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Comparative Evaluations of Shell, Block, Flake and Slush Ice in Terms of Workability, Physical Characteristics and Cooling Effects on Fish

A. Slush Ice made from Salt Water
B. Shell, Block and Flake Ice

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COMPARATIVE EVALUATIONS OF SHELL, BLOCK, FLAKE AND SLUSH ICE IN TERMS OF WORKABILITY, PHYSICAL CHARACTERISTICS AND COOLING EFFECTS ON FISH

A. Slush ice made from salt water.
B. Shell, block and flake ice.

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ABSTRACT

Burns, B.G., P.J. Ke, D.C. Sloan, W.K. Rodman, C.D. MacGregor and A.J. Hebda, 1985. Comparative evaluations of shell, block, flake and slush ice in terms of workability, physical characteristics and cooling effects on fish. (A) slush ice made from salt water, (B) shell, block and flake ice. Can. Ind. Rept. Fish. Aquat. Sci. No. 159, 52p. (1985).

Ice to be used in the chilling of fish has been extensively studied in terms of cooling effects on fish tissue, workability , meltage rates, sanitary quality deteriorations pH and suspended particulate matter changes during storage, transportation and fishing operations. Capital costs of icemaking equipment is also briefly discussed. Four types of ice were studied, three of which are available locally (shell, block, flake). The fourth was obtained from a plant providing ice crystals from a supercooled brine or saltwater solution (slush ice). This report contains two independent papers, the first dealing mainly with slush ice testing, the second dealing with the more traditional ice types (shell, flake, block). In conclusion this report provides information and technology on the various types of ice used to chill and transport fish, in order to improve overall fish quality. Comparisons of workability and ice quality changes have been discussed, and the technical analysis of advantages and limitations provide some guidelines for the fishing industry to select the most effective and practical ice supply and facility.

RÉSUMÉ

Burns, B.G., P.J. Ke, D.C. Sloan, W.K. Rodman, C.D. MacGregor et A.J. Hebda, 1985. Évaluation comparée de la glace en coquille, glaçon, paillette et neige mouillée, en termes de caractéristiques physiques et d'adaptation au travail, et d'effets en matière de réfrigération sur le poisson. A) Neige mouillée provenant de l'eau salée, et B) Glace en coquille, glaçon et paillette. Can. Ind. Rept. Fish Aquat. Sci. no. 159, 52p. (1985).

La glace qu'on emploie dans le refroidissement du poisson fait ici l'objet d'études détaillées en termes d'effets de la réfrigération sur les chairs du poisson, d'adaptation au travail, de taux de fonte et de modifications des propriétés sanitaires, du pH et du contenu en matières en suspension, au cours des opérations de pêche, d'entreposage et de transport du poisson. Les coûts d'investissement des équipements servant à la préparation de la glace sont également brièvement discutés. On a étudié dans ce rapport quatre types de glace, dont trois pouvaient facilement être obtenus localement (coquille, glaçon et paillette) et le quatrième, d'une usine produisant des cristaux de glace à partir de machine à glace utilisant la saumure ou l'eau salée (neige mouillée). Ce rapport contient deux rapports de sources indépendantes: le premier traite surtout de tests faits avec la neige mouillée, l'autre, de tests faits avec d'autres types de glace (coquille, glaçon et paillette). Le rapport détermine, en conclusion, des renseignements et des techniques portant sur les divers types de glace qu'on emploie pour réfrigérer et transporter le poisson, afin d'en améliorer surtout la qualité. Des comparaisons portant sur l'adaptation de la glace au travail et les modifications apportées à la qualité de la glace font l'objet de discussions dans ce rapport, et des analyses techniques des avantages et des inconvénients fournissent des directives pouvant servir à l'industrie de la pêche afin de choisir les approvisionnements et les installations de glace les plus efficaces et les plus utiles.

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(B) Preliminary studies on ice workability during storage and of ice quality and quantity changes during transportation and storage for shell, block and flake ice.

Page

PART A

PRELIMINARY INVESTIGATION ON SLUSH ICE MADE FROM SALT WATER IN TERMS OF WORKABILITY, PHYSICAL CHARACTERISTICS AND EFFECTS ON COOLING AND SALT UPTAKE IN COD

INTRODUCTION

Ice has been used for more than a century in the preservation of fish and continues to be an important method for keeping fish fresh. When fish die spoilage quickly begins through bacterial, chemical and natural enzymic action. While fish are alive bacteria are resisted through natural protective mechanisms, however at death bacteria quickly invade body tissues. Enzymes also continue their action after death and are responsible for flavor changes during the first few days storage. In addition chemical changes may also take place, such as oxygen from the air reacting with mackerel and herring fats producing rancidity and off odors. Spoilage through these processes is inevitable but can be slowed by chilling to ice temperatures. Therefore the more rapidly fish can be chilled, the longer the expected shelf life.

The use of ice as a cooling medium offers several advantages over mechanical refrigeration in that it has a large cooling capacity for a given weight, it is portable and fairly inexpensive. Ice, in addition to keeping the fish cool, also keeps the fish moist and glossy and prevents the drying that may accompany other chilling methods. Freshwater ice melts at 0°C while water containing salt will freeze at a slightly lower temperature. For example, the point of equilibrium for sea fish iced soon after catching is approximately -1°C (the system contains residual blood and salt; Waterman and Graham 1975). Practically no enzymic action takes place at these temperatures and the bacterial growth rate is only about one half that at +2°C (Hess, 1932).

The production of ice from seawater offers several advantages and disadvantages when compared with freshwater ice. On the plus side, because ice produced from saltwater tends to be rather soft and flexible (because of the brine content) good surface contact is made with the fish promoting heat transfer and therefore more rapid cooling to ice temperatures. The extension of shelf life is therefore a possibility. Also there are no sharp edges or corners to bruise or gouge the fish. In addition, seawater can be used as sourcewater enabling the use of ice plants aboard fishing vessels. On the minus side, the melting point of ice made from salt water depends on salt content and may therefore be inconsistent or variable as the salt leaches out with the meltwater. The possibility also exists of freezing or partially freezing the fish and thereby damaging the texture if the meltpoint should become too low. Adverse effects on tissue quality due to long freezing times have been reviewed (Dyer 1971). It was noted that a freezing point depression is exerted during this process due to the minerals and salts present. Most of the water in the tissues is frozen out between -1 and -5°C and damage due to slow freezing generally occurs in this zone (Dyer 1971, Connell 1975). Salt uptake by fish exposed to the brine/meltwater solution is also a concern.

A new type of ice machine recently introduced to the market produces ice from a brine or seawater solution by forming small ice crystals in a solution which is supercooled (slush ice). The machine reportedly has several advantages over other types of ice-making equipment (shell, block, flake) in that:

1. it is less expensive to operate,
2. it can use either a fresh (salt added to form brine) or saltwater source to form ice, and
3. through the use of a mechanical separator the machine can produce either a "dry" (drained; basically freshwater ice) or a pumpable "wet" (contains approximately 30% liquid) ice.

The advantages of a pumpable type ice in an ice delivery system are obvious:

4. the machine produces ice "constantly" upon demand eliminating the need for extensive back up storage areas,
5. Because the ice producing/storage unit is very compact, its use onboard fishing vessels at sea is a distinct possibility.

Further details of this type of ice machine are given in Appendix A.

In response to requests for more information on this ice type and keeping the above mentioned factors in mind a limited study was initiated to determine such factors as cooling efficiency, workability, meltage rate and whether uptake of salt by cod placed in the ice would be significant.

SAMPLING AND METHODS

GENERAL

Slush ice was obtained from a commercial operation in Port Dover, Ontario and from a demonstration model in Toronto, Ontario. The commercial ice had been made two weeks previously and was drained. This ice could be considered quite dry. Slush ice from the demonstration model was not allowed to drain before testing and was pumped into the test container.

Ten cod fish (weight range: 1.0-1.4 kg) which had been held on ice for 4 days were purchased from a local Halifax, Nova Scotia retailer. The fish were transported to the test sites in an insulated container containing a number of freezer packs wrapped loosely in paper.

ICE COOLING CURVES

Two gutted cod (approximately 1.2-1.4 kg each) were used for these evaluations. The fish were warmed to 10-12°C either in a warm water bath or by warming through ambient temperatures. Thermister probes were then inserted into the dorsal portion of the fish (Figure A-1) in the thickest portion of the fish. The complete thermister shaft was retained in the flesh in order to minimize conductivity cooling along the probe from metal/ice contact (FAO 1975). A second probe was inserted just below the skin surface of one fish to record the surface temperature. A probe was hung in the air near the temprinter recorder to measure ambient room temperatures and another was placed in the ice itself.

A total of five probes were remotely coupled to a model 535F Temprinter (Pulsar Electronic Ltd.) and set to record the temperatures at 10 minute intervals with hourly averaging. Measurements were continued until temperatures were deemed stabilized (less than 0.1°C change/30 minutes). Freshly exposed ice was used for all cooling trials in order to eliminate any ice which might have been structurally modified through melting, etc. At the end of each cooling run the thermister probes were calibrated by strapping the five probe ends to a low range thermometer and allowing them to equilibrate.

ICE WORKABILITY

There appears to be no standard methods in the literature to determine the "workability" of ice. Therefore for this study, workability has been defined as the ease with which ice can be shovelled and clumping has been defined as the structural modification of the individual fragments. Initial trials using shell ice to note the applicability of various tests for penetration, workability of the ice and tendency to clump allowed methods to be defined and standardized. The tests were designed to simulate work in handling the ice and were carried out in a manner to minimize disturbance of the ice in order not to affect later tests.

The workability of the ice may be quantified by four methods:

1. pressure to break the ice surface,
2. depth of penetration of weighed penetrometer,
3. pressure required to pivot a shovel, and
4. determination of size of ice fragments.

Pressure to Break the Ice Surface

A wooden stick with an end area of 2.2 cm^2 (1.8 cm x 1.2 cm) was placed vertically on the surface of the ice at three positions, chosen at random. A weight was applied directly downwards on a measuring balance mounted on top of the stick (Figure A-2). The pressure required to break through the surface was measured. Accuracy was estimated at ±2 kgs.

Depth of Penetration of a Weighted Penetrometer

A 4.5 kg weight was placed on top of a wooden metre stick (end 3.0 cm x 0.3 cm) at three locations chosen at random. It was allowed to drive the stick into the ice by gravity (Figure A-3). Depth of penetration was measured in centimeters. Accuracy was ±0.5 cm. This method allowed for determination of the tendency of the ice to form a crust.

Pressure Required to Pivot a Shovel

A metal shovel with the blade measuring 23 cm x 18 cm and a wooden handle of 76 cm was inserted into the ice to the full depth of the blade at three locations chosen at random. A spring (balance) was attached to the upper end of the handle and a pull was applied until the shovel moved in the ice (Figure A-4). Since 11.4 kg was the maximum force that could be applied before the blade would begin to bend, pressures in excess of 11.4 kgs were not attempted and values were recorded as 11.4 kgs. This test simulated the pressure or work required to move a shovel in the ice. A small shovel was used because larger shovels were found to destroy the ice surface, affecting later measurements. The accuracy of measurement was estimated at ±1 kg.

Determination of Size of Ice Fragments

A 25 cm x 25 cm (625 cm^2) quadrat (square frame) was placed at a random location on the surface of the ice. The 3 largest fragments of ice within the quadrat were chosen and measured along their longest axis. Clumped fragments were defined as more than one individual piece of ice sticking together and lying loosely on the surface. If no such loose pieces of ice were found then the surface was described as solid.

MELTAGE

Where possible X-actics containers with interior dimensions of 109 x 98 x 51 cm (l x w x h) with walls and lids being 4 cm thick were used. A port at the base of each box was used for drainage. Where possible, meltage rates were determined in ambient air temperatures as close to 20°C as possible. The boxes were filled to capacity for meltage rate tests and were then tested at set intervals.

After each box was opened for testing, general observations were made, such as the amount of shrinkage of the ice from the sides of the box and the general appearance of the ice. Ice temperatures were recorded to the nearest 0.5°C using a mercury thermometer.

Water was then drained from the individual boxes and its volume measured in litres. A one litre sample of drain water was retained for later testing. Periodically a 1 litre (vol) sample of the surface ice was also taken for testing.

The height of the ice surface was measured each sampling time at the same three locations in the box: in the center, front and one side. If it was impossible to drive the metre stick through the center of the ice, then an additional measurement was made on a second side.

SALT UPTAKE

Undrained slush ice freshly prepared from a brine solution was used for all tests and was pumped into the test containers. Samples of tap water, brine before icemaking, the ice brine slurry that was pumped, and the remaining brine solution were collected during the icemaking process in one litre polyethylene wide mouth bottles for later salinity testing.

Four dressed cod (weight range 1.0 - 1.5 kg) were placed belly up on a 15 cm layer of slush ice. The container had an elevated drainage rack to allow the drain/melt water to escape. The fish were then covered with a fresh layer (15 cm) of slush ice. Fish in this position will have the best chance to pick up any of the salt present in the drainage water as it passes over them. One litre samples of melt/drain water were collected at three hours and twelve hours for later salinity testing. At approximately 20 hours, the fish which had been sitting belly up in the melting ice were removed and placed in a cooler for transport back to the lab. Upon arrival, the fish were frozen at -20°C until analysis.

LABORATORY TESTS

Salinity Tests

The conductivity meter was turned on and allowed to equilibriate for approximately thirty minutes. The instrument was calibrated and compensation made for the temperatures of the test solutions. Salinity and temperatures of the test solutions were recorded directly from the instrument.

Fish Salinity Tests

A steak cut through the center of the cod was removed with a small hand saw from a control and a test fish. Two parts water were added for one part fish and the mixture homogenized with a Polytron. A sample of the water extract was removed by filtration and tested for salinity/conductivity.

A control and a test fish were allowed to thaw and the fillets removed and washed. 50 g of fillet was homogenized with 100 ml water in a Virtis blender flask and a sample of the water extract removed by centrifugation and tested for salinity.

A small sample of flesh from each of the test fillets was placed in a beaker covered with plastic wrap and cooked in a microwave oven for two minutes. The flavor was compared to that of a control fish prepared in the same way.

RESULTS FROM SLUSH ICE TESTS

COOLING

Cooling curves for cod placed in drained and undrained slush ice are shown in Figures A-5 and A-6. Both types of slush ice cooled the fish cores quite rapidly. The drained ice cooled fish cores to less than 2°C in approximately one hour (Figure A-5) while the undrained took only 35 minutes to cool the fish to the same temperature (Figure A-6). For both drained and undrained slush ice cooling of the skin surface is very rapid and within ten minutes surface temperatures have dropped to approximately 4 and 2°C respectively (Figures A-5 and A-6). This rapid cooling rate is desirable as degradation by bacteria and enzymes is quickly suppressed at the lower temperatures and the fish are kept fresher.

The average core cooling rates for various ice types are shown in Table A-1. Values for flake, shell and block (crushed) ice are taken from Part B of this report and are used for comparison purposes. Values of 0.24°C/minutue for drained slush ice is the highest recorded for any of the "dry" ice types during the first thirty minutes. Values of 0.42°C/minute for the undrained form is more than double that of flake, block or shell for the first 30 minutes (Table A-1). This rapid cooling can be attributed to the slightly colder ice having a little extra cooling capacity but more importantly the small size of the ice particles promotes very efficient heat transfer in the early stages as a result of maximum surface contact with the fish.

The average cooling rates for fish cores in shell, drained and undrained slush ice determined in 30 minute increments (Table A-1) are illustrated in Figure A-7. The undrained ice shows a very dramatic cooling effect immediately while the drained ice shows a similar pattern to the shell but also cools more quickly (Figure A-7).

Salt water ice in general cools fish more rapidly than fresh water ice because of the lowered freezing point (Peters and Slavin 1958). However, if the fish temperature falls too low the water is slowly frozen resulting in the formation of large ice crystals. Tissue damage is a result noticeable mainly in texture losses. At -2.7°C three quarters of the water is slowly frozen and the damage is fairly extensive but at the recommended superchilling temperature of -2.2°C (Waterman and Taylor 1967) only one half of the water is frozen and the number of large ice crystals formed is not critical. Fish cores never reached ice temperatures during cooling evaluations but remained 1-2°C above ice temperatures. Fish kept overnight in the undrained slush ice reached a minimum temperature of

$-1.67^{\circ}C$ which is well within the range recommended for superchilling. Fish held at these temperatures should be expected to form only very small ice crystals with minimal if any damage. The fish might also be expected to have a longer shelf life than fish held in freshwater ice as bacterial action is reduced at these lower temperatures (Waterman and Taylor, 1967; Maslova and Nozdrunkova, 1970; Stern and Dassow, 1958; Power and Morton, 1965; Ming, 1981; Scarlatti, 1965, 1969). For example, white fish in crushed ice (fresh water) remain edible for approximately 15 days, while at $-2.2^{\circ}C$ the shelf life may be extended to 26 days (Waterman and Taylor, 1967).

Later as the ice drains and fresh water is added through meltage the temperature of the ice/water mixture will rise as the salt content is lowered. The temperature of this drained ice should be quite similar to that of freshwater ice.

WORKABILITY

The drained ice used in this test was prepared over two weeks previously and had been stored in an insulated container (Sunwell Engineering Company Ltd.). There was a surface layer approximately 2-4 cm thick which had hardened appreciably but could still be easily shovelled and broken up. Under this "thickened" layer the ice was in excellent shape although the ice crystals had grown during storage to the size of coarse salt. The addition of water to this ice easily refluidized it however, including the thickened surface layer.

MELTAGE

Only a very limited quantity of fresh slush ice was available for testing. However, ice stored in an insulated container (28 l x 55 w x 28 d cm) provided 5 litres of melt/drainwater over a 12 hour period (ambient air temperature $22^{\circ}C$). Shrinkage from the ends was 0.5 cm and from the sides 0.25 cm. The surface dropped 6.5 cm. Most of the shrinkage is probably as a result of the removal of the drainage water. The temperature of the melting ice after 12 hours was $-0.55^{\circ}C$.

SALT UPTAKE

When fish is immersed in low temperature brine it absorbs salt and depending on the brine concentration the fish may taste salty. The amount of salt gained by the fish will depend on the concentration of the brine as well as the immersion time. The salinity of various test solutions are shown in Table A-2. The starting solution for the test ice was 3.75% while after icemaking the brine concentration rose to 5.20%. The slurry consisting of ice plus brine pumped onto the test fish contained 3.15% and the initial meltwater consisting of brine drainage and meltwater was 4.30%. The meltwater collected the following morning contained 0.70%. Well drained ice contained 0.12%. Salt at this concentration is not noticeable. Initial chilling of fish in a brine solution for several hours with a salt concentration of approximately 11% before holding in a refrigerated hold has been recommended as a method of preserving the freshness of fish (Ming, 1981). Little, if any, adverse effect were noted when chilling by this method. Storage of fish in refrigerated seawater (3% salt content) at temperatures between $-1.67^{\circ}C$ and $-0.55^{\circ}C$ has also been recommended over storage of fish in crushed ice (freshwater; Stern and Dassow, 1958). No difference in flavour between fillets taken from a control fish and a fish held in undrained slush ice for 20 hours could be noted. Conductivity measurements of a water extract of either steaks or fillets taken from control and test fish were identical indicating that salt pickup from the surrounding medium was neligible.

ENERGY, CAPITAL EQUIPMENT AND TRANSPORTATION COSTS

Slush ice cost estimates were obtained from an operating 10-20 ton/day facilitiy in Port Dover, Ontario. Energy consumption was estimated to be 35 kwh of energy to produce one ton of ice. Cost of the complete system including a storage and separation system was estimated to be $61,000. Transportation costs are identical to those estimated for other ice types,being $7.50/ton for 100 km travel versus $11.25/ton for 300 km travel based on a minimum load of 40 tons.

CONCLUSIONS OF PRESENT STUDY

1. Slush ice especially in the undrained form should provide more rapid cooling of fish through better surface contact and therefore better heat exchange.

2. Temperatures reached by the fish cores should not promote significant texture changes.

3. The colder holding temperatures may prevent the growth of bacteria and will slow autolysis, thus shelf life may increase.

4. The low concentrations of salt found in drained ice or even in the brine used to form the ice should not allow for significant pick up of salt by the fish.

5. Slush ice remains very workable even after two weeks storage.

6. A proper slush ice to fish ratio will have to be determined to obtain optimum results as slush ice shrinks noticeably in the first few hours after application and may expose some fish.

7. Some idea of the durability an ease of operation of the equipment will have to be established.

8. Once a full scale commercial machine is in routine operation, these preliminary tests should be repeated and a full scale series of tests should be carried out.

9. Slush ice as yet cannot be considered superior to other ice types with regards to the chilled storage of fish but, its versatility with regards to cooling (wet or "dry") and storage/handling (may be stored dry and rewetted or may be shovelled or pumped) may offer many advantages for the design of an efficient easy to use ice storage and delivery system.

10. The use of both wet or dry slush ice would appear to be acceptable methods for the chill storage of cod.

SUMMARY

Tests on general workability and various physical characteristics of slush ice made from saltwater by a new type of ice plant were preliminarly investigated. The results showed that this type of ice is comparable with shell, flake and block ice.

Core and surface cooling curves were determined for cod placed in drained and undrained slush ice. Both the drained and undrained forms of slush ice promote more rapid cooling of the fish cores than traditional freshwater ice types. No significant amount of salt appears to be picked up by the fish as a whole or by the fillets when stored in the undrained slush. The drained form remains workable well past two weeks when held in insulated storage. Meltage rates of slush ice as compared to the traditional ice types has yet to be carried out. It is concluded that both the drained and undrained forms of slush ice are acceptable methods for the chill storage of cod.

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Table A-1 Average core cooling rates (°C/minute) for 30 minute intervals for various ice types[a].

Time Interval (Min)	Flake Ice	Shell Ice	Block Ice	Slush Ice (drained)	Slush Ice (undrained)
0 - 30	0.17	0.21	0.20	0.24	0.42
30 - 60	0.07	0.08	0.09	0.13	0.09
60 - 90	0.04	0.04	0.03	0.05	0.03
90 - 120	0.01	0.02	0.02	0.03	0.01
120 - 150	0.006	0.01	0.01	0.02	--
150 - 180	--	--	--	0.01	--

[a] Values for flake, block and shell obtained from Part B of this report.

Table A-2 Salinity of various test solutions during icemaking and storage.

Sample		Salinity (%)
Tapwater (Sunwell)	# 1	0.05
	# 2	0.05
Startup Brine Solution	# 1	3.75
	# 2	3.78
End Brine Solution	# 1	5.20
	# 2	5.20
Slurry (Ice and Brine)	# 1	3.15
	# 2	3.15
Meltwater (3 hours)*	# 1	4.30
	# 2	4.30
Meltwater (12 hours)	# 1	0.70
	# 2	0.70
Ice (drained)	# 1	0.12
	# 2	0.13

* Includes the initial drainage of excess brine solution from the ice.

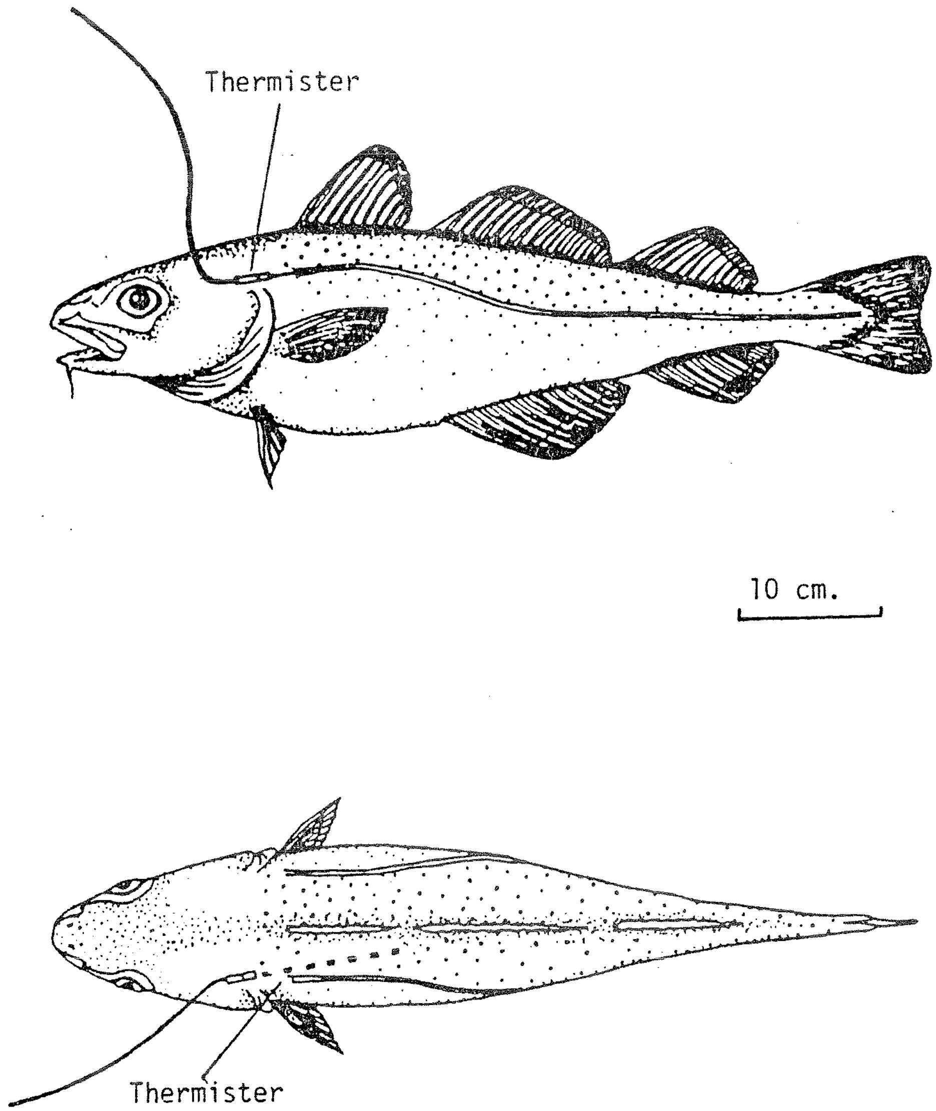

Figure A-1

Position of thermister probes in cod
for cooling curve determinations

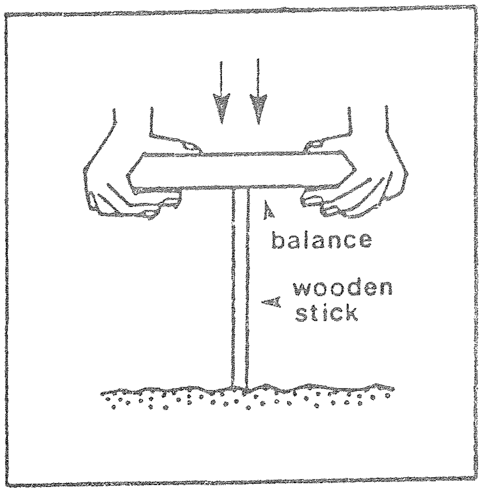

FIGURE A-2

Measuring the pressure required to break the surface of the ice by applying weight to a scale on top of a wooden stick

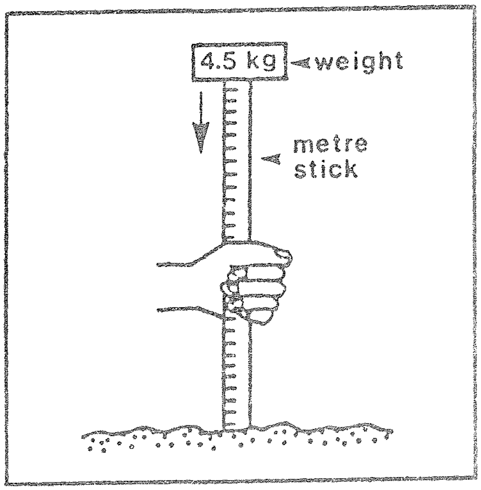

FIGURE A-3

Measuring the depth of penetration into the ice of a metre stick with a 4.5 kg weight

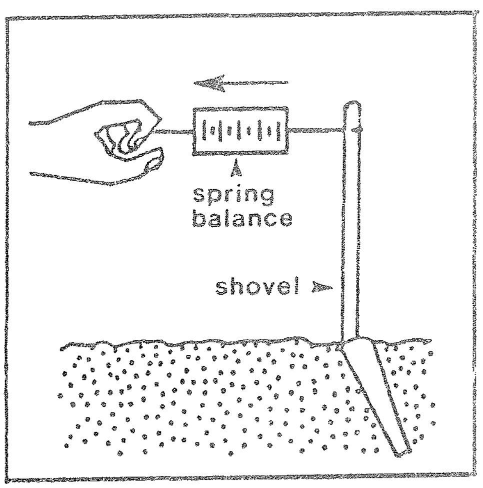

FIGURE A-4

Measuring the pressure required to pivot a shovel inserted into the ice

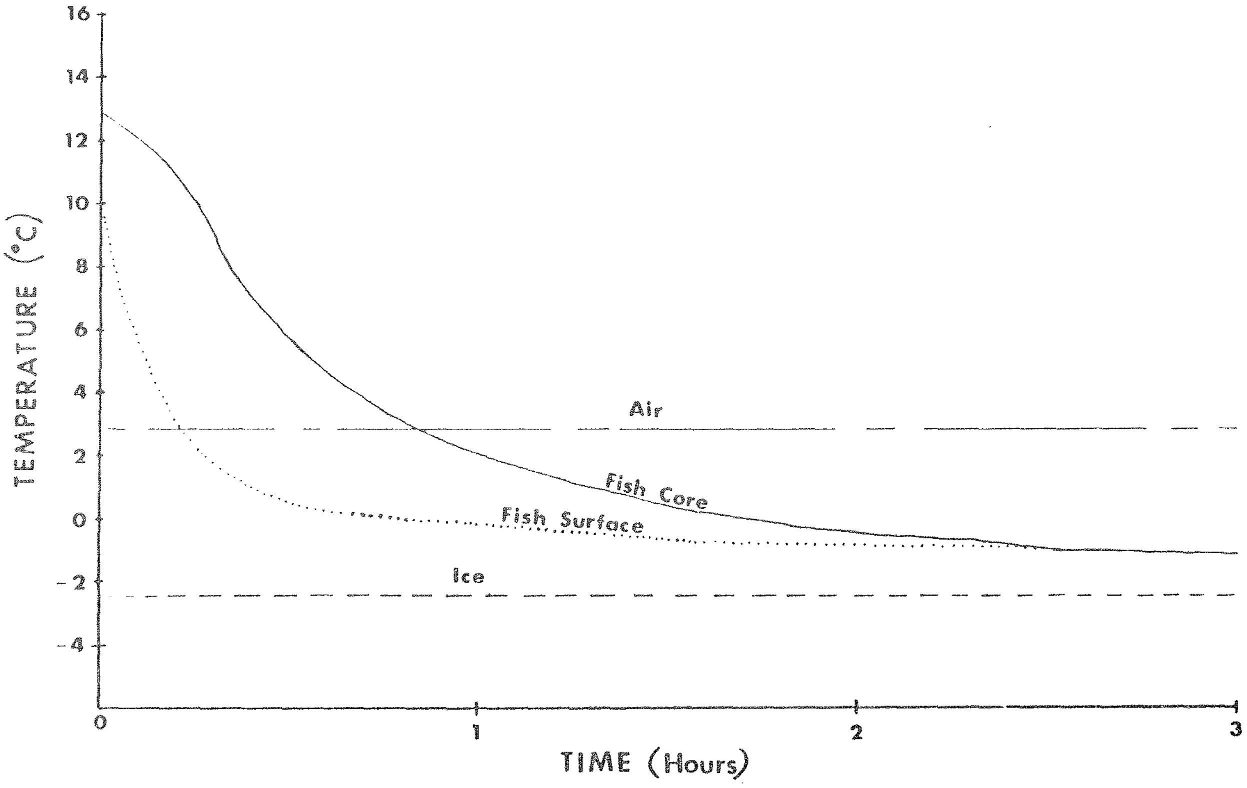

Figure A-5: COOLING CURVE FOR DRAINED SLUSH ICE AS DETERMINED FOR CORE AND SURFACE TEMPERATURES OF COD (2 Fish).

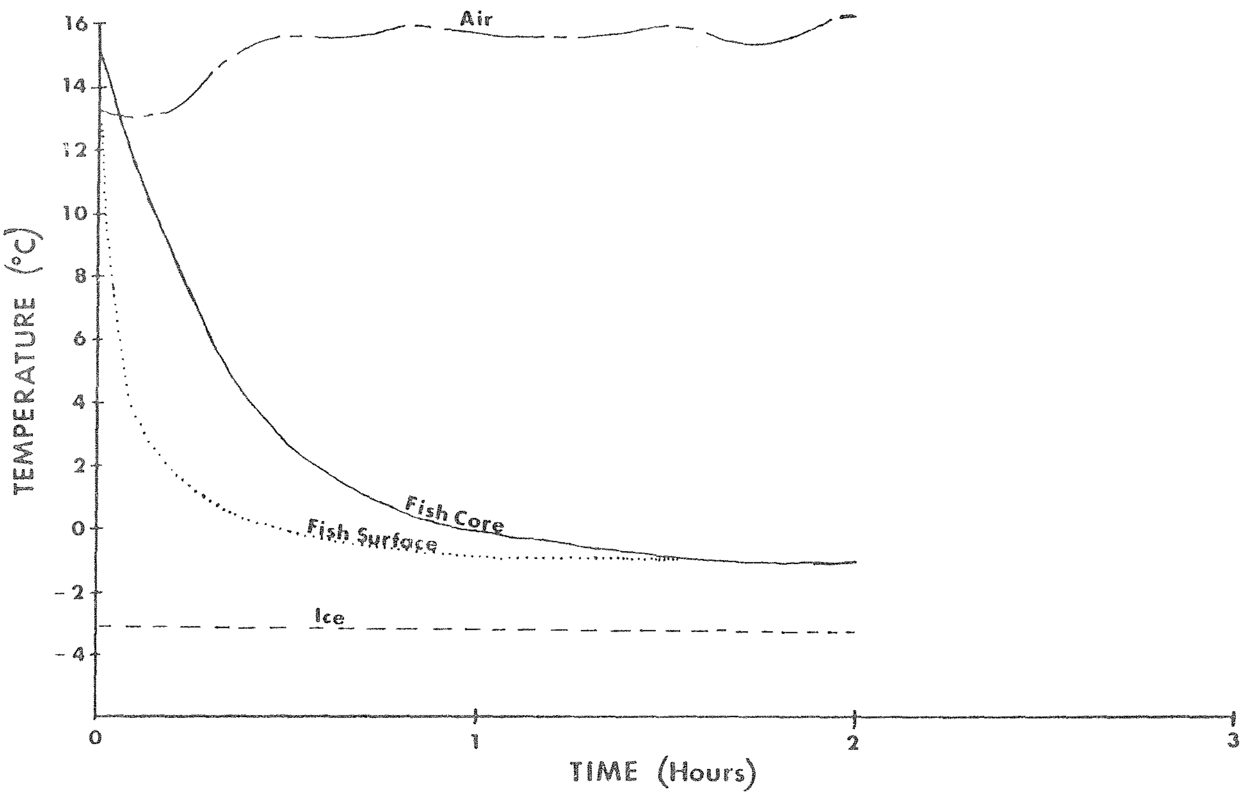

Figure A-6: COOLING CURVE FOR UNDRAINED SLUSH ICE AS DETERMINED FOR CORE AND SURFACE TEMPERATURES OF COD (2 Fish).

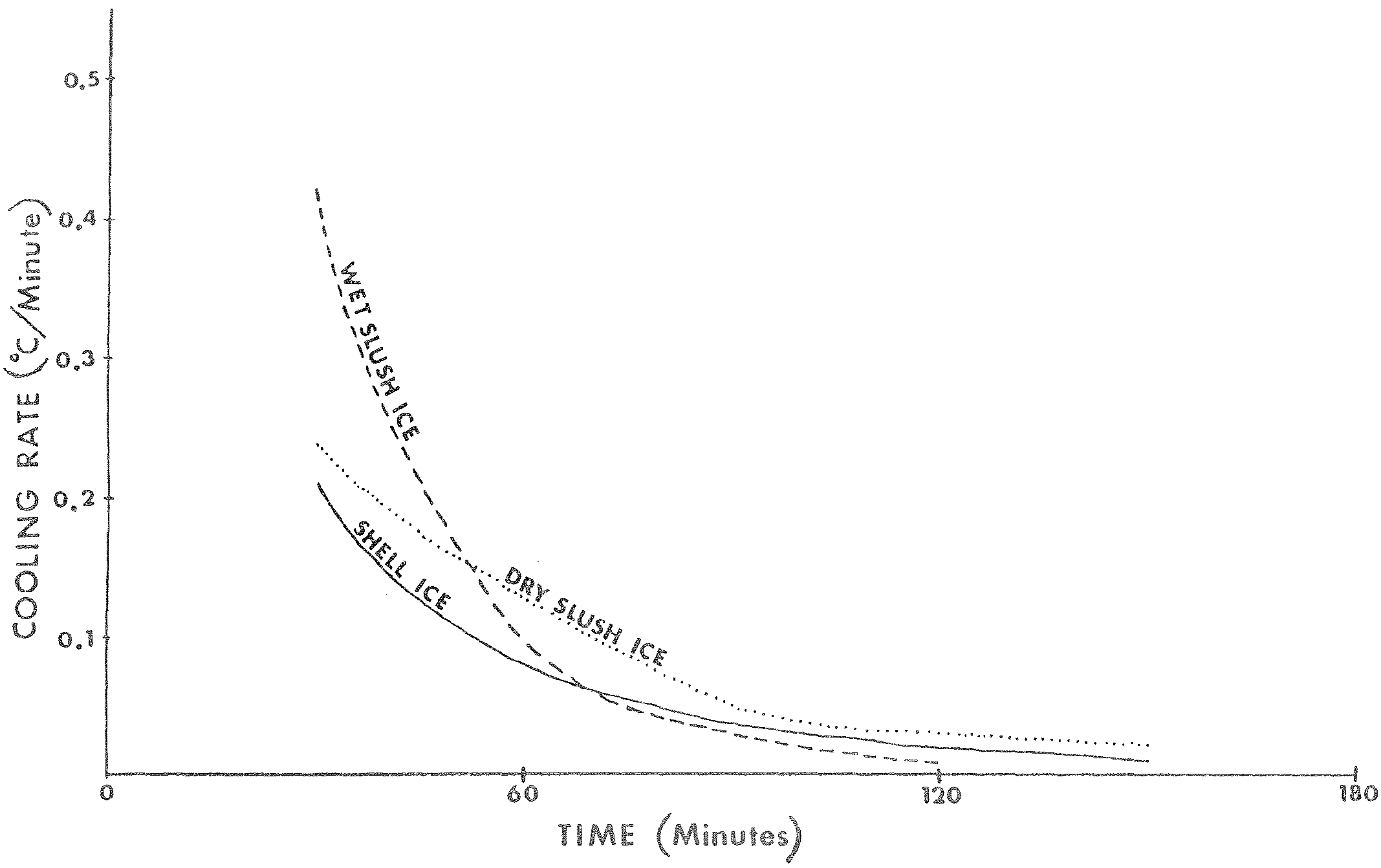

FIGURE A-7: AVERAGE COOLING RATES FOR FISH CORES DETERMINED IN 30 MINUTE INCREMENTS FOR COD COOLED IN SMALL, DRAINED SLUSH AND UNDRAINED SLUSH.

PART B

PRELIMINARY STUDIES ON ICE WORKABILITY DURING STORAGE AND OF ICE QUALITY AND QUANTITY CHANGES DURING TRANSPORTATION AND STORAGE FOR SHELL, BLOCK AND FLAKE ICE

INTRODUCTION

The possible contamination of ice during processing through contaminated sourcewater, processing equipment or poor handling practices is a source of concern as clean ice is required to ensure optimum sanitation, appearance and a top quality product. Volume and weight losses as well as structural changes must also be taken into account when comparing various ice types during transportation and storage. The ideal ice type would closely adhere to the following desirable criteria: (1) be of a suitable size for handling (2) be a little subcooled (3) must cool the fish quickly (4) that will not stick together in storage (5) that will not damage the fish and (6) stays during longer voyages (Ten Hacken, 1979).

The development of different manufacturing technologies for production of ice for the fishing industry has followed several routes. The relative cost- effectiveness of the respective production processes and transportation options have not been determined.

This study was carried out to address the following points:

1. compare the degree of bacterial and physical degradation of block, flake and shell ice during transportation and storage,

2. compare the cooling effects of block, flake and shell ice on fish placed in the ice,

3. determine the changes in workability and ice volume for each ice type during storage and/or transport,

4. and to determine the relative transportation and production costs for each ice type.

MICROBIOLOGICAL

The maintenance of prefreezing or preprocessing quality of fish is essential to the fishing industry in the production of a high quality product.

The effects of ice on the quality of fish and fish products have been studied intensively for a number of fish species from the point of view of retardation of enzymatic and bacterial activity as well as chemical degradation. However, the sanitary quality of the ice itself, may, under certain circumstances, contribute to the quality of the preserved product, especially when a contaminant is introduced during the production or handling of the ice.

The degree of presence of colony forming bacteria, as determined by Standard Plate Count (SPC) in the final product, is symptomatic of the degree of contamination that is introduced to the fish from the moment they are caught (Neufeld, 1971; MacCallum, 1971). The presence of faecal coliforms on a final product are a specific example of insanitation during handling or processing (Neufeld, 1971). Microbiological activity does not cease until temperatures of -10°C are reached (Connell, 1975; Gould and Peters, 1971). Therefore, in fresh and frozen foods, product degradation may be due to large numbers of psychrophilic bacteria (Neufeld, 1971; Guderson and Peterson, 1977). However, with the use of ice, growth of common mesophilic bacteria is only retarded and not stopped (Ingraham, 1962). Thus, psychrophiles should not necessarily be the only consideration in the quality of products maintained on ice.

Thatcher (1971) indicated that, at sea, ships surfaces and ice that is contaminated once on board ship are the main contributors to worsening of bacterial quality no matter what the quality of the fresh caught fish was before handling. Also Londahl (1981) and Banks _et al_ (1977) cited the need for use of clean ice on board the vessels. Connell (1975) illustrated that, in general, relatively few micro-organisms are picked up in the raw process water, and that the balance come from handling. Quality standards, currently in effect for fish plant process water, state that source water (at the point of use), must meet the public health bacteriological standard of 2 coliform organisms per 100 ml (MPN coliform) (Brownlee, 1971) (Schedule I and II Fish Inspection Regulations D.F.O.). The same standards would include ice production facilities.

The importance of using clean ice is also emphasized in Schedule III of the Fish Inspection Regulations. Banks et al (1972) indicated that bacteriological tests on ice in the holds of fishing vessels showed bacterial counts to be as high as 5 million bacteria/ gram of ice. They recommended only the use of chlorinated or potable water in ice plants and that the ice should be stored under sanitary conditions. They also cited the need to discard unused ice from the vessel at the end of each trip to eliminate ice contaminated by meltwater. Removal of meltwater contaminated ice is also strongly recommended by Londahl (1981).

PROCESS CONTAMINATION

Bacterial contamination of ice is generally assumed to be associated with the handling and transfer of the final product. However, in certain cases, contamination may be introduced with the process water, in the process equipment or during storage. These latter inputs tend to be of a more minor nature in facilities with automated or semi-automated systems. However, in manual systems such as block ice plants, a greater potential for in process contamination exists. An outline of the various types of ice plants from which ice was obtained in the studies is attached (Appendix A).

Contamination of ice as monitored in the end product may occur at a number of points in the production and delivery lines, specifically:

1. Contamination of process water through:
   a. inadequate treatment;
   b. contaminant in storage vessels (reservoir);
   c. contaminant in delivery system (pipe joints, valves, etc.).
2. Contamination in process equipment:
   a. contaminant in process equipment;
   b. process area of block ice plants;
   c. poor housekeeping practices.
3. Contamination at discharge point from process line to storage (manual or by conveyor).
4. Contamination during transfer from discharge point to storage facility or vessel.
5. Contamination during storage.
6. Contamination during discharge from storage to transportation vessel.
7. Contamination from transportation vessel.
8. Contamination during transportation in open containers (air borne particulates).

In addition, block ice may be subject to possible additional contamination due to further processing by crushing and transportation. These points are illustrated in Figure 1 for the specific product lines. Flake and shell ice are illustrated together since the points of potential contamination are similar for both process lines.

WORKABILITY AND STRUCTURAL MODIFICATION OF ICE UPON STORAGE

In Atlantic Canada, the use of ice is limited by the fact that a large number of small ports have very limited access to ice plants. One solution to this availability problem is to ship ice, in bulk, to these ports, and store the ice at dockside for use by the smaller inshore vessels. However the workability and final useable volumes of ice will vary considerably, even in rudimentary insulated storage due to such factors as melting, meltwater saturation and reconsolidation. Thus, reduced ice volumes after relatively short term storage, or unworkable ice masses due to freezing in mass, could cause problems in reliability of supply of useable ice. In addition, the formation of modified ice fragments (large, sharp, etc.) would introduce the potential for damage to fish during icing procedures.

A comparison of the workability of three types of ice available in Atlantic Canada; shell, flake and crushed block ice in a standardized insulated containment system and the determination of the relative storage potential of each type would be of benefit to both fishermen and processors.

SAMPLING AND METHODS

Three types of ice were obtained from commercial suppliers in Nova Scotia. A subsample of each was loaded directly from the process line or storage dispensing line into an open tranportation vessel to determine contamination/degradation due to transportation. A second subsample was collected in polyethylene bags (25 L) and returned to the lab for determintion of contamination/degradation during storage. Two additional subsamples were collected in covered insulated containers for use as controls for the two experiments. In addition equal volumes of each ice type were divided between two 109 x 98 x 51 cm (l x w x h) arctics boxes. The boxes were then covered with insulated lids for the workability study.

SAMPLING

Transportation Trials

The transportation trial was divided into truck and static facility phases in order to simulate depositional and temperature effects. The trials were carried out with the use of Techstar 0.5 m^3 capacity insulated container in the back of an open ½ ton vehicle (Figure 2).

All containers were disinfected with the use of a commercial disinfection agent (Lysol) and rinsed out three times with cold water before each run. Plant operators were interviewed to obtain technical information on the equipment employed and a brief examination was made of the equipment with special care being paid to possible sources of contamination. Samples of source water were taken for analysis. Staff at the ice plant were requested to load the container in the manner used for regular bulk ice shipments. Two control samples were collected in the same manner in covered 0.05 m^3 capacity insulated coolers. An additional subsample was taken in polyethylene bags for the storage experiment.

The following sampling and monitoring regime was then employed utilizing the time frame outlined in Table 1. One set of random surface samples (in triplicate) was taken for bacteriological evaluation and an additional random set (in triplicate) was taken for physical evaluation. Samples were obtained by the use of a metal scoop (approximately 500 ml capacity) which was sterilized by immersion in 85% denatured alcohol followed by flaming. The scoop was allowed to cool for 10-15 seconds, then samples were scooped, or scraped off the surface of the ice mass, and placed in polyethylene bags which were sealed. The samples were stored in a cooler. The scoop was sterilized between individual samples. Samples for physical evaluation were taken in the same manner, but were placed in prerinsed 500 ml bottles (Nalge). Temperature measurements were taken of both the air and ice mass, using an expanded scale mercury thermometer and meltwater was collected and drainage volumes determined. Culture plates containing nutrient agar were placed open-face up on top of the insulated container (Figure 2). The control ice was sampled in a similar manner but at reduced intervals (Table 2). No drainage volume was determined for the controls and no bacteriological samples were taken from the shell ice run.

The vehicle was driven over a random route for four hours to expose the ice mass to particulate deposition. At the end of the fourth hour the transportation container was removed from the vehicle and placed in a storage facility at room temperature (18-25°C) for two hours. Bacterial analyses were carried out at 4, 4.5, 5, 5.5 and 6 hours.

Storage Trials

A pre-weighed volume of ice obtained from the ice plants and transported in polyethylene bags as described in Section B.2.1.1 was placed in a previously disinfected 0.5 m^3 Techstar insulated container held in a cold room at 5.0°C ± 0.5°.

Control and sample ice was sampled as per Section B.2.1.1 but at 6-12 hour intervals. Samples were analyzed immediately after sampling.

Workability and Meltage

Equal volumes of shell, block and flake ice were placed in 0.5 m^3 X-actics insulated boxes with lids. The boxes were held at room temperature (approximately 20°C) and the ice was tested for meltage and workability at set intervals (0, 24, 48, 96 and 168 hours) over a seven to eight day period.

Ice Cooling

Ice retained at the end of the tranportation experiment was used for determination of cooling curves in fish. Fresh, gutted cod (1.2-1.4 kg) were used for these evaluations.

EVALUATION PROCEDURES

Bacteriological Methods

Samples taken during the transportation and storage trials were held in 5°C storage until they were processed. Sample processing occurred within 4-8 hours of sampling. Subsamples were taken for SPC (Standard Plate Counts). These were plated on nutrient agar in the following dilution series: 1.0 ml, 0.1 ml, and 0.01 ml. The plates were incubated at 37°C for 48 hours and were subsequently counted. The results were reported as number of colonies per gram of sample. Subsamples were also taken for the coliform determination (Faecal). Coliforms were enumerated using the MPN (Most Probable Number) technique. The specific assay employed was a 3 x 3 assay with 10 to 1.0 to 0.1 dilution using brilliant green bile at 37°C.(Presumptive Test). Results were reported as MPN/ml or MPN/100 ml of sample for ice and drainage water.

Physical methods

pH and SPM

Ice samples were allowed to melt by ambient warming. Water samples were analyzed without pre-warming. A sub-sample was taken from each of the retained physical samples for pH determinations. This measurement was done with the use of a Model H55-03-1 portable pH meter with a a Model H5503-11 combination electrode (Canlab). The read-out accuracy on the meter is ±0.03 pH.

The balance of the samples were filtered through preweighed 0.45 u cellulose acetate filters (Sartorius). The volume of water filtered was determined by graduated cylinder. The filters were dried in a microwave oven, dessicated, and reweighed. SPM in mg/L was then calculated based on weight difference and volume filtered. The method has an accuracy of 0.1 mg/l with a limit detection of 0.01 mg/l.

Workability and Meltage

Workability and meltage tests were carried out as per part A of this report.

Ice Cooling

Ice cooling evaluations were carried out as per part A of this report.

Calibration and Standardization Procedures

Three one litre and one 25 litre capacity bags per package that were used for sample holding were taken, and each was rinsed with 250 ml of sterilized water. This water was then analyzed for coliforms in the same manner as the other trial samples. Unexposed culture plates were returned in conjunction with the transportation and storage trial plates. These were treated in the same manner as the exposed plates. The calibration of the pH meter was verified after 10 sample analyses. In addition, a sample of 250 ml of glass-distilled water was passed through each of the filter discs as an internal standard check for (suspended) particulate matter at the beginning of each run.

EQUIPMENT AND TRANSPORTATION COSTS

Local suppliers of the production equipment used by the processors sampled, were canvassed. Specific information on energy requirements and operational costs were obtained for equipment within a production range of 10-20 tons.

Six transport companies were contacted for price estimates on moving a standard volume (40 tons) of ice (in containers), by refrigerated and non-refrigerated means to two locations, one, at a distance of 100 km, the second at a distance of 300 km.

RESULTS

SOURCE WATER

Water sampled from the municipal systems exhibited suppressed bacterial levels commensurate with the degree of treatment (10 colonies/100 ml; Table 2). The chlorinated well supplied water used by one of the processors did exhibit some elevation in total counts (averaging approximately 275 colonies/ 100 ml). In all cases, there were no detectable faecal coliforms in the samples although it is noted that analysis was be presumptive test only.

The pH levels of the source water tended to be in the 8 to 9.0 range (Table 2), with the exception of flake ice trial 2. Although that specific water supply is normally pH-adjusted to give a tap pH of 8.0, during the second run the pH was depressed to values of 6.25 to 6.85. The shell ice facility used a combination of well and trucked municipal water and exhibited pH levels of approximately 7.7. Values of SPM varied from an average of 9.6 mg/l to 0.01 mg/l. There was some variability within the two locations that were sampled repeatedly. However, levels generally tended to be low.

TRANSPORTATION TRIALS

Suspended Particulate Matter (SPM)

SPM data is presented in Figure 3 for shell, block and flake ice. The data shows some variation from one sampling period to the next but the amount of SPM reamins fairly consistent between 5 and 20 mg/l. There appears to be no significant increase or decrease in SPM values during the transportation trial either during the outdoor or indoor portion of the study.

Acidity

Values for pH generally tended to decrease during the periods of transportation (Figure 4) for block, flake and shell ice.

Temperature and Drainage Volume

Ice temperatures averaged -0.30 ± 0.3; -0.60 ± 0.2; and -1.3 ± 0.8 for flake, shell and block respectively. Ambient outdoor air temperatures ranged from 1 to 10°C for block ice; 1 to 11°C for flake ice and 22 to 27°C for shell ice respectively. Drainage volumes were neglible during the winter trials (block, flake) however, the summer shell ice trial resulted in a significant drainage volume (average 16.9 ± 14 litres/hour for a 400 kg sample). Drainage SPM ramined relatively constant throughout the experiment averaging 8.5 ± 3 mg/l while the pH of the drainage water gradually decreased (range 7.7 to 7.0).

Bacteriological Results

Plate count results are illustrated in Figure 5. Flake ice averaged 1247 colonies/gm vs. 78 colonies/gm for block ice over the sampling period. The higher values showed considerably more variability among replicates and between sample periods. This type of pattern is not atypical of results obtained from sampling populations with patchy distributions. The reduced variability exxhibited in the block ice was probably reflective of a more uniform population distribution (through the ice mass and/or covering the ice surface). In general, no particular patterns emerged during the samping period for either block or flake ice. Faecal coliforms were found to be present at low levels (5/100 ml) in most of the ice samples analyzed. Their virtual absence in the control samples indicated that they came from an external source (particulates during transportation, etc.). Exposed air culture plates also demonstrated low counts (40/g).

STORAGE TRIALS

The storage trials were carried out under a more controlled regime from the point of view of ambient temperatures and exposure to particulate deposition.

Suspended Particulate Matter Data

Levels of SPM from the storage experiment tended to be similar to the levels measured during the transportation trials. However, they exhibited considerably more variation among replicates and between samples than did the latter trials. Changes in the SPM detected in this storage trial reflected the release of particulate matter in the ice mass through melting as opposed to by deposition. However, due to the nature of the melting process (after ice saturation), it was noted that melting could result in uneven rinsing of the ice surface, resulting in greater patchiness. Averaged SPM values for block, flake and shell ice are presented in Figure 6.

Acidity

Values for pH measurements in the storage trials showed very similar patterns to those of the transportation trials in that the pH generally tended to decrease with time.

Temperature and Drainage Volumes

Through the use of controlled environment facilities, the ambient temperatures for the storage trials remained relatively consistent (5.0 to7.0°C). Measured ice temperatures also tended to be uniform throughout the trials although the temperatures were somewhat closer to zero than during the transportation trials averaging -0.07 ± 0.70; 0.05 ± 0.05 and -0.71 ± 0.49 for flake, shell and block respectively.

Rates of production of water, as measured by drainage, did not show any consistent patterns. It was anticipated that drainage volume would increase consistently as the ice mass melted. However, it was found that loose ice (flake and shell) would tend to collapse down into the melt-water after periods of melting, and act as 'sponges', thereby reducing the specific volumes of water for sampling. Variability between trials of single ice types was high. The highest losses occurred with the shell ice trials where 49% of ice mass was lost in 48 hours. A summary of losses and percent losses is given in Table 3.

Bacteriological Results

Plate count results are illustrated in Figure 8. Flake ice averaged 106 colonies/g vs 47 colonies/g for block ice over the sampling period. These levels tend to be lower than those from the transportation trials however there again was considerable variability among replicates reflecting what appears to be patchy populations.

Faecal coliforms were virtually absent from the storage trials with levels averaging less than 3/sample. Drainage water tended to reflect the levels obtained on the surface of the ice. Exposed air culture plates demonstrated lower counts than the transportation phase (10/g).

ICE COOLING EVALUATIONS

Temperature data from individual fish were averaged, to give single curves for the respective ice types. The cooling curves are presented in Figure 9, A, B and C for flake ice, shell ice and block ice, respectively. Both shell and block ice cooling curves demonstrated short time lags (2 to 3 minutes) before commencement of cooling whereas flake demonstrated an immediate cooling effect.

The average core cooling rates for the various ice types are shown in Table 4. Values of 0.17; 0.21 and 0.20°C/minute were experienced for the first 30 minute interval for flake, shell and block ice respectively and there appears to be no significant differences throughout the test period (Figure 10).

Shell ice and block ice trials resulted in cooling of the fish cores almost to the ice temperature (within 0.5°C). Both resulted in cooling of the cores to less than 0°C. Whereas in the flake ice trial the fish temperatures never went below 0°C and at the end of 2½ hours were almost 2°C warmer than the recorded ice temperatures (Figure 9).

CALIBRATION AND STANDARDIZATION

The results of the quality checks carried out during the trials are summarized below.

Analysis of rinse water from new 1 litre sample bags carried out on nine bags produced only one sample with positive readings (bacterial counts of 4/ml) while analysis of rinse water from new, 25 litre sample bags did not produce any positive bacteriological results. Unexposed culture plates did not produce any colonies and calibration checks of the pH meter did not demonstrate significant variation. Distilled water passed through new filter discs indicated no detectable changes in processed filter weights.

WORKABILITY AND MELTAGE

The results are based on two trials with three measurements taken per sampling period for each trial. The ambient air temperatures averaged approximately 20°C and were generally within 2°C of each other throughout. Ice temperatures varied from -0.5°C for crushed block to 0°C for flake and shell ice.

The meltwater production, as determined in litres/hour is presented in Figure 11. Meltwater production occurs in three phases: Phase I, (0 to 48 hours), where the rate of ice melting generally increases. (The data does not reflect the volume of meltwater required for ice mass saturation prior to availability of free water for drainage.) Phase II, (48 to 96 hours) during which meltwater production remains relatively constant and Phase III, (96 to 192 hours) during which meltwater production generally increases. The lowest loss, as a percentage of the original mass, occurred with crushed block ice, possible due to its larger mass and greater resultant heat capacity. Crushed block ice lost 12.6% of its original mass. Shell ice lost 15.5% of its mass and flake ice lost 18.2% of its original mass.

Figure 12 represents the height of ice surface in the containers. The trends in surface levels indicate a relatively constant decrease with time throughout the study, although there was relatively little change in the height of shell ice surface from 48 to 96 hours. These indicate the degree of compressability of the ice types.

Figure 13 indicates the pressure in kilograms required to penetrate the ice surface or crust. Shell ice was unchanged over the seven day study period. Both flake and crushed block ice required approximately twice as much force to penetrate the crust by the end of the study as compared to the start. However, the block ice required considerably more force (24 kg vs. 3 to 7 kg) for initial surface penetration.

Figure 14 indicates penetration of meter stick under constant pressure. Penetration was most for flake ice and least for crushed ice. As with the production of meltwater, the relative penetrability of the ice occurred in three phases (0 to 48 hours - fastest decrease in penetration) (48 to 96 hours - relatively constant) and (96 hours plus - relatively decreasing).

Figure 15 demonstrates the most direct technique for measuring workability. It was not possible to shovel crushed block ice after 24 hours (greater than 11.4 kg force required) and flake ice by 7 days. Shell ice remained amenable to shovelling throughout the study period.

The mean sizes of clumped fragments on the ice surface are presented in Figure 16. Both crushed block ice and flake ice had a solid surface in 24 and 72 hours respectively. Shell ice did not appear to change structurally to any significant degree during the study period.

The pH of the drainage water is presented in Figure 17. All ice types showed decreases in pH. Block ice meltwater showed the smallest pH decrease (0.6 pH units). Flake ice demonstrated a 1.0 pH unit decrease while shell ice drainage water illustrated the greatest decrease (1.3 pH units) during the study period.

The SPM in drainage water is shown in Figure 18. The SPM data demonstrate a decrease in levels for the first 48 hours, followed by a relatively constant 48 to 96 hour period. Specifically, the ice surfaces are being flushed during initial meltwater production. This removes the particulate matter deposited on ice surfaces during collection and transportation. After the 48 hour point, SPM levels tend to reflect release of material bound up in the ice matrices themselves.

Freshly procured shell ice had the largest particle size with an average size of 5 cm. Flake ice was second largest at 3 cm and block ice 1 cm though it had clumped considerably between procurement and deposition in the test containers. The sizes and shapes were directly reflective of the procedures used in production of the respective ice types.

ENERGY, CAPITAL EQUIPMENT AND TRANSPORTATION COSTS

Data for the respective capital equipment and transportation costs are summarized in Table 5. Capital costs are given for facilities with different capacities within the range of 5 to 30 tons/24 hours. It is noted that specific demand requirements dictate that many of the facilities are not operating at full capacity.

Transportation costs are given for containerized product being shipped 100 and 300 km in refigerated and unrefrigerated vehicles (Table 5). It is noted that costs were actually the same. Estimates for energy consumption are based on 15.6°C inlet water temperature.

Specific costs for complete systems and/or principal components were not readily available, since final costs are location and layout (facility) dependent. In addition, certain systems (block ice) are built specifically to capacity specifications. Therefore costs listed in Table 5 are not directly comparable. Flake, shell and block ice specifications do not include storage.

Each ice production type had its own operational advantages and disadvantages. Block ice production volumes are limited by production space available, since a large surface area is required and tends to be tied up for a relatively long time (up to 24 hours per run). However, storage and transportation volume/weight ratios are very small, thus making it relatively easy to store and transport. These procedures are also amenable to some degree of mechanization. Block ice usage generally requires additional processing (crushing) generally by the end user. However, it presents a limited surface area for contamination and with enforcement of sanitary protocols, it should provide a high quality product.

Both shell and flake ice systems depend more on mechanical production requirements than the block ice system and produce a relatively high purity product. However, storage and handling protocols currently in use make it susceptible to greater contamination than the block ice product.

DISCUSSION

As can be seen in the previous section, there is a considerable amount of variability in the sanitary quality of the ice studied. Variation is noted both between types of ice product, as well as between different trials on a single ice type. Methods for loading and transferring ice were strictly manual (shovels, ice picks, etc.). As a result, this variability in contamiation may be more a reflection of housekeeping practices and delivery protocols in force at the time of specific trials.

Specifically, each aspect of variability may be attributable to any of a number of sources within the process/storage system, and cannot be attributed to any specific event.

SOURCES OF VARIABILITY

Variability in data can be attributed to a number of specific factors. Process factors such as source water, production equipment, storage and delivery systems, as well as protocols employed are discussed. Variability due to experimental design is covered separately.

Process Factors

Source Water

Although municipal water supplies tend to be monitored and regulated somewhat more rigourously than private (well) systems, it was noted that fluctuations in measured parameters can occur. This was most evident in the pH depression noted in the source water during the second flake ice trial. This paralleled a slight increase in SPM levels, but was not reflected in changes in bacteriological parameters (Table 2).

The degree of pre-treatment of water supplies also depends on the stability of raw source water quality (at the treatment facility). Therefore seasonal changes or diurnal fluctuations in surface water quality due to factors such as overturns, phytoplankton blooms, or precipitation, dictate that specific treatment regimes will vary accordingly. Therefore process source water may not necessarily be of consistent quality (physical or chemical), but should fall within a given range within the standards set for the specific water supply. Variation in sanitary parameters within municipal systems (Halifax) has been noted in the past and stability of source water quality for ice production has also been addressed in a number of internal studies carried out at Health facilities (Wort, personal communication). It was found that fluctuations in bacteriological parameters do occur, but have not been found to be of a magnitude to cause concern.

Process Equipment

Introduction of contamination by equipment, per se, will occur under a limited number of circumstances for 'in-line' systems.

1. Activation of a new water supply causing equipment contamination.

2. Activation of a new machine that has not been disinfected or flushed.

3. Re-activation of a machine after storage with no disinfection or flush.

4. Activation of a machine after servicing.

5. Contamination of equipment during operation due to manual adjustments or other manipulations.

Introduction of contamination by equipment in block ice facilities cannot be characterized in the same specific forms. It can be more readily classified as due to:

1. Activation of new water supply.

2. Ambient particulate deposition.

3. Manipulation of product.

Variability can be introduced at each of these stages, specifically due to the amount of equipment flushing, if any, employed before resumption of production.

In general, the longer the production equipment is run, prior to start of production of marketable ice, the greater the opportunities for purging of the system. However, once a bacterial contaminant is introduced to the equipment, it will remain present, until the equipment is disinfected.

Delivery to Storage

The variability at this stage will tend to be minimal, since, in general, ice is discharged by gravity into storage.

However, in the case of block ice, blocks were found to be manually removed from the production area to the storage area, over a 'weathered' wooden surface. Therefore protocols specific to individual employees would tend to introduce variability at this type of facility.

Storage and Delivery

This is the first point at which all the systems sampled during this study became significantly open to contamination.

Contamination at this stage is primarily due, not to the actual storage environment (except, in part, block ice), but rather to the degree of manipulation of product in storage, immediately prior to delivery.

Specifically, when ice is shovelled into containers for distribution, individuals doing the shovelling have to stand within the storage area. Thus contamiation through footwear may occur. In the case of co-location of the ice storage area with the fish processing area, this tends to be a potentially greater problem than at facilities where the storage area is discrete from the processing area. However, most delivery areas tend to retain some degree of outside contamination from vehicle tires, etc., so contamination by footwear is considered to be a major factor. In addition, unless specific operational protocols are adhered to, such as dedication of given equipment to specific areas and tasks, the variability in contamination could be very high. The effects and variability in contamination tend to be maximized in circumstances where manual contact is frequent. Specifically, this will occur during delivery of small amounts of ice (several hundred kgs) when automated delivery systems are not employed.

EXPERIMENTAL DESIGN

Once the product has been removed from the production facility, it is open to contamination from a number of sources. However, this impact on ice quality is more reflective of natural events. This is due to the use of standard protocols for manipulation of ice as well as sampling and analysis, thus limiting sources of variability.

Transportation Containers

Variability of contamiation of containers was minimized by use of precleaned or new containers. As was noted in the quality control section, bacterial contamination of these systems was low.

Transportation Environment

Since all the trials were not conducted on the same day, a number of environmental factors were introduced in the experimental design. Specifically, weather conditions varied considerably between trials. Although transportation trials were not carried out during periods of precipitation, ambient temperatures were found to vary from 1° to 27.5°C.

Quantities of suspended particulate matter in the air tend to illustrate some seasonality (Kozak, personal communication). Differences in temperature also would tend to vary the melting rate of the ice mass during the transportation experiment. In addition, patterns of particulate deposition from highway driving vary considerably from urban delivery. Thus the monitoring of drainage water alone might tend to produce data that are not necessarily comparable to events occurring on the ice surface.

Storage Environment

Due to specific protocols employed and facilities used, variability due to experimental design was minimized.

Sampling Regimes

Variability due to sampling protocols was also minimized by experimental design considerations. However, in the case of block ice, due to the nature of the surface to be sampled, sample depth was not consistent with the non-block trials.

DRAINAGE WATER

Coliform levels (approximately 5/100 g) of some of the drainage water and surface ice samples were found to be comparable to levels found by MacCallum (1971) in thawing-washing water. The presence of such apparently high levels in ice water is a point of some concern in that the drainage water temperature is normally around 0°C (not the optimum temperature for bacterial proliferation). Whereas, the immersion thawer operated at a nominal temperature of 13 to 18°C. Therefore the presence of these levels of microorganisms points to a need for more attention to be paid to protocols currently being used. The measured levels are, still, considerably lower than those that would be considered problem levels from the point of view of the final product (processed fish). However, since one of the main aims in quality control in the fisheries is to reduce unnecessary contamination, resulting in a better quality product, the production of a consistent high quality ice would be recommended.

Drainage water volumes did not indicate consistent patterns for single ice types, although melting during the 48 hour observation period varied from 5 to 49%, with highest losses coming from the shell ice. It should be noted that the ice mass for block ice was only 38% of the flake.

COOLING EVALUATIONS

The cooling curve determinations relates to the actual cooling effiency and tissue temperature of the fish studied. In the case of block ice, where a time lag was noted before the cooling effect was seen, the temperatures of fish neared the temperature of the ice within $2\frac{1}{2}$ to 3 hours remaining around -1°C. Thus the measured tissue temperatures were close to the critical zone demonstrated by Dyer (1971) but remained above the recommended superchilling temperature of -2.2°C (Watermen and Taylor 1967).

Flake and shell ice which had warmer temperatures (approximately 0°C) did not exhibit the same degree of heat transfer resulting in fish temperatures of between 0 to 1.5°C.

CONCLUSION OF PRESENT STUDY

A degree of bacterial contamination from the point of delivery of the ice onward, was noted but it was of a relatively minor nature. Variability in the data was high, reflecting the effect of a number of parameters, specifically the degree of manipulation of product.

Cooling evaluations showed little difference in cooling rates between the different ice types. However, there was a slight difference in the final temperatures reached with block ice reducing fish core temperatures to slightly below 0°C. Fish kept in flake and shell ice remained slightly above 0°C.

Volume losses, measured as drainage water varied considerably in the initial 48 hour storage trial. However in the larger workability and meltage study, water losses (drainage) were comparable for all three ice types after 48 hours averaging 2% weight loss/day.

Factors, such as pH, and ice appearance indicated a reduction in general ice quality with storage, although meltwater SPM demonstrated a surface purging effect, resulting in cleaner meltwater after 48 hours.

The workability of the three ice types, as defined by the factors of pressure to break ice surfaces, depth of gauge penetration, pressure to move a shovel, and size of clumped fragments was rated in the following manner:

- Shell Ice - completely workable through seven days.
- Flake Ice - workable to 48 hours but workable with difficulty after 96 hours.
- Block (Crushed) Ice - unworkable after 24 hours.

Based on these preliminary finds, the greatest workability and relative quality was retained by the shell ice.

The availability of comparable costs for ice production/storage units or principal components was limited, with little directly comparable data available. Capital requirements were found to vary extensively with facility requirements and plant layout.

In summary, improvement of the quality of block, flake and shell ice may be attained at little cost with strict adherence to strict sanitary protocols at the manipulation and storage phases. Based on workability, meltage and other factors shell ice retains the highest quality during prolonged storage.

SUMMARY

Investigations were carried out on three types of ice available from commercial suppliers in the Atlantic region (shell, flake and block). Quality, quantity and workability changes in association with periods of non-refigerated transportation and storage were investigated. The cooling rates of the various ice types on fish tissues were also studied.

The sanitary quality of the ice (determined by standard plate counts and faecal coliform determinations) varied considerably with the degree of bacterial contamination related to the degree of, and methods of, handling the final product before distribution. Changes in measured physical and

chemical parameters reflected the washing of ice mass surfaces during melting, as well as pH reduction in meltwater. Meltwater production was found to be consistent for the three ice types once the ice masses had been saturated.

Cooling evaluations demonstrated similar patterns among all ice types, with block ice cooling the fish to the lowest temperature (-1°C).

Method were developed for measuring workability of ice types during insulated storage of up to 7 days. Shell ice remained completely workable through seven days while flake ice was workable only with difficulty after 96 hours. Crushed block ice was unworkable after 24 hours due to refreezing of the material into a single ice mass. Factors such as pH, and ice appearance indicated a reduction in general ice quality with storage.

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Table B-1 Time Frame for Sampling for Ice Transportation Trials Used in Ice Quality Evaluations

SAMPLE TYPE	TIME (hours)								
	0	1	2	3	4	4.5	5	5.5	6
Trial Ice									
Bacteriological Samples	x	x	x	x	x	x	x	x	x
Physical Samples	x	x	x	x	x	x	x	x	x
Air/Ice Temperature	x	x	x	x	x	x	x	x	x
Drainage Volume	x	x	x	x	x	x	x	x	x
Air Culture Plate	x	-	-	-	x	-	-	-	x
Control Ice									
Bacteriological Sample	x	-	-	-	x	-	-	-	-
Physical Samples	x	-	-	-	x	-	-	-	x
Air Culture Plate	x	-	-	-	x	-	-	-	x

Table B-2 Water Quality for Source Water at Ice Production Facilities Used for Ice Quality Evaluation[a]

TRIAL #	TOTAL COLIFORM (colonies/100m)	FAECAL COLIFORM #/ml	pH	SPM (mg/l)
Flake Ice, Trial #1	1 ± 1	0	8.72 ± 0.06	.01
Flake Ice, Trial #2	0	0	6.46 ± 0.15	4.27 ± 2.81
Flake Ice, Trial #3	276 ± 306	0	9.12 ± 0.03	4.60 ± 1.49
Shell Ice	-	-	7.73 ± 0.06	9.67 ± 5.05
Block Ice, Trial #1	6 ± 4	0	8.33 ± 0.32	0.40 ± 0.68
Block Ice, Trial #2	-	0	8.33 ± 0.13	.01

[a] Average of three determinations.

Table B-3 Volume of Meltwater Drainage (Litres) from Three Types of Ice (Flake, Block, Shell) During Storage at 5°C

ICE TYPE	WEIGHT OF ICE USED (kg)	TIME (hours)						
		0	6-12	24	30	46-48	TOTAL	%*LOSS
Flake Ice, Trial 1	200	0	0	6	2	2	10	5%
Trial 2	200	0	0	2	12	30	44	22%
Trail 3	200	0	0	10.5	12	5	27.5	14%
Shell Ice, Trial 1	180	0	32.5	22.5	9	24	88	49%
Block Ice, Trial 1	75	0	1.5	8	4	11	24.5	33%
Trial 2	75	0	0	2	2	10	14	19%

* % by weight.

Table B-4 Averaged Cooling Rates (°C/minute) at 30 Minute Intervals for Three Ice Types

TIME INTERVAL	FLAKE ICE	SHELL ICE	BLOCK ICE
0 - 30	0.17°/min.	0.21°/min.	0.20°/min.
30 - 60	0.07°/min.	0.08°/min.	0.09°/min.
60 - 90	0.04°/min.	0.04°/min.	0.03°/min.
90 - 120	0.01°/min.	0.02°/min.	0.02°/min.
120 - 150	0.006°/min.	0.01°/min.	0.01°/min.

Table B-5 Summary of Energy, Capital Equipment and Transportation Costs for Ice Production and Distribution

ICE TYPE	ENERGY CONSUMPTION [1] (kwh/ton of ice)	CAPITAL COSTS [2] (estimated)	TRANSPORTATION (refrigerated) 100 km.	TRANSPORTATION (refrigerated) 300 km.	TRANSPORTATION (non-refrigerated) 100 km.	TRANSPORTATION (non-refrigerated) 300 km.
Flake	50 - 60	[3] 49,000	7.50/ton [6,7]	11.25/ton	7.50/ton	11.25/ton
Tube/Shell	40 - 60	[4] 40,000	7.50/ton	11.25/ton	7.50/ton	11.25/ton
Block	40 - 50	[5]	7.50/ton	11.25/ton	7.50/ton	11.25/ton

1 F.A.O., 1983

2 Cost estimates for installed ice production unit

3 Capacity 10 - 11.8 tons/24 hours - no storage

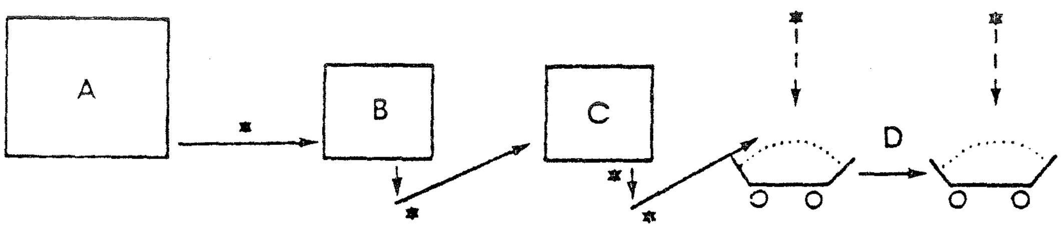
4 Capacity 5 tons/24 hours - no storage

5 Capacity - refrigeration unit only

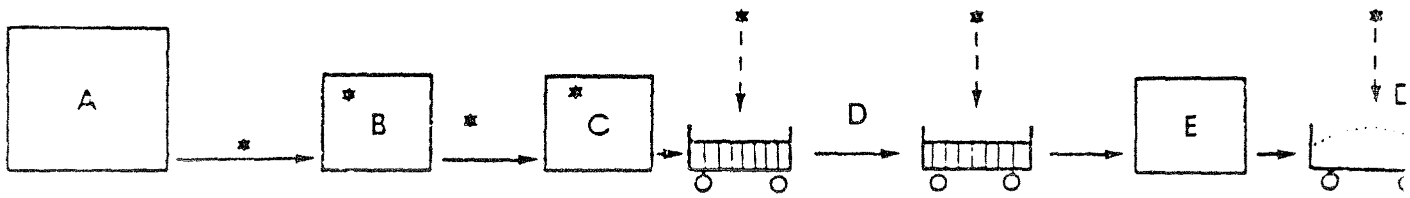
6 Based on minimum load of 40 tons

7 Based on carrying of insulated containers with total weight of 40 tons

Flake & Shell Ice



Block Ice



A - WATER SUPPLY

B - ICE MAKING EQUIPMENT

C - ICE STORAGE

D - TRANSPORTATION EQUIPMENT

E - ICE CRUSHER

* - POINTS OF CONTAMINATION

FIGURE B-1

POTENTIAL POINTS OF CONTAMINATION IN
ICE PRODUCTION AND DELIVERY PROCESS FOR THREE PRODUCTION SYSTEMS

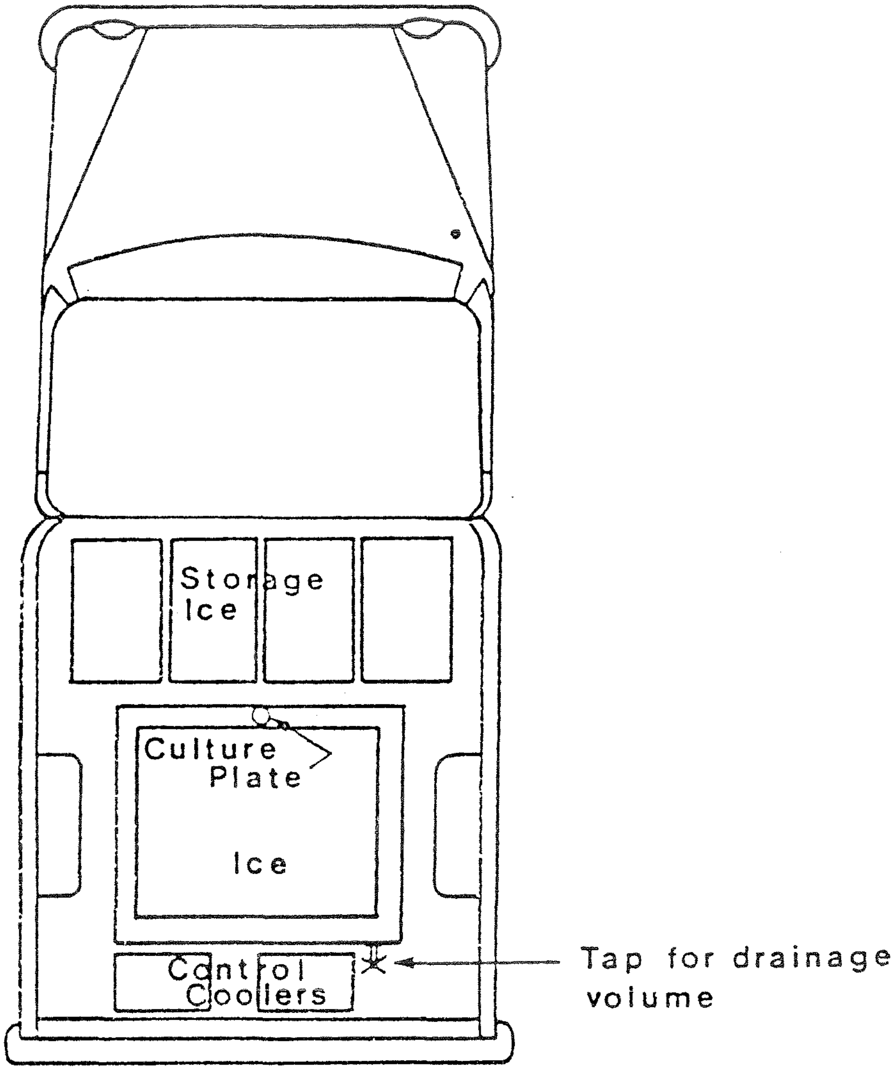


Figure B-2: TOP VIEW OF LAYOUT FOR TRANSPORTATION OF ICE
(1/2 Ton Pick-up)

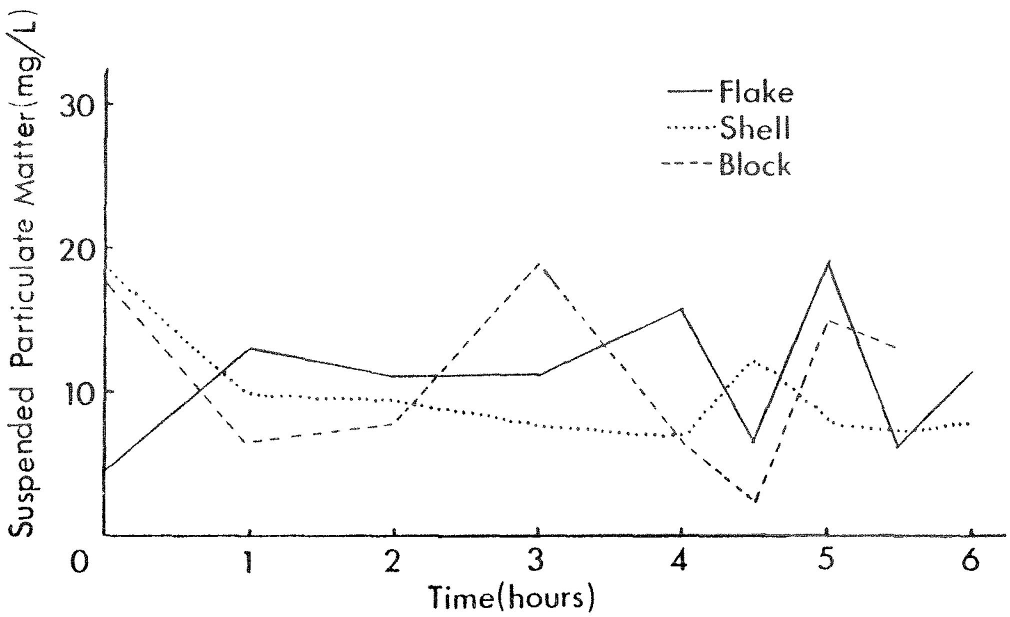


Figure B-3: SUSPENDED PARTICULATE MATTER (SPM) DATA FOR BLOCK (2 TRIALS), FLAKE (3 TRIALS) AND SHELL (1 TRIAL) ICE TRANSPORTATION TRIALS

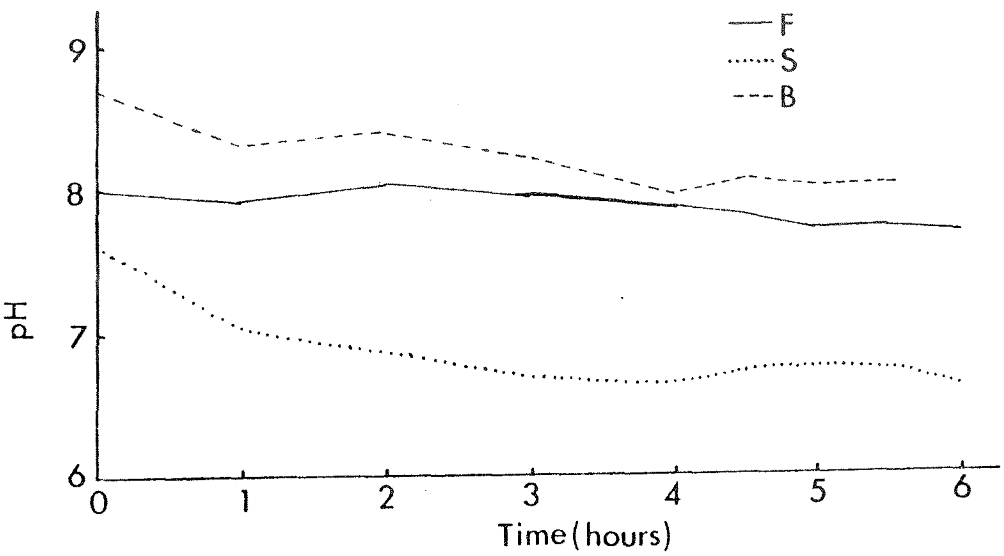


Figure B-4: pH VALUES FOR BLOCK (2 TRIALS), FLAKE (3 TRIALS) AND SHELL (1 TRIAL). ICE TRANSPORTATION TRIALS

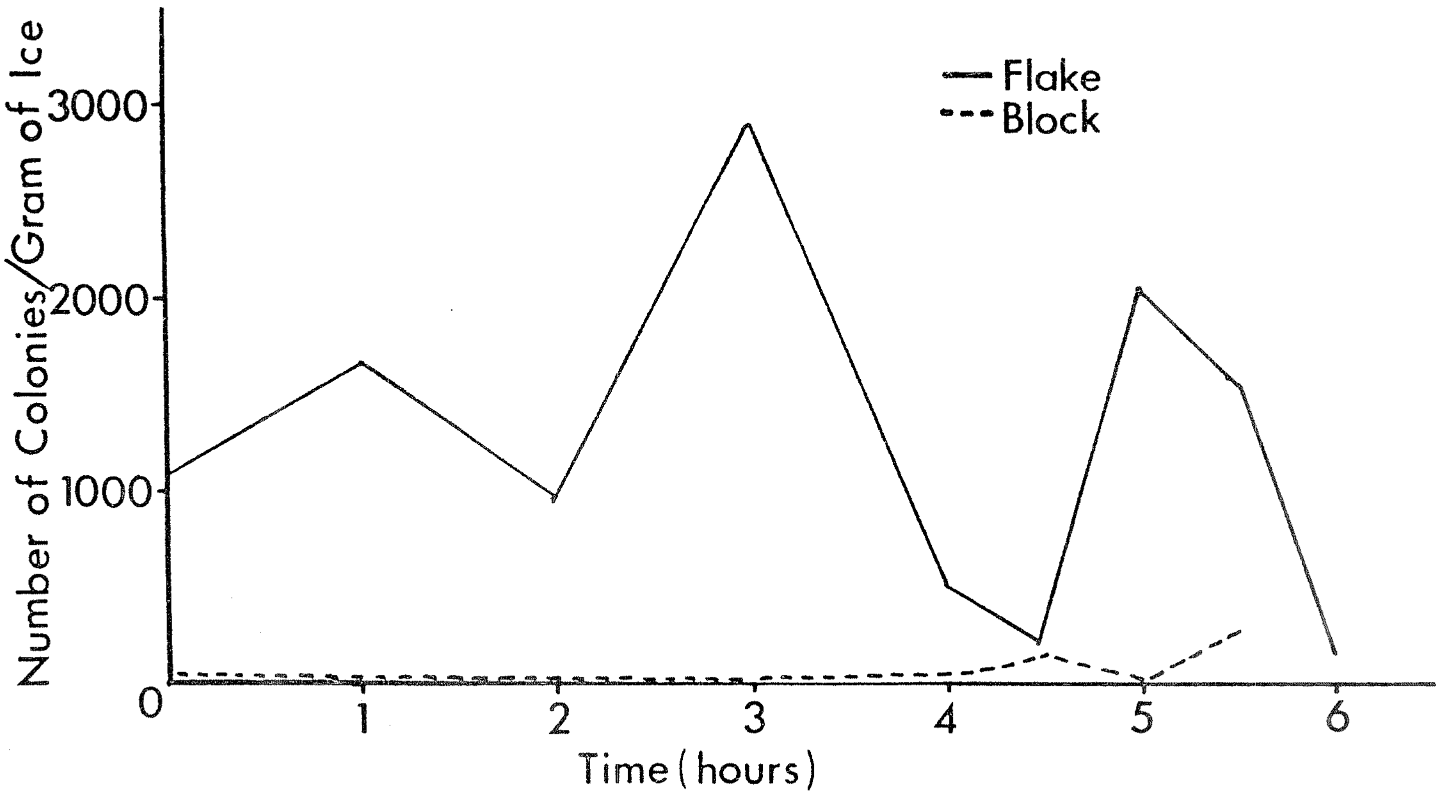


Figure B-5: STANDARD PLATE COUNTS (SPC) FOR TRANSPORTATION TRIALS; BLOCK (2 TRIALS) AND FLAKE (3 TRIALS) ICE

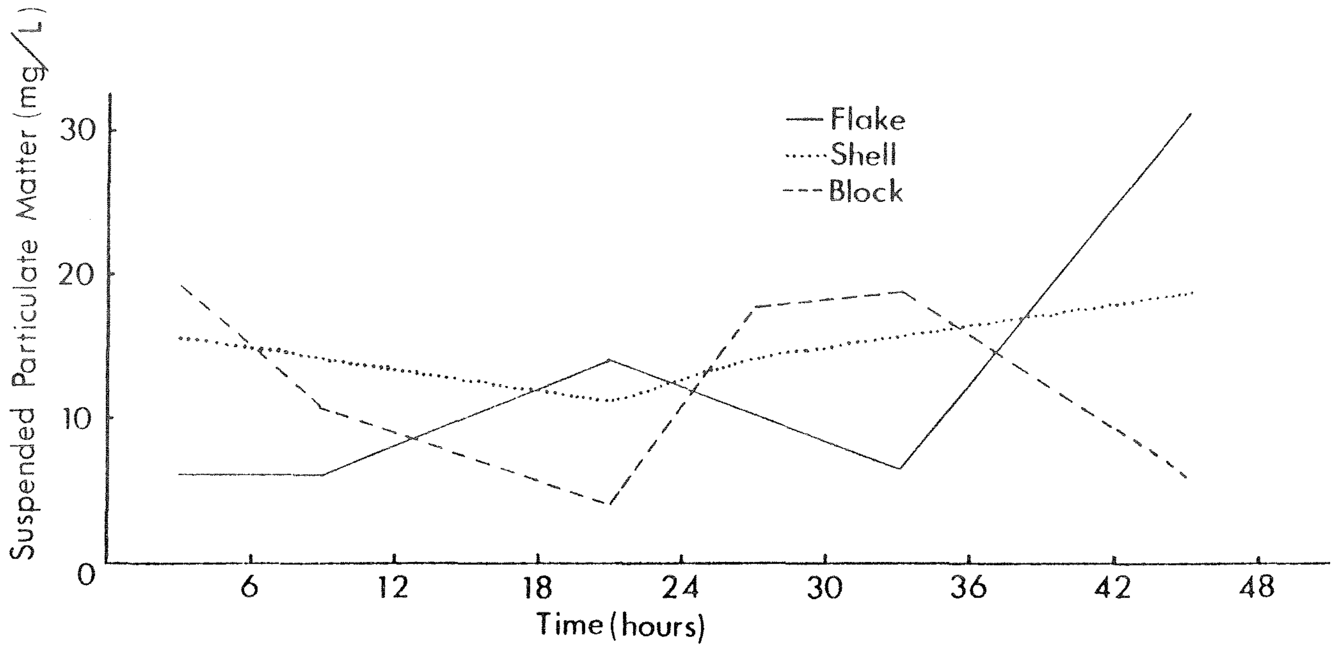


Figure B-6: SUSPENDED PARTICULATE MATTER (SPM) DATA FOR BLOCK (2 TRIALS), FLAKE (3 TRIALS) AND SHELL (1 TRIAL) ICE STORAGE TANKS

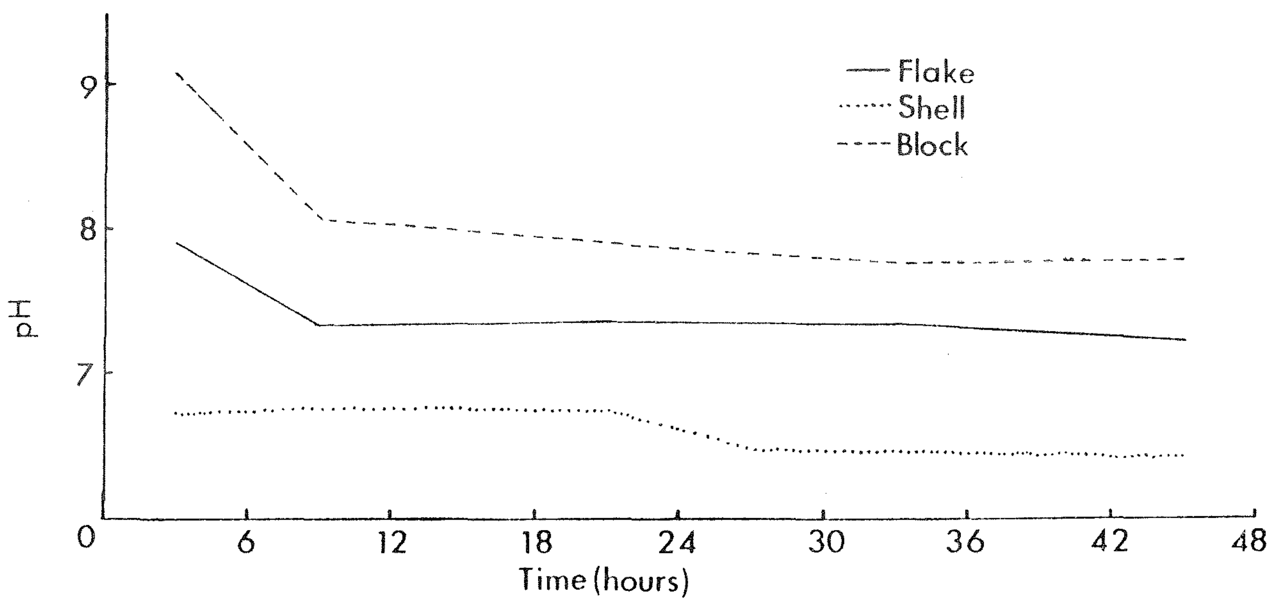


Figure B-7: pH VALUES FOR BLOCK (2 TRIALS), FLAKE (3 TRIALS) AND SHELL (1 TRIAL) ICE STORAGE TRIALS

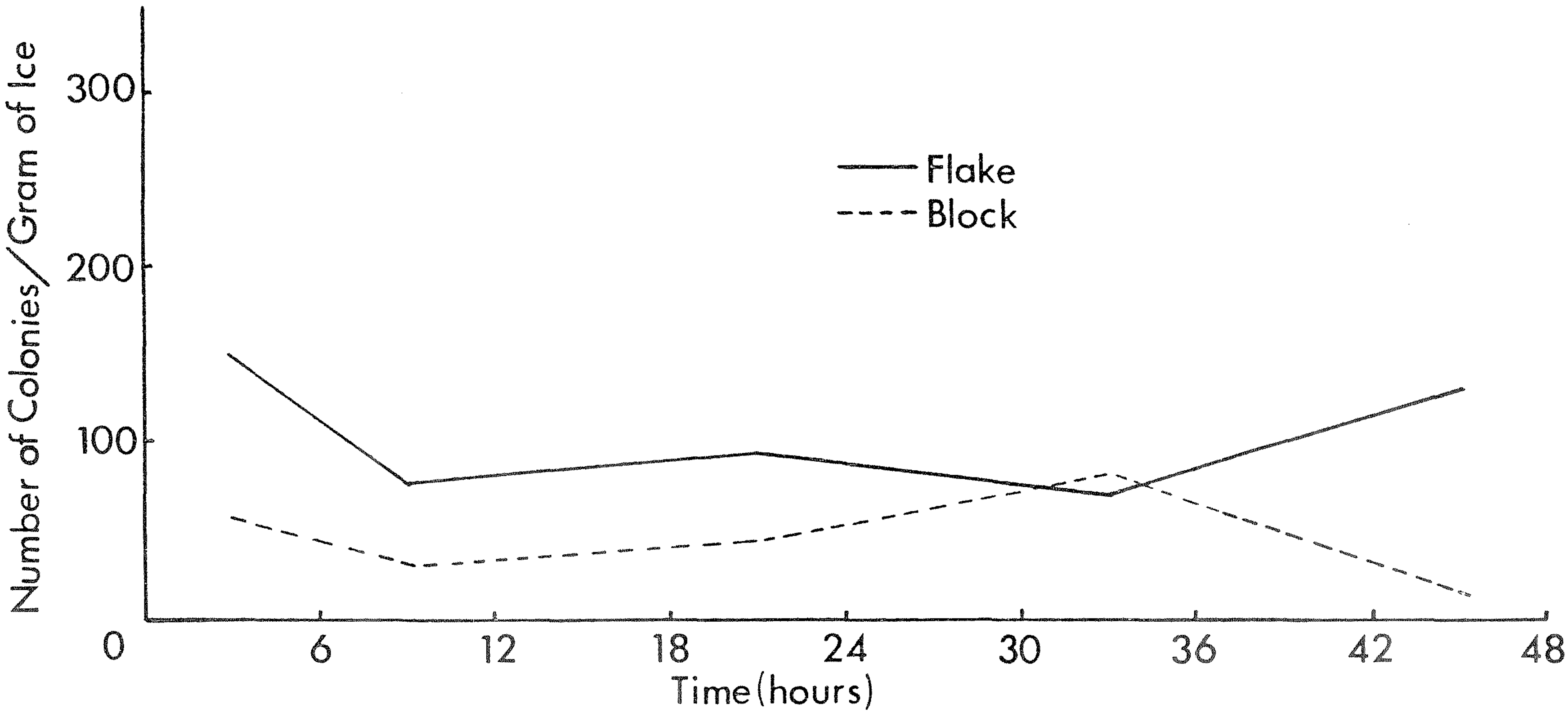


Figure B-8: STANDARD PLATE COUNTS (SPC) FOR STORAGE TRIALS, BLOCK (2 TRIALS) AND FLAKE (3 TRIALS) ICE

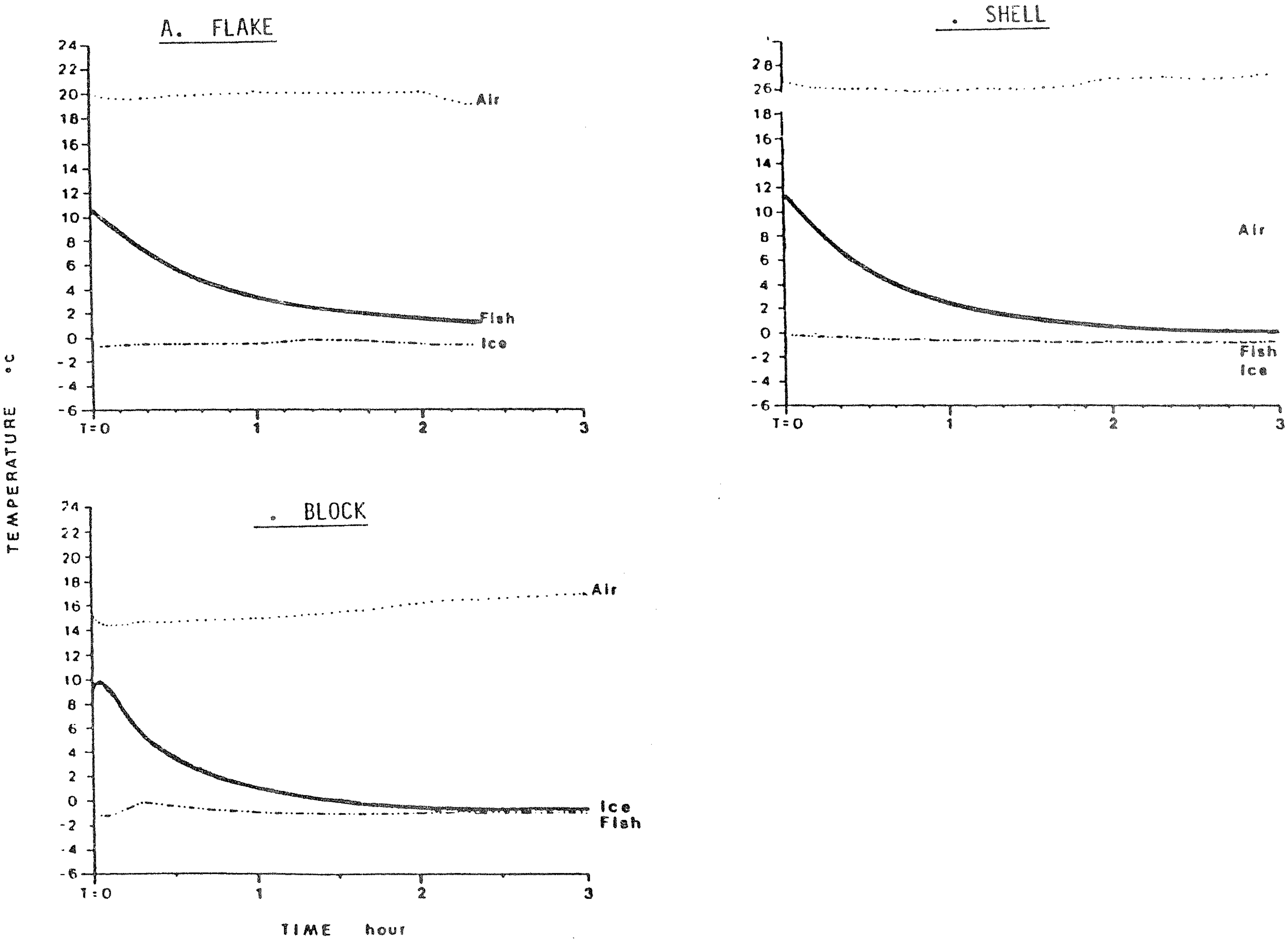


FIGURE 9: COOLING CURVES FOR FLAKE, SLUSH, SHELL AND BLOCK ICE DETERMINED AS AVERAGED VALUES (3) FOR CORE TEMPERATURES OF COD

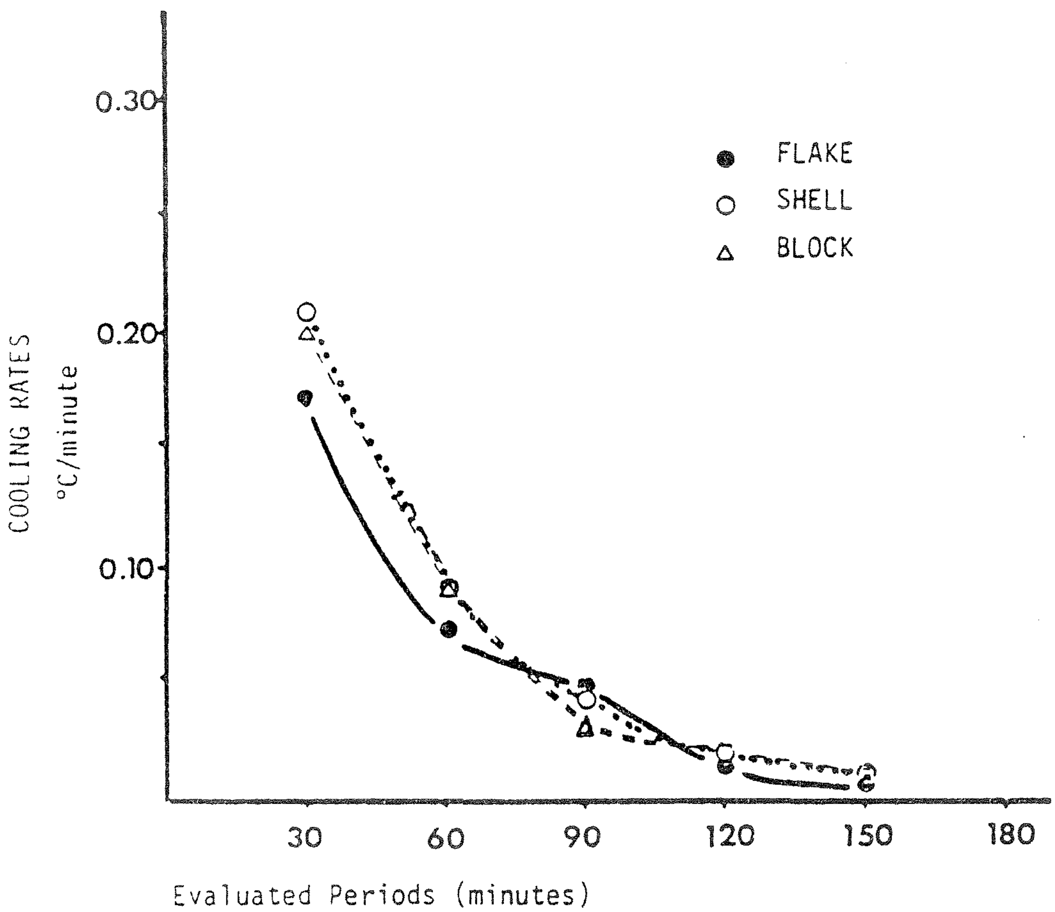


Figure B-10: AVERAGED COOLING RATES FOR FISH CORES DETERMINED IN 30 MINUTE INCREMENTS (3 cod per trial)

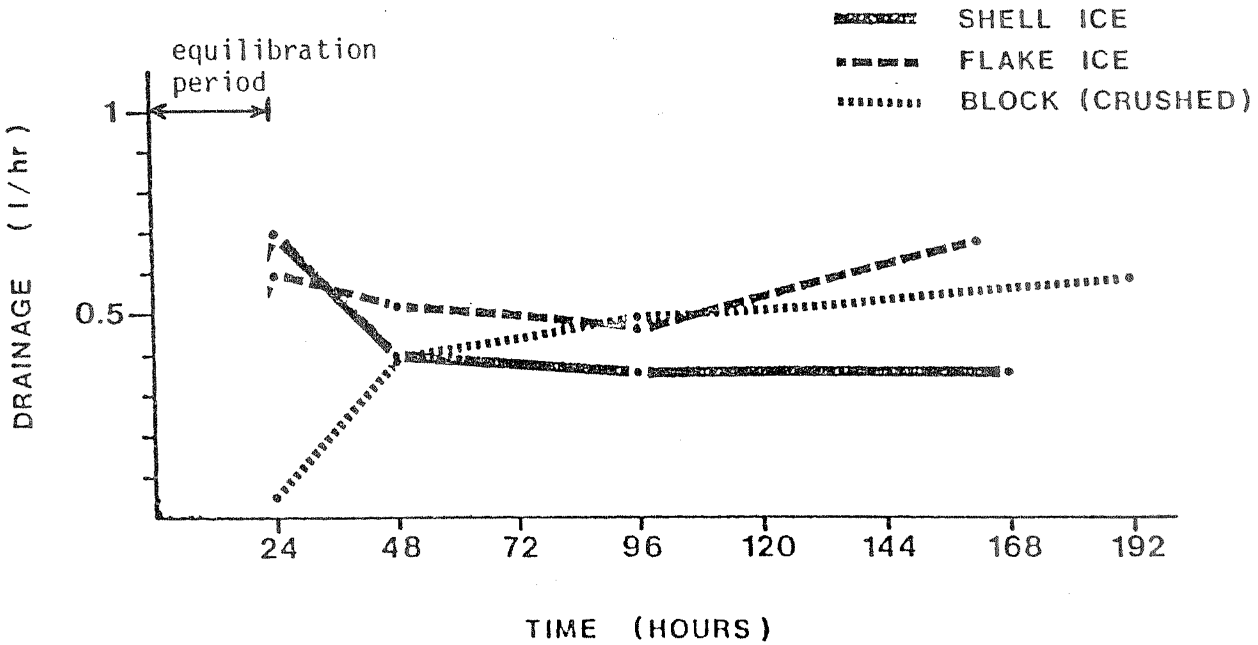


Figure B-11: MELTWATER PRODUCTION IN L/HR. FOR THE 3 TYPES OF ICE TESTED

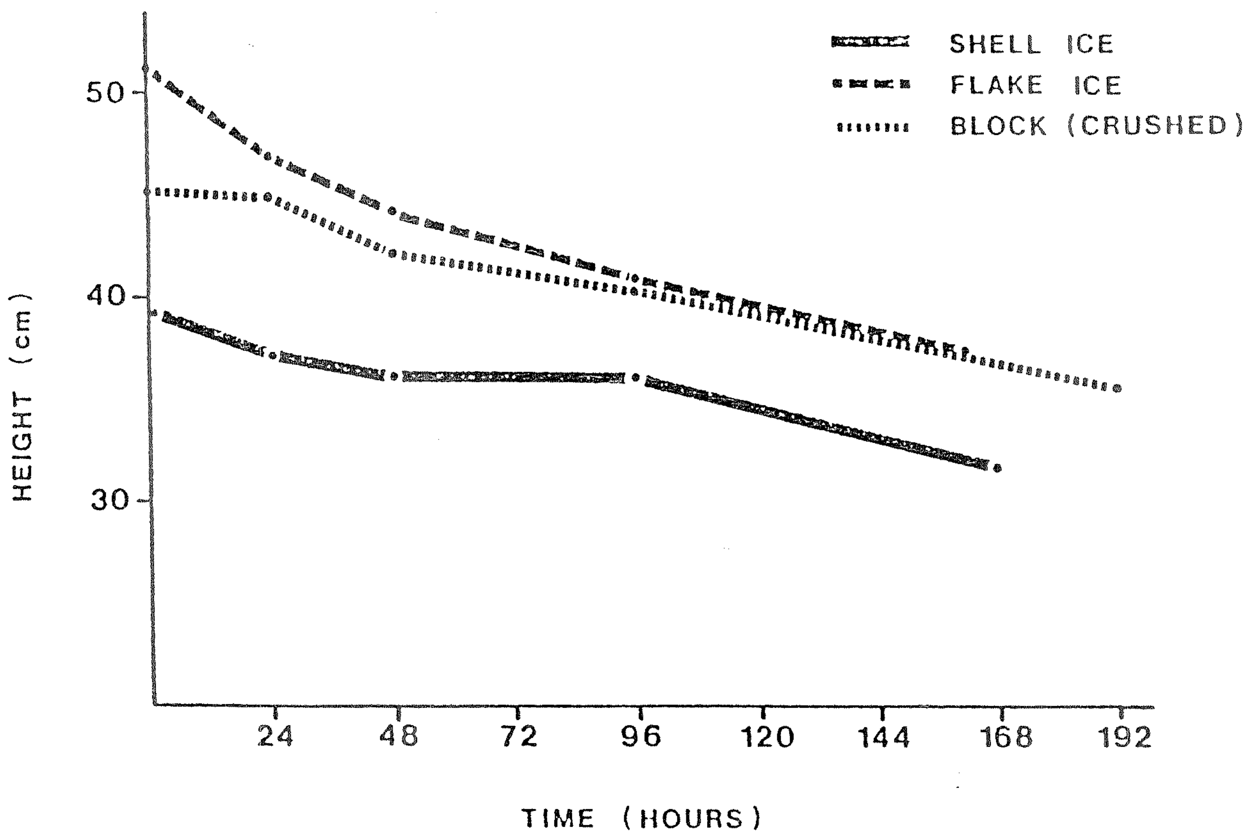


Figure B-12: HEIGHT OF ICE IN CONTAINER FOR EACH OF THE 3 TYPES OF ICE TESTED

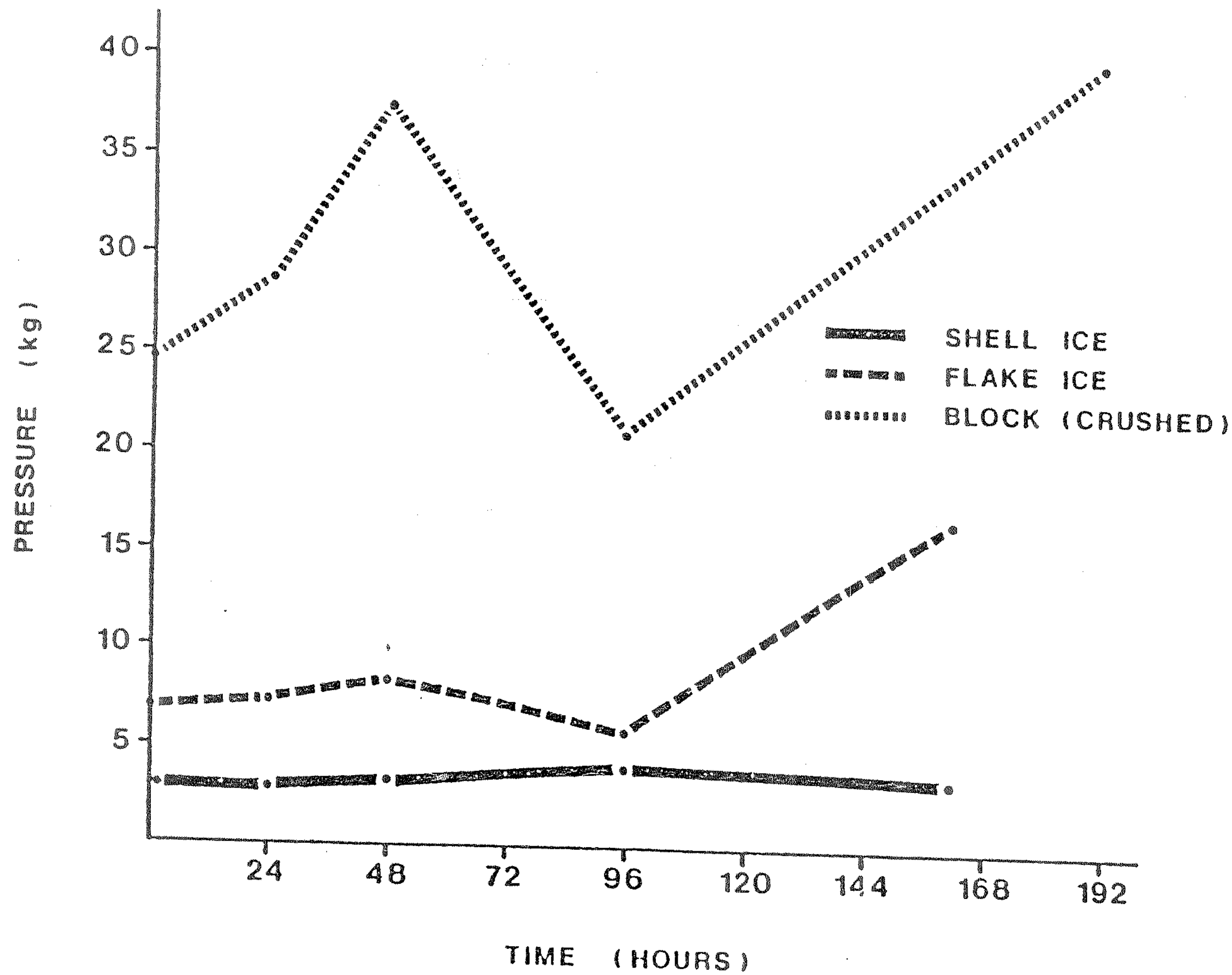


Figure B-13: PRESSURE REQUIRED TO PUCH A STANDARDIZED SURFACE OF EACH OF THE THREE TYPES OF ICE

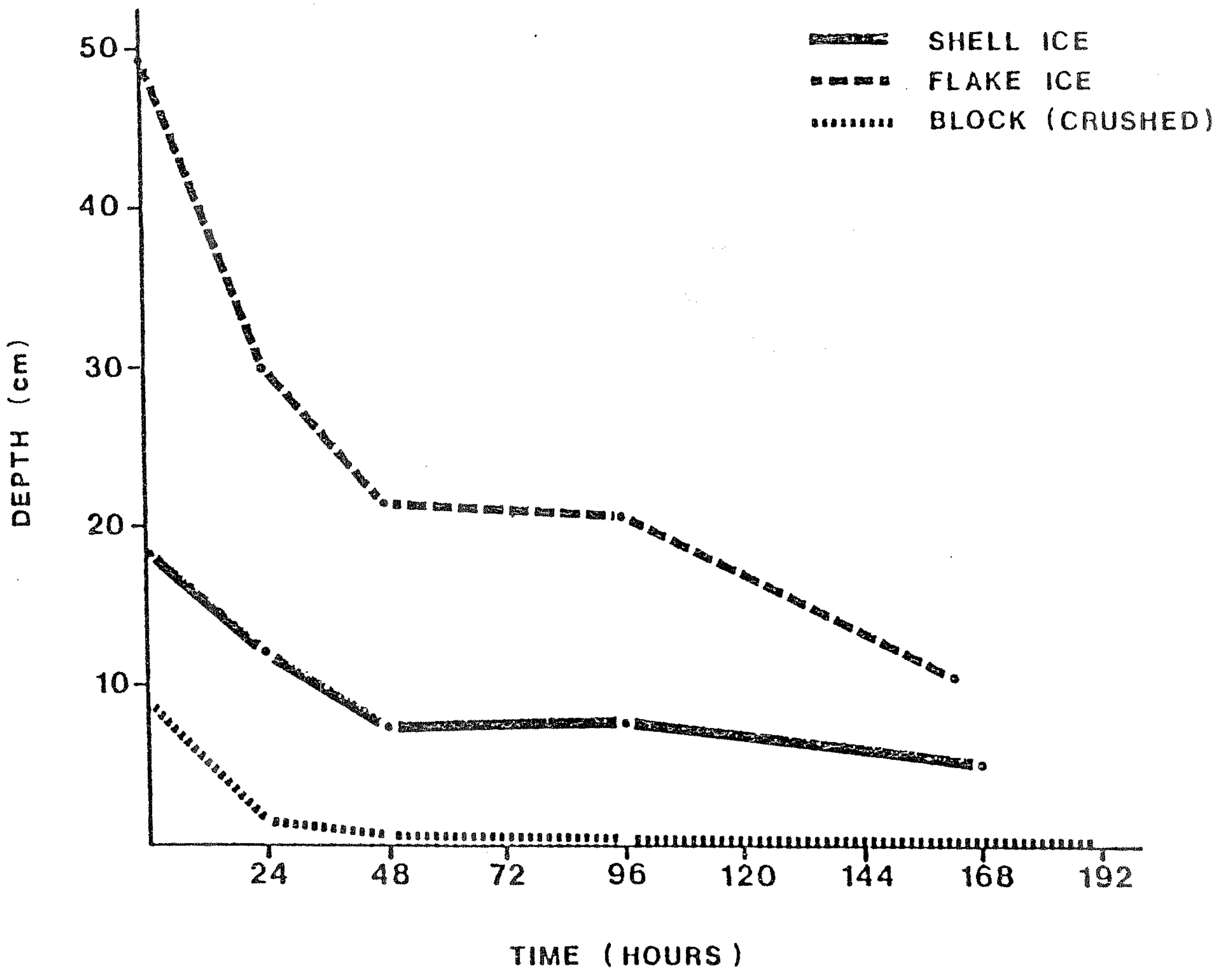


Figure B-14: DEPTH OF PENETRATION INTO THE ICE OF A WEIGHTED PENETROMETER (4.5 kg.) FOR EACH OF THE 3 TYPES OF ICE TESTED

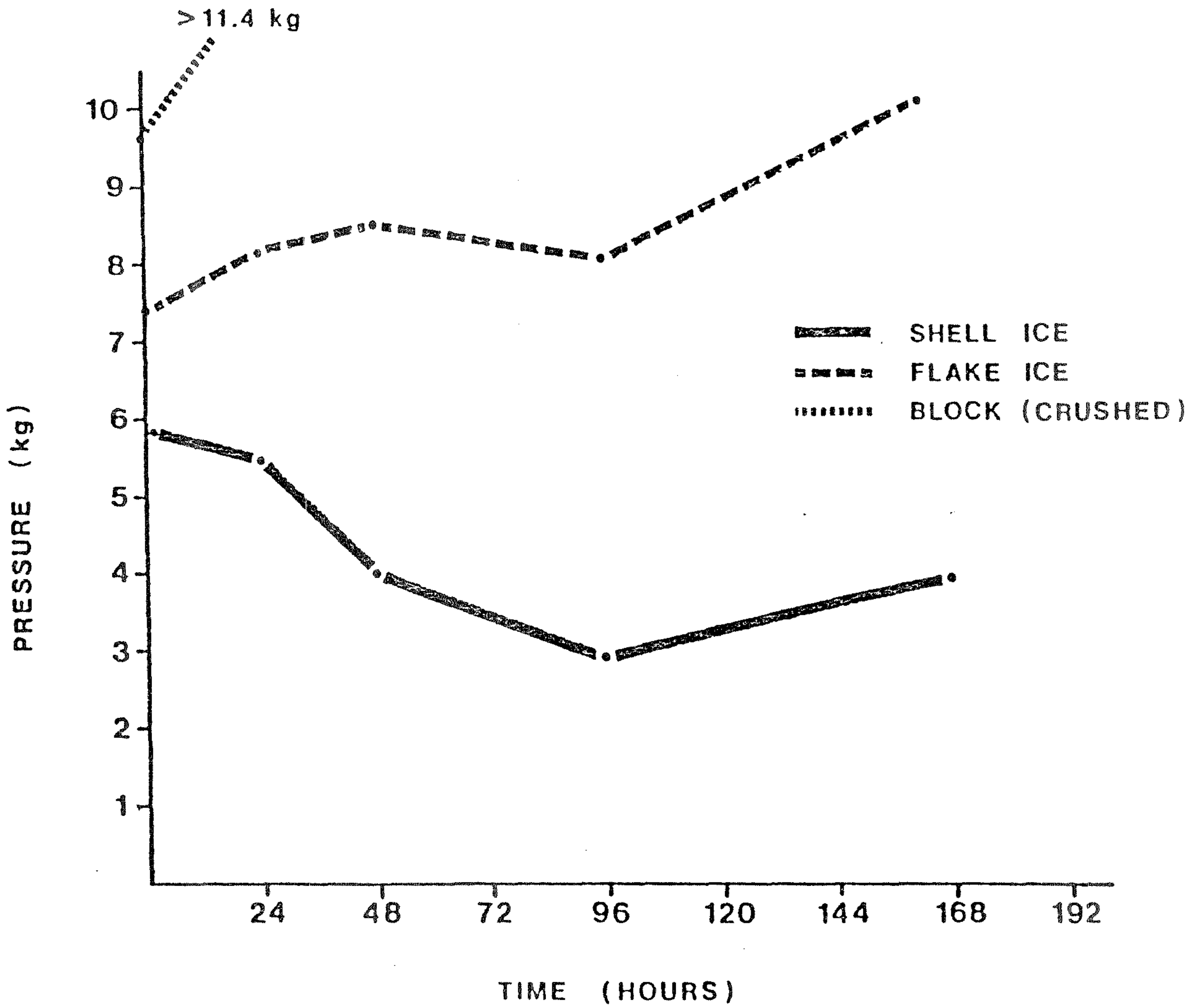


Figure B-15: PRESSURE REQUIRED TO PIVOT A SHOVEL IN THE ICE FOR EACH OF THE 3 TYPES OF ICE TESTED

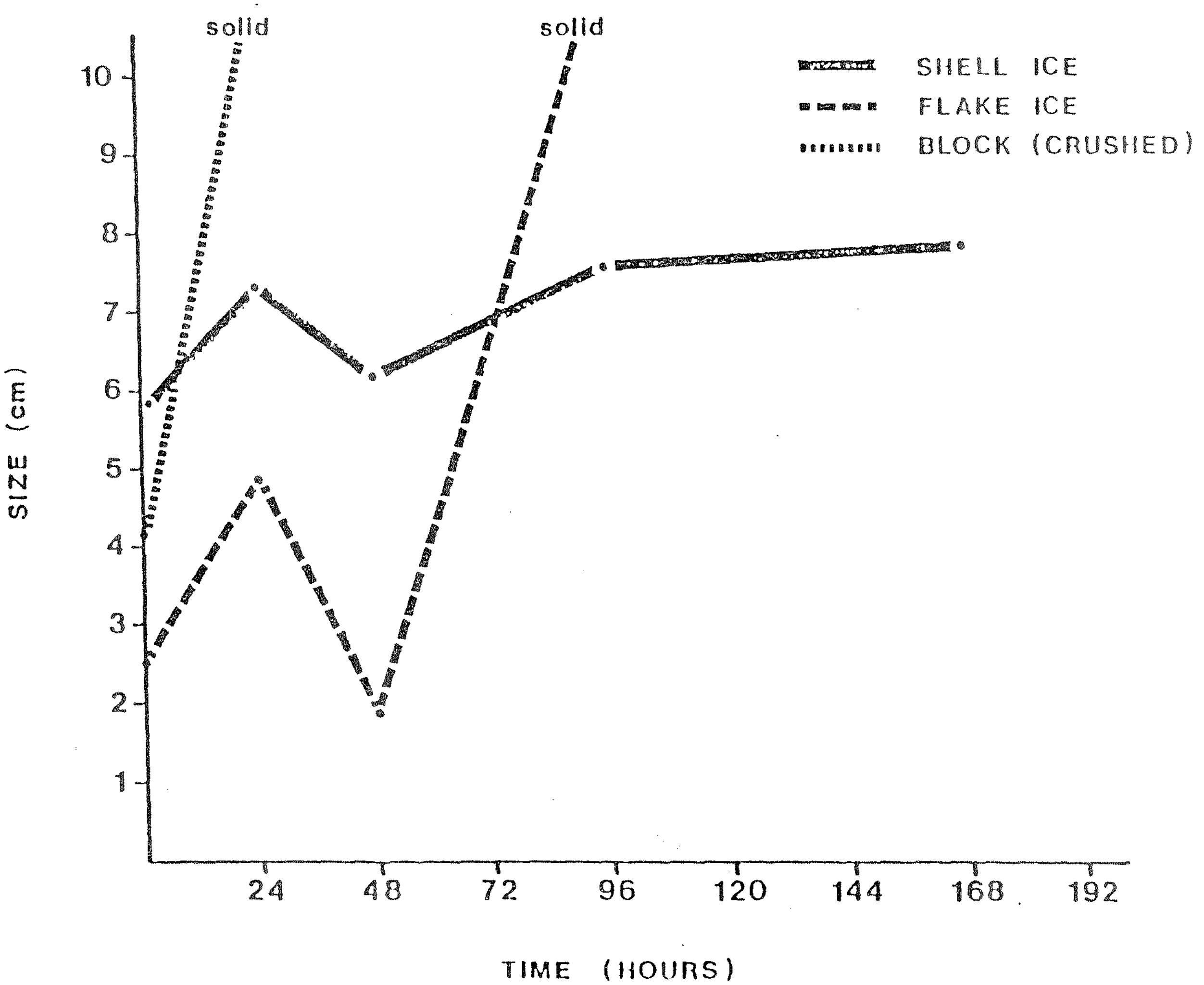


Figure B-16: SIZE OF CLUMPED FRAGMENTS IN A 25 cm x 25 cm (625 cm^2) QUADRAT ON THE SURFACE OF THE ICE FOR EACH OF THE 3 TYPES OF ICE TESTED

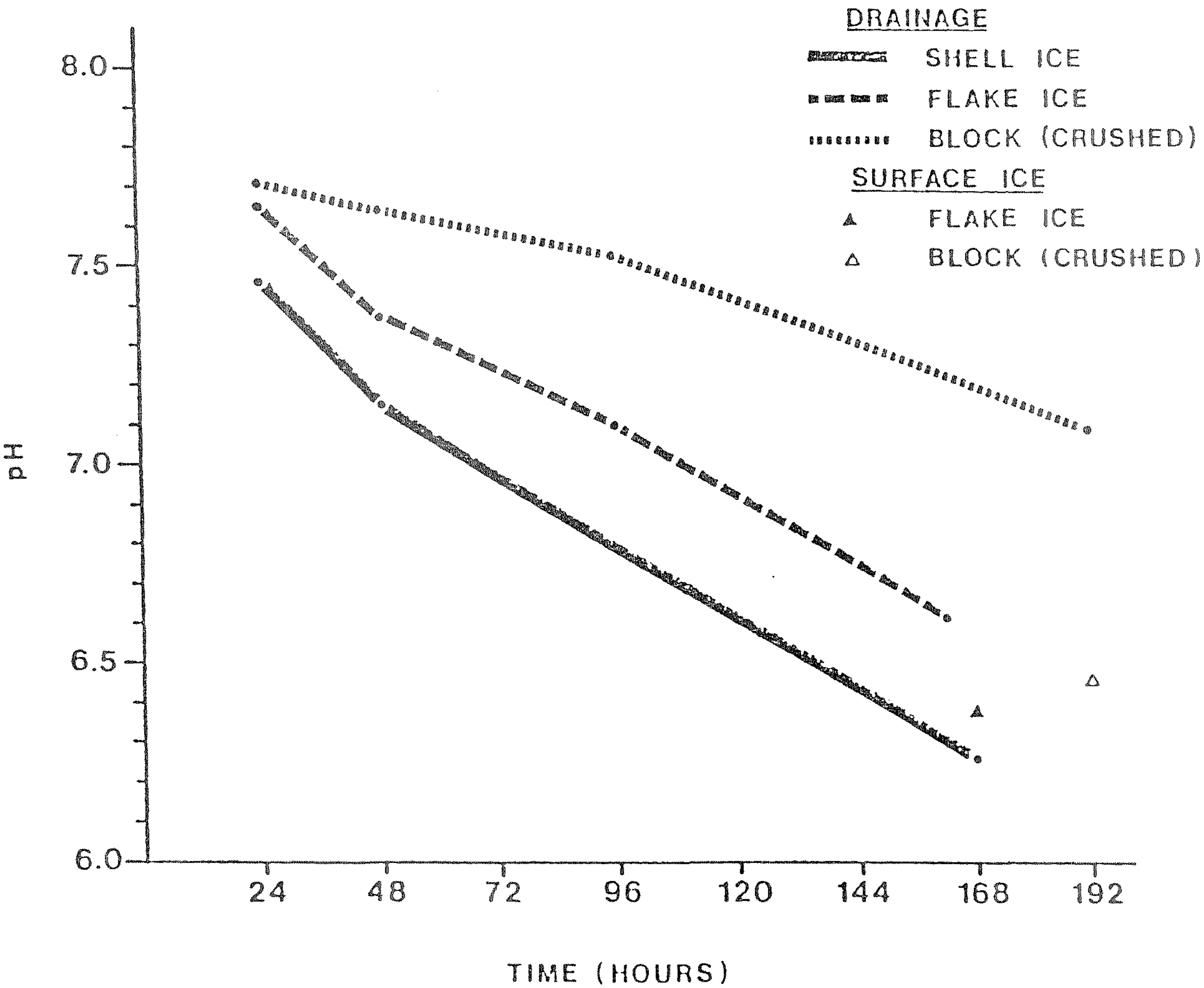


Figure B-17: pH OF THE DRAINAGE WATER AND OF THE SURFACE ICE ON THE FINAL DAY OF TESTING FOR EACH OF THE THREE TYPES OF ICE TESTED

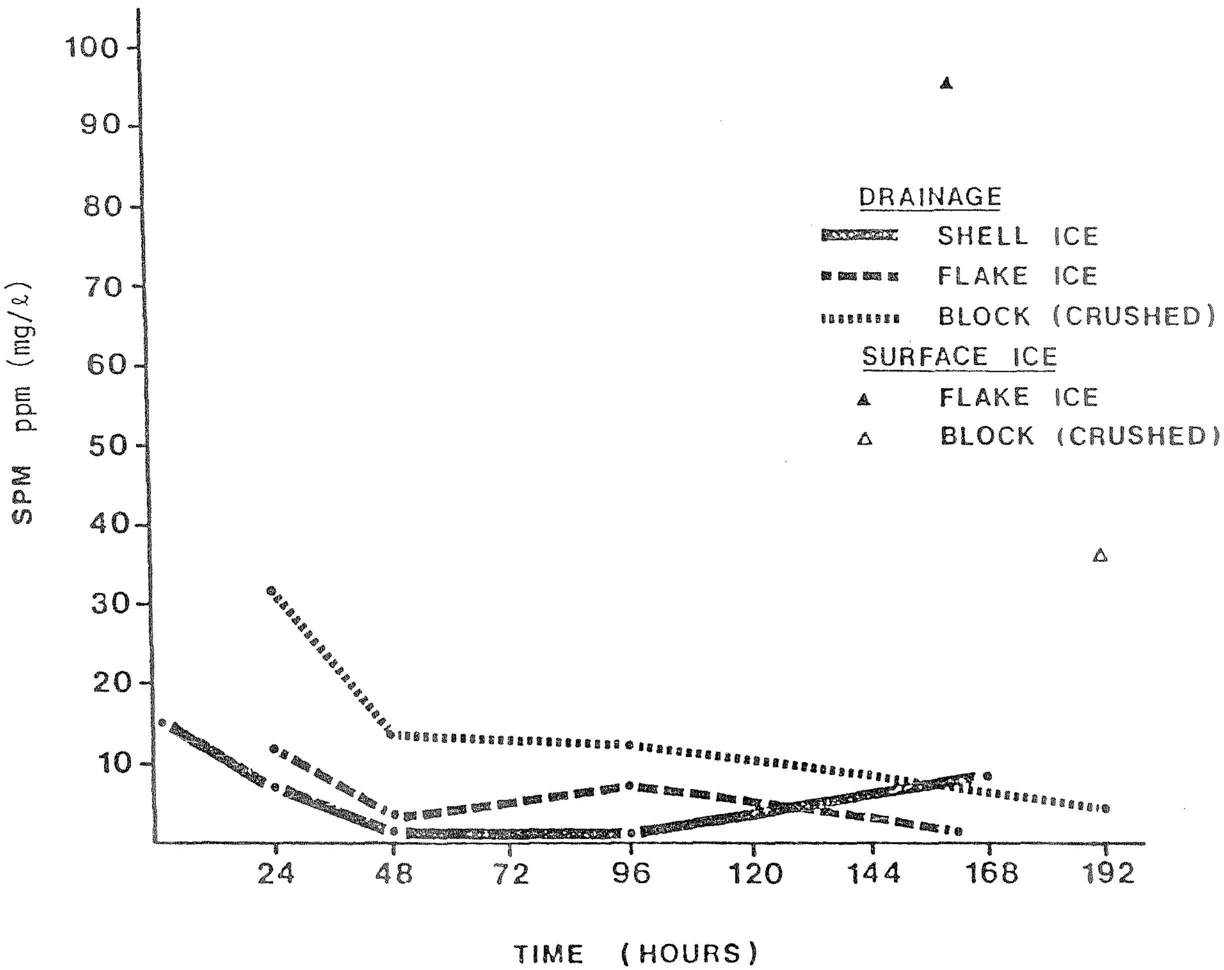


Figure B-18: SUSPENDED PARTICULATE MATTER IN DRAINAGE WATER AND IN SURFACE ICE ON THE FINAL DAY OF TESTING FOR EACH OF THE THREE TYPES OF ICE TESTED. (Halifax water standard is 0.3 ppm)

A P P E N D I X " A "

ICE PRODUCTION FACILITIES

INTRODUCTION

Ice-making methods have changed over the years. At present, there are two main methods of ice production used in the Canadian fishery; flake or slice ice; and shell ice. Block ice, the first form of mechanically produced ice, is now produced by a limited number of facilities.

FLAKE ICE

The flake ice machines were developed to produce ready-to-use ice on a continuous basis (Figure 1). The machines consist of a drum with a cavity between the inner and outer linings. The refrigerant is circulated in this cavity, and water is then distributed on the inner or outer sub-cooled surface (depending upon the specific manufacturer). As the water strikes the surface, it freezes as a film approximately 1.0 to 3.0 mm thick. A knife edge, rotating about the central shaft, following the water distributor, scrapes off the built-up ice. In some models the drum rotates and the knife is stationary. To produce ice which will flake easily, a small amount of salt may be dissolved in the water before application to the drum. Ice produced is generally discharged by gravity.

SHELL ICE

Shell ice is generated in a manner somewhat similar to flake ice. Refrigerant is caused to expand into a tube generally 100 - 200 mm in diameter (Figure 2). Water is then sprayed or flowed over this cooled surface producing a film of ice. The flow of refrigerant is stopped and hot gas is pumped into the tube directly from the compressor. This gas is generally at 15 - 30°C and causes an immediate expansion of the tube so that the film of ice cracks and falls away. The ice is shattered when it hits the receptacle and the small peices are generally removed by screw auger or put in storage by gravity. The cycling of the machine is controlled by timers and electrically controlled valves. The thickness of the ice is controlled by the cycle time. Shell ice tends to take up more volume and is sharper in structure than flake ice.

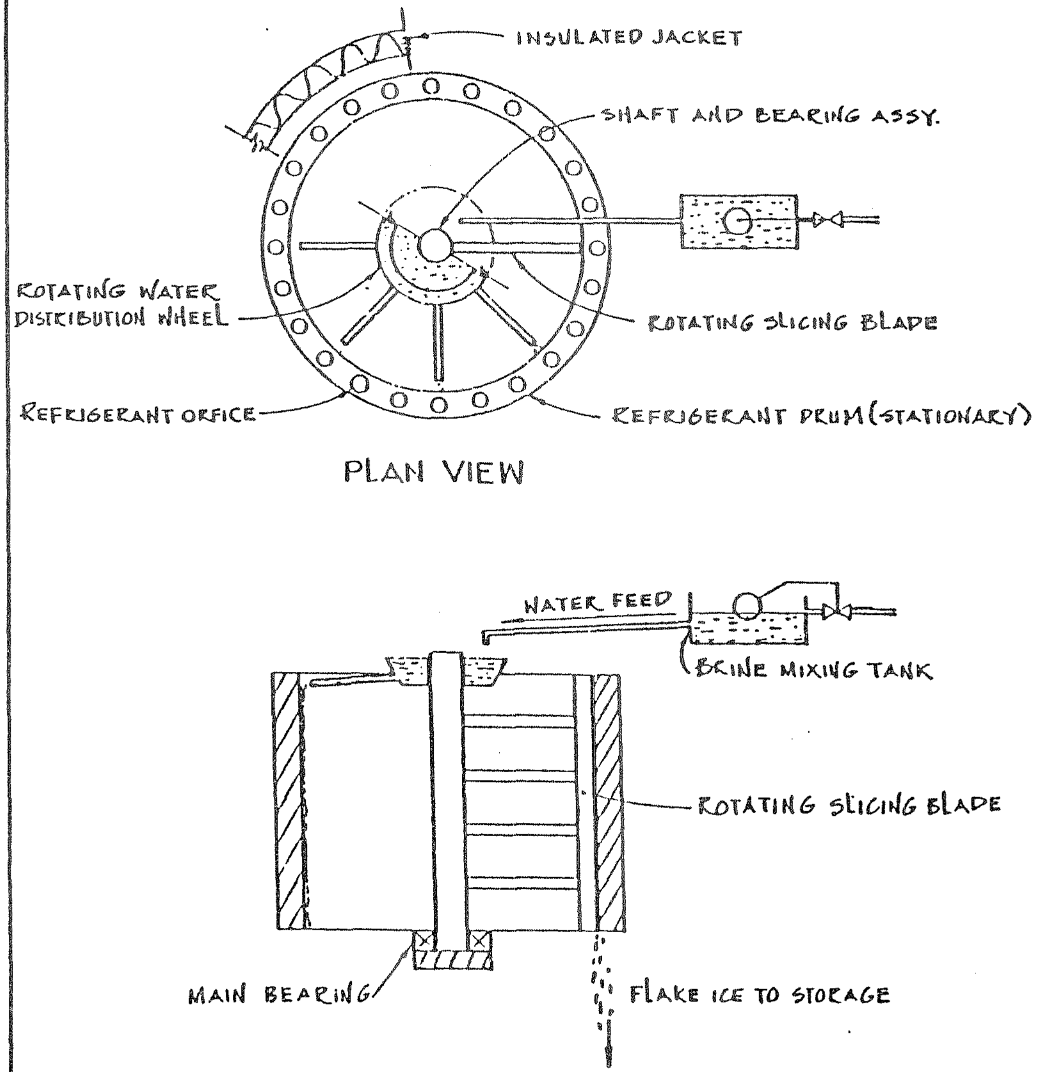
BLOCK ICE

Block ice is produced by freezing cans or containers of water by circulating a secondary solution, usually calcium chloride, sodium chloride or ammonia around them in a pit or tank (Figure A.3). The surrounding brine conducts the heat away from the cans. The brine in turn is cooled through a secondary heat exchanger.

Once the contents are frozen, the cans are raised by a hoist out of the brine and the ice is removed by a slight warming of the mold. The can is refilled and the process is repeated. It takes from 8 to 24 hours to freeze the container, so that a large production space is required. The rate of freezing is time-regulated to prevent too-rapid freezing, which would result in a brittle product. Block ice plants are being gradually replaced by more modern, automatic ice making equipment.

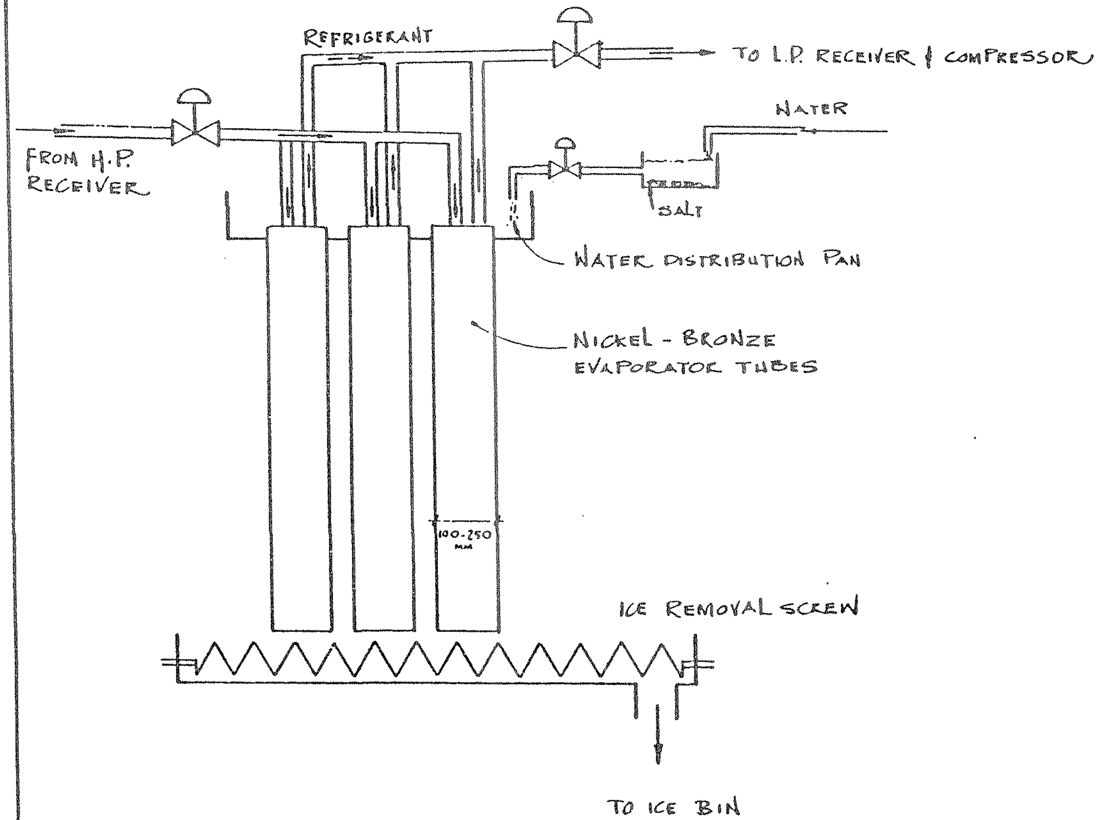
SLUSH ICE

The slush ice generator system consists of a standard refrigeration unit which supplies refrigerant to a scrapped surface heat exchanger (Figure 4). Ice does not form on the cooling surface as in flake or slice ice machines. Rather, it is formed inside a solution which is cooled below the solution's freezing temperature in the form of small ice crystals. Ice produced by this system has a small round crystalline structure and is free flowing. The slurry of ice crystals and water may be pumped to a tank with a mechanical separator to give a "dry" ice form.



NOTE:
- UNIT IS ENCLOSED BY INSULATED JACKET
- SIZE OF UNITS VARY BY TONNAGE.

FIGURE 1
FLAKE ICE MAKING MACHINE
(NTS)



NOTE:
FREEZING CYCLE SHOWN FLOW REVERSES FOR DEFROST CYCLE TO RELEASE ICE.

FIGURE 2
SHELL ICE MACHINE
(NTS)

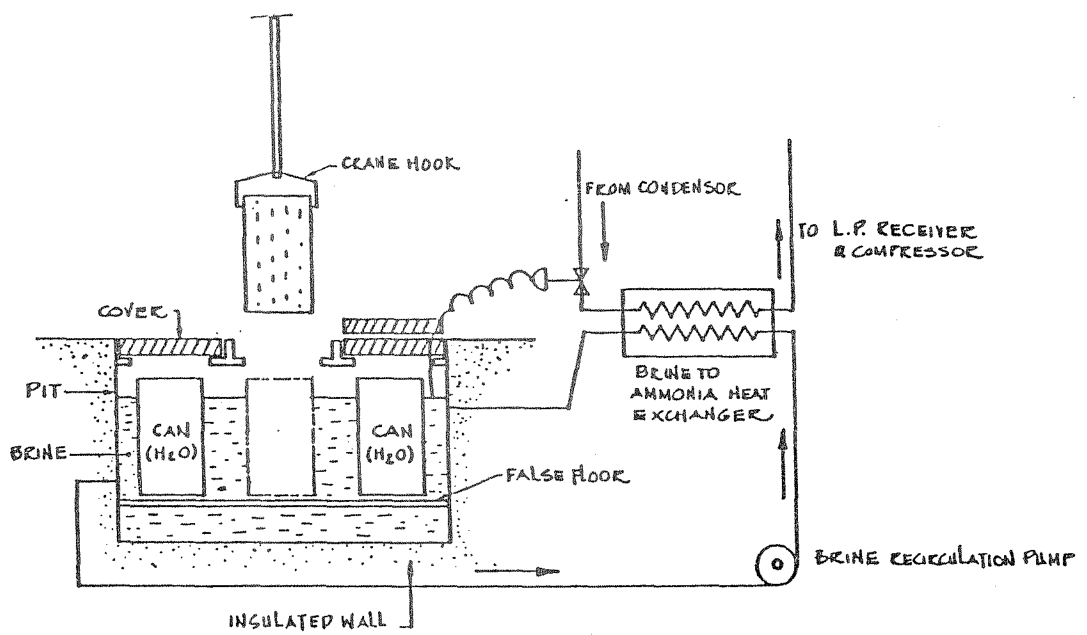


FIGURE 3
BLOCK ICE PLANT
(NTS)

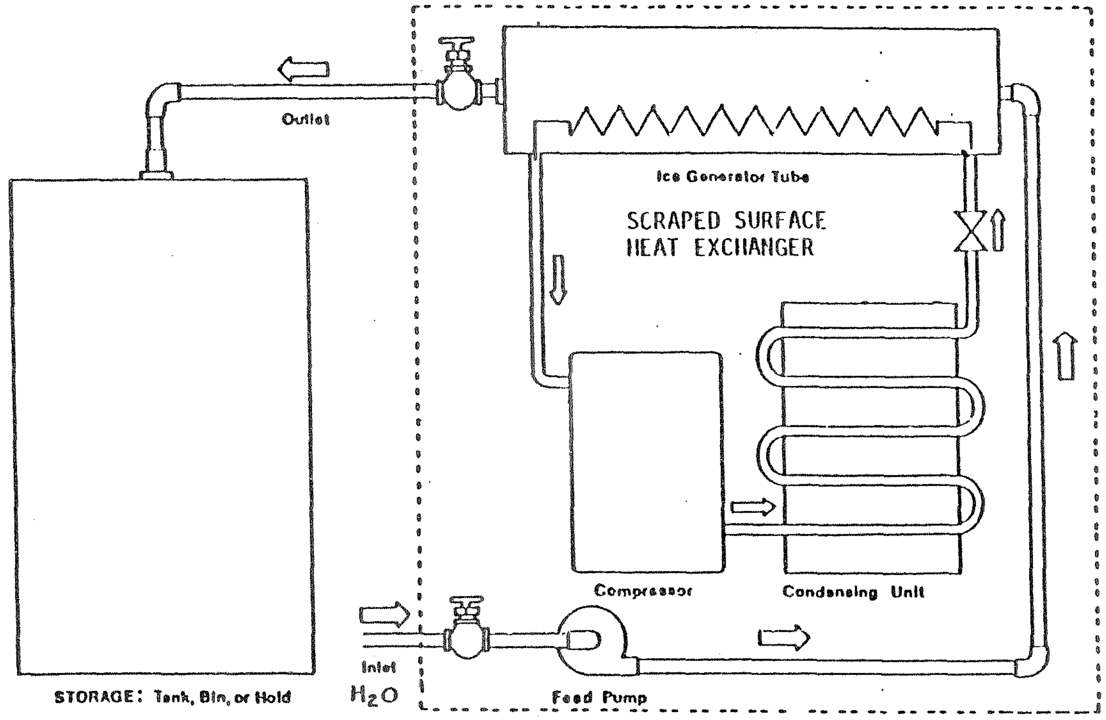


FIGURE 4
SLUSH ICE GENERATOR
(NTS)