FISHERIES TRAINING PROGRAMME
PO Box 1390, Skulagata 4
120 Reykjavik, Iceland

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# THE EFFECTS OF DIFFERENT COOLING TECHNIQUES ON QUALITY PARAMETERS OF HERRING IN RELATION TO MALAYSIAN FISHERIES AND DESIGN OF REFRIGERATION SYSTEM SUITABLE FOR MALAYSIAN VESSELS

**Ab. Razak Bin Hassan**
Malaysian Fisheries Development Authority
**Malaysia**

Supervisor: Sigurjon Arason (IFL) sigurjon@rf.is
Gustaf Helgi Hjalmarsson (IFL) gustaf@rf.is

## ABSTRACT

A comparison of three different cooling systems was carried out with the environmental temperature at 2°C and 25°C using herring (*Clupea harengus*) as raw material. Ungutted herring was stored in flake ice, CSW, and liquid ice using un-insulated polyethylene boxes for a period of 10 days. During storage protein, fat, salt, total volatile nitrogen compounds (TVB-N) and total plate count (TPC) were monitored in fillets as well as the core temperature of the fish and the temperature of the cooling media. At 2°C, the best results were a 6 day shelf life of herring with CSW. However, the best result at 25°C was herring stored in liquid ice, giving a shelf life of 2 days. Salt content in herring stored in liquid ice increased over the storage period above paradigmatic limits. A new design of RSW for Malaysian trawlers and purse seiners is proposed

**Key words:** Refrigeration system, Herring (C*lupea Harengus*), fish quality.

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## 1. INTRODUCTION

In tropical countries like Malaysia, where ambient temperatures are high (above 25°C) fish spoil easily and begin to deteriorate in few hours if left on deck. Normally fishermen on Malaysian fishing boats grade the fish by species and size. This is done on deck in windy conditions in direct sunlight. The surface of fish exposed to sunlight and wind will dry and the core temperature increase resulting in accelerated degradation processes. Only after grading is the fish immersed in some cooling media. Commercial cooling methods used by Malaysian fishermen are not suitable at present for chilling the catch to near 0°C. Therefore, most fish landed has been subject to poor handling and is not properly iced/chilled. To maintain quality, fish should be cleaned and chilled as fast as possible to 0°C (FAO 1973). Delayed cooling, with environmental temperatures between 15°C and 20°C, will shorten the shelf life by several days (Burt *et al*.1992). At high temperatures, the fish will spoil because of enzymatic processes and microbial activities. Physical damages on fish will speed up the deterioration processes and reduce the quality and shelf life.
There is a great need to improve the cooling techniques used in Malaysian fisheries, especially on commercial fishing vessels and in the deep-sea fishing industry. This study focuses on a comparison of the effect of different cooling systems on herring at environmental temperatures of 2°C and 25°C.
The main objectives of this work are to compare shelf life of herring stored in flake ice, liquid ice and CSW. The melting rate of liquid ice kept in different type of boxes, sizes and conditions will also be studied.
Selection of proper chilling is important for fishermen in tropical countries and should be based on the distance of the fishing ground, duration of fishing trips, species and quantity of fish to be handled at one time (Burt *et al*.1992).

## 2. LITERATURE REVIEW

### 2.1 Background

In 1997, the fishing fleet in Malaysia consisted of 32,672 licensed vessels (Table 1), of which 20,365 units were located in Peninsular Malaysia (west Malaysia) and the rest in east Malaysia (FAO 2000). In 1980 Malaysia declared its 200 nautical miles Exclusive Economic Zone (EEZ).

Table 1: Location and number of boats in Malaysia ranked according to size and number of boats in various size groups (FAO 2000).

| **Location** | **Number of boats** | **Tonnage** | **Number of boats** |
|---|---|---|---|
| Peninsular Malaysia | 20.365 | below 15GRT* | 20.583 |
| East Malaysia | 12.307 | 15 - 40 GRT | 7.841 |
| total licences | 32.672 | 40 - 69 GRT | 2.679 |
| | | **Over 70 GRT** | **1.569** |

* Gross registered tonnage

This study focuses on fishing boats between 40 GRT and 70 GRT (Table 2). These boat normally fish between 12 nm and 30 nm from shore. The length of the trips depends on the size of boats and type of gear, ranging from 3 to15 days. Vessels above 70 GRT are designated for deep-sea fishing and fish beyond 30 nm.
The fishing area in Malaysian waters is divided into fishing areas/zones (A, B, C and C2) according to distance from shore (Table 2). The size of vessel and gear type determines where they can fish.

Table 2: Malaysian fisheries fishing zones (FAO 2000)

| **Zone** | **Nautical miles** | **Tonnage/gear** |
|---|---|---|
| A | within 5 | Traditional fishery |
| B | 5 to 12 | 40GRT (trawler/purse seine) |
| C | 12 to 30 | 40GRT to 70GRT |
| C2 | beyond 30 | 70GRT and above |

Most of the fishing boats in Malaysia depend on ice for the fishing trips. Insufficient supply of ice for the fishing trips is common. Often the main difficulty for fishermen is having to wait hours, or even days, to get ice. Then they have to crush it and carry on board. In addition, the ice is very expensive in relation to the value of the catch. During peak season the demand for ice is very high and the price of ice increases from what it is usually in a normal season. Most of the fish landing centres are scattered around Malaysia and fishermen go fishing in relation to tides. Waiting for ice complicates the onset of the fishing, especially if fishermen need to wait for high tides.

## 2.2 The importance of the quality

Quality of fish and fish products is the most importance issue in the fisheries industries, particularly in the developing countries. Fishermen realise the importance of quality products, in order to get better returns of their catch. Fresh fish from temperate waters is very susceptible to spoilage (Grossly 1990). Shelf life of fish is mainly determined by the growth of microorganisms. To prevent or delay the growth of such organisms, chilling is the most important factor along with high level of hygiene. Therefore it is important to have a good refrigeration system installed on board, to keep the fish chilled and maintain the high quality of the fish.
The demand for high quality fish is generally increasing in the world. This has put pressure on fishermen to fish more and maximise the quality of the product (Burt *et al.* 1992).
Often, customers prefer to buy fresh fish rather than frozen. Thus, fresh fish of high quality can become marketing advantages for those who can offer high quality unfrozen fish to the customer (Burt *et al.* 1992). Companies processing or distributing food cannot be self-sustaining for long unless they recognise the importance of quality. That means the safety and quality system need to be put into operation in the processing establishments.

## 2.3 Spoilage and refrigeration of fish

### *2.3.1 Spoilage process of fish*

Spoilage begins as soon as the fish dies. The factors contributing to the spoilage are degradation of protein, development of oxidative rancidity and the action of microorganisms (Johnston *et al.* 1994).
The enzymes remain active after the fish dies, and cause self-digestion especially in small fatty fish. The rate of self-digestion by enzymes depends on temperature, the time of the year and species. Due to self-digestion the belly wall becomes weak (Johnston *et al.* 1994). In sardines, herring and some other pelagic fish the belly can burst only a few hours after catch. Chilling of the fish just above the freezing point does not stop, but retards self-digestion. The enzymes also break down compounds that result in changes in flavour, texture and appearance of the fish. Enzyme action can be reduced and controlled to some extent by other methods than cooling, such as salting, drying and marinating (Johnston *et al.* 1994).
Microorganisms can also affect the spoilage pattern of fresh fish. There are many different types of microorganisms, each type having optimum growth under particular conditions. By cooling the fish to around 0°C, some of the bacteria groups responsible for the spoilage will stop growing. Therefore, cooling the fish to around 0°C will reduce the rate of spoilage (FAO1994, Burt *et al.* 1992).

Ambient temperature as well as the presence and amount of moisture, oxygen and water activity in the fish muscle affects the microbiological activity. The cooling effectiveness mainly depends on the melting of the ice. Therefore, the rate of fish spoilage depends also on the melting rate of the ice. Where the fish is in contact with surfaces such as wood, metal or other fish and no oxygen can access the fish, foul odours can arise due to the action of anaerobic microorganisms.

Obvious signs of spoilage are:
i) Detection of off odours
ii) Slime formation
iii) Off flavour
iv) Discoloration
v) Changes in texture

The development of these spoilage conditions in fish is due to a combination of microbiological and chemical reaction. This is reflected in gradual developments of undesirable flavours, softening of the flesh and eventually substantial losses of fluids containing water-soluble proteins as well as some liquefied fat.

### *2.3.2 The effect of temperature on spoilage*

There are three important ways of preserving the freshness of fish: cooling (as previously explained), hygienic practice and good handling (Graham *et al.* 1992).
Care in handling is important because unnecessary damage of the fish can provide access through cuts and wounds for the spoilage bacteria.
Fish should be cleaned (gutted) and thoroughly washed, removing the main source of bacteria (and enzymes). Cross-contamination can be kept to a minimum by ensuring the fish is always handled in a hygienic manner.

Time is also an important factor in reducing the deterioration of raw material. The growth rate of microflora and the activity of enzymes is affected by temperature. As temperature is higher more microbial activity is observed. Therefore fish at higher ambient temperatures has to be processed sooner the fish kept in a cool environment. The easiest and the best way of doing this is to use plenty cooling media (Burt *et al.* 1992).

#### *2.3.3 Preservation methods*

Number of measures can be taken to reduce spoilage rates. Proper handling on board and storage of products under anoxic conditions (vacuum packed or modified atmosphere packed) can prevent chemical spoilage or development of rancidity. The effect of hygiene in the control of spoilage varies depending on the type of contamination, which may take place. Great effort to reduce the general contamination during handling of the catch on board does not lead to any significant delay in spoilage as only a very small part of this general contamination is made of specific spoilage bacteria.

### 2.4 Methods of chilling at sea

There are other ways of chilling besides using ice. Fish can be immersed in chilled water or can be exposed to cold blowing air. Seawater, cooled mechanically (RSW-refrigerated seawater) or by the addition of ice (CSW-chilled seawater) is a suitable alternative to rapidly chill large quantities of small pelagic fish (Graham *et al.* 1992).

Most common chilling methods used at sea are:

i) Icing the fish (flake ice or tube ice)
ii) Fish stored in liquid ice
iii) Refrigerated seawater (RSW)
iv) Chilled seawater (CSW)

#### *2.4.1 Using ice (Flake ice or tube ice)*

Ice made from fresh water has played a major role in the chilling fish on board. The ice is placed above and below the fish. The amount of ice required depends on the amount of fish to be chilled. The possible chilling by of the ice depends on the melting temperature of the ice. Therefore, the mass of the ice will control the potential cooling performance. Fish that is completely surrounded by melting freshwater ice will be chilled to about 0°C. Fish temperature slightly below 0°C can be achieved by adding salt to the water, lowering the melting point of the ice. Using ice alone, however, the fish temperature cannot be reduced to the point at which freezing begins, between –1 to –2°C. Each fish should be in constant contact with melting ice so that fish temperature is reduced as quickly as possible and maintained as low as possible. The melting rate of ice is higher when the fish are warmer or in warmer climates (Graham *et al.* 1992). For higher fish temperature an increased amount of ice must be used.

### *2.4.2 Liquid ice*

Liquid ice is one of the cooling media used for chilling the catch or products, at sea or on shore. Micro-crystals in liquid ice enable quick cooling and can maintain a low temperature for a long time. It is made from a mixture of water and salt (approximately 3% concentration of NaCl of mass volume). Micro-crystals in liquid ice are often as small as 1/10 of the size of regular ice crystals. Today, liquid ice is a more practical and convenient cooling method compared to the other methods. Advantages of liquid ice are a faster cooling rate, no additional handling of the catch is needed, and longer storage time (Iskerfi pers. comm.). The disadvantage of using liquid ice is that heavy salt penetration into fish muscle can occur for fish stored in liquid ice over a period of time.

### *2.4.3 Refrigerated Seawater*

Refrigerated seawater (RSW) is generally used when a mechanical refrigeration unit cools the water from seawater temperature down to below 0°C (Graham *et al.* 1992). In some cases, brine of about the same salinity as seawater is used. RSW has and will not displace the usage of ice, but it has been used as a cooling medium for certain species of fish, especially pelagic fish.
The main advantages of using RSW have been greater speed of cooling, reduced pressure on the fish, low holding temperature and suitable for large quantities of fish. The penetration of salt (NaCl) into the fish muscle discourages the use of RWS in many fisheries. The amount of salt that penetrates the fish depends mainly on size and species of fish. The amount of salt taken up by the fish cannot exceed 1% by weight, and the ratio of fish to seawater of should be 4:1. The RSW system has been used for sardine, salmon, halibut, menhaden, shrimp, mackerel, herring, blue whiting and capelin (Graham *et al.* 1992). In Iceland, the standard limit of salt content for fishmeal production is 0.7% but for fish food production, the limit is about 2% (Arason pers. comm.).

RSW systems can be used for various species and some of the more successful commercial applications are:

i) Salmon: The method has been used for storing and transporting large quantities of salmon prior to processing into a canned product. In this application salt uptake is relatively unimportant and the ease of handling, usually by brining, gives the system an advantage over iced storage.

ii) Industrial fish: Industrial fish such as menhaden are chilled in RSW system to maintain the quality until such time as they are unloaded for processing into fishmeal. Previously, the fish was processed within a day of capture, but longer trips have made it necessary to cool the fish in order to keep it firm and suitable for processing (Graham *et al.* 1992).

iii) Purse seine fishing vessels use RSW systems for chilling catch, mainly of pelagic fish. Unlike drifters, who bring the catch slowly on board, purse seines catches large quantities, which require quick handling and chilling. The fish is therefore pumped or brailed from the net direct into RSW tanks.

iv) Large freezer and factory trawlers: RSW systems are often used on freezer and factory trawlers when a delay between catching and processing is likely. Fish stored in bulk and not refrigerated between catching and processing will deteriorate quickly, especially in warmer climates (Graham *et al.* 1992)

RSW systems have been successfully used:

i) Where the disadvantages of salt uptake are not important, so comparatively long periods of storage are possible.
ii) For chilling industrial fish to allow longer trips, improve handling and reduce losses.
iii) For bulk chilling on fishing vessels which have to handle large quantities of fish quickly.
iv) For bulk chilling fish prior to processing, without the need for excessive handling.

The above applications cover a wide range of circumstances. A prior investigation of all the factors should be made for commercial application (Graham *et al.* 1992).

#### *2.4.4 Chilled Seawater (CSW)*

Seawater when mixed with ice and fluid, which temperature is lowered down to –1°C is known as, chilled seawater or CSW. Seawater is chosen to be used in this cooling method because of its characteristic due to high salt content. The advantages of CSW, are that the catch can be cooled rapidly, process of loading and unloading is easy and less affected by handling (being crushed and bruised) (Torry 2001). Other advantages are effective washing and a tendency to firm the flesh of the fish, which can aid further processing. Disadvantages of the method are as some species, herring for example, keep as well or better in CSW than in ice for 3-4 days but thereafter spoil quickly. Some species take up unacceptable amounts of water and salt when kept in seawater. Other species, capelin for example, are reported to keep better in ice even during the first few days. For these reasons the method is usually confined to short term storage of particular species that are caught in large quantities within in a short period of time, for example herring, mackerel, sprats and blue whiting in UK fishery, particularly since these fish are usually too small and numerous for gutting or sorting for size (Torry 2001). On larger vessels, because of large quantity of ice required, the size of the tank and the difficulty of making a homogenous ice/water mixture, CSW is not commonly used (Burt *et al*.1992).

### 2.5 The effect of hygiene practices

#### *2.5.1 Onboard handling*

Emphasis has been placed on hygienic handling of the fish from the moment of catching, in order to ensure good quality and long storage life. The importance of hygiene during handling onboard has been stressed. The quality and storage life of fish depends on how good the handling process onboard is, including the used of clean plastic boxes with clean ice (Merritt 1969). The construction of fish boxes should be able to prevent the ice melt-water from one box draining to another underneath. Melting water usually contains a large number of bacteria. Therefore, by using this system some bacterial contamination of fish in the bottom boxes would be avoided.

### *2.5.2 Treatment of fish before stowage*

It is important to chill the catch as soon as possible after it is landed on deck, especially in a warm climate. A delay of two hours may be excessive. Good handling of fish should be emphasised to avoid bruising the fish and unnecessary cuts. Clean conditions keep the number of spoilage bacteria at minimum. The deck, baskets, boots and other items that are in contact with the catch should be thoroughly washed before fish are landed on deck. Cleaning should be carried out immediately after each haul of fish (Merritt 1969).

### *2.5.3 Bleeding*

Bleeding of the fish is essential as soon as possible after being caught. The fish should be kept below 5°C, before and after the cutting operation for best results if blood discoloration is to be avoided and clotting of the blood to be prevented. The time required for adequate bleeding varies considerably depending on the condition of the fish and on temperature. In most cases one hour in ice or chilled water is sufficient. Proper handling and stowage in ice provides good conditions for bleeding (Merritt 1969).

### *2.5.4 Gutting*

Removal of fish gut depends on species of fish, size and quantity. For many species such as herring, blue whiting and particularly small fish, gutting is never carried out. Rough and spiny fish are left ungutted because it is difficult to gut by hand. Gutting can reduced spoilage and discoloration during storage. Blood discoloration on white flesh fish can be avoided by early gutting and storage in melting ice will bleed the fish effectively (Merritt 1969).

### *2.5.5 Washing*

The fish are usually washed before stowage although it is not always necessary. When the catch is dirty, it is advisable to wash the fish by hosing with water. It is a normal practice to wash the fish in seawater during sizing and grading. There are various methods of washing, such as by hand in batches with a hose. Washing in small batches is more effective to avoid a long delay between batches (Merritt 1969).
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## 2.6 Review of refrigeration systems in Icelandic fisheries

There were about 2,000 vessels registered in the Icelandic fishing fleets in the year 2000. Small undecked boats are 1,100 units and decked vessels are 900. Total capacity of the fishing fleet is about 175,000 tons (Ministry of fisheries 2000). Most of the freezers are trawlers equipped with a refrigeration system on board such as contact freezer or plate freezer, cold room and IQF (individual quick-freezing). However liquid ice is used to chill the fish before it is frozen or processed. About 85% of the boats above 115 tons have ice making machines on board, while 15% are using two methods of chilling, cooling whole fish on the deck and icing if the fish is kept in the store room. Flake ice or tube ice is mainly used by fishing boat between 10 to 115 tons (99%) and only 1% is using liquid ice. Small boats between 2 to 10 tons normally use ice or slurry ice (seawater) from onshore ice factory kept in plastic tubs (Arason pers. comm.).

## 2.7 Refrigeration system in Malaysian fisheries

Presently, in Malaysian fisheries, few of the trawlers are equipped with a refrigeration system. The system, which was introduced in 1990, uses conventional methods of cooling. This system has some disadvantages and can cause problems to the operators. So far, none of the purse seiners are equipped with this system. The cost of installing the refrigeration system ranges between USD 7000 for B zone trawlers to USD 15000 for C2 zone. Most purse seiners are still using ice. The cost of ice per month ranges from USD 500 to USD 1900 (Currently USD 1 = RM 3.8). The cost of maintenance of the refrigeration system on board depends on size of boat and competency of the operator. Minor repairs cost between USD 100 to 250.

### *2.7.1 Design of the existing system*

In the existing system (Figure 1), trawlers use a pipe grid in every compartment of the boat. The pipe grid is installed on the sidewalls and on the under the deck of the fish storage room. A wooden bracket is used to clamp the copper pipe onto wall to make it firm and secure. This pipe grid is controlled by individual control valves and can be isolated when necessary. The pipe grid acts as a cooling coil or evaporator of the system. It is usually made from 20 mm diameter copper pipe with 2 mm wall thickness. The reason copper pipe is used instead of steel pipe is because it is lighter, easy to fabricate and joint together. The compressor is run by belt, driven through power take-off (PTO) from main engine and speed of compressor is determined by the engine speed (RPM). The main engine is also used to run a seawater pump to cool the water-cooled condenser. Normally Freon 22 (Monochlorodiflumethane-$CHClF_2$) is used as a medium of refrigeration system. Design temperature for this particular system ranges between 0°C to – 3°C. The refrigeration system can be engaged and disengaged from the main engine by using mechanical jockey pulley. That is practical but has some disadvantages if one or more of the belts breaks or slips off the pulley, the refrigeration and cooling system will not function.

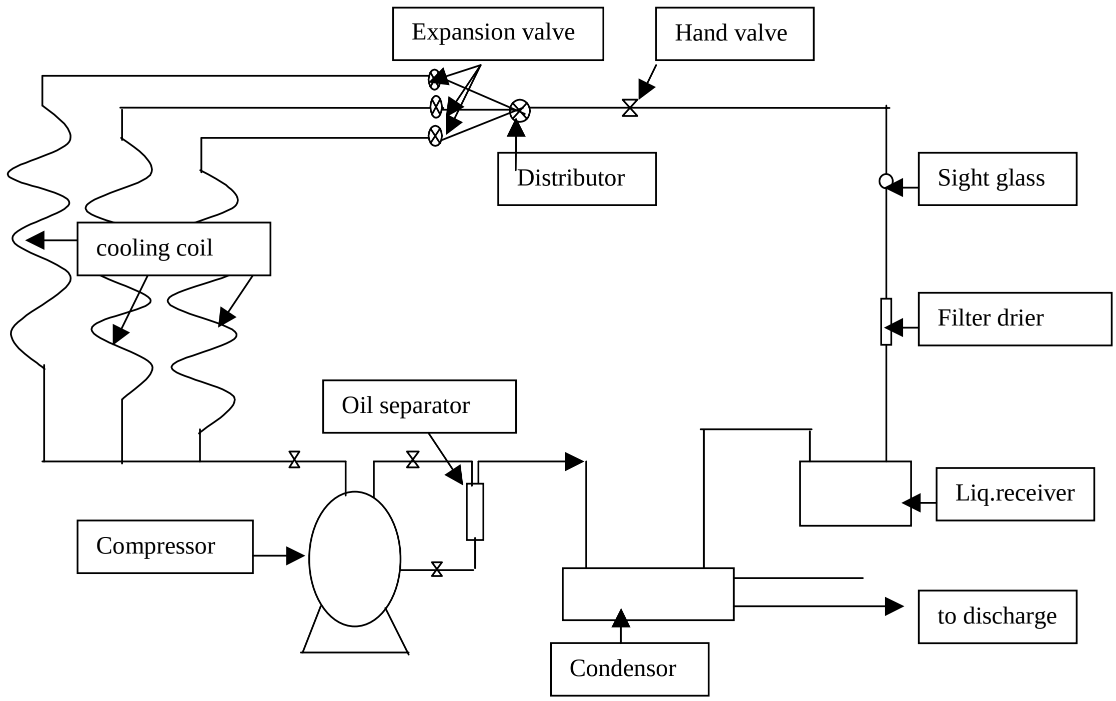


Figure 1: Refrigeration piping system layout installed in most existing fishing boats, especially trawlers, in Malaysia.

### *2.7.2 Refrigerating cycle*

The refrigerant is compressed in a compressor from low temperature pressure vapour to high temperature pressure vapour (in the same state). This vapour is then condensed to liquid state (no change in temperature) by rejecting heat through cooling medium used in the condenser (seawater). Liquid refrigerant is kept in liquid receiver before passed through the expansion valve (refrigerant control valve), where it changes to low temperature and low-pressure liquid. In the cooling coil or in the evaporator this liquid is turned to vapour again by absorbing heat load from the product (One coil represents as one compartment) thus this process continues (Dossat 1981).

### *2.7.3 Disadvantages*

Based on experience, this system has some disadvantages for the user. Since there is no alternative they have to face these difficulties. The disadvantages are:
i) Difficult to control the system when any part of pipe grid leaks because the fish hold is closed all the time with the hatch cover.
ii) Refrigerant used is odourless and when there is a leakage it is not detected.
iii) Fluctuation of compressor speed due to speed of main engine, for example the main engine speed becomes high when trawling and compressor speed is too high. Whereas, when the main engine is idling, the compressor speed becomes slow. This reduces the refrigerating efficiency and cause short life span of the compressor.
iv) The system depends on the main engine. When the main engine breaks down the system will not work and catch might spoil.
v) High maintenance and operating costs to replace belting, compressor, refrigerants due to items ii, iii, and i.

vi) Since the system depends on the main engine, no suitable safety devices can be used to control the system in terms of high or low operating pressure.

### 2.8 Present method of fish handling on board in Malaysian boats

Fish handling on board depends on types of gear used and the sizes of the boat. Pelagic fish such as Hairtail scad (*Megalapis cordyla*), Indian mackerel (*Rastrelliser kanagurta*), Round scad *(Decapterus russelli*) caught by purse seiners are put into fish hold and soaked directly in chilled seawater (CSW) with the ratio 1:3 (ice to seawater). No plastic boxes or insulated containers are used. The fish is unloaded and scooped into plastic baskets on the deck. Hook and pulley are then used to hoist the basket onto the auction hall for sorting. The stainless steel sorting table is used for this purpose. For trawlers, fish such as Red Snapper (*Lutianus argentimaculatus*), Coral cod (*Epinephelus sexfascratus*), Printed sweetlip (*Lethrisnus nebolosus*) landed on deck are sorted according to species and size. These fish are put into plastic baskets and cleaned by fresh seawater to remove slime, mud and other material. Fish is then kept in plastic bags weighing approximately 8 kg each and soaked in plastic containers which are a quarter filled with chilled freshwater. The mechanical refrigeration system is used to chill freshwater by means of surface contact of plastic container with chilled seawater outside the container. The temperature difference between seawater and freshwater is about 2-3° C.

## 3. MATERIALS AND METHODS

### 3.1 Materials

Herring (*Clupea harengus*) caught 02.12.02 at Vopnafjardargrunn by the trawler Beitir NK-123 was used in the experiment. The fish was transferred iced from the landing site (Neskaupstadur) to the headquarters of IFL (Icelandic Fisheries Laboratory). The iced herring was received in sealed plastic barrels. The herring was used as raw material three days after capture. It was in good condition and fresh based on sensory evaluation using the quality index method (QIM) scheme for herring. The herring was re-iced with three layers of ice (bottom, middle and top) and kept overnight at 0 °C. Liquid ice machine model B-105 was installed with compliments of liquid ice Iskerfi **(http://www.liquid-ice.is).** This machine is capable of producing 9 tons of liquid ice (25% purity of ice) per day. Industri Salt (Dansk Salt) was used to mix with water for production of liquid ice with no less than 3% salt concentration. Salt content was measured by using PC hydrometer model ERTCO (Nalge, USA). Daily monitoring of fish core temperature and fluid temperature was done by using digital thermometer model EBRO TFX 429 (Germany).

### 3.2 Methods

Total Plate Count (TPC), Total Coliforms, Faecal Coliforms, TVB-N, fat, salt, protein and moisture measurements from samples of raw material were carried out based on Icelandic Fisheries Laboratory standard methods of measurement.

### *3.2.1 Protein content (Kjeldahl method)*

2 g of the minced herring fillet was weighed and transferred into Kjeldahl method digesting flask with a catalyst (2 tablets) and 17.5 ml $H_2SO_4$ and heated for 3 hours at 420°C. Then, the solution was cooled and measured in auto distillation unit (ISO 1979).

### *3.2.2 Fat content (Soxtec method)*

After drying, 5 g of minced herring was weighed and transferred into a paper filter (extraction thimble) and put in a tin calume match in the soxtec system. Fat was extracted with petroleum at 60°C for 82 minutes (AOSC 1997)

### *3.2.3 Moisture content*

5 g of minced herring were weighed and put into a metal dish with lid. The sample was placed in the oven and heated at 102-105°C for 4 hours. The sample was then removed from the oven and allowed to cool to ambient temperature in the desiccator and weighed to the nearest 1 mg. The change in mass between the two weighings shall not exceed 0.1% of the mass of the dried sample (ISO 1983).

### *3.2.4 TVN method (steam distillation)*

100 g of minced herring was mixed with 200 ml of 75% aqueous trichloroacetic acid. Steam distillation was performed using a Kjeldahl type distillator (struer TVN).
25 ml of mixture were transferred into the distillation flask and 6 ml of 10% NaOH was added. The beaker mixture of 10 ml boric acid, 0.04 ml methyl and bromocresol green indicator was placed, under the condenser for the titration of ammonia. The boric acid solution turned green after 4 minutes distillation and titrated with 0.0317 sulphuric acid using 0.05 ml graduated burette. The solution colour turned pink obtained when complete neutralisation (AOAC 1990).

### *3.2.5 Salt content (Volhard method)*

0.5 g of minced herring was put into 250 ml bottle with 200 ml $H_2O$. The solution was shaken for 45 min. A 20 ml solution was pipetted into a 100 ml beaker with 20 ml of $HNO_{3.}$ The solution was stirred with a magnetic stirrer on a tinometer titrator (716 DMS Titino)(JAOAC 1973).

### *3.2.6 TPC (pour plate method)*

A herring sample was minced using a sterilised mincer in a microbial laboratory. A 25 g sample was mixed with 225 ml dilution buffer and mixed in a stomacher. 1 ml of the 1/10 dilution was transferred with pipettes to petri plates. LST broth was used in each dilution. Melted 45°C iron agar was poured into the plate and mixed thoroughly. The plates were incubated at 22°C for 48 hours. White colonies are counted separately from black colonies (APHA 1992).

## 3.3 Trials/experiments

The experiment was divided into trial 1 and trial 2

### *3.3.1 Trial 1: Herring stored in different cooling systems*

Trial 1 was carried out for 11 days (Dec. 5 to Dec 15-including date of reception). The herring was kept in flake ice, liquid ice and CSW. The trial was performed at two different environmental temperatures, 2°C and 25°C. The temperature in an insulated room was kept between 25- 28°C by an electric heater. The reason for increasing the temperature is to make a realistic environment, similar to the fellow's country ambient temperature (average 28°C ambient temperature). Six uninsulated 30 litre plastic containers were used under whole herring in each medium. The core temperature measured in herring was maintained as close to 0°C by adding ice from time to time and re-ice if necessary. Data, daily monitoring and information about the trials are shown in appendix 3 and 4.

### *3.3.2 Sampling and sample preparation*

The initial measurements of raw material were taken on day 0, i.e. total plate count, total coliforms, faecal coliforms, TVN, protein, fat, salt content and moisture. These measurements were taken day 2, 4, 6, and 8. Four fishes were taken from each box each day of sampling and weighed. Each sample was put in a marked plastic bag according to the type of medium and temperature. Herring were filleted and de-skin. Four fishes from each sample were mixed in one collective sample. The sample was then divided into 2 parts, one for chemical and physical measurements and the other for microbiological measurement. During these measurements fillets for chemical measurement were minced in Braun electronic blender model 00606 for 20 seconds at speed 4. Fillets for microbiological measurement were minced by standard methods at the microbial laboratory.

### *3.3.3 Trial 2: Test on melting rate of liquid ice*

Ice melting test was done in three different boxes using liquid ice stored at 20°C ± 2°C. Three different types of boxes were used, 300 litre plastic tubs, 30 litre plastic container and 10 litre polystyrene insulated box. The experiment was done using both covered and uncovered boxes. Ten units of battery operated temperature monitoring logger Optic stowaway were used to monitor the temperature. For the plastic tubs, three thermometers were needed to monitor temperature at three different levels (Figure 12). Two loggers were required for the plastic container and one for the polystyrene box. One of the thermometers was used to monitor the room temperature throughout the test.

The test was carried out from December 23 - 27 2002. The results of these tests are in Appendix 8.

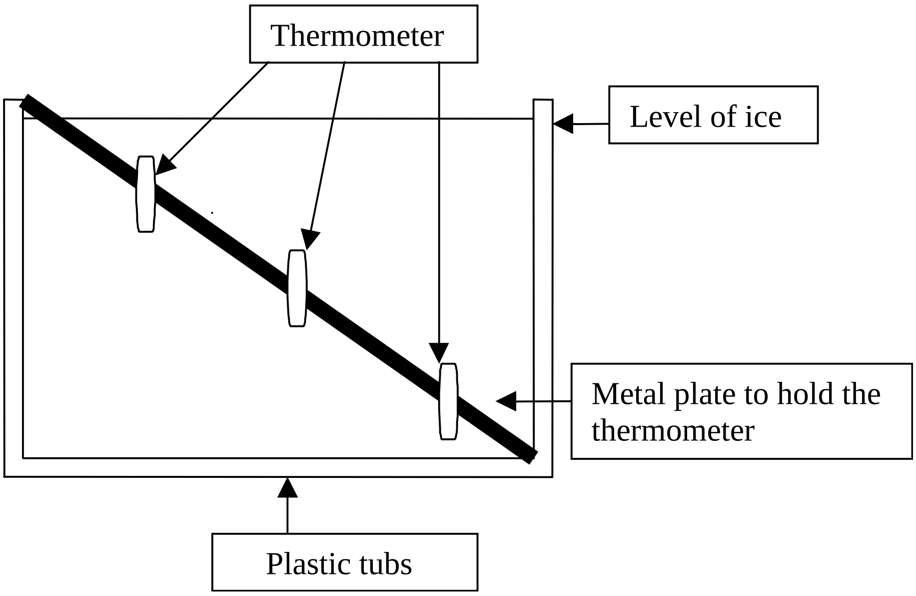


Figure 2: Location of the three onset thermometers in plastic tubs during ice melting trial to log the temperature.

# 4. RESULTS

## 4.1 Trial 1: Raw material analysis

Results of the chemical and microbiological analysis of the raw material are shown in tables 3 and 4.

Table 3: Chemical measurement from raw material of herring fillets (received: 05.12.02)

| Measurement | Method | Unit | Value |
|---|---|---|---|
| Protein(Nx6.25 | AM-00903 | % | 17.6 ± 0.4 |
| Fat (ether extraction) | AM-00901A | % | 12.8 ± 0.4 |
| Moisture | AM-00904 | % | 68.3 ± 0.4 |
| Salt ( NaCl) | AM-00902C | % | 0.5 ± 0.1 |
| TVN | AM-00906 | mg N/100 g | 17.5 ± 0.7 |

Table 4: Number of bacteria in raw material of herring fillets (received: 05.12.02)

| Measurement | Method | Unit | Value |
|---|---|---|---|
| Total Plate Count | AB-00301 | No/g | 5.500 |
| Total coliforms (MPN) | AB-00501A | MPN/g | 46 |
| Faecal coliforms (MPN) | AB-00501B | MPN/g | <0.3 |

## 4.2 Sample analysis (trial 1)

### *4.2.1 Herring stored at 2°C*

Dry matter measured in herring kept in liquid ice at 2°C (Figure 3) increased from 68.3 % to 75 % on day 2, decreased on day 4 to 72.5% during 2 days of storage. A decrease was observed between day 2 and 4 (72.5%) followed by a constant value throughout the storage time. However, dry matters in herring in CSW increased to 74% on day 4 and increased over the storage time. For herring in ice, dry matter measurement taken until day 2 but the dry matters also increased to 72.6%.

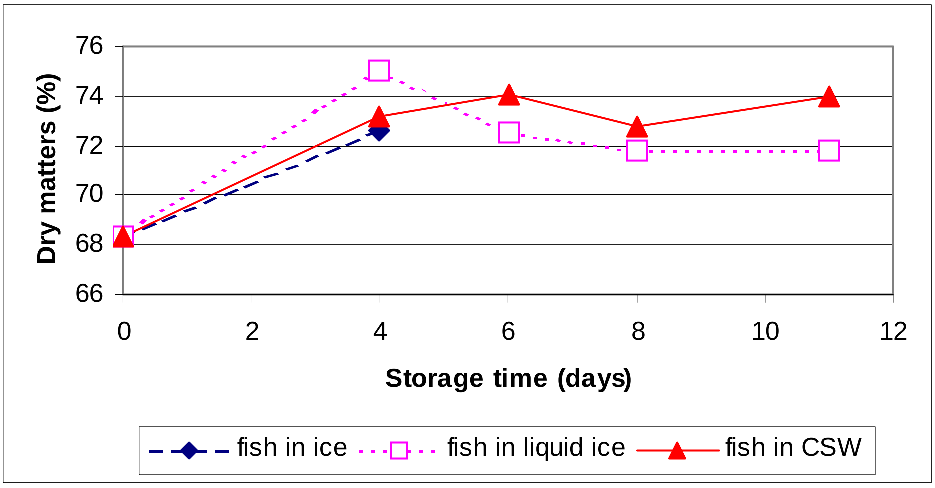


Figure 3: Dry matter (%) in herring kept in ice, liquid ice and CSW at 2°C. Sampling was done on the raw material (day 0) and on day 2, 4, 6, 8 in each system (average of 4 fillets).

Salt content in raw material was 0.5%. Salt content in fillets stored in liquid ice at 2°C (Figure 4) increased to 2.2% during storage time. This value exceeded acceptable limit of salt content for pelagic fishes for fishmeal which is 0.7% and 2.0% for fish for food production (Arason pers. comm.). However in CSW system, salt content in fish was 1%, at day 8. The salt content in fillets stored in liquid ice was significantly higher in fillets kept in CSW (Student's T-test, $p<0.05$).

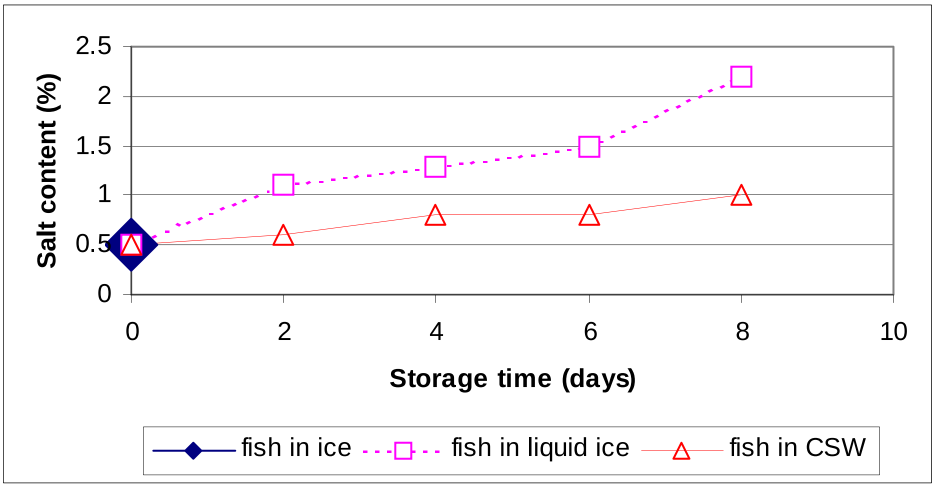


Figure 4: Salt content (%) in herring kept in ice, liquid ice and CSW at 2°C. Sampling was done on raw material (day 0) and on day 2, 4, 6, 8 in each system (average of 4 fillets).

TVN in herring was 17.5 mg N/100g in raw material (Figure 5). For the herring in ice, TVN increased from 17.5 mg N/100g to 56.4 mg N/100g during storage of 8 days at 2°C, and had exceeded acceptable limits (>35 mg N/100 g) after 4 days. In liquid ice, TVN read as 23.6 mg N/100g and exceeded the fresh limit on day 6. However in CSW, TVN value on day 4 was 34.9 mg N/100g just under the acceptable limits. But TVN value from these 3 cooling systems was still within the quality limits for whole fish (IFL 2003). TVN value found in herring kept in ice was significantly higher compared to CSW (student's T-test, $p<0.05$).

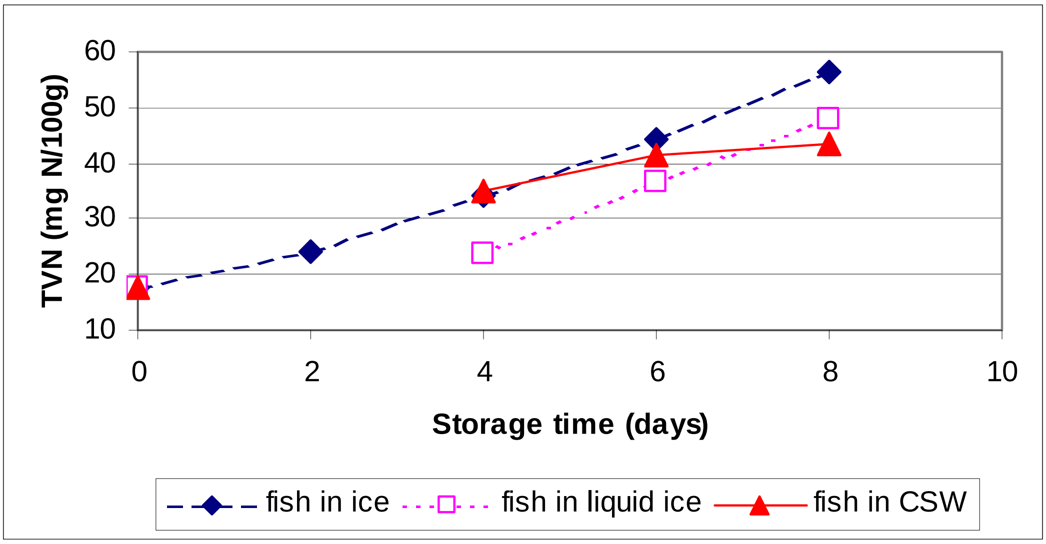


Figure 5: TVN (mg N/100g) in herring kept in ice, liquid ice and CSW at 2°C. Sampling was done on raw material (day 0) and on day 2, 4, 6, 8 in each system (average of 4 fillets).

The level of bacteria in herring at 2°C room temperature, measured in raw material on day 0 was 3.75 log no/g (Figure 6). TPC in herring in ice increased to 6.5 log on day 6. Since TPC on day 6 was significantly high further measurements were not necessary. The TPC in liquid ice has increased on day 2 but decreased on day 4 to about 4 log no/g. Then increased again to 6.2 log at the end of storage. The trend (decreased on day 2) was very strange for TPC measurement. This may because of some mistake or misreading during analysis. Meanwhile, TPC in herring stored in CSW increased to log 5.1 on day 2 and was constant towards end of trial. From Figure 6, it seems that herring in ice gave poor results compared to herring stored in CSW. Acceptable limit for fresh fillets is less than 5.5 log no/g.

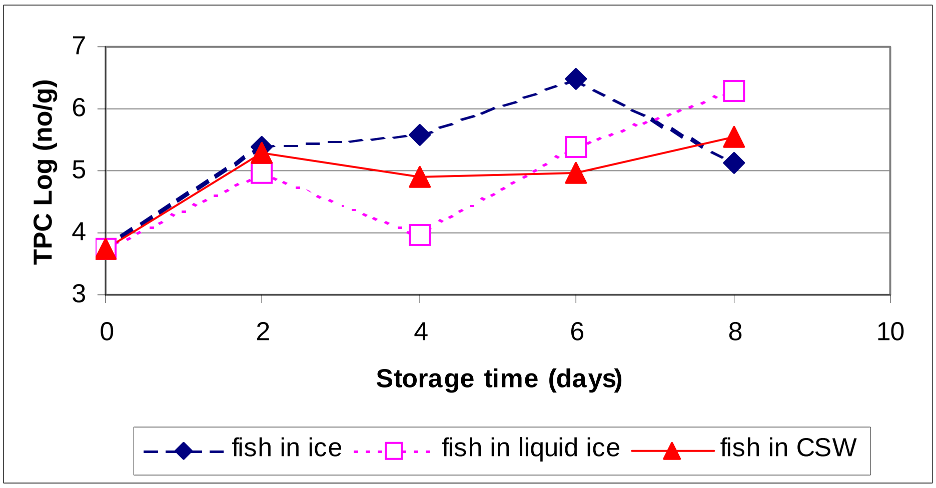


Figure 6: TPC (log no/g) in herring kept in ice, liquid ice and CSW at 2°C. Sampling was done on raw material (0 day) and after 2, 4, 6 and 8 days in each system (average of 4 fillets).

### *4.2.2 Measurements of herring stored at 25°C room temperature*

Dry matter of herring in raw material was 68.3 % (Figure 7). Herring in liquid ice, dry matter measured 73.9% on day 2 but from day 4-8 it was around 72%. Dry matter of herring in CSW increased on day 2 to 73.7% and ended at 73.2 at the end of storage time.

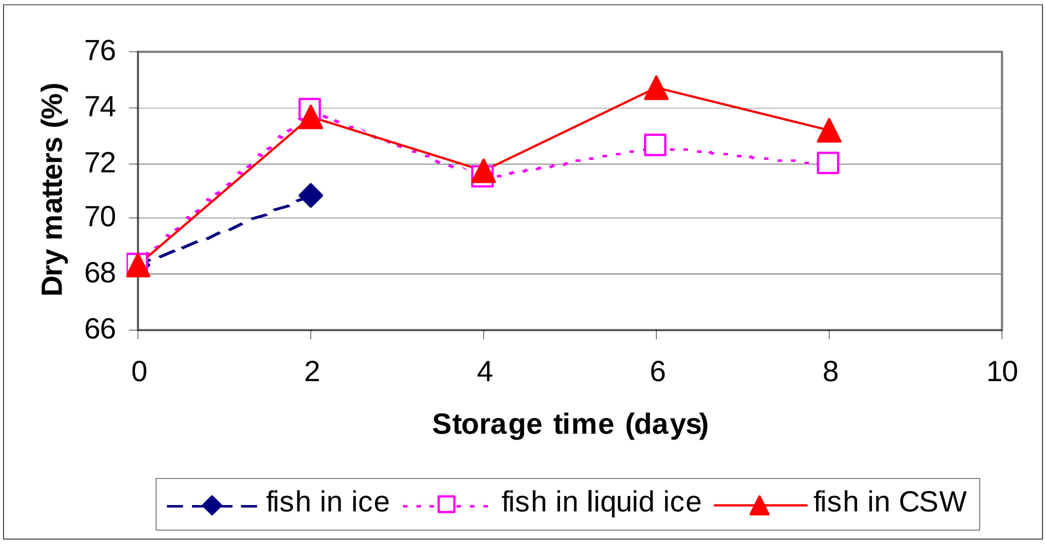


Figure 7: Dry matter (%) in herring kept in ice, liquid ice and CSW at 25°C. Sampling was done on raw material (day 0) and on day 2, 4, 6 and 8 in each system (average of 4 fillets).

Salt content in raw material was 0.5% (Figure 8). In CSW, salt content was found almost constant throughout the trial of 8 days. However salt content in liquid ice increased from 0.5% to 3.1% at the end of storage time. The salt content exceeded acceptable limits for pelagic fishes for fishmeal (0.7%) and for fish food production, 2.0% (Arason pers. comm.). The salt content in fillets stored in liquid ice was significantly higher compared to the fillets stored in CSW (Student's T-test, $p<0.05$)

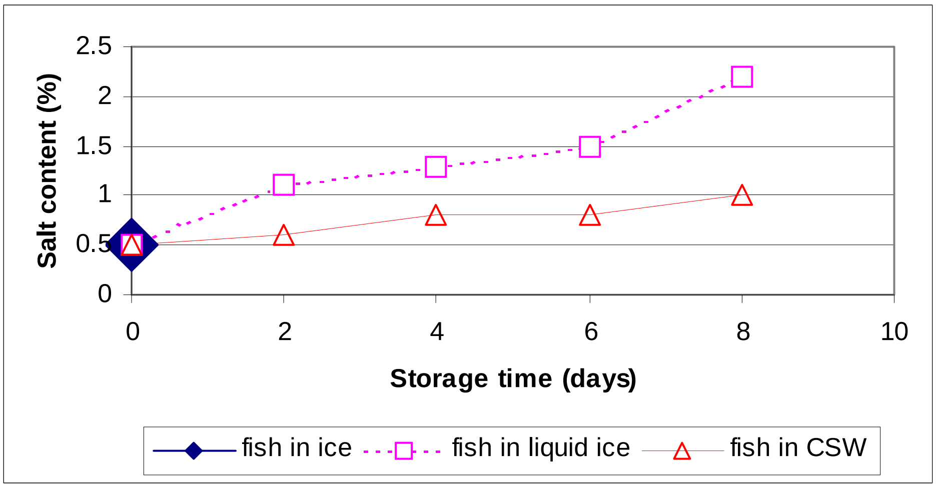


Figure 8: Salt content (%) in herring kept in ice, liquid ice and CSW at 25°C. Sampling was done on raw material (day 0) and on day 2, 4, 6 and 8 in each system (average of 4 fillets).

TVN measured in raw material of herring was 17.5 mg N/100 g (Figure 9). For herring in ice, TVN increased to 36.1 mg N/100g on day 4 but decreased to 28.4 mg N/100g by the end of trial. No measurements were taken on Herring in liquid ice on day 2 but the TVN value on day 4 shows an increase to 42 mg N/100g before dropping to 31.8 mg N/100 g on day 8. For herring in CSW, TVN value increased to the highest point 50.3 mg N/100g on day 4 and back to 31.8 mg N/100 after 8 days of storage.

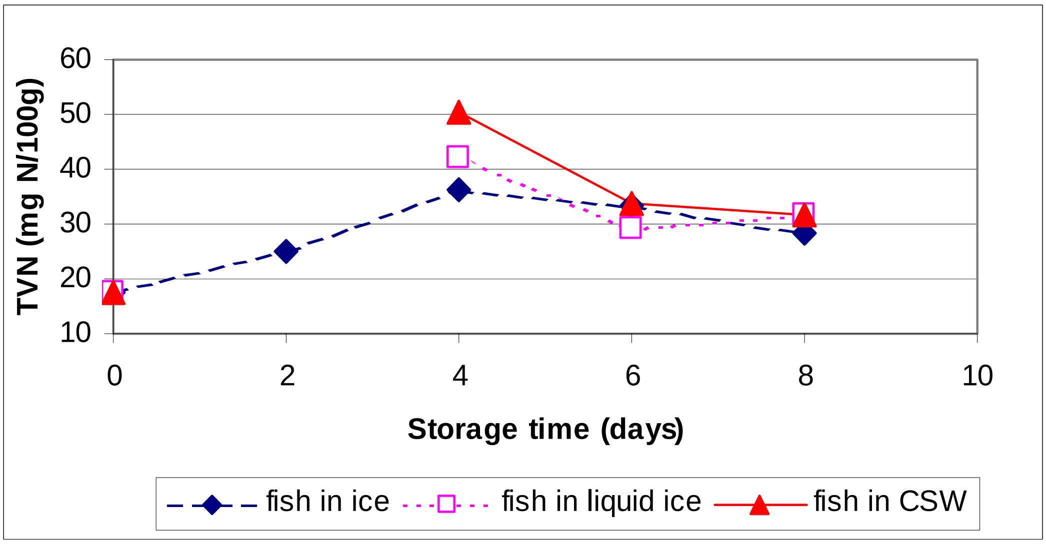


Figure 9: TVN (mg N/100g) in herring kept in ice, liquid ice and CSW at 25°C. Sampling was done on raw material (day 0) and on day 2, 4, 6, and 8 in each system (average of 4 fillets)

TPC measured in raw material was log 3.75 (Figure 10). For herring in ice, TPC increased to 7.6 log after 8 days of storage. For herring stored in liquid ice, TPC increased to 6.5 log after 8 days of storage. However TPC in CSW was only measured until day 6 since the TPC value was extremely high (8.2 log). Herring kept in ice, liquid ice and CSW at 25°C may have reached unacceptable limits on day 1 since the TPC was far above acceptable limits of 5.4 log no/g on day 2 (IFL 2002). High bacteria count in herring stored in all types of cooling medium might came from the gut in herring. Based on this result TPC found in CSW was significantly higher compared what was found in liquid ice.

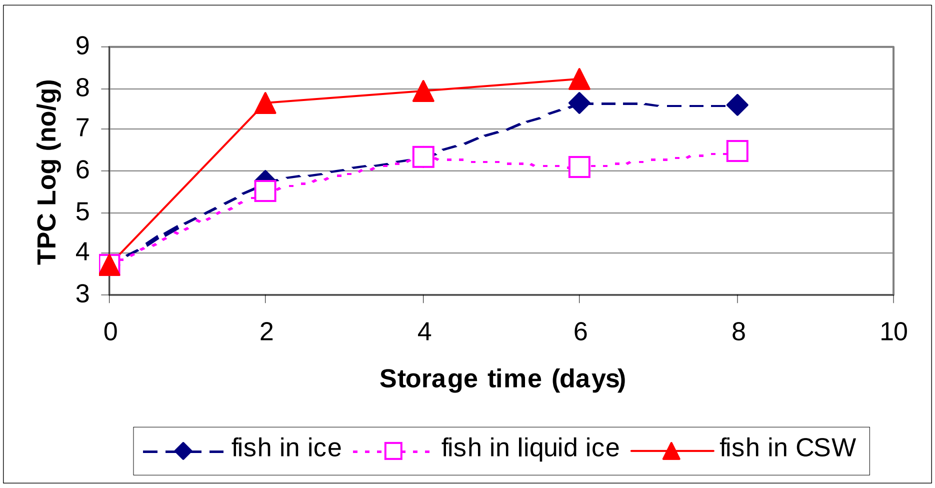


Figure 10: Total plate count (TPC) in herring kept in ice, liquid ice and CSW at 25°C. Sampling was done on raw material (day 0) and on day 2, 4, 6, and 8 in each system (average of 4 fillets).

The core temperature of fish kept in liquid ice fluctuated between –1.8 to 1.5 °C with the highest values on days 3 and 6. Additional ice was added on days 3 and 6. Correlation between fish temperature and fluid temperature is $r^2$ =0.90 over 10 day's storage. Characteristic of liquid ice gives rapid chill over the fish in short time, shown on day 4 and day 8 where re-icing was done.

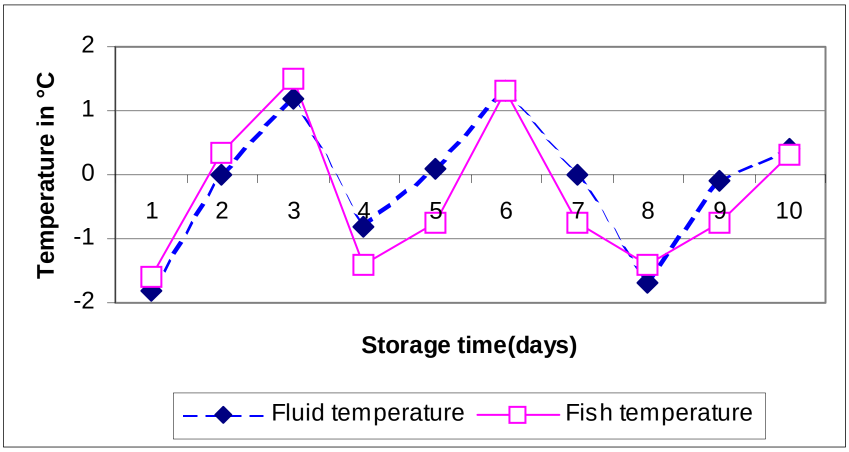


Figure 11: The core temperature of fish kept in liquid ice at 2°C taken daily

Fish temperature was slightly high at initial stage because the fish was exposed to surrounding temperature while taking some measurements and preparation of cooling system. After being kept in CSW, the core temperature decreased to –0. 4°C and remained constant throughout trial. Correlation coefficient for herring in CSW, fish and fluid is $r^2$ = 0.72.

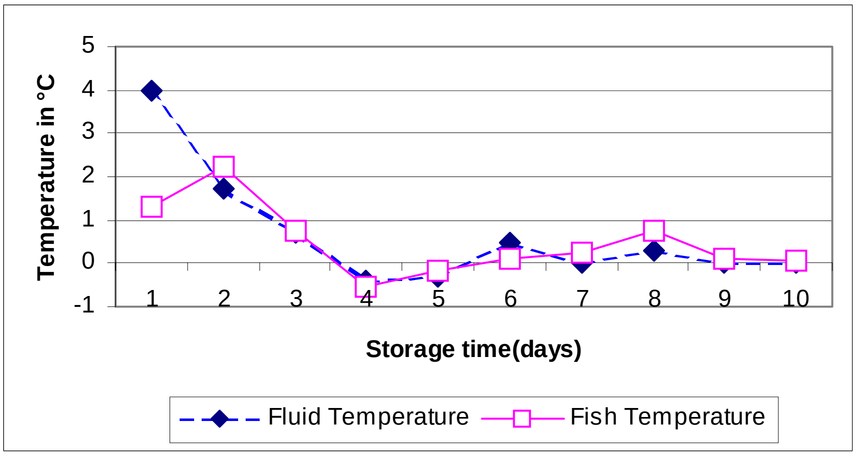


Figure 12: Core temperature of herring kept in CSW at 2°C taken daily.

Core temperature of herring kept in ice was almost constant from day 1 to day 10. From trial record, core temperature was always 0°C when re-icing took place on day 4, 6 and 9.

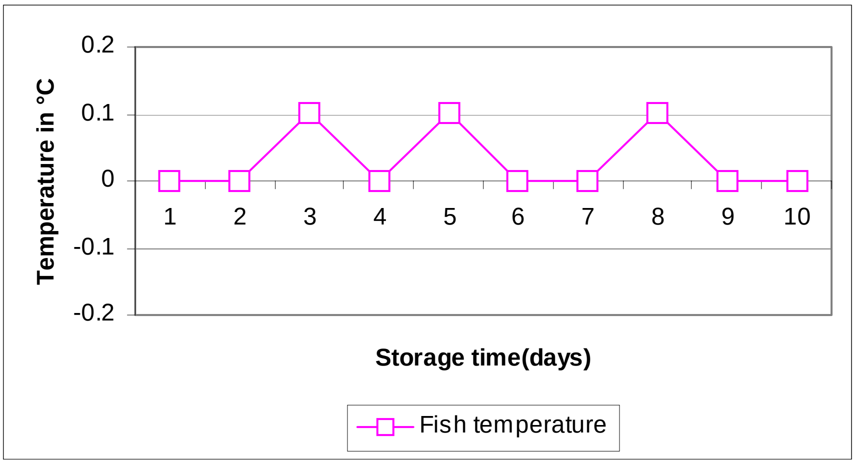


Figure 13: Core temperature of herring in ice at 2°C taken daily.

Core temperature of fish and fluid followed almost the same trend. Fish and fluid temperature correlation ($R^2$) is 0.97. Observed 10°C fish temperature on day 5 was because re-icing took place and a total of 60 kg of liquid ice was put into the plastic box.

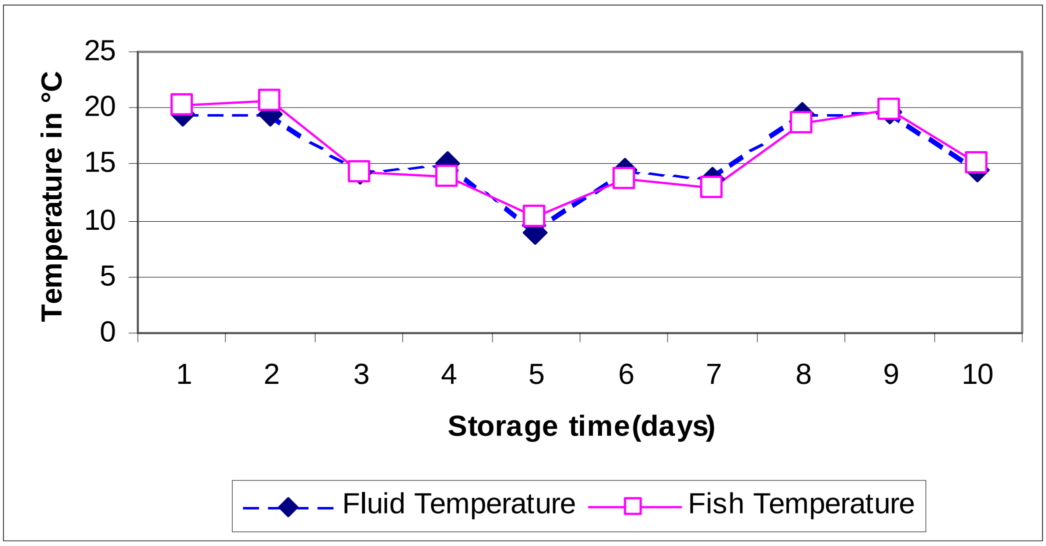


Figure 14: Core temperature of herring in liquid ice at 25°C taken daily.

Core temperature of fish was as high under the high room temperature conditions. Temperature measurements were taken daily when most of the ice melted (total melt) overnight. Temperature was lower on day 5 to day 8 because of higher ratio of ice to fish, 2:1 and on day 8 the ice:fish ratio 5: 1 ($R^2$ = 0.93). Correlation of 0.93 between fish and fluid temperature.

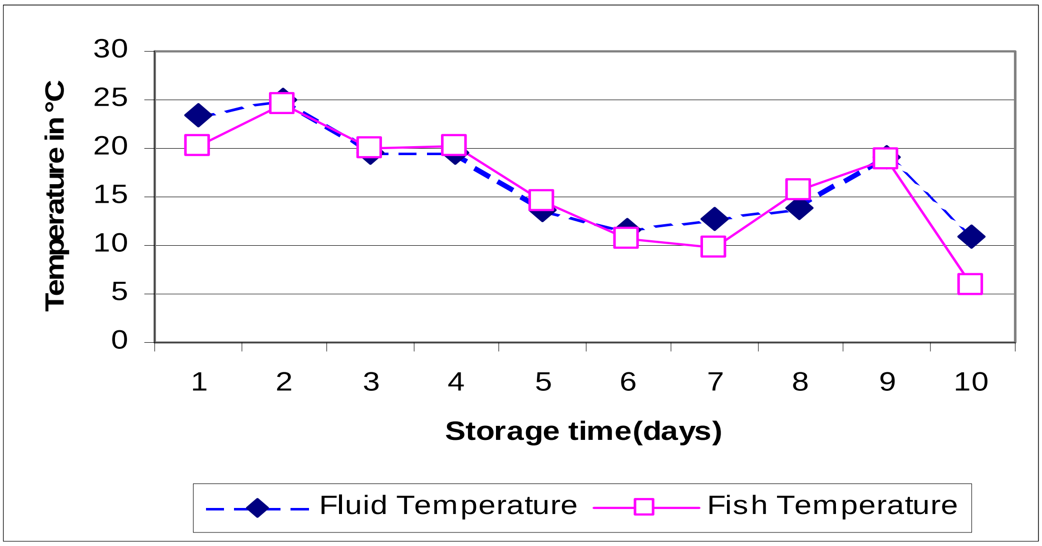


Figure 15: Core temperature herring kept in CSW at room temperature of 25°C. Measurements were taken daily.

Correlation between fish and fluid temperature of herring in ice is 0.99. Core temperature of fish fluctuated over the period from 21°C down to 4°C. Low temperature on day 3, 4, 5 and 9 was because re-icing with extra amount of ice (20 kg of ice to 4.5 kg of fish).

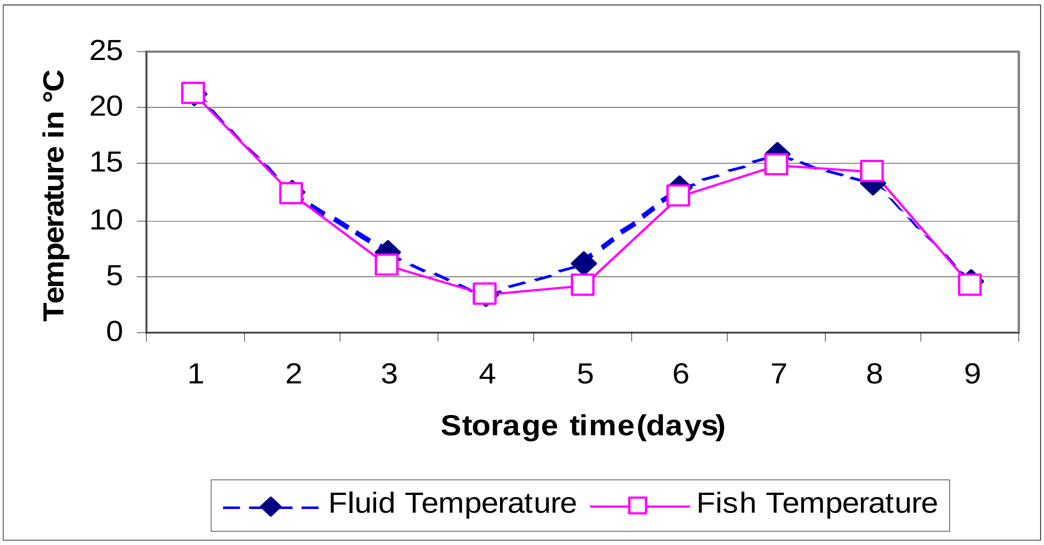


Figure 16: Core temperature of fish kept in ice at 25° room temperature. Measurements were taken daily.

## 4.3 The melting test (trial 2)

Liquid ice in plastic tubs with cover, took 2 hours longer to melt than the ice in the uncovered tubs and a 3 hour difference was found between covered and uncovered liquid ice in the plastic container (uninsulated). Liquid ice kept in polystyrene box with cover took as long as 27 hours to melt. The ice in the uncovered box melted in 6 hours. Heat transfer between the ice and the environment was fast for liquid ice kept in the uninsulated plastic container. The high heat caused the ice to melt in a short time. Insulation can prolong the melting time for ice kept in tubs and polystyrene box. The thickness and material of insulation also plays an important factor to determine how long fish can be kept in insulated box and how much ice is required to cool the fish stored in it.

## 5. NEW DESIGN OF RSW FOR MALAYSIAN TRAWLERS AND PURSE SEINERS

### 5.1 Proposed design of RSW system for purse seiners

Clear seawater is pumped into a brine tank or water chiller tank (Figure 17). Seawater to be chilled from (seawater temperature in Malaysia) 25 °C to –3 °C by refrigeration equipment. Then it is delivered to fish hold by PVC pipes according to number of partitions on board. Chilled seawater is to be sprayed over the fish by spray nozzles (Figure 18). The number of nozzles required is based on the size of each hold (surface area). Warmed seawater (above 0 °C) is pumped back to chiller by overflow perforated pipe, chilled and sprayed all over again. This process will continue so that catch is kept at -1 °C brine solution. Temperature of seawater in every compartment will be controlled by a thermostat (temperature control) at -1°
to -2 °C and a flow switch. Seawater will stop flowing when the brine temperature in fish hold has reached -1 °C. The thermostat will activate the flow switch to close, which can stop the flow of water automatically. Differential temperature of thermostat is set for ± 5°. Fish holds should be fully insulated and leak-proof to prevent heat loss and loss of refrigeration efficiency. Refrigeration equipment shall run separately either by generating set or auxiliary engine.

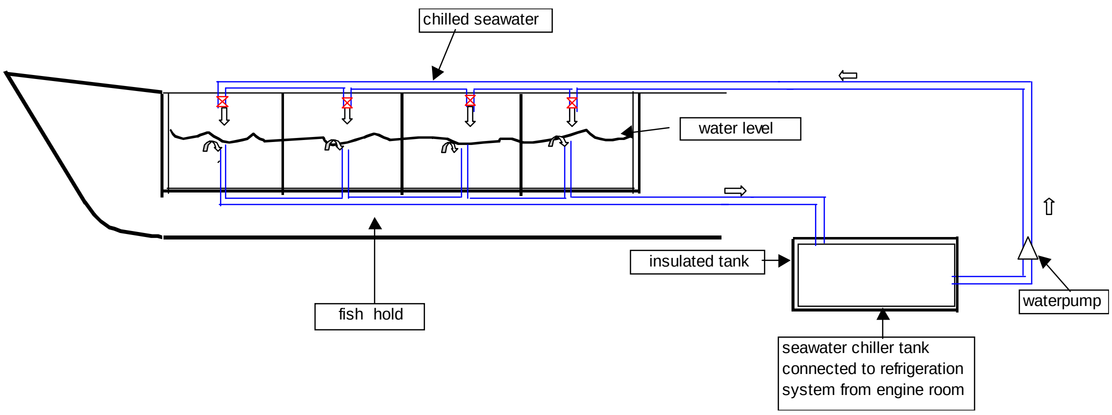


Figure 17: Proposed design of RSW system for a purse seiner.

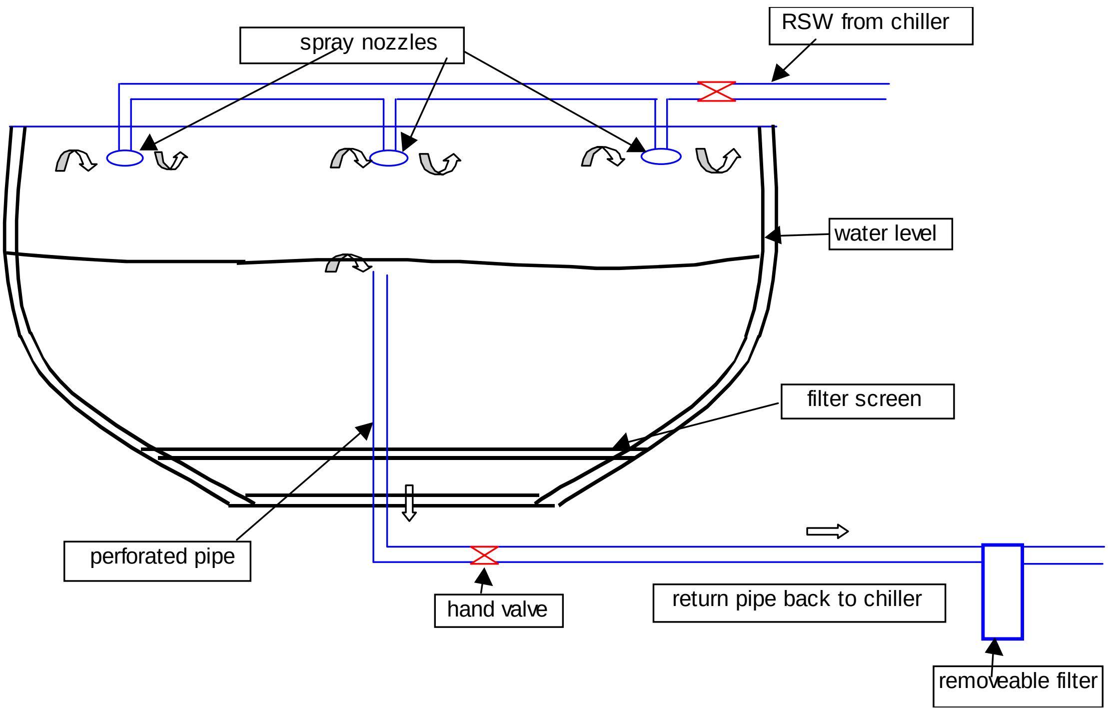


Figure 18: Cross section of RSW tank for a purse seiner.

## 5.2 Proposed design of RSW system for trawlers

A number of insulated tanks are required for this proposal (Figure 19). Galvanised or stainless steel is suitable material for making these tanks. Existing fish holds can be used to for the tanks based on the number of compartment. Tanks can be divided e.g. according to species of fish. The operational of this system similar to RSW system for the purse seiner, except a vertical pipe is used with spray nozzle (Figure 20). High pump capacity is required for good circulation and homogeneous temperature in the tank.

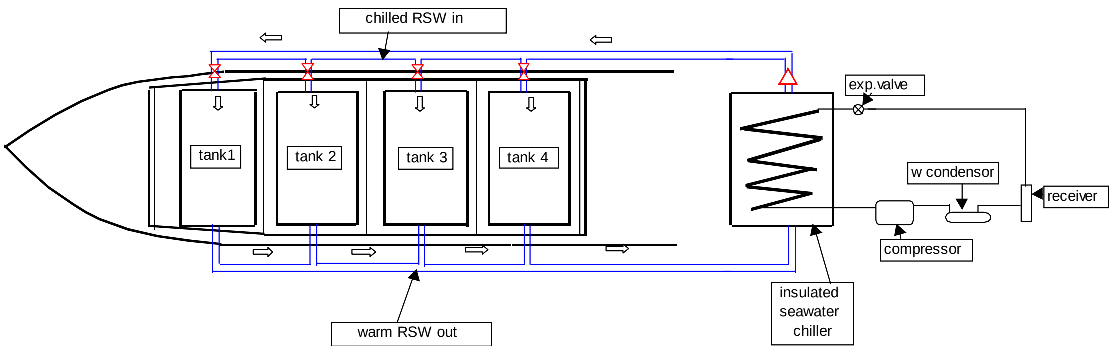


Figure 19: Proposed RSW system for a trawler.

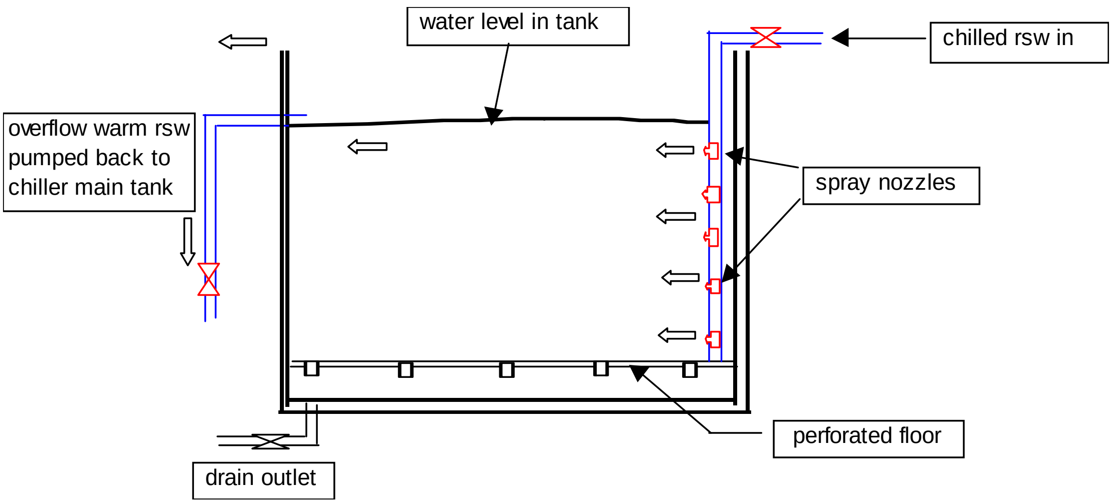


Figure 20: Cross section of RSW tank for trawler.

## 6. DISCUSSION

The freshness of fresh or frozen fillets is normally determined by measuring bacteria content, e.g. with the total plate count (TPC) and chemical components such as TVN from the flesh. Guidelines, issued by Icelandic Fisheries Laboratories (IFL) for fresh fish, determine good quality fish using TPC as having bacteria numbers lower than 5.4 log no/g. As the bacteria count goes above these safe limits, the quality decreases. At 2°C, herring kept in CSW gave good TPC result (4.95 log) compared with herring in ice and liquid ice. Based on this, most of the bigger fishing vessels use CSW or RSW on board, especially in large quantities of fish. Herring kept in CSW is little better than in ice for three to four days and after that it spoils more quickly (Torry 2001). Other species like capelin are better in ice for the first few days. However, at 25°C environmental temperature, herring kept in liquid ice gave better results until day 2 (5.53 log). In warmer climates/conditions, fish tend to spoil very fast if proper cooling technique is not available (Burt *et al.* 1992). High bacteria count in herring, especially at 25°C, possibly came from ungutted herring or contamination from ice used in this trial. The ice used was measured for microbiological analysis and the TPC level in ice from institute (IFL) was 1,160/ml and 19,800/ml from Fiskaup company. These bacteria numbers exceeded the allowable limit of 100 TPC/ml.
The TVN limits IFL uses for fresh fillets and whole fish are 20 mg N/100g and 50 mg N/100g respectively. For herring stored at 2°C, TVN measurements for all cooling mediums showed an increase towards the end of storage time. However, herring in liquid ice gave the best results. The characteristic of liquid ice that enables the quick cooling of products may cause low TVN levels of herring kept in liquid ice (Liquid ice Iskerfi 1999). However at 25°C room temperature, TVN measurements fluctuated and decreased at the end of 8 days in all cooling medium, especially in the CSW medium. The reason for this decrease at the end of the experiment is probably that in higher temperature and longer storage time the rate of spoilage occurs faster. Therefore as the fish start to decompose and nitrogen is released from the flesh. TVN could not be detected in the fluid because of re-iceing during trial. Result from TVN measurements of herring stored at 2 °C and 25 °C, show that fillets are still within acceptable limits if based on guidelines for whole fresh fish issued by IFL.

The high bacteria count can be explained by either possible contamination from ungutted herring or that the ice was contaminated (same source of ice). The ice used in this trial had TPC of 1,160 in (laboratory) and 19,800 (Fiskkaup). These figures exceed acceptable limit of < 100 TPC/ml (IFL 2003).
Percentage of salt content in pelagic fishes for feed meal factory is 0.7% and for fish food production about 2% (Arason pers. comm.). The salt content in herring kept in liquid ice increased towards at the end of 8 days storage in both room temperatures. Salt content exceeded the acceptable limit for fish food production and feed meal factory. Herring should therefore not be kept longer than 4 days in liquid ice. The liquid ice is good for super-chilling catch or product prior to further processing (Liquid ice Iskerfi 1999).
Core temperature of fish kept in liquid ice, ice, and CSW, especially in 2°C room temperature, was almost stable. Throughout the trial less amount of ice was required. Core temperature was extremely high for herring kept in liquid ice, ice, or CSW at 25°C room temperature. During this trial, core temperature of herring was always above 4°C and the highest temperature recorded was 25°C, similar to room temperature. Most of ice in the container melted due to high room temperature but not from product heat load. Liquid ice in insulated and covered plastic tubs melts slower (by two hours) than ice in uncovered tubs, but ice can last as long as 6 to 30 hours in 25°C room temperature in insulated containers. It is not practical to keep liquid ice in uninsulated plastic container with high room temperature because the ice melting rate is 7.5 hours in covered plastic containers and 4 hours in uncovered plastic containers. Fish can be kept together with ice in a plastic container but only for short time. Liquid ice kept in insulated boxes and covered with the same material and thickness can last longer. For example, liquid ice kept in 25 mm thick, 0.012 $m^3$ polystyrene boxes with lid can last as long as 27 hours in 25°C room temperature.

## 7. CONCLUSION

Findings from a series of experiments carried out in this study, and from discussion with producers and researchers in the field of cooling techniques, the following conclusions can be drawn.

1. When determining the cooling technique (ice, CSW or RSW) to be used on board vessels, one has to consider the species of fish, the quantity of fish to be handled and the type and value of product.
2. Ice is the most suitable medium for chilling fish on board, especially on boats less than 40 GRT such as in the Malaysian fisheries. In many countries, addition of ice to cool the catch is extensively used on smaller boats and it seems to be the best option. Small boats cannot have ice-making machines. Therefore ice can be supplied in fishing ports in insulated plastic tubs. Smaller boats, using boxes/insulated containers with ice and CSW can improve handling of fish and increase quality of the catch. This is the most economic way for small trawlers and long liners. For this to be practical, the fish hold must be properly insulated and easily cleanable with hose water after use.
3. RSW or CSW systems should be applied on purse seiners because of large quantities of fish caught. Rapid chilling in short time is vital to maintain high fish quality. If a RSW system is to be installed on board, the space available for

additional machinary must be taken into consideration. Ice from port can be used for CSW, but then a proper sea water tank must be used.

4. Boats bigger than 100GRT can use both systems by installing ice making machines or RSW systems on board. It is not practical to carry tons of ice for bigger boat because large quantity of ice requires a good size tank and a homogenous mixture is difficult of making. Therefore CSW should not be used on larger vessels.
5. Good handling of fish onboard and good hygienic practices are as important as the cooling of fish. The use of proper and suitable plastic tubs can provide better cooling and keep spoilage and contamination at a minimum.

## 8. RECOMMENDATIONS

Since most of the Malaysian fishing vessels are less than 100 GRT and in relation to the findings of this study the following suggestions are made:

**i) Trawlers, purse seiners and hooks and liners < 40 GRT**
Ice should be used as medium for chilling fish on board. The ratio of ice to fish should be 2:1 because of high ambient temperature. Proper icing between layers of fish is important to ensure equal distribution of ice/fish in the boxes. Insulated plastic boxes with lid/cover (similar material and thickness) shall be used for the ice/fish. Emphasis should be on bleeding bigger fish, especially in trawlers. Gutting and washing should also be done as soon as possible on board. Fishing vessels using ice as a cooling medium should not stay at sea longer than five days because the fish start to spoil after day 6.

**ii) Trawlers >70 GRT and purse-seiners 40-70 GRT**
RSW and CSW can be used as a cooling medium on bigger fishing vessels. A certain space for the machines and tanks is required. The fish temperature must go down to 0°C in a few hours. Normally, the ratio of water to fish 1: 4 is recommended but sufficient water must be in the tanks. The cool water circulation should be high enough to establish uniform temperature distribution. The used of fully insulated tanks should keep the heat leakage to a minimum.

**iii) Purse seiners > 70 GRT**
RSW system is the most suitable effective way of cooling fish, especially single species pelagic fish in large quantities. At present, the use of ice for pelagic fish for human consumption is regarded as economically inefficient. The use of the spray method where chilled seawater is sprayed over the fish is another approach to get an even distribution system. The chilled seawater is evenly filtered down through the bulk of the fish, and then re-circulated from the bottom of hold, into the pipes again where it is re-chilled.

## ACKNOWLEDGEMENT

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Special thanks also go to Mr.Bjarki, engineering master student from University of Iceland for his support and exchanged views, trial and information on similar subject. Liquid Ice Iskerfi for their support and valuable advice and for using their liquid ice machine for my trial.

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# APPENDIX

## Appendix 1: Quality Index Method (QIM) Scheme for Herring

Name: Herring raw material for trial

Date 5/12/02

| Quality parameters | | Description | score | No of sample | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 |
| Appear-ance | Skin | Very shiny | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Shiny | 1 | | | | | |
| | | Mat | 2 | | | | | |
| | Blood on gillcover | None | 0 | | | | | |
| | | Very little (10-30%) | 1 | 1 | 1 | 1 | 1 | 1 |
| | | Some (30-50%) | 2 | | | | | |
| | | Much (50-100%) | 3 | | | | | |
| | Odour | Sea fresh odour | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Neutral | 1 | | | | | |
| | | Slightly secondary odour | 2 | | | | | |
| | | Strong secondary odour | 3 | | | | | |
| | Consistency | Hard | 0 | | | | | |
| | | Firm | 1 | 1 | 1 | 1 | 1 | 1 |
| | | Yielding | 2 | | | | | |
| | | Soft | 3 | | | | | |
| | Belly | Firm | 0 | 0 | 0 | 0 | | 0 |
| | | Soft | 1 | | | | 1 | |
| | | Burst | 2 | | | | | |
| Eyes | Brightness | Bright | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mat | 1 | | | | | |
| | Shape | Convex | 0 | 0 | | 0 | | 0 |
| | | Flat | 1 | | 1 | | 1 | |
| | | sunken | 2 | | | | | |
| Gills | Colour* | Characteristic red | 0 | 0 | 0 | | | |
| | | Somewhat pale, non-glossy,opaque | 1 | | | 1 | 1 | 1 |
| | Odour | Fresh, seaweedy, metallic | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Neutral | 1 | | | | | |
| | | Some secondary odour | 2 | | | | | |
| | | Strong secondary odour | 3 | | | | | |
| Quality Index ( 0- 20 ) | | | | 2 | 3 | 3 | 5 | 3 |

* can be omitted in tank Herring

## Appendix 2: Trial data. Herring kept in 2°C room temperature.

| Days | Fish in ice | Fish in liquid ice | Fish in CSW |
|---|---|---|---|
| Day 1<br>6/12<br>Fri | Fish 6.095kg,Ice 2.25kg,time 2.50pm,9.45pm add 2kg of ice | Fish 5.995kg<br>liquid ice 12.074kg | Fish 6.149kg<br>Ice 1.047kg<br>water 0.964<br>time 2.15pm |
| Day2<br>7/12<br>Sat | Re-ice 9.589kg | - | - |
| Day3<br>8/12<br>Sun | - | - | Fish 6.328kg<br>ice 0.987kg<br>water 0.89kg(salt 30gm |
| Day4<br>9/12<br>Mon | Sampling 4 herring 1.2kg<br>Add ice 2kg | Sampling 4 herring 1.50kg<br>Re-ice 10.77kg | Sampling 4 herring 1.34kg |
| Day5<br>10/12<br>Tue | - | - | - |
| Day6<br>11/12<br>Wed | Sampling 4 herring 1.277kg.<br>Re-ice 3 kg | Sampling 4 herring 1.355kg | Sampling 4 herring 1.289kg |
| Day7<br>12/12<br>Thu | | Add ice 5kg | Add ice 2.5kg,water0.375kg<br>salt 11gm |
| Day8<br>13/12<br>Fri | Sampling 4 herring 1.223kg | Sampling 4 herring 1.493kg<br>Add ice 10kg | Sampling 4 herring1.435kg<br>time 10.30am |
| Day9<br>14/12<br>Sat | Add ice 2.5kg | Add ice 5kg | Add ice 2kg<br>water 0.300kg<br>salt 10gm |
| Day10<br>15/12<br>Sun | | | |
| Day11<br>16/12<br>Mon | Sampling 4 herring 1.212kg | Sampling 4 herring 1.35kg<br>Sampling fluid | Sampling 4 herring 1.353kg<br>Sampling fluid |

## Appendix 3: Trial data. Fish kept in 25°C room temperature.

| **Days** | **Fish in Ice** | **Fish in liquid ice** | **Fish in CSW** |
|---|---|---|---|
| Day1<br>6/12<br>Fri | Fish 5.899 kg<br>Ice 6.065 kg<br>RT 26°C, time 2.45 p.m.<br>Add ice 2 kg at 9.45 p.m. | Fish 6.075 kg<br>Ice 12.268 kg<br>time 6.25 p.m. | Fish 6.331 kg<br>Ice 1.585 kg<br>RT 26°C, time 2.30 p.m.<br>Re-ice 1.58 kg, water 0.396 kg, salt 12 g |
| Day2<br>7/12<br>Sat | Re-ice 9.58 kg | Re-ice 30.37 kg (5X) | Re-ice 1.5 kg<br>water 0.319 kg<br>salt 10 g |
| Day3<br>8/12<br>Sun | Re-ice 12 kg | Re-ice 41.44 kg (8X)<br>Fish 6.314 | Re-ice 3.205 kg<br>water 0.642 kg<br>salt 20 g. RT 26 °C |
| Day4<br>9/12<br>Mon | Sampling 4 herring 1.275 kg<br>Re-ice 19.68 kg | Sampling 4 herring 1.39kg<br>Re-ice 57.33 kg | Sampling 4 herring 1.35 kg<br>Re-ice 5.45 kg, water 1.08 kg, salt 35g<br>RT 23°C, time 8.45 a.m. |
| Day5<br>10/12<br>Tue | Re-ice 27.20 kg | Re-ice 60 kg<br>time 4.30 p.m. | Re-ice 11.35kg<br>water2.5 kg, salt 75 g<br>RT 23 °C, time11.00 a.m. |
| Day6<br>11/12<br>Wed | Sampling 4 herring 1.178 kg<br>Re-ice 3 kg | Sampling 4 herring 1.346 kg | Sampling 4 herring 1.364 kg, re-ice 15 kg<br>water 4 kg, salt 120 g<br>RT 21°C, time 10.30 a.m. |
| Day7<br>12/12<br>Thurs | Add ice 6 kg<br>RT 24 °C<br>time 2.00 p.m. | Re-ice 50 kg | Re-ice 15 kg<br>water 4 kg, salt 120 g<br>RT 22 °C,time11.00 a.m. |
| Day8<br>13/12<br>Fri | Sampling 4 herring 1.23 kg<br>Re-ice 10 kg | Sampling 4 herring 1.34 kg<br>Re-ice 20 kg | Sampling 4 herring 1.39 kg, re-ice 10 kg<br>water 1.0kg, salt 50gm<br>time 10.40 a.m. |
| Day9<br>14/12<br>Sat | Re-ice 20 kg | Re-ice 25 kg | Re-ice 15 kg, water 0.75kg, salt 25 g, RT 22 °C time 11.00 a.m. |
| Day10<br>15/12<br>Sun | Re -ice 30 kg | Re-ice 25 kg | Re-ice 20 kg, water 1.1 kg, salt 40 g, RT 24 °C time 5.00 p.m. |
| Day11<br>16/12<br>Mon | Sampling 4 herring 1.21 kg | Sampling 4 herring 1.26 kg<br>Fluid sampling | Sampling 4 herring 1.21 kg<br>Fluid sampling |

**Appendix 4: Ice melting calculation.**

The sizes of boxes used in this trial are shown below:

1) Plastic tub 85 cm * 66 cm * 31 cm = 173.9 $cm^3$ or 1.73 $m^3$
Thickness of insulation 25 mm

2) Plastic container 36.5 cm * 51.5 cm * 26.5 cm = 49.8$cm^3$ or 0.049 $m^3$

3) Polystyrene insulated box 30 cm * 42 cm * 10 cm = 12.6 $cm^3$ or 0.012 $m^3$.
Thickness of insulation 25 mm

Calculation of ice melting rate inside the container due to heat transferred from the surrounding air is as below. (Graham *et al.* 1992)

$$m_i = \frac{A.U.(t_o - t_c)}{L_i}, \text{ kg/day}$$

where $m_i$ = mass of ice melted (kg/ day)
$L_i$ = latent heat of fusion (80 Kcal/kg)
$t_o$ = temperature outside
$t_c$ = temperature inside
A = surface area ($m^2$) in container
U = overall heat transfer coefficient (Kcal/ day $m^2$°C)

$$U = \frac{L_i.M_i}{A(t_o - t_c)}$$

If m, is measured over a period other than one full day then the rate per day can be calculated as follows:

$$m_i = (M_x - M_y)\frac{24}{(x-y)}$$

Where:
$m_i$ = ice melting rate (kg/day)
($m_x$ – $m_y$) = weight lost due to melting between X and Y (kg)
(X – y) = time interval between X and Y (hours)

Therefore ice melting in plastic tubs:
Where:
$L_i$ = latent of fusion of ice (80 Kcal/kg)
$M_i$ = ice melting per day (kg/day)
A = surface area of container ($m^2$)
$t_o$ = temperature outside of the container (°C)
$t_c$ = temperature inside of the container (0 °C)

$$U = \frac{80\left(300kg\ \frac{24}{30}\right)}{1.73x24} = 462Kcal / day\ m^2 °C$$

Whereas in plastic container:

$$U = \frac{80\left(30kg\ \dfrac{24}{4.5}\right)}{0.049\ x\ 24} = 10{,}816 Kcal / day\ m^2 \,°C$$

Appendix 5: Information regarding types, sizes of boat, fishing duration and ice consumption.

| **BOAT INFORMATION** | **TRAWLER** | | |
|---|---|---|---|
| | **B ZONE** | **C ZONE** | **C2 ZONE** |
| ENGINE SIZE(HP) | 300 | 425 | 500 |
| FISH HOLD CAPACITY | 20MT | 40MT | 60MT |
| BOAT SIZE(Lm * Bm * Dm) | 15 X 4.5 X 1.6 | 18 X 6.0 X 2.0 | 20 X 6.9 X 2.5 |
| DAYS OPERATION/MTH | 24 DAYS | 21 DAYS | 20 DAYS |
| ICE REQUIREMENT | RSW | RSW | RSW |
| COST OF ICE | NA* | NA* | NA* |
| BOAT INFORMATION | **PURSE SEINE** | | |
| | **B ZONE** | **C ZONE** | **C2 ZONE** |
| ENGINE SIZE(HP) | 250 | 425 | 500 |
| FISH HOLD CAPACITY | 20MT | 40MT | 60MT |
| BOAT SIZE(Lm * Bm * Dm) | 14 X 4.5 X 1.5 | 17 X 5.5 X 2.2 | 24 X 8.0 X 2.5 |
| DAYS OPERATION/MTH | 20 DAYS | 20 DAYS | 25 DAYS |
| ICE REQUIREMENT | 200BLOCKS | 400BLOCK | 800BLOCKS |
| COST OF ICE/MONTH | USD 500 | USD 1000 | USD 1900 |

* Not applicable

Measurement to be taken from fish kept at 2°C room

| **Duration** | **2 day** | | | | **4 day** | | | | **6 day** | | | | **8 day** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DM | Salt | TV | TPC | DM | Salt | TVN | TPC | DM | Salt | TVN | TPC | DM | Salt | TVN | TPC |
| In Ice | 1 | - | 1 | - | - | - | 1 | 1 | - | - | 1 | - | - | - | - | - |
| Liq.Ice | 1 | 1 | - | - | - | - | 1 | 1 | 1 | 1 | 1 | - | 1 | - | - | - |
| CSW | 1 | 1 | - | - | - | - | 1 | 1 | 1 | 1 | 1 | - | 1 | - | - | - |

DM: dry matters, S: salt, TVN: total volatile nitrogen, TPC: total plate count

Measurement to be taken from fish kept at 25°C room

| Duration | 2 day | | | | 4 day | | | | 6 day | | | | 8 day | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DM | Salt | TVB | TPC | DM | Salt | TVB | TPC | DM | Salt | TVB | TPC | DM | Salt | TVB | TPC |
| In Ice | 1 | - | 1 | - | - | - | 1 | 1 | - | - | 1 | - | - | - | 1 | 1 |
| Liq.Ice | 1 | 1 | - | - | 1 | 1 | 1 | 1 | 1 | 1 | 1 | - | 1 | 1 | 1 | 1 |
| CSW | 1 | 1 | - | - | 1 | 1 | 1 | 1 | 1 | 1 | 1 | - | 1 | 1 | 1 | 1 |

DM: dry matters, S: salt, TVN: total volatile basic nitrogen, TPC: total plate count

## Appendix 6: Result of dry matter measurement fish kept at 2°C.

| No of days | Ice | liquid ice | CSW | Unit |
|---|---|---|---|---|
| Day 0 | 68.3 | 68.3 | 68.3 | % |
| Day 2 | 72.6 | 75.0 | 73.2 | % |
| Day 4 | No sample | 72.5 | 74.1 | % |
| Day 6 | No sample | 71.8 | 72.8 | % |
| Day 8 | No sample | 71.8 | 74.0 | % |

Result of Salt measurement fish kept at 2 °C

| No of days | Ice | Liquid ice | CSW | Unit |
|---|---|---|---|---|
| Day 0 | 0.5 | 0.5 | 0.5 | % |
| Day 2 | **No sample** | 1.1 | 0.6 | % |
| Day 4 | No sample | 1.3 | 0.8 | % |
| Day 6 | No sample | 1.5 | 0.8 | % |
| Day 8 | No sample | 2.2 | 1.0 | % |

Result of TVN measurement fish kept at 2 °C

| No of days | Ice | Liquid ice | CSW | Unit |
|---|---|---|---|---|
| Day 0 | 17.5 | 17.5 | 17.5 | mg N/100 g |
| Day 2 | 24.1 | **No sample** | No sample | mg N/100 g |
| Day 4 | 34.3 | 23.6 | 34.9 | mg N/100 g |
| Day 6 | 44.2 | 36.8 | 41.5 | mg N/100 g |
| Day 8 | 56.4 | 48.1 | 43.5 | mg N/100 g |

Result of TPC measurement fish kept at 2 °C

| No of days | Ice | Liquid ice | CSW | Unit |
|---|---|---|---|---|
| Day 0 | 5.500 | 5.500 | 5.500 | no/g |
| Day 2 | 250.000 | 95.000 | 200.000 | no/g |
| Day 4 | **380.000** | 9.100 | 82.000 | no/g |
| Day 6 | 3000.000 | 240.000 | 90.000 | no/g |
| Day 8 | 130.000 | 1900.000 | 350.000 | no/g |

Result of dry matters measurement fish kept at 25 °C

| No of days | Ice | Liquid ice | CSW | Unit |
|---|---|---|---|---|
| Day 0 | 68.3 | 68.3 | 68.3 | % |
| Day 2 | 70.8 | 73.9 | 73.7 | % |
| Day 4 | **No sample** | 71.5 | 71.7 | % |
| Day 6 | No sample | 72.6 | 74.7 | % |
| Day 8 | No sample | 72.0 | 73.2 | % |

## Appendix 7: Result of Salt measurement fish kept at 25°C.

| No of days | Ice | Liquid ice | CSW | Unit |
|---|---|---|---|---|
| Day 0 | 0.5 | 0.5 | 0.5 | % |
| Day 2 | No sample | 1.7 | 0.3 | % |
| Day 4 | No sample | 2.0 | 0.4 | % |
| Day 6 | No sample | 2.8 | 0.6 | % |
| Day 8 | No sample | 3.1 | 0.4 | % |

Result of TVN measurement fish kept at 25 °C

| No of days | Ice | Liquid ice | CSW | Unit |
|---|---|---|---|---|
| Day 0 | 17.5 | 17.5 | 17.5 | mg N/100 g |
| Day 2 | 25.0 | No sample | No sample | mg N/100 g |
| Day 4 | 36.1 | 42.0 | 50.3 | mg N/100 g |
| Day 6 | 33.5 | 29.1 | 33.9 | mg N/100 g |
| Day 8 | 28.4 | 31.8 | 31.8 | mg N/100 g |

Result of TPC measurement fish kept at 25 °C

| No of days | Ice | Liquid ice | CSW | Unit |
|---|---|---|---|---|
| Day 0 | 5.500 | 5.500 | 5.500 | no/g |
| Day 2 | 590.000 | 340.000 | 45000.000 | no/g |
| Day 4 | 2300.000 | 2300.000 | 91000.000 | no/g |
| Day 6 | 46000.000 | 1300.000 | 160000.000 | no/g |
| Day 8 | 40000.000 | 3100.000 | No sample | no/g |

Fluid and Fish temperature kept at 2 °C Room

| Days | Liquid ice | | CSW | | Ice |
|---|---|---|---|---|---|
| | Fluid | Fish | Fluid | Fish | Fish |
| Day 1 | -1.8 | -1.6 | 4.0 | 1.3 | 0.0 |
| Day 2 | 0.0 | 0.3 | 1.7 | 2.2 | 0.0 |
| Day 3 | 1.2 | 1.5 | 0.7 | 0.7 | 0.1 |
| Day 4 | -0.8 | -1.4 | - 0.4 | -5.5 | 0.0 |
| Day 5 | 0.1 | -0.7 | -0.3 | -0.1 | 0.1 |
| Day 6 | 1.3 | 1.3 | 0.5 | 0.1 | 0.0 |
| Day 7 | 0.0 | -0.7 | 0.0 | 0.2 | 0.0 |
| Day 8 | -1.7 | -1.4 | 0.3 | 0.7 | 0.1 |
| Day 9 | -0.1 | -0.7 | 0.0 | 0.1 | 0.0 |
| Day 10 | 0.4 | 0.3 | 0.0 | 0.0 | 0.0 |

**Appendix 8: Fluid and fish temperature kept at 25 °C room temperature.**

| Days | Liquid ice | | CSW | | Ice | |
|---|---|---|---|---|---|---|
| | Fluid | Fish | Fluid | Fish | Fluid | Fish |
| **Day 1** | 19.4 | 20.1 | 23.3 | 20.2 | N/a | 16.0 |
| Day 2 | 19.5 | 20.5 | 25.0 | 24.5 | 21.3 | 21.1 |
| Day 3 | 14.3 | 14.3 | 19.5 | 20.0 | 12.5 | 12.3 |
| Day 4 | 15.0 | 13.8 | 19.6 | 20.1 | 7.1 | 6.0 |
| Day 5 | 8.9 | 10.2 | 13.6 | 14.4 | 3.3 | 3.3 |
| Day 6 | 14.5 | 13.7 | 11.7 | 10.6 | 6.2 | 4.2 |
| Day 7 | 13.7 | 12.8 | 12.7 | 9.7 | 12.8 | 12.1 |
| Day 8 | 19.5 | 18.6 | 13.8 | 15.7 | 15.8 | 14.8 |
| Day 9 | 19.6 | 19.8 | 19.0 | 18.8 | 13.3 | 14.2 |
| Day 10 | 14.4 | 15.0 | 10.8 | 6.0 | 4.5 | 4.1 |

Melting time record (actual) based on data unloaded from thermometer

| Type of box | Start | End | Total hours |
|---|---|---|---|
| **Tubs with cover*** | 24/12 21.21 | 26/12 03.45 | 30 hrs 06 min |
| | 24/12 21.20 | 25/12 00.14 | 26 hrs 54 min |
| | 24/12 21.21 | 26/12 02.39 | 29 hrs 18 min |
| **Tubs w/o cover** | 26/12 13.00 | 27/12 16.24 | 27 hrs 24 min |
| | 26/12 13.00 | 27/12 16.24 | 27 hrs 24 min |
| **Plastic container with cover*** | 23/12 14.48 | 23/12 21.21 | 6 hrs 33 min |
| | 23/12 14.33 | 23/12 23.03 | 7 hrs 30 min |
| **Plastic container w/o cover** | 23/12 14.29 | 23/12 17.32 | 3 hrs 32 min |
| | 23/12 14.41 | 23/12 18.41 | 4 hrs 0 min |
| **Polystyrene w/cover**** | 24/12 20.25 | 26/12 00.04 | 27 hrs 39 min |
| **Polystyrene w/o cover** | 25/12 18.32 | 26/12 00.29 | 5 hrs 57 min |
| | 26/12 13.11 | 26/12 19.35 | 6 hrs 24 min |

* Cover with transparent plastic sheet
** Cover with lids (similar material and thickness)

Microbiological guidelines for frozen fish and fresh fillet as well
(Issued by Icelandic Fisheries Laboratory)

| Measurement | Good | Fair | Poor |
|---|---|---|---|
| Plate count/g 35 °C | <100,000 | 100,000 – 200,000 | > 200,000 |
| Plate count/g 30 °C | <150,000 | 150,000 – 350,000 | >350,000 |
| Plate count/g 22 °C | <250,000 | 250,000 – 500,000 | >500,000 |
| Total coliforms, MPN/g | <100 | 100 – 200 | > 200 |
| Faecal coliforms, MPN/g | <0.3 | 0.3 – 4 | > 4 |