression is removed by heat exchangers. The cooled compressed air is allowed to expand through specially designed valves and/or turbo-expanders. This expansion causes the air to chill itself to the point of liquefaction, producing a mixture of principally liquid nitrogen and liquid oxygen. This mixture is then separated or fractionated in distillation columns, similar to those used to separate petroleum fractions into gasoline and other fuel oils, by taking advantage of the fact that liquid nitrogen and liquid oxygen have differing boiling points. The liquid nitrogen is collected in a vacuum-jacketed (vacuum insulated) tank at its boiling point of –320F. Some of the oxygen is similarly recovered and some is vaporized to provide refrigeration to help cool down the incoming air. The process is costly in terms of the expensive hardware and the significant quantities of power required to drive the compressors. The larger the plant, the less costly is the nitrogen produced. The very large user of nitrogen can economically justify a generating facility for his operation. The average user of liquid nitrogen is more economically served by having the liquid delivered to a vacuum-insulated tank located near his point of consumption. The break-even size depends upon such factors as consumption, location, costs of power and labor, and continuity of consumption. Very few processors can justify an on-site generator unless the point of consumption is extremely remote from the usual commercial sources of supply.

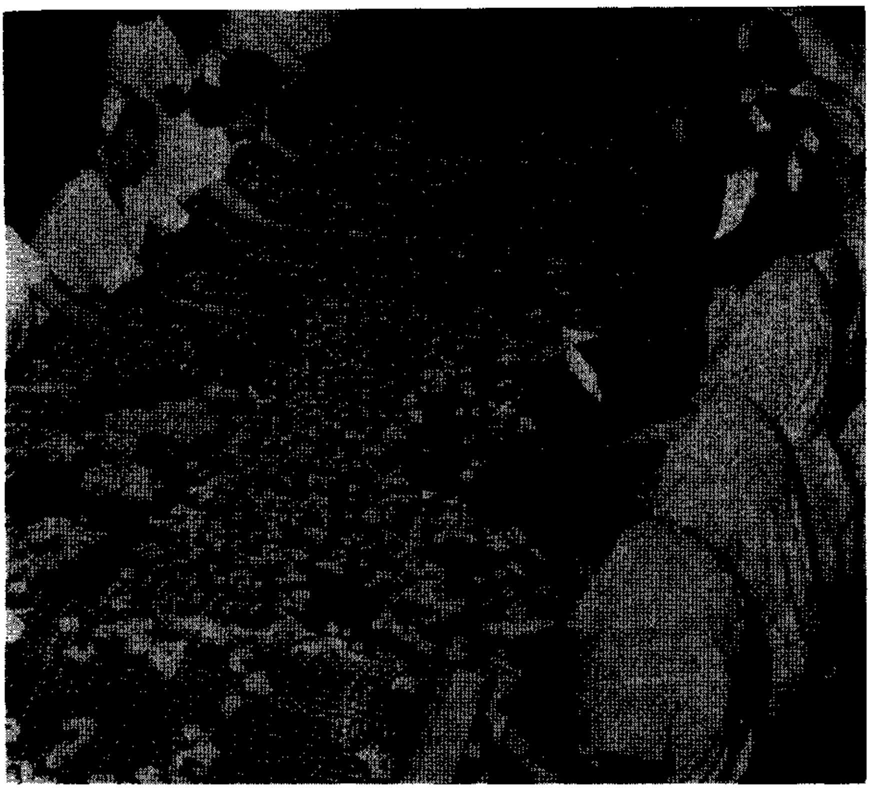

FIG. 2. Shrimp are distributed so as to cover 50-60% of the surface of the endless belt before entering the liquid nitrogen freezing tunnel. Courtesy of "Fishing Gazette."

THE APPLICATION OF LIQUID NITROGEN TO THE FREEZING OF SHRIMP

There are today many applications of liquid nitrogen to the freezing of fish and fish products, and several of these applications are for P&D IQF shrimp. The largest of these freezes and glazes over 16,000 pounds of shrimp per day. In this operation, P&D shrimp are conveyed from a slush ice tank to the bedding table (Fig. 2) of a large tunnel freezer. The shrimp are bedded on the table in their normal cruciform shape such that 50% to 60% of the stainless steel mesh endless belt is covered by the shrimp itself. The shrimp (Fig. 3) pass down the tunnel countercurrent to the nitrogen gas, in intimate contact with the gas, being cooled by the gas as they approach the liquid nitrogen spray. The chilled shrimp, approximately 60% frozen, pass through the spray and, being much warmer than –320F, cause the liquid in the spray to vaporize to nitrogen gas at –320F. The nitrogen gas is caused to move toward the feed end of the tunnel, being warmed by the incoming shrimp and removing heat from the shrimp, effecting the freezing. The completely frozen shrimp leave the spray and enter a quiescent equilibration zone where the much colder surface of the shrimp equalizes in temperature against the warmer core, permitting the shrimp to leave the tunnel (Fig. 4) at –40 to –50F, depending upon the size of the shrimp. The subcooled shrimp enter a glazing tank where, in a controlled time period, 2 ounces of glaze per pound of shrimp is picked up on the shrimp

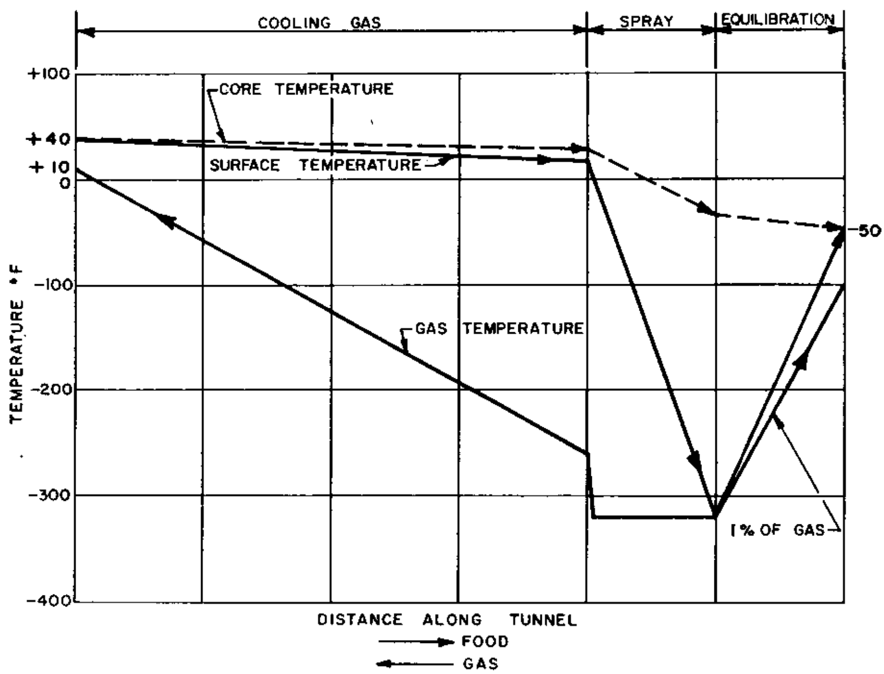

FIG. 3. Idealized temperature distribution when freezing shrimp with liquid nitrogen.

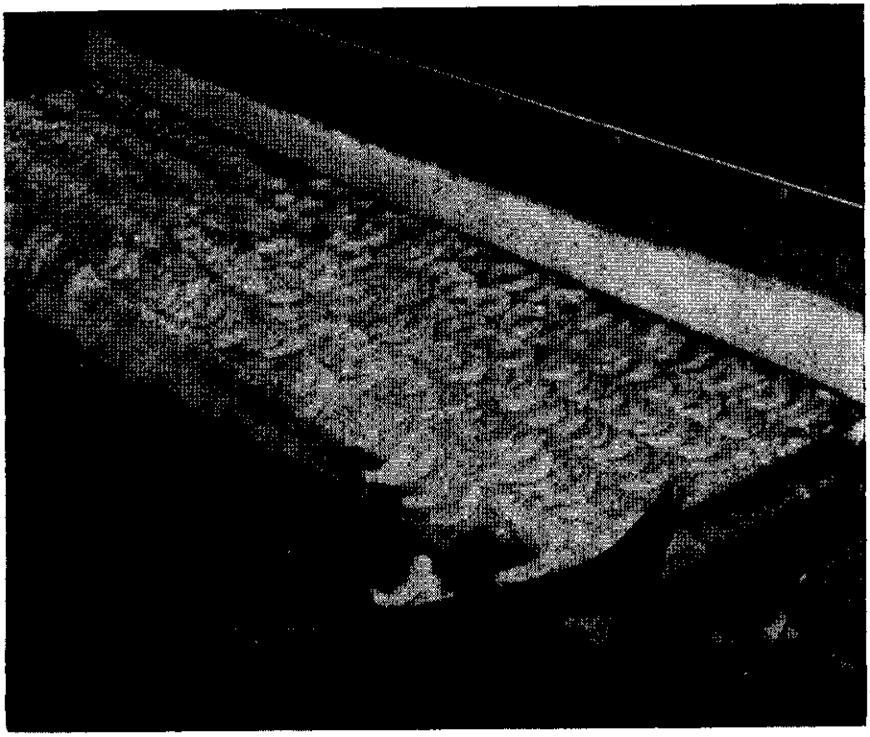

FIG. 4. Frozen shrimp leaving liquid nitrogen freezing tunnel. Courtesy of "Fishing Gazette."

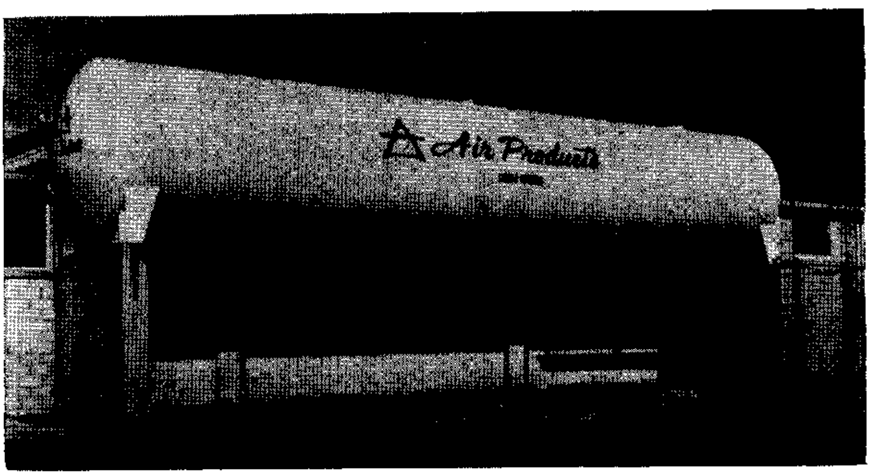

FIG. 5. 20,000 gallon vacuum-jacketed nitrogen storage tank.

from water at 33F. The refrigeration to freeze the glaze comes from the shrimp itself, raising the temperature of the glazed shrimp to –20 to –10F, ready for weighing, packaging, boxing, and moving to holding rooms at –10 to –5F.

The liquid nitrogen is delivered to a 20,000 gallon vacuum-insulated storage tank (Fig. 5) located just outside the wall from the freezer. The liquid is delivered in 15,000 gallon vacuum-insulated railroad cars or 4,000 gallon tank trailer trucks and pumped to the storage tank on a routine delivery basis.

THE ECONOMICS OF LIQUID NITROGEN FREEZING

The advantages of liquid nitrogen freezing over conventional blast-tunnel or blast-room freezing are the following: 1. lower investment, 2. less operating labor, 3. less maintenance, 4. less product dehydration and drip loss, 5. less product deterioration — oxidative, enzymatic, and bacteriological, 6. better product appearance, 7. improved product keeping qualities, 8. less space requirements, 9. higher productivity through reduced retention time in processing, and 10. overall—less cost per pound of frozen product on the loading dock.

Investment

A liquid nitrogen freezing system can cost significantly less than a conventional blast freezer of the same production capability. The conventional blast freezer has not only the freezing cabinet or tunnel, but also all of the high-side refrigeration equipment (compressors, coolers, and condensers to reliquefy and subcool refrigerant) and associated recirculation piping. The cabinet also has considerable connected horsepower and associated switch gear. In contrast, the liquid nitrogen freezer is smaller, has far less connected horsepower and switch gear, and has no recirculation piping and no high-side equipment. The equivalent of the high-side equipment (Fig. 5), a vacuum jacketed storage tank for liquid nitrogen, is owned, installed and maintained by the gas supplier.

Investment cost is of the order of one-fourth that of a grass roots conventional system, and one-half that of an incremental conventional system tied into existing high-side equipment.

Operating Labor

Liquid nitrogen freezing is a fully conveyorized, in-line, continuous freezing system. Starting with automatic feeders to properly bed the belt and ending with automatic weighing, packaging and boxing equipment, the product is bedded, frozen, packaged, and moved into refrigerated holding rooms in as little as 15 minutes of total exposure. Productivity per manhour is greatly increased. While such conveyorized handling also is characteristic of conventional blast freezing equipment, freezing time and thus total processing time is significantly longer than with nitrogen freezing. Productivity per manhour is commensurately greater. Freezing in blast rooms or cold rooms is characterized by considerable manual handling and rehandling, and by significant cost for repair and maintenance of the manually operated equipment.

Maintenance

Liquid nitrogen freezing tunnels are inordinately simple in design and construction. There is a minimum of moving parts—a few fans and belt drives. All hardware is off-the-shelf. Maintenance of the tunnel *per se* is minimal. As pointed out above, there is no high-side equipment. And maintenance of high-side equipment is a major cost in conventional freezing. High-side maintenance in liquid nitrogen freezing is borne by the gas supplier at his liquid nitrogen producing facility and at the storage tank. It has been estimated by a knowledgeable and experienced leader in custom food freezing that maintenance costs are of the order of one-tenth that of conventional systems.

Dehydration and Drip Loss

A significant cost to the freezing processor of shrimp is yield loss, primarily caused by dehydration during freezing. In conventional blast-tunnel and blast-room freezing of shrimp, dehydration can be as high as 5%. For high-priced food products such as shrimp, dehydration loss can cost the processor as much as 5 cents per pound of frozen product. Such dehydration results from chilled air circulating through the blast tunnel, unsaturated with regard to moisture at the exit temperature, becoming saturated upon contacting the shrimp and giving up this picked-up moisture as frost on the external chilling coils. These chilling coils cool the air blast and simultaneously unsaturate the air (relative to tunnel exit temperature) permitting the recirculating air to pick up moisture from the product on each pass across the shrimp. When one considers that a given parcel of air can contact shrimp up to 100 times in the course of travel of the shrimp through the freezing process, high levels of dehydration are obviously possible even for air at 30 to 40F below zero.

In contrast, nitrogen freezing is characterized by negligible dehydration. The liquid nitrogen, vaporized upon contact with the food, is caused to work its way down the tunnel in intimate contact with the food. The nitrogen, however, never leaves the tunnel until its work is done and, in properly designed tunnels, gives up little of its accepted moisture to cooler surfaces. The maximum moisture pickup by the nitrogen (and thus the maximum dehydration of the product) is, in this instance, that amount of moisture just sufficient to saturate the nitrogen gas at the temperature of the exhaust—say 10 to 20F above zero. This is a very small amount of moisture.

At the P&D IQF freezing operation referred to above, 1400 pounds per hour of nitrogen is vaporized. This produces only 300 standard cubic feet per minute of nitrogen gas. At 20F, each standard cubic foot of nitrogen can only accommodate 0.00016 pounds of water. For 1200 pounds per hour of shrimp, this is 0.0025 pounds of water per pound of shrimp, or 0.25% dehydration (Fig. 6). This is a 99.75% yield during freezing. This is to be compared with a loss of 4 to 5% in conventional blast freezing.

Drip loss is the weeping of frozen shrimp upon being thawed. Drip loss is caused largely if not entirely by large ice crystals which penetrate cell walls permitting cellular moisture to drain into intercellular space and then to waste. Nearly all the moisture in foods is contained within the cells. Rupturing of these cells permits the moisture to drain away, carrying dissolved food constituents, flavor constituents and nutrients. Further, much of taste is determined by texture, and texture is related to moisture content. No product of less than natural moisture content tastes like fresh food. The importance of little or no drip loss on the quality of thawed foods cannot be overemphasized. Quality food-serving houses recognize this and are prepared to pay premium prices for frozen products which have negligible drip loss.

For conventional freezing, aside from the dehydration discussed above with its adverse effect upon texture and taste, drip loss is often on the order of 3% or more. This drip loss results from the large ice crystals which form during slow freezing. With liquid nitrogen freezing, the freezing is done so rapidly that the ice crystals are extremely small, sometimes having negligible crystallinity.

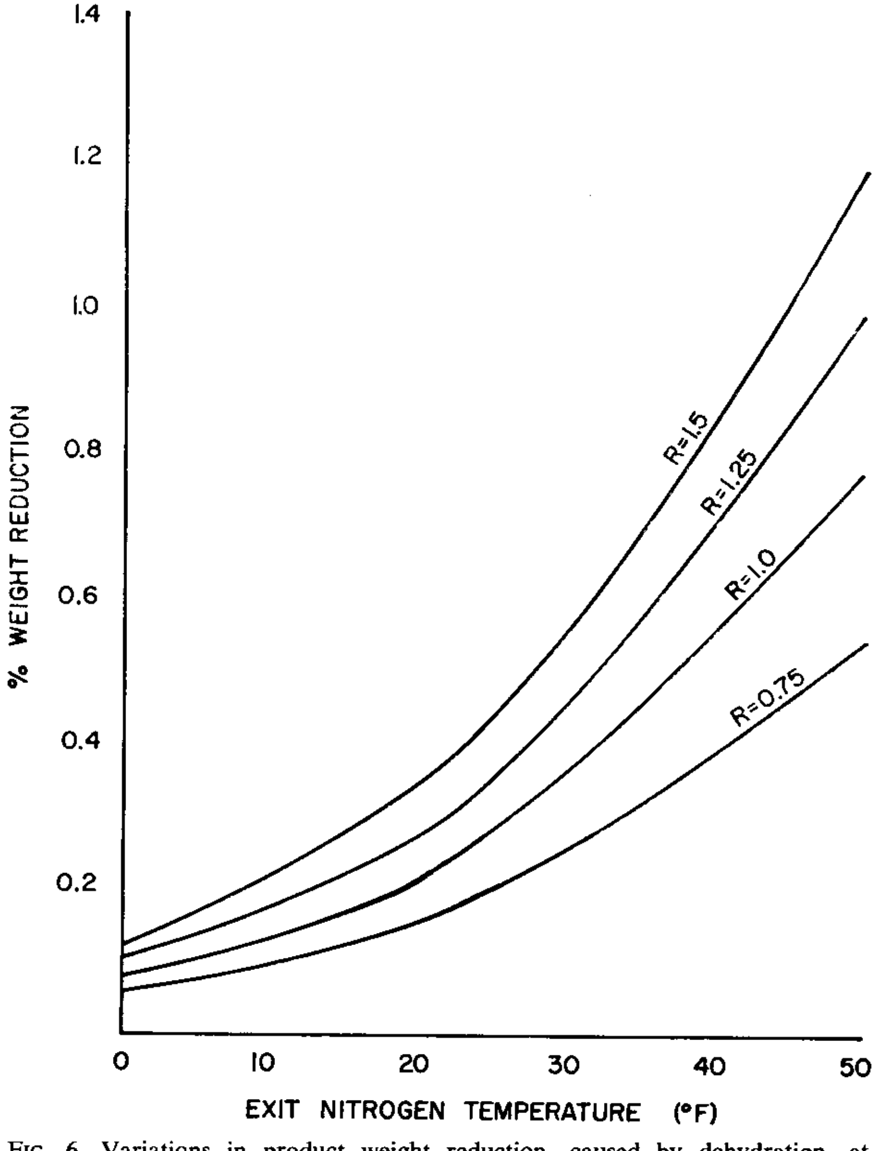

FIG. 6. Variations in product weight reduction, caused by dehydration, at different exit nitrogen temperatures for various liquid nitrogen to product weight ratios (R).

Minimal rupturing of cell walls results, and no drip loss occurs upon thawing.

Dehydration and drip loss, properly recognized and accounted for in the economics of freezing, will often pay for the costs of liquid nitrogen and freezing equipment, disregarding all other factors such as productivity, labor savings, etc.

Deterioration

Deteriorative processes in foods—oxidative, bacteriological, enzymatic—all take place faster at higher temperatures. The faster the food can be processed and frozen, the less deterioration of fresh qualities will take place. Liquid nitrogen freezing permits this faster processing and freezing since the freezing is often the bottleneck to greater overall production. A factor not to be overlooked is that aerobic bacteria cannot live in a nitrogen atmosphere. Bacteria counts are therefore reduced. A further advantage, only recently discovered, is that many bacteria cannot survive the tremendous heat flux, or rate of heat removal, effected by liquid nitrogen. Ultra-fast freezing has been found to kill bacteria; stored food, frozen with liquid nitrogen, has been determined to have lower bacteria counts months after freezing than at the time of freezing. The inert atmosphere, devoid of oxygen, precludes oxidative deterioration while in the tunnel and significantly reduces such oxidative deterioration of the frozen product.

Appearance

P&D IQF shrimp frozen with liquid nitrogen generally have a superior appearance. The lack of dehydration permits the shrimp to maintain its fresh bloom. The extreme rapidity with which the glaze is formed causes the glaze to be very uniform and clear, permitting the superior condition of shrimp to be readily discernible.

Keeping Qualities

All frozen foods are subjected to considerable abuse in cold room storage, loading, in-transit refrigeration, unloading, display, and customer handling and storage after purchase, including the all-important thawing. Ice crystals tend to grow even with slight changes in temperature. The manifold variations in temperature to which frozen food is subjected between the processing freezer and the home freezer cause ice crystals to grow significantly, resulting in further cell damage beyond that done during the initial freezing. It follows that the smaller the ice crystals in the initial freeze, the more abuse the article can accommodate before ice crystals grow to sizes sufficient to effect additional damage to cell structure. Liquid nitrogen freezing provides this additional protection against abuse by heat shock.

Space Requirements

As mentioned above, the liquid nitrogen tunnel freezer is smaller than the cabinet or tunnel of conventional blast freezers of comparable capacity. This means less floor space and, therefore, more working room. Most important, however, is the space not needed by high-side equipment not installed—and the much less space required by maintenance people not needed—and the less space required by a smaller operating force. The freezing plant of tomorrow will be smaller and less costly in many ways, for many reasons.

Productivity/Processing Time

Freezing with liquid nitrogen is done in a matter of a few minutes. Freezing with conventional equipment takes from several minutes to as long as 24 hours. Faster freezing rates mean higher production per manhour—less labor costs. A significant consideration is that a conventional freezer has a definite maximum productive capacity which cannot be exceeded without producing inadequately frozen food. A liquid nitrogen tunnel freezer has unlimited capacity—2 times, 3 times, 4 times nominal. Of course, liquid nitrogen consumption per pound of product increases as nominal capacity is exceeded. But one may exceed it when special circumstances dictate. This option is not available to the user of conventional freezing equipment.

Cost Per Unit of Food Shipped

The objective of every processor-freezer is to minimize his costs on the loading dock while maintaining or improving quality. It matters not whether Cost A increases significantly, if there is a more than commensurate reduction in Cost B or in a combination of Costs B, C and D. A systems analysis is required where all factors affecting the cost of product on the loading dock are recognized, quantified and adequately reflected in a balance sheet. It has been demonstrated that when such a study is made, a liquid nitrogen freezing system, properly designed, installed, operated, maintained, and integrated into the balance of the operation, will yield lower costs on the loading dock with attendant significant improvements in quality. It is an economic fact that the cost of removing heat from food with liquid nitrogen, when considered alone, is more expensive than with conventional electro-mechanical systems. However, when differences in dehydration, drip loss, operating labor, maintenance, overall quality, and versatility are adequately reflected in a complete cost analysis, freezing with liquid nitrogen is often less expensive. The higher the food value, the more pronounced the savings. This is particularly true of processed shrimp.

There are available today several liquid nitrogen freezing tunnels of varying designs. These vary from (1) vacuum-jacketed high-speed tunnels to (2) somewhat more complicated tunnels for obtaining highly specific time-temperature profiles during the freezing process to (3) simpler, foam insulated tunnels. Time does not permit a more detailed description of these devices. Each has claimed advantages over the other. Principal differences lie in investment cost and efficiency of utilization of liquid nitrogen.

The liquid nitrogen freezing tunnel can also be used to advantage in conjunction with existing freezing equipment by producing rapidly and relatively inexpensively a crust-freeze on the shrimp which works to reduce dehydration during the balance of the freezing in conventional equipment. This can be accomplished at one-third to one-half the cost of complete freezing and further suffices to increase the productivity of the conventional freezer by as much as 25%.

THE APPLICATION OF LIQUID NITROGEN TO THE PRESERVATION OF CATCH

A novel application of nitrogen is that explored by Air Products and Chemicals, Inc. for the preservation, for extended periods, of green headless shrimp in a gaseous nitrogen atmosphere. The shrimp is maintained at the temperature of incipient freezing, i.e., 28 to 30F. The shrimp so preserved can be landed 14 days after catch with all the quality characteristics of fresh shrimp and can be held up to 20 days with a resultant quality at dockside superior to iced shrimp 9 to 10 days after catch. There is no darkening of the product by

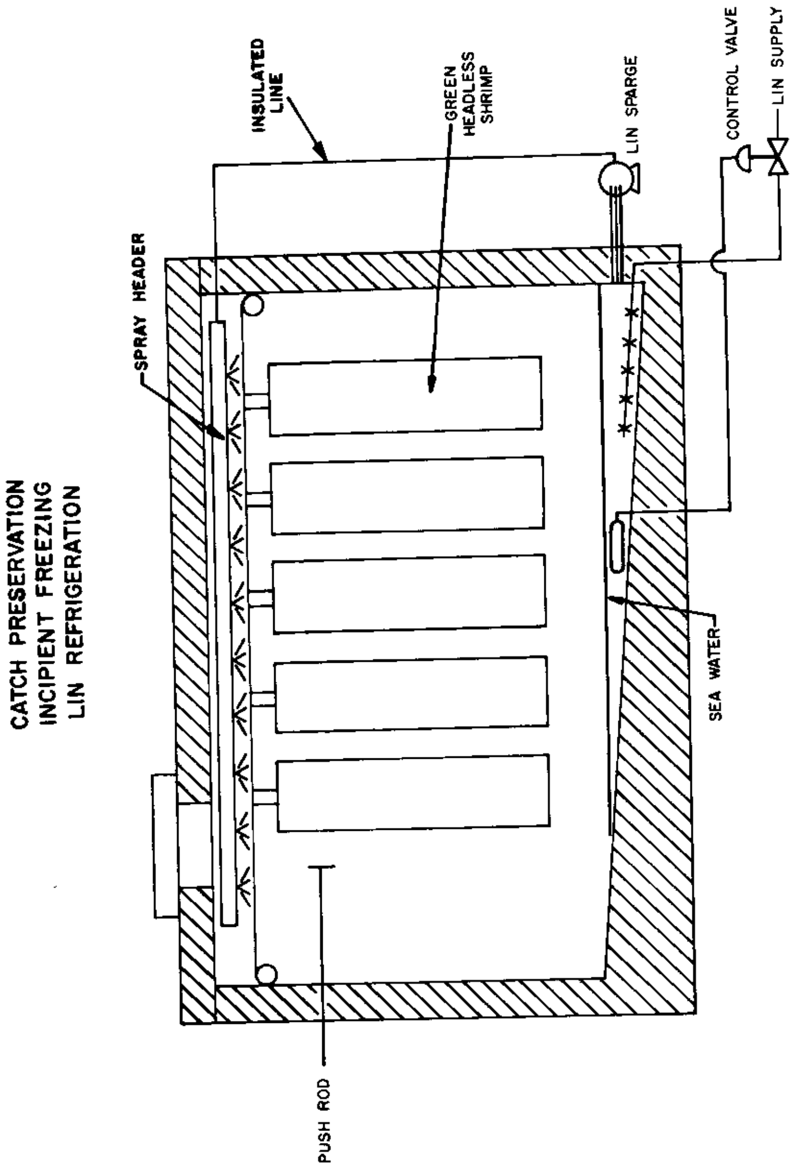

FIG. 7. Diagram of shipboard installation for freezing shrimp through the use of liquid nitrogen and sea water.

melanosis and the inert atmosphere has significantly reduced if not precluded all deterioration by oxidation and by aerobic bacteria.

While there are several variations of equipment for applying this technique, the simplest involves the use of a large insulated catch-box outfitted to accept shrimp in mesh baskets (Fig. 7). A sea-water brine, chilled to 28F by sparged liquid nitrogen and recirculated by means of a pump, is continuously sprayed over the shrimp. The sea water rapidly lowers the temperature of the shrimp to 28F, where it is maintained. The liquid nitrogen used to chill the sea water is vaporized by the sea water and the resultant nitrogen gas maintains an inert atmosphere in the catch-box.

This application is particularly suited to the close-in run where the shrimp-boat returns to port every 2 weeks or less. The use of liquid nitrogen in this application extends the catch-time, reduces running time in proportion to total time, precludes the need for ice, eliminates ice handling charges and cumulative water damage, reduces the amount of broken shrimp, reduces fuel oil consumption, and lands a preferred quality of shrimp to the shoreside processor.

Extensive studies conducted with a processing firm in Louisiana and in conjunction with the Food Science Department of Louisiana State University have conclusively proven the superior quality of the landed shrimp. As compared in Table 1 to an iced control, the shrimp maintained in nitrogen had less than 3,500,000 bacterial count (colonies/gm.) after 14 days, while the iced control had a count of 16,500,000. Shrimp with more than 4,500,000 count must be declared less than "good," and above 10,700,000, less than "fair." Similar studies of trimethylamine content and indole content (Table 1) indicate analogous results with regard to these two indices of quality. Organoleptic taste panels conducted with 125 individuals further confirm these quantitative results. These panels considered odor, appearance, sweetness, flavor, and texture.

The economics of this technique have yet to be fully explored, but preliminary economic analysis would indicate promise if all pertinent costs are quantified and properly reconciled in the balance sheet.

The long-haul shrimper, working Campeche and Latin American waters, cannot employ this technique, for shrimp cannot be held at incipient freezing for the requisite 50 to 60 days. For this shrimper, one must consider the freezing of shrimp. However, this is not economically feasible with liquid nitrogen produced in the United States and carried aboard the shrimp boat. There are, however, three possible solutions: 1. Barge liquid nitrogen to the fishing grounds in large quantities for several boats in a fleet. 2. Bring liquid nitrogen to the fleet from nearby shore-based liquid nitrogen generating facilities. 3. Produce liquid nitrogen at the fishing grounds by a large shipboard generator, serving several shrimp boats on a continuing basis.

Of these alternatives, only the third appears to have a significant merit for further consideration, given the present state of the art and science. It dictates, however, the probable formation of a cooperative venture among several fleet operators to share the significant cost of a generating facility and to permit the largest possible facility to be built, thereby reducing the costs of liquid nitrogen. Such a facility would, however, permit other possibilities to be simultaneously followed. The preservation of catch at incipient freezing for 10-day satellite runs is possible; the processing and freezing of P&D IQF shrimp at sea is also made possible at some savings in liquid nitrogen over freezing green headless shrimp due to not freezing the shell.

TABLE 1

QUALITY COMPARISON TESTS OF ICED AND INCIPIENT FROZEN SHRIMP

Age in Days	Bacterial Counts - Colonies/gm.[1]		Trimethylamine N_2 - mg./100 gms.[2]		Indole Content - μg/100 gms.[3]	
	Iced Control	N_2+H_2O Spray	Iced Control	N_2+H_2O Spray	Iced Control	N_2+H_2O Spray
0	7,000	7,000	0.00	0.00	0.00	0.00
2	185,000	100,000	0.00	0.00	0.00	0.00
4	420,000	180,000	0.01	0.00	1.40	0.00
6	950,000	340,000	0.20	0.00	1.60	0.00
8	2,200,000	600,000	0.35	0.00	2.90	0.80
10	5,100,000	1,100,000	0.61	0.00	4.15	1.20
12	9,200,000	2,150,000	1.20	0.15	5.30	1.45
14	16,500,000	3,500,000	1.32	0.21	8.10	1.80
16	24,300,000	5,450,000	1.40	0.47	11.42	1.85

[1]Shrimp with more than 4,500,000 colonies are considered less than "good," and above 10,700,000 colonies less than fair.

[2]A trimethylamine nitrogen value of 1.50 mg. per 100 gm. of shrimp is a definite indication of spoilage.

[3]An indole value of 2-8 μg/100 gm. is an indication of shrimp of fair quality. With an indole value of above 8 μg shrimp are spoiled.

The freezing with liquid nitrogen of shrimp immediately after catch at the fishing grounds has one significant advantage over mechanical freezing. The significant damage done to the structure of the shrimp during slow freezing by conventional means is damage that can never be repaired. Preferred processing at a later date on shore can do no more than preserve such quality as is delivered to the shore. This quality will be significantly greater if the shrimp is frozen with liquid nitrogen as opposed to conventional mechanical equipment.

Again, the economics of such operations have not been refined. An expressed willingness to consider such operations on the part of a group of fleet owners is a requisite to further development.

ATTENDANT USES FOR NITROGEN

The use of nitrogen for other purposes has been touched on above. To such techniques as inert packaging of prepared products must be added other uses such as the economic utilization of the low-level refrigeration values present in the off-gas from freezing tunnels and in-transit refrigeration of frozen products to storage, market or further processing. These supplemental uses become mandatory of consideration for the processor who is using relatively large quantities of liquid nitrogen for freezing. The significantly lower price for nitrogen which accompanies its consumption in large quantities often makes these ancillary considerations highly attractive.

The large scale use of liquid nitrogen in the shrimp industry is here. Its present application to the freezing of shrimp and shrimp products for consumer and institutional markets will undoubtedly always be the principal application. However, the economic application of liquid nitrogen to other aspects of the shrimp industry may well be a significant factor in the near future.