SEAFISH

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Seafish Technology and Training

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Further Trials of the Pumpable Icing of Fish

Summary:

SUMMARY REQUIRED

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1 Introduction

Pumpable ice is a slurry of fine crystals or particles of ice, suspended in brine or seawater. An excellent cooling medium, when applied to fish the slurry effectively envelopes or blankets the product and extracts heat quickly.

A further advantage is that pumpable ice allows fish to be stored at slightly lower temperatures than those generally found when using solid ice such as flake ice. This benefit is a direct result of the incorporation of salt in the slurry.

Pumpable ice technology is relatively new and as yet there are no defined precise words for the different types of ice available to the seafood industry. This report uses the following definitions:

Pumpable ice is available in two forms:

1. **Binary ice** is a mixture or slurry of tiny crystals of ice made directly from and suspended in a brine. It is made in a dedicated machine using brine or seawater as the raw material.

2. **Particulate ice** is made by crushing or grinding solid ice into very small particles before mixing it into a slurry with brine solution. Raw materials are a supply of solid ice plus brine or seawater.

Solid ice is whole ice and is available in various forms including flake, tube and plate ice.

Binary and particulate ice are generically referred to in this report as pumpable ice, with distinctions made where necessary. Binary ice is the most widely used and nearly all of the work was carried out with this type of pumpable ice.

The rapid cooling effect and low fish storage temperatures afforded by pumpable ice potentially slow enzymic and bacterial spoilage activity. Work undertaken in the 1960s (Refs erences 1 and 2) on the refrigerative 'superchilling' of white fish, showed potential benefits of sub zero storage of white fish. Trials found that fish stored at -2.2^{o}C could benefit from up to 11 days extra chilled storage life, compared with that stored in solid ice at about -0.5^{o}C. The work on superchilling showed chilled storage advantages, but the technique lacked the control of temperature and the rapid chilling capabilities possible with pumpable ice. Temperature control is important, because fish held at temperatures much below -1.0 ^{o}C can experience quality loss effects such as dulling and toughening, due to partial freezing.

Preliminary trials by Seafish (Reference 3) on the effects of binary ice on whitefish, pelagic fish and *Nephrops*, found that it cooled product more rapidly than solid ice, and attained storage temperatures down to -1.7^{o}C.

Partial freezing effects on whitefish such as dulling of the skin were found to be largely reversible on de-icing, and there were slight textural and salt uptake effects on whitefish after extended storage. However filleting trials showed that the fish stored in binary ice could be filleted as well as those stored in flake ice.

Cooked freshness quality was substantially improved in fish stored in binary ice compared with that in flake ice, and an extension of chilled storage life of up to 40% was noted for cod. There were also indications of benefit for haddock, mackerel, herring and *Nephrops*.

The main recommendations of the work were to carry out further investigations into the icing and storage effects of pumpable ice on fish. In order to undertake such trials, a nominal 5 tonne per day crystalline ice plant was installed in the Seafish Laboratory at Hull. A number of observations and trials using binary ice were also made in co-operation with commercial operations at sea and onshore.

These laboratory and field trials are detailed in Table 1 and are the subject of this report. They cover the effects of pumpable ice on fish temperatures, quality and product yields. Solid icing of fish was used as the control treatment.

Table 1. Outline of laboratory and field trials carried out with pumpable icing of fish

Trial Type	Date	Fish Species	Nature of Trials	Parameter Measured
Lab trials	Nov 1998 to Jan 2003	Cod, Plaice Mackerel *Nephrops*	Comparison of pumpable and solid icing of fish for extended storage	Fish freshness, chilled storage life, salt content and microbiological quality
Sea and shore trials	June 1999	Plaice	Fish precooling and storage on trawlers	Fish temperature control and practical use of ice
	Oct. 1999	Cod		
	Oct 2000	Mackerel	Fish cooling on purse seiner	Fish temperature/ freshness
	June 2000	Whitefish	Fish cooling on fish market	Fish temperature/ appearance
	Oct 99-Jan 01	Cod	Defrosted fish processing	Fish temperature, salt content/weight change and yields
	Oct 1999	Cod	Fish processing	Fish temperature/quality/ yields
	July 2003	*Nephrops*	Fish cooling and storage at sea and onshore	Fish temperature, salt/water content change, quality and processing yield

Sections 2 to 6 of this report cover an introduction to the technology of pumpable ice, the methods used in the trials, the results and conclusions. The technical work, observations and trials, are covered in Appendices 1 and 2.

2 Pumpable Ice Technology

2.1 Physical Characteristics

Pumpable ice exists in two forms: Binary ice is a slurry of tiny crystals of ice crystallised from a brine solution, and particulate ice is made from small, crushed particles of freshwater ice mixed in brine. The individual ice particles in particulate ice tend to be larger and coarser than those in binary ice, but are equally pumpable. Both forms are slurries of ice and brine, with the salt concentration or strength of the brine determining the temperature at which the ice melts.

Pumpable ice technology has been developing over the last 25 years, and applications directed at the fishing industry have been available for around ten years.

Binary ice is made by cooling brine until ice crystals form. As they do so, the ice crystals effectively remove water from the brine solution, thus increasing its concentration. This in turn lowers the temperature of the mixture. The higher the ratio of ice to brine (known as the ice fraction) in the slurry, the lower the temperature of the ice.

The relationship between brine concentration used, % ice fraction and ice temperature is illustrated in Fig 1. It shows that at a brine concentration of 3%, which is similar to seawater, the temperature of the ice at 20% ice fraction would be around -2.2°C, whereas at 40% ice fraction it would be around -3°C.

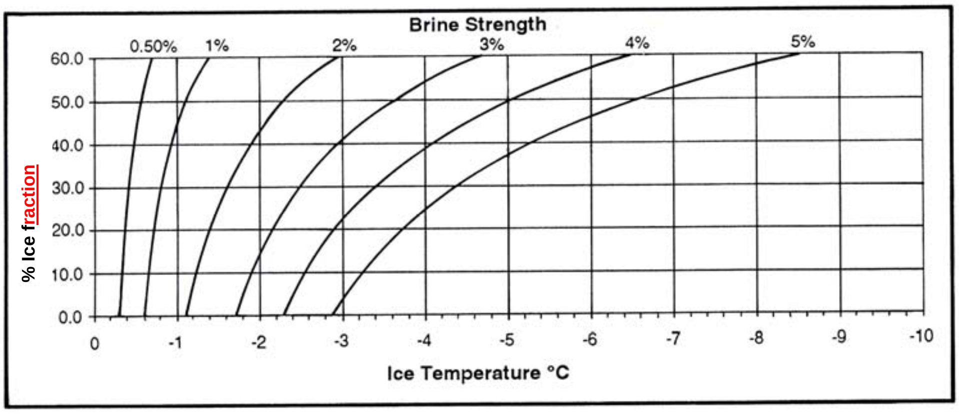

Figure 1 - Temperature of binary ice at different ice fractions and initial brine concentrations.

Particulate ice is less complex than binary ice as it is a mixture of ice and brine, the temperature of which does not change at different ice concentrations. To form binary ice, an initial brine concentration of at least 3% is required, whereas particulate ice can be made in 0% brine concentrations, ie in freshwater.

The temperature range of particulate ice slurry at approx -0.5^{o}C to -4.5^{o}C is wider than that of binary ice, at approx -1.7^{o}C to -4.5^{o}C.

The viscosity of both forms of pumpable ice increases at high ice fractions and those greater than 50% cannot readily be pumped. With both forms ice crystals tend to separate out from the brine and float if left static, due to the positive buoyancy of ice.

2.2 Manufacture

Binary ice is formed by passing brine over the inner surface of a chilled stainless steel cylinder where ice crystals form. These are removed by a multi-bladed scraper mechanism or rotating augur and become suspended within the brine to form a liquid ice.

Figure 2 - Installation of 10 binary ice making cylinders on a large pelagic vessel

Binary ice is produced continuously and stored in a tank until required, but with ice fractions greater than about 30% requiring re-circulation through the ice plant to achieve the required temperature. However, technological improvements to binary ice-generating machinery are ongoing, and new generation machines have improved specification and output.

Particulate ice is made with pre-produced solid ice. This is ground or crushed using equipment located either just before, or inside an ice/brine mixing tank. Grinding/ crushing units can produce particulate ice rapidly, so production of this type of pumpable ice is normally on a batch basis to a specified brine and ice fraction.

2.3 Storage and Delivery

Pumpable ice systems need to integrate the ice making, storage and delivery stages, together with a brine make-up unit if the installation is sited on land. Pumpable ice storage tanks are designed to keep the ice in suspension and are generally cylindrical, with an integral impeller or paddle type agitation mechanism.

Figure 3 - Pumpable ice tank in fish room of a white fish trawler

Due to its slower speed of production, binary ice needs to be made further in advance than particulate ice if large quantities are required. It is then dependent on appropriate tank storage after production. The particulate ice method requires an efficient silo/mechanical conveyor to transfer the ice for grinding from the ice maker into the crusher.

Plastic pipework of relatively small bore can be used to convey pumpable ice through extensive delivery networks if the system of tank, pumps and valves is designed suitably. Computer control units are used increasingly to aid the automatic production of ice to the fraction and temperature required.

2.4 Icing Procedures

Pumpable ice may be added to fish in a number of ways. Fish can be packed in conventional fish boxes and the pumpable ice transferred via a hose into the box. Alternatively, the fish can be put into a non draining container and immersed in the pumpable ice as a form of chilled seawater. A third option is to add drained binary ice crystals, sometimes referred to as snow ice, onto fish in either draining or non-draining boxes. This latter method is similar to conventional icing techniques and potentially loses the rapid chilling advantage of pumpable ice, by not flowing around the fish to cool all the surfaces. However, snow ice can be favourably used to maintain low temperatures on fish that are already cold, i.e. pre-cooled fish.

Whatever the method of application, the icing technique needs to achieve the potential of intimate contact with the fish product, and to control against partial freezing and salt uptake.

2.5 Pumpable ice in UK seafood sectors.

This technology has only been available to the UK seafood industry for around 10 years and in that time, considerable advancements and improvements have been made. Historically, installations were limited to shore-based operations, eg processors, but in the last couple of years fishing boats (pelagic, whitefish and *Nephrops)* have had systems fitted. The majority have been retro-fits, but at least one 19m whitefish/prawn boat has been designed and built with a pumpable ice system installed during the build.

One of these boats has demonstrated that an onboard pumpable ice system does bring quality benefits to its catch and these in turn reap financial rewards. Fish from this boat are particularly sought after by buyers due to their longer shelf life and perceived higher quality.

Processor uses include a *Nephrops* packing plant and a whitefish primary processing and freezing operation. There are also pumpable ice systems in use in pelagic processing factories.

2.6 Other uses, non-seafood.

Pumpable ice has useful applications in other industries beyond the seafood industry. Existing applications and developments with pumpable ice include:

- as a refrigerant
- in the field of medicine
- in air-conditioning systems
- in freezing.

The technology of production, storage and supply is being actively researched and improved globally, with positive benefits accruing to applications within the seafood industry.

2.7 Novel applications in the seafood industry

The many advantages of pumpable ice open up new uses within the seafood industry, for example in sashimi market, where demand and prices are high for the very freshest raw products. It is more than simply a convenient replacement for solid ice, and its unique characteristics offer chill storage benefits right across the seafood industry.

3 Methodology

The work detailed in Appendices 1 and 2 of this report and discussed here, has taken place over a number of years. It compares the benefits of using pumpable ice versus solid ice for fish storage under laboratory conditions, at sea, and in processing units.

The trials follow on from previous Seafish work that demonstrated the rapid chilling effect of pumpable ice and the associated quality benefits in stored fish. This work is detailed in references [3] and [4].

3.1 Laboratory Trials

The laboratory work took place at the Seafish Laboratory in Hull and examined the icing and storage effects on cod, *Nephrops*, plaice and mackerel, of three different types of binary ice in comparison to solid ice. Binary ice was made using different brine strengths and ice fractions, resulting in different temperatures. 3.5% brine with a 30% ice fraction gives a temperature of -2.9°C, 3.5% brine with 20% ice gives -2.5°C, and 2.0 %brine with 20 % ice gives –1.4°C. These facilitated storage at different temperatures and allowed assessment to be made of effects such as partial freezing , microbiological loading, salt uptake and freshness benefits.

Fish for these trials was taken from various commercial fishing boats.

All fish and *Nephrops* were transported to the laboratory in lidded insulated containers to ensure the cool chain was not compromised. At the laboratory they were re-iced into smaller polystyrene lidded boxes for storage, using different strengths of binary ice, with flake ice as a control.

Flake ice was applied to the top and bottom of the boxes and binary ice slurry was dispersed throughout the box, before being allowed to drain, leaving the fish encased in ice crystals. The ratio of fish to drained ice in all cases was 1.5:1.

Raw and cooked fish were assessed for freshness at 2-3 day intervals, with skin on fillets steamed for 20 minutes prior to cooked fish assessment. Microbiological and salt assessments were carried out at the beginning, middle and end of the storage time, which was itself determined by fish reaching the limit of consumer acceptability.

3.2 Commercial Trials

A series of commercial trials complementing the laboratory trials was conducted to assess fish cooling, storage, quality and processing effects, and the practicalities of using pumpable ice in different commercial conditions. Six different trials took place and locations included a flatfish trawler, pelagic purse seiner, roundfish trawler, *Nephrops* day boat, fish market, and chilled and frozen processing units.

Measurements taken varied with the type of trial and included temperature, freshness quality, salt content and microbiological count, and also of product yield in the case of the processing units.

On each occasion, the method of delivery and the icing technique used, were monitored to assess fish cooling and storage. In most cases, solid ice was used as a control.

- Trials on the flatfish trawler examined use of different ice fractions for pre-cooling and chilled storage, and secured fish for later examination under processing conditions.

- Work onboard the pelagic purse seiner enabled comparison to be made of quality parameters between fish held in pumpable ice and the vessel's own RSW tanks.

- On an extended trip onboard a whitefish trawler, fish temperatures and quality parameters were monitored from precooling stage, through storage, to a processing unit.

- Grimsby fish market provided an environment for trials to take place with pumpable ice storage of fish in an ambient environment.

- Assessment of the effects of pumpable ice on defrosted fish prior to and during processing, took the chilled storage trials a step further down the chain.

- Work onboard a *Nephrops* day boat introduced pumpable ice to this sector for the first time and enabled useful observations to be made of the advantages to the processor of efficiently chilling *Nephrops* from the point of capture. Two separate trials examined the short-term effect on salt/ water content of *Nephrops* held in different ice treatments, and the effects on freshness, salt/water content, microbiological loading and processing yield from icing at sea.

4 Results

4.1 Laboratory Trials

4.1.1 Temperature

Temperature readings taken from cod and *Nephrops* put into 3.5% brine strength binary ice soon after capture, reached 0^{o}C within 45 minutes and 12 minutes respectively. After 2 hours, *Nephrops* stored in flake ice had cooled to a mere 4.5^{o}C and cod to around 3^{o}C.

In general, binary ice was found to keep fish at between -1.9^{o}C and -1.0^{o}C for between 8 and 14 days, whereas flake iced fish kept at around -0.4^{o}C. The saltier 3.5 % brine ices kept the fish the coldest. A rise in temperature was found towards the end of storage time with binary ice, but this is consistent with the ice crystals gradually melting, and washing away the remaining salt within the snow ice.

4.1.2 Salt Content

Comparing storage in binary ice with flake ice, slight increases in the salt content of whole and fillet cod and mackerel were found. In whole and filleted plaice the increases in salt levels were particularly significant with salty flavours detected during cooked assessment at the end of storage. It is thought that this was due to the plaice having higher surface area to volume ratio.

With both whole and tail *Nephrops* stored in binary ice, a marked increase was found in salt content compared with flake ice. However, a slight salt content decrease was found during subsequent storage in both ice types and this was attributed to either a leaching effect as the ice melted, or a water uptake affecting the salt concentration.

4.1.3 Microbiological Effect

Initial TVCs of skin-on fish flesh were between 10^2 and 10^5 with cod at the bottom of the range and plaice at the top. During storage *Pseudomonad* bacteria tended to predominate, although it was found that binary ice retarded their growth on whole fish by a factor of 10 by the end of storage. In fish fillets the result was more variable and less clear.

The greatest difference in *Pseudomonad* growth was seen with whole and fillet cod and mackerel where the difference between binary and flake icing was 0.5 to 2 log/g of skin-on flesh. The colder, 3.5% brine, ices had the most effect. There was no appreciable difference in *Pseudomonad* growth between ice type in plaice or *Nephrops*.

4.1.4 Freshness Effects

Binary iced whitefish tended to show effects of partial freezing such as stiffening and dulling of the skin during extended storage. However, these effects generally reversed after slight warming although there were signs of irreversible loss of seafresh slime and sheen with cod and plaice.

In **whole cod**, raw and cooked freshness was retained for a longer period during storage in binary ice than in flake ice and suggested an additional two days shelf-life to give a total of 14 days. The same benefits were not found in **cod fillets**, where the useful storage life was found to be 12 days with both types of icing. One result worthy of note is that whole fish was found to last longer than fillets, irrespective of treatment.

Binary iced **whole Nephrops** retained their raw and cooked freshness scores for around 2 days longer than those stored in flake ice, but no discernible difference was found with *Nephrops* tails in either ice type. One notable difference was that binary iced *Nephrops* peeled more easily than those held in flake ice.

No appreciable difference with ice type was found for **plaice**, although a loss of seafresh sheen on the skin was noted in binary iced fish during the raw freshness assessment. The only fish in which salty flavours developed in binary ice was plaice, whole and filleted, this may have resulted in a lower cooked freshness score. The useful chilled storage life was found to be 12 days irrespective of icing type.

Whole freshness scores for **Mackerel** were more variable than with other species but there was no difference between ice type with respect to cooked freshness. This was attributed to fish being held at high initial temperatures (it was summertime) and so reaching rigor at an earlier stage, with a consequent loss of freshness. Overall, whole and fillet mackerel had a useful chilled storage life of 8 days.

4.2 Commercial Trials

Overall the commercial trials showed positive storage advantages across the sectors through use of pumpable ice. These positive effects were noted in terms of improved chilling, lower microbiological loading, enhanced freshness and chilled storage life.

4.2.1 Flatfish trawler

Where fish was pre-cooled in binary ice for 3 hours before storing in fish boxes, they had cooled from 14^o to 3^{o}C, average. However, the range was –1.6^{o}C to + 9.2^{o}C which indicates that the icing technique used did not adequately disperse ice throughout the mass of fish.

Experiments with fish icing technique showed binary top icing did not chill all fish in the box. Binary ice dispersed throughout the box was the most effective means of chilling the fish in boxes, to about –1.0^{o}C.

Binary ice at 30% ice fraction flowed amongst fish easily. The continental type fish box, with small drainage holes, allowed brine to drain without losing the ice. However it was not possible to effectively ice fish in the trial using a stack-only type of fish box because the ice drained out from the large slots in the bottom. This type of box is currently still in widespread use in Scottish box pools.

Partial freezing effects were not found in the commercial catch. This may have been due to relatively inefficient use of binary ice, which only applied ice to the fish in the top of the box.

4.2.2 Pelagic purse seiner

Observations onboard a pelagic purse seiner, where mackerel was initially held in a 100m^3 tank in a fish : ice/seawater mix of 50:50 or in a 660L bin with a fish: pumpable ice ratio of 50:50, showed that on average fish cooled rapidly from 12^{o}C to 0^{o}C in half an hour. As would be expected, smaller fish cooled more rapidly than larger fish and in both cases there was no sign of partial freezing, nor of appreciable salt uptake in prolonged storage in the bin.

Fish kept for in the bin for 7 days was commercially considered to be as good a quality as would normally be expected from RSW storage for just 2-3 days. Pumpable ice, therefore, appeared to be particularly effective as a storage medium for pelagic fish.

4.2.3 Whitefish trawler

Onboard the large whitefish trawler, fish temperatures before pre-cooling with pumpable ice in the cooling/bleeding tank were found to be in the range 4.9^{o}C to 5.3^{o}C, but some 20 minutes later had cooled rapidly to an average temperature of 1.6^{o}C.

Similar advantages were found during storage, where the temperature of binary iced fish, at about –1.0 ^{o}C, was appreciably lower than that held in solid ice (at about –0.5^{o}C). Some signs of stiffening due to partial freezing were found with fish at about –1.1 ^{o}C. However, these effects disappeared on thawing.

Comparison of freshness quality found an increase in chilled storage life of 1-1.5 days with binary iced storage of fish in bins for 10 days. There was no difference between the fillet yields of fish with type of ice.

4.2.4 Market icing of fish

A trial pumpable ice system of the particulate, ground, type ice was used. Under ambient conditions, boxes of top iced fish with pumpable ice took less than an hour to cool from 7.5^{o}C to 3^{o}C, compared with 9 hours for fish, top iced with solid ice. The latter were found to be above 4^{o}C for the first four hours of holding. Whichever type of ice is used, it is clear from the trials that under summer conditions, there is a short time limit in which it is effective, before complete ice melting takes place.

Temperature readings showed variability across ice types in cooling rates at the top, middle, bottom, and sides of boxes. The particulate pumpable ice gave the best and most rapid cooling performance. This was due to the percolation of cold brine and ice crystals through the mass of fish. There appeared to be no particular disadvantage with the coarseness of particulate ice.

Plaice was perceived by one assessor to have lost its sheen layer of seafresh slime after contact with pumpable ice and there was some concern that this effect could influence perceptions of freshness and hence quality.

4.2.5 Icing of defrosted cod prior to processing

Defrosted fish held in pumpable ice prior to processing, was found to gain weight quickly during the first eight hours of the trials through water uptake, whereas no such effect was found with fish held in solid ice and some fish exhibited a loss of weight after 15 hours storage.

There was a pattern of salt increase in fish with pumpable ice during the first 24 hours. Fish held in the highest brine content slurry exhibited a three-fold increase, noticed during the cooked taste assessment.

Fish held at sub zero temperatures in binary ice for 15 hours were considered to be awkward to fillet due to slight partial freezing. However this did not affect the yields from pumpable iced fish as they were similar to those held in solid ice. This indicates that any weight change effect with binary iced storage of fish should feed through to final yield.

4.2.6 Nephrops trials

When comparing the effects of drained binary ice with solid ice on the salt and water content of small, whole and tail *Nephrops*, relatively little difference was found between whole and tailed samples. There was little salt uptake with solid ice or the drained, least salty binary ice treatment, but a trebling of salt in *Nephrops* held in undrained binary iced treatments. Here, a salty flavour was noted after just 2 days in storage.

In general there was a slight increase in water content across the ice treatments and was most noticeable in the first three days of storage.

By the end of storage, *Nephrops* held in the least salty undrained ice treatments were found to have enhanced freshness scores equivalent to a chilled life extension of about 2 days, compared with those in solid ice.

The iced storage trial of whole small *Nephrops* held for 2 days prior to processing, found that chilling effects were better with pumpable ice than with solid ice. No partial freezing effects were noted, and there was no salt increase with flake or drained pumpable ice, although a small increase was found with undrained pumpable ice.

Pumpable ice was found to reduce growth of spoilage bacteria by approximately 1 log in the icing at sea trial. Comparing the use of flake with pumpable ice at sea a 2 days loss of freshness to the packed whole *Nephrops* was found with flake ice compared to pumpable ice.

Contrary to previous trials on binary icing of *Nephrops*, no improvement of yield was found with whole chilled product.

5 Discussion

These trials have followed on from previous Seafish work that demonstrated the rapid chilling effect of pumpable ice and the associated quality benefits in stored fish. The work has taken place over a number of years evaluating the benefits of using pumpable ice versus solid ice for chilling and storing a number of species of fish (and *Nephrops*) under laboratory conditions, at sea, and in processing ashore.

Pumpable ice, with its particularly rapid cooling properties and slightly sub-zero storage (super-chilling) potential is increasingly gaining favour and use within the seafood industry. The main effects on freshly caught fish at sea are twofold: a) in physiological terms it can postpone the onset of rigor mortis, b) bacteriologically its benefit is slowing down the rate of growth of *Pseudomonad*s, the predominant cold-water fish spoilage bacteria.

During rigor-mortis (stiffening after death), intracellular changes occur in animal and fish flesh that allow the enzymic decomposition process to start. If after capture and the death of fish, the onset of rigor can be delayed then the shelflife of the fish will be increased.

Benefits from pumpable ice ashore can include postponing rigor if the fish is very fresh and pre-rigor, but are predominantly related to slowing down *Pseudomonad* growth and maintaining an intact chill-chain. This can also include re-icing as necessary, for instance on fish markets etc.

Brine used in pumpable ice is the causative agent responsible for the sub-zero temperature of the medium and determines the actual temperatures during manufacture and application of the slurry. The particularly rapid cooling is largely due to the fluid nature of the ice giving it all-round contact with the fish.

Fish type and shape are factors that influence storage behaviour. Mackerel are less prone to partial freezing than whitefish, possibly due to higher oil content. Salt uptake was found to be dependent on shape and thickness of product, this is possibly related to the surface area to volume ratio, plaice and nephrops absorbed more salt than other fish tested.

Successful chilling and storage of seafood with pumpable ice is determined by identification and use of an icing regime that minimises exposure to salt and temperatures that could cause partial freezing of the fish.

Extending the storage life of fish (eg whole cod by two days) suggests a need for re-visiting the Torry and QIM freshness schemes that were written based on the use of solid ice for preserving fish. There are also visual effects noted associated with pumpable ice (eg loss of seafresh slime on plaice) that are not accounted for in either Torry or QIM.

It has become apparent during these trials that to derive maximum benefit from pumpable ice consideration must be given to the whole system that produces, stores, pumps and applies this product. Otherwise failures or deficiencies in one part of the system can limit the capability of the entire system, eg inadequate storage capacity imposes limits on the volume of slurry available when needed.

To reap the full potential of this technology, system-wide vision is needed from both technology suppliers and end-users, and requires careful consideration of all relevant factors.

During the design stages, consideration should be given to the development of application techniques for pumpable ice, especially in situations where pre-cooling is required, such as in fish hoppers. South African prawn trawlers use hoppers for pre-cooling built so that the pumpable ice can disperse through the catch in the hopper from underneath (R. Long, pers comm). Present UK practice is to apply pumpable ice from above in the fish hopper, making it perhaps more difficult for the ice to penetrate down into the mass of the catch.

6 Conclusions

Freshness Quality

- There is a general pattern of less freshness loss with pumpable ice compared to solid ice, however there was less of an effect on fish fillets. This is to be expected given that the *Pseudomonad* bacteria are predominantly found on the skin of living fish and it takes time for them to get into and grow within the flesh on a whole fish. However they are transferred in large numbers onto fillets during filleting and this accelerates their growth and reduces freshness.

- There is a freshness benefit found with whole cod and *Nephrops* in both the laboratory and field trials and these results are in agreement with previous trials.

- No freshness benefits were found from pumpable icing of mackerel in laboratory trials although freshness benefits were found with pumpable ice on pelagic vessels. The taste panel found that quality was lost before applying the ice in the laboratory trials and this points to a need for prompt cooling (ie precooling). This would delay rigor by reducing temperature soon after capture, maintaining quality for longer.

- No freshness benefits were found with plaice, possibly the negative visual effects and a salty flavour influenced the result. There is no immediately obvious reason why pumpable ice should not have benefits as per other whitefish.

- Sensory assessment of fish quality such as the TRS and QIM schemes may need modification to take account of possible appearance and chilled storage effects with the use of pumpable ice and pre-cooling.

Cooling

- This is potentially very rapid compared to solid ice. As product temperatures approach 0°C the improved performance of pumpable ice over solid is particularly noticeable.

- However, (observing the performance of precooling installations and different icing practices) there is a need to ensure enough ice is used and thoroughly mixed with the fish.

- If the pumpable ice is thoroughly mixed with the fish, then brine can be allowed to drain without delay to minimise long-term exposure to salt and potentially to partial freezing.

- The importance should be emphasised of the need for rapid processing on board the vessel and in good icing practices.

- Using pumpable ice in direct substitution for ordinary ice may not demonstrate the full potential for quality improvement as current practices at sea create delays before icing. Hence rigor is not likely to be postponed by use of binary ice, until those practices change.

- Pumpable ice enables fish cooling to be a separate and distinct process from the iced storage, in the fishroom and therefore to be carried out at an earlier stage, eg. In the fish reception hopper.

Chilled storage

- Given sufficient ice and adequate mixing with fish, then chilled storage temperatures are lower than with solid ice, but are dependent on the final brine concentration in the slurry. However, the brine part of the pumpable ice is normally allowed to drain to leave behind ‘snow’, and this loss of brine means the temperature of the remaining snow ice increases.

- The immersion time of whitefish and *Nephrops* in pumpable ice slurry should normally be kept to a minimum to decrease the potential for salt uptake, partial freezing and negative appearance effects. However, these trials have shown that pelagic fish, usually kept in RSW, did not suffer ill-effects from extended storage in pumpable ice slurry.

- These trials and other work have shown that whitefish at storage temperatures much below –1.0 °C start to partially freeze but at storage temperatures no lower than approx. –1.5°C the effects (appearance, 'stiffness' for filleting etc) are reversible upon warming. Cod at temperatures around -1.7°C show slight but permanent textural effects (noticeable as a slight chewiness), together with reduced rates of freshness loss (especially by flavour). The lower the temperature during storage, the longer the fish will last.

- Regardless of ice type, whole cod were found to last half a day longer than fillets, presumably due to fillets being bacterially contaminated during filleting.

Salt Uptake

- In general the tendency is for less salt uptake with less salty ice treatments. There is less effect with larger fish (but depends also on shape and type of fish ie oily pelagic fish, round or flatfish and nephrops), also slightly more salt uptake with fillets. When common-sense storage was practiced in an effort to minimise salt uptake, during later taste tests salty flavours were rarely detected. The single exception was for whole and filleted plaice. This does not necessarily preclude plaice from the use of pumpable ice, however greater control of icing practice would be needed.

- Icing technique influences salt uptake, for example if you use low strength brine and let the brine drain away, and avoid prolonged storage in undrained binary ice then the fish is least likely to suffer increases in salt.

Microbiological Effects

- It was found that TVCs (total viable count of bacteria) were independent of ice type

- Psuedomonad counts (fish spoilage bacteria) were not independent of ice type. Pumpable ice did slow down the rate of growth of *Pseudomonad* bacteria. This was especially noticeable with whole fish but less so with fillets.

- Colder ices in general appear to slow *Pseudomonad* growth more; the colder the ice, the slower the rate of growth.

- These results confirm the findings from taste panels, that the colder the ice used then the longer the fish lasts, and the better it tastes However, in storing whitefish, beware of possible negative freezing effects below about -1.5°C.

Processing effects

- The weight of defrosted whitefish increased during short term storage in undrained pumpable ice slurry.

- Recent trials with a UK boat (to be reported elsewhere) showed a slower rate of drip loss from haddock in snow compared to flake ice. This was a saving of up to 2% of the net weight.

- Normally, fillets will yield approximately 45 to 50% of the weight from a whole gutted cod (weight of fillet divided by starting weight of fish). The yields are approximately the same from fish stored in either solid or pumpable ice. Therefore if fish stored in pumpable ice lose less weight through drip loss than fish in solid ice, this 'extra' or 'saved' weight will increase the final yield.

- No benefit to pack-out yield was found with binary iced *Nephrops* two days after capture. However, previous work on improved flake icing of *Nephrops* at sea on inshore vessels (ie short trip vessels) did show a packout improvement. This is possibly due to there being lower standards of acceptability now for whole *Nephrops* because longer trip caught *Nephrops* are now a major source of raw material.

Application techniques

- There are some whitefish boats that have pumpable ice systems with tanks to cool fish, however those observed were not very efficient due to ineffective mixing of ice with fish.

- Efficient icing of fish within fish boxes or tubs also depends on effective mixing of ice with fish.

- Where Pumpable ice is used to supplement and enhance the speed of chilling on pelagic boats it requires effective mixing in the RSW tanks.

Ongoing development of Pumpable Ice systems

- This technology has advanced significantly from the failures initially experienced in the UK fleet.

- However further development is needed to meet the needs of other sectors of the seafood industry.

- To reap the full potential of this technology, system-wide vision is needed from both technology suppliers and end-users, and requires careful consideration of all relevant factors.

Pumpable ice in industry, suggested applications

- Small vessels: Consider taking ice to sea in insulated containers
- Intermediate and Large vessels: Consider installations to enable pre-cooling and improving iced storage.
- Fish markets: Consider installations to re-ice fish and improve chilling and temperature control.
- Fish processors: Consider installations for better chilling, for pre-cooling prior to freezing, and for cooling of cooked products. The aim is to extend the benefits further along the distribution chain.
- Pumpable ice should be seen as much more than merely a useful substitute for solid ice.
- Suitability for production and preservation of ultra-fresh products such as raw sashimi
- If chilled *Nephrops* temperature is controlled carefully from the point of capture the result can be a product of equal or better quality than 'live' trawl-caught, especially after distribution to its markets. Although the 'live' *Nephrops* appear better quality, their flesh can be of poorer eating quality because of stresses they undergo during capture, storage and transport to market (recent Seafish research: Jacklin, M; in press)

Comment [A1]: Need reference details - where published etc.

- It is hoped that industry can take advantage of the cutting edge of pumpable ice technology and develop a new generation of chill chain operation, preferably married with commercial traceability of the chilled seafood products.

7 Recommendations

- The seafood industry is advised of the advantages of using pumpable ice and is encouraged to adopt the technology wherever suitable. Suitable applications at sea include pelagic, whitefish and prawn trawlers. Onshore processing plants, fish markets and chilled product distribution are also taking advantage of pumpable ice.
- Production, storage and delivery systems should be designed as a whole with consideration to the place and use, eg boat/processor, batch/continuous, quantities needed, 8 or 24 hour demand etc. System providers are increasingly adopting this wider vision.
- When pumpable ice is used for containerised chilling and storage, it should be evenly distributed throughout a container, box or tank and efficiently mixed with the product. Sufficient ice must be used.
- In general, to avoid salt uptake, allow brine to drain swiftly leaving the product encased in snow ice. This not only removes brine, it also raises temperature and

avoids partial freezing, although it is not required for oily pelagic fish.

- In order to advance use of pumpable ice still further, it is recommended that there is further research on the following:

  – The design and operation of pre-cooling systems on vessels

  – Further applications for pumpable ice, for example in factories, through chilled distribution to retailers, enabling the benefits to be felt throughout the supply chain.

  – A re-evaluation of the Torry and QIM schemes to take account of the extended shelf life (and perhaps visual effects) resulting from the correct application of pumpable ice.

8 References

1. Commercial Trial of Superchilling on MT Boston Phantom. Seafish Technical Memorandum TM31, 1965

2. Waterman JJ, Taylor D H. Superchilling. Torry Advisory Note No. 32

3. Prout P. Further Trials to Investigate the Effect on White Fish Quality of Storage in Pallet Bins and Initial Investigationsof the Use of Binary Ice. Seafish Report No SR515, 1998.

4. Prout P, Boulter M. Initial Trials of the Binary Icing of Fish - Progress up to November 1997. Seafish Report No. SR518

Appendix 1

Lab Trials

Appendix 1 - Lab Trials

1 Introduction

Previous Seafish work (Reference 4) demonstrated the rapid chilling characteristics of binary ice and the associated quality benefits in stored fish. There were some signs of partial freezing of white fish using ice at temperatures below $-1^{o}C$, and salt uptake after prolonged storage.

This Appendix reports on further icing trials conducted by Seafish on commercially caught fish, which investigate the effects on fish quality, of using binary ice for cooling and storage.

Separate trials were undertaken on cod, *Nephrops*, plaice and mackerel, with flake ice used as the control. All fish were iced within 2 hours of capture and icing took place in two stages for each trial.

Stage 1: initial icing after capture for transport to the Seafish Laboratory, Hull.

Stage 2: experimental icing of fish for extended storage at Laboratory.

At the start of stage 2, batches of fish were split, with some being filleted (tailed in the case of *Nephrops*) to enable a comparison to be made with icing effects on whole fish. Binary iced fish were subjected to 3 different binary ice treatments, which facilitated different storage temperatures, and allowed assessment of the relative effects on fish quality, including possible partial freezing and salt uptake.

Freshness quality was assessed by sensory methods at the Seafish Laboratory, and microbiology and salt content by external laboratories. The results of the trials are described by comparing temperatures and quality across all the species, with an overall discussion at the end.

2 Method

2.1 Equipment

Binary ice was supplied either from a binary ice plant capable of producing a nominal 5 T per day in the Seafish Laboratory at Hull, or from a plant onboard the Dutch trawler taking part in some of the trials.

Insulated, Borgarplast 350L lidded containers were used to transport binary ice to trials locations. These were used in conjunction with 70L insulated and lidded boxes to transport fish to the Seafish Laboratory. Fish and *Nephrops* were then re-iced into smaller polystyrene lidded boxes for extended chilled storage.

Handheld thermocouple digital thermometers were used to measure fish and ice temperatures before storage. Temperature changes during fish cooling were monitored with thermocouples connected to a data logger, and placed in the thickest part of fish in the centre of the mass of fish in the box.

Figure 4 - Fish temperature being taken
Haddock in snow ice, **t = -1^{0}c**

2.2 Fish Preparation

In each trial, fish were taken from the same haul to allow direct comparison of results. The fish handling and preparation undertaken at the start of each stage is summarised in Table2.

Table 2. Summary of handling and preparation of fish samples

Species	Method (capture	Stage 2. ry icing and storage)	
		Filleted	Tailed
Cod	Trawl	Yes	--
Plaice	Trawl	Yes	--
Mackerel	Handline	Yes	--
Nephrops	Trawl	No	Yes

Figure 5 - Box of iced fish in laboratory trails

2.3 Icing and (

Icing and storage pro

Ice typ	for transport to laboratory	Re-icing for extended storage at laboratory		
Flake (control icing)	Flake	Flake		
Binary (experimental icing)	Binary ice (3.5% strength brine)	Brine strength %	Ice fraction (ice:brine ratio) %	Ice Temperature ^{o}C
		2.0	20	-1.5
		3.5	20	- 2.2
		3.5	30	-2.7

Control fish were flake iced top and bottom, according to conventional practice. Binary ice was dispersed through the mass of fish, then the brine allowed to drain, leaving the fish encased in ice crystals or snow ice.

The temperature of binary ice slurry depends on the strength of brine used to produce it, and the ice concentration. This relationship is explained in section 2 of the main report. Brine of 3.5 % strength was used, as this has a similar concentration to seawater and relevance to the catching sector.

Control and binary iced fish were iced at a ratio of about 1.5:1 fish to drained ice, and the fish storage room kept at 0°C.

2.4 Microbiology and Salt Uptake

Fish were analysed at the beginning, middle and end of stage 2 for total bacterial numbers (Total Viable Count or TVC) and *Pseudomonad*s, which are a common type of spoilage bacteria. Analysis for salt content using the Volhards method was carried out at the same intervals.

At each sampling, flesh was taken from 3 whole fish and from 3 fillets, from each icing treatment. 100g of the middle part of the fillet including skin, was aseptically taken for microbiological assessment, and 100g of rinsed and drained head and tail ends of the fillet were homogenised for salt analysis. In the case of *Nephrops*, 100g of shelled tail flesh was used.

Bacterial analysis was undertaken at the Public Health Laboratory in Hull, while a private laboratory in Rotherham carried out salt analyses.

Samples for microbiological assessment were stored chilled in plastic bags prior to laboratory analysis on the day of sampling. Samples for salt content were frozen in bags and kept frozen until analysed.

2.5 Assessing Freshness Quality

Freshness quality of fish was assessed during stage 2 by a panel of four Seafish Fish Technologists, using Torry Research Station (TRS) sensory scoring schemes for raw and cooked fish freshness. Copies of these schemescan be found in Appendix III.

Fish were assessed at 2 - 3 day intervals during storage until they reached the limit of consumer acceptability, beyond which off flavours start to develop.

Three fish from each icing treatment were assessed on each occasion. Pieces of skin-on fillet were rinsed in fresh water, then steamed for 20 minutes prior to cooked fish assessment.

3 Results

3.1 Temperature

The cooling temperature of whole cod and *Nephrops* during the first few hours of iced storage in Stage 1 of the trials, are shown in Figures 1 and 2. These fish being the largest and smallest used in the trials, showed the slowest and fastest cooling rates respectively.

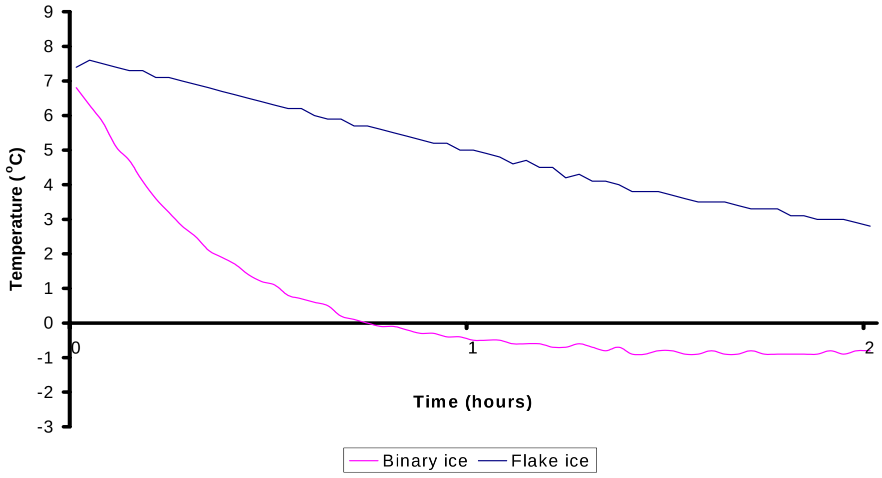

Figure 6. Temperature of cod during cooling in binary and flake ice at Stage 1

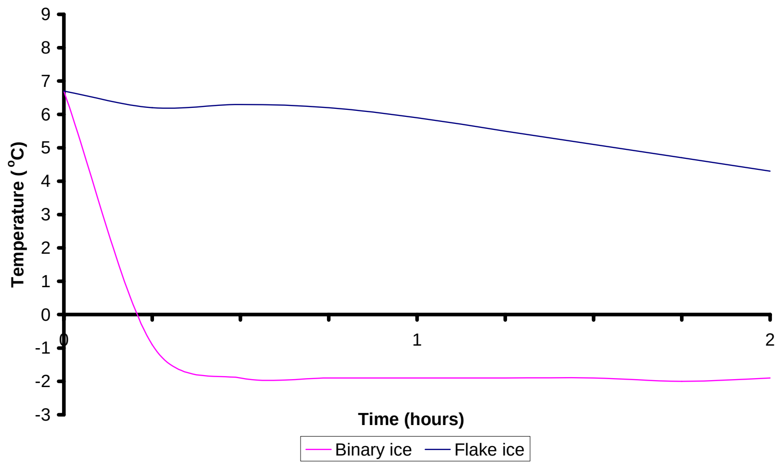

Figure 7. Temperature of Nephrops during cooling in binary and flake ice at Stage 1

Binary ice cooled the fish rapidly, with cod and *Nephrops* reaching 0°C within 45 and 12 minutes respectively. The slower cooling rate of flake ice indicate that cod would have taken at least 5 hours to reach 0°C and *Nephrops* even longer.

Figure 8 below shows the pattern of temperatures during whole fish storage. The lines are polynomial best fit and indicate typical temperatures of fish over time, for each icing treatment.

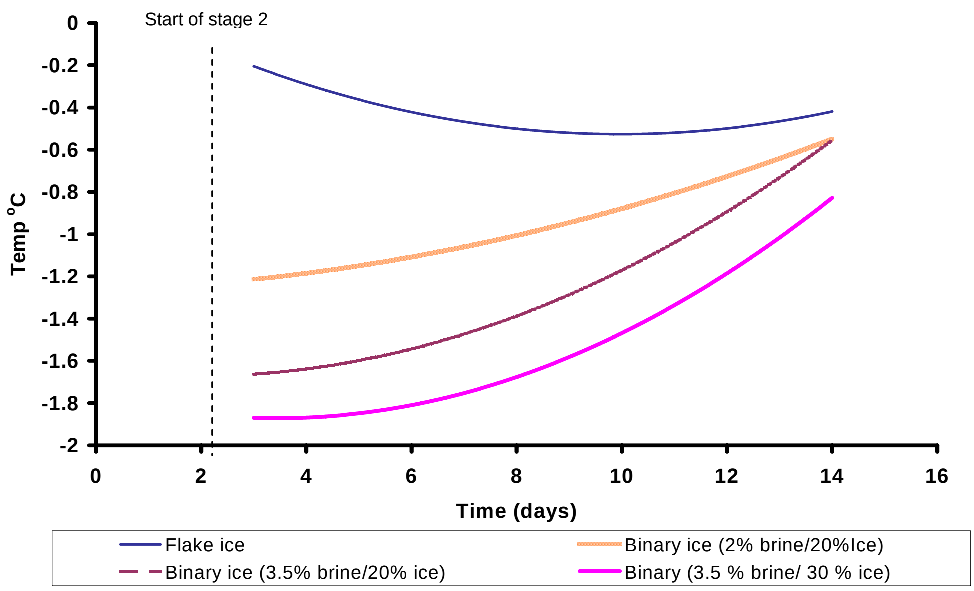

Figure 8. Temperatures of whole fish during storage in binary and flake ice at Stage 2

Flake ice stored fish at around –0.4°C, whilst all 3 binary ice treatments maintained lower temperatures. The coldest binary ice (3.5% brine, 30% ice) initially kept the fish at about –1.9°C but slowly warmed to -1.0°C after 12 days, towards the end of storage. The least cold binary ice (2% brine, 20% ice) warmed from -1.2°C to -0.5°C. This is consistent with ice crystals gradually melting and washing away remaining salt within the snow ice. The ice crystals themselves contain very little salt.

3.2 Salt Content

Figures 9 to 12 show the salt content in the flesh of skin-on whole and fillet fish (shelled tail meat for *Nephrops*), by species during storage. The results for the binary ice treatments are combined as they were broadly similar, but notable differences are mentioned. Cod and plaice, being whitefish, are considered together

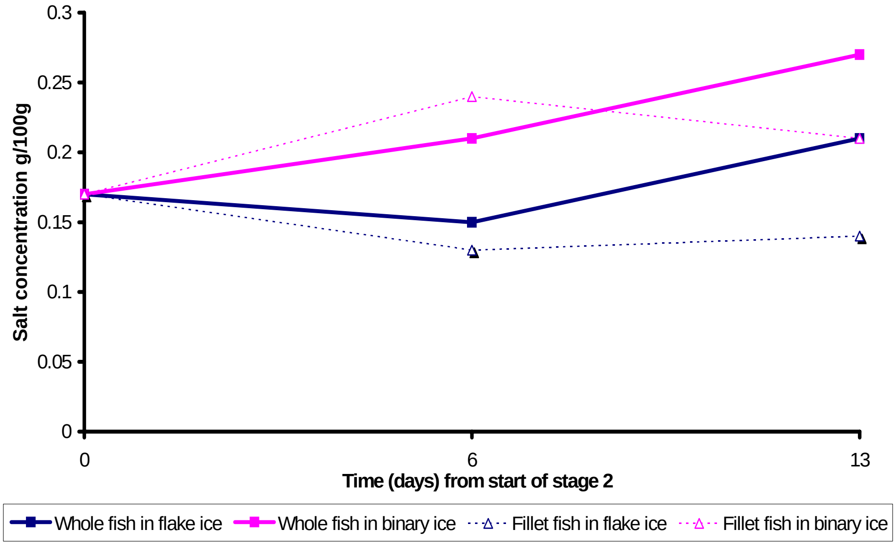

Figure 9. Salt content of whole and fillet cod during storage in binary and flake ice at Stage 2

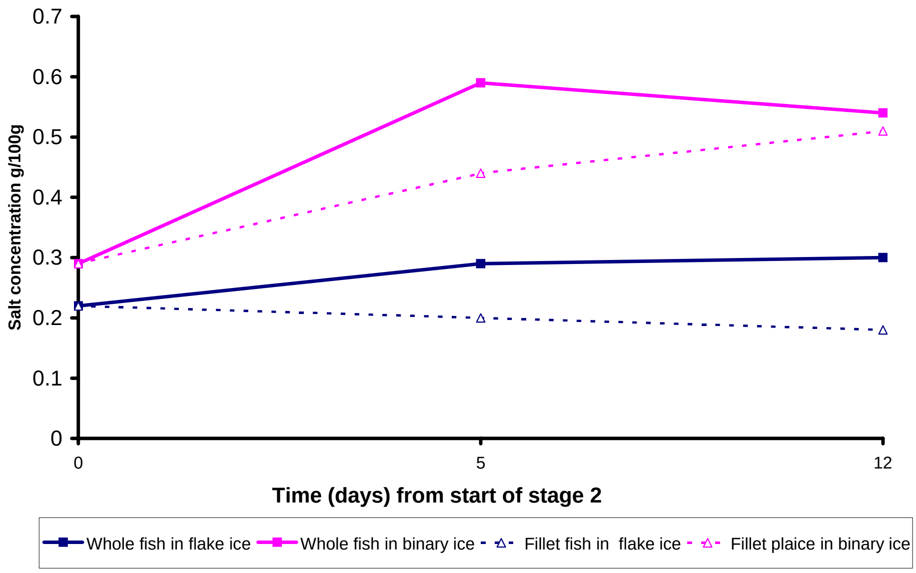

Figure 10. Salt content of whole and fillet plaice during storage in binary and flake ice at Stage 2

There was little effect on the salt content of whole and fillet cod and plaice in flake ice.

Whole and fillet cod in binary ice showed some increase in salt content, whereas the increase with whole and fillet plaice in binary ice was large. This increase appeared to start with initial icing after capture. The salt content of plaice approximately doubled to about 0.5 g/100g by the end of storage, compared with the flake iced equivalents. Binary iced whole and filleted plaice both had developed distinct salty flavours towards the end of storage.

The substantial increase in salt content with the plaice was likely due to their thinness compared with cod, especially as the plaice were small, with a higher surface area to volume ratio

Binary iced mackerel appeared to take up some salt after initial icing. However there was little further increase in the salt content of binary iced whole and fillet fish compared with their flake iced equivalents.

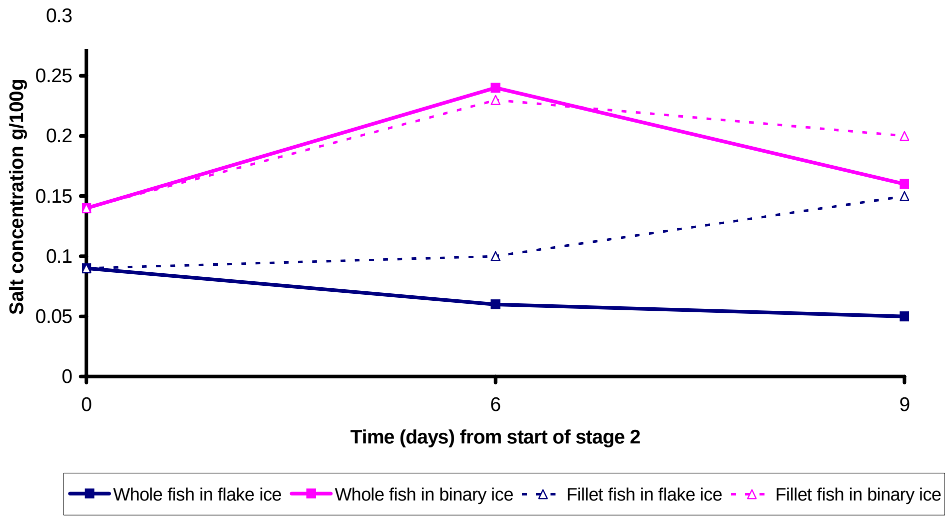

Figure 11. Salt content of whole and fillet mackerel during storage in binary and flake ice at Stage 2

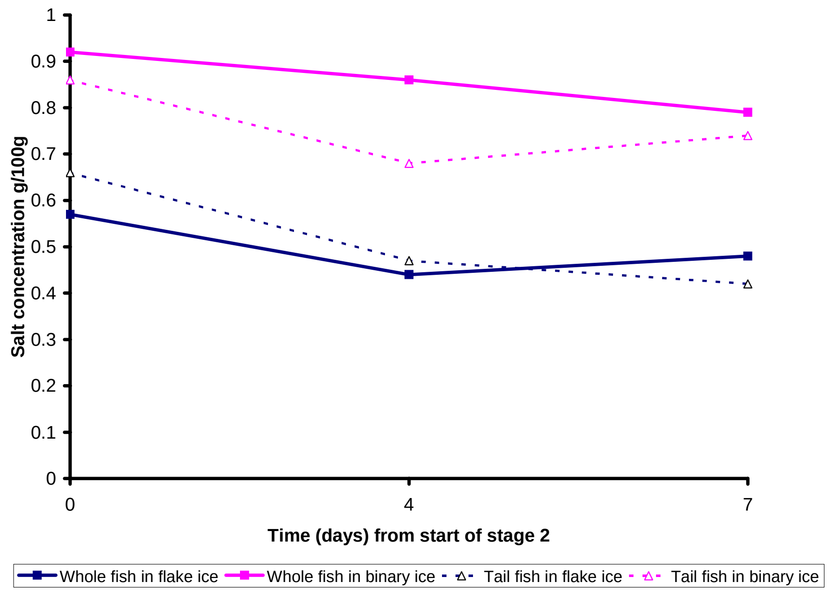

Figure 12. Salt content of whole tail Nephrops during storage in binary and flake ice at stage 2

Nephrops samples were not taken at stage 2 until day 3 of storage. At that point there had been an increase of approximately 50% to about 0.9g/100g for both the whole and tail *Nephrops* held in binary ice, compared with those in flake ice at 0.6 g/100g.

Comment [A2]: This graph (fig 12) needs amending!!

There were indications of slight salt content decrease during subsequent storage for whole and tail *Nephrops* in both types of ice. This could have been due to a leaching effect during ice melting, as both binary and flake ice particles are essentially freshwater and contain very little salt. There could also have been a water uptake ef

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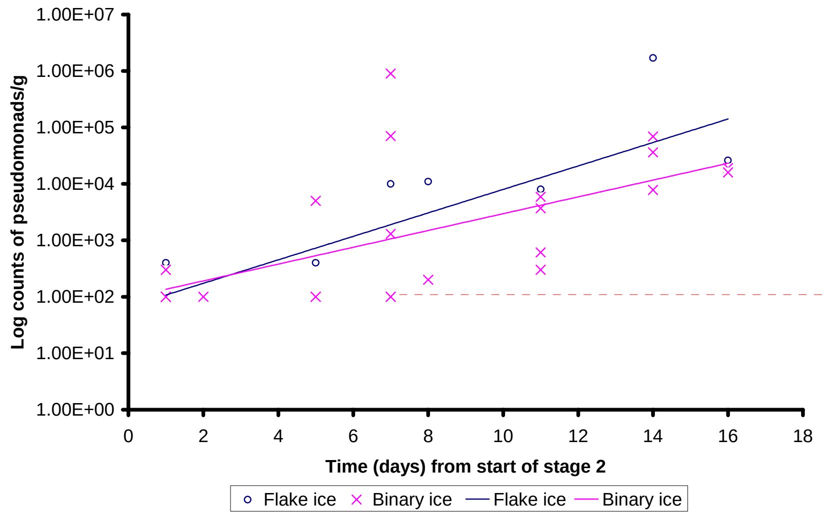


Comment [A3]: Figs 13 & 14 - graphs need amending

Figure 14. Psuedomad counts for fillet fish (including Nephrops tails) during storage in binary and flake ice at Stage 2

Binary icing retarded the growth of *Pseudomonad*s on whole fish by a factor of about 10 compared to flake ice by the end of storage. There was more variability in *Pseudomonad* counts in stored fillets, and a less clear result.

There was relatively little difference in *Pseudomonad* counts between ice types for whole and fillet plaice and whole or tail *Nephrops*. The greatest difference in *Pseudomonad* growth was seen in whole and fillet cod and mackerel, where typically the counts were between 0.5 and 2 log/g lower than with solid icing by the end of storage. The colder, saltier 3.5 % brine slurry tended to slow growth the most.

3.4 Quality

3.4.1 Condition of fish on removal from ice

At storage temperatures below about –1.0 ^{o}C the binary iced cod and plaice showed effects of partial freezing such as stiffening and dulling. It was noted that the colder the fish, the more obvious were the effects. These usually reversed after slight warming in ambient conditions, but there were signs of irreversible loss of ‘seafresh’ slime and sheen, with binary iced cod and plaice.

It is possible that the rapid temperature shock caused by binary icing of live *Nephrops* can cause them to lose their claws. A small sub-sample was tested and indicated that this was 4 times more likely to happen than with flake icing. Binary iced *Nephrops* did, however, tend to peel more easily than those held in flake ice.

3.4.2 Raw and cooked freshness

Although raw and cooked freshness were assessed, greater emphasis is given to the results for cooked freshness as they represent eating quality. The results are shown as linear regression curves, and indications of freshness benefits with binary ice are derived from these lines. Scores for the different binary ice treatments have been combined. Where relevant, notable differences are mentioned.

Whole Cod

The raw and cooked freshness results for whole cod during stage 2 are shown in figures 15 and 16.

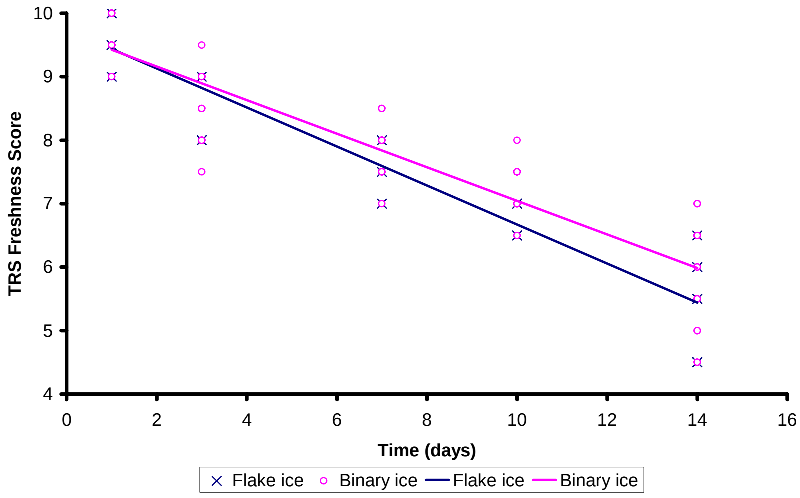


Figure 15. Raw freshness scores of whole cod stored in binary and flake ice

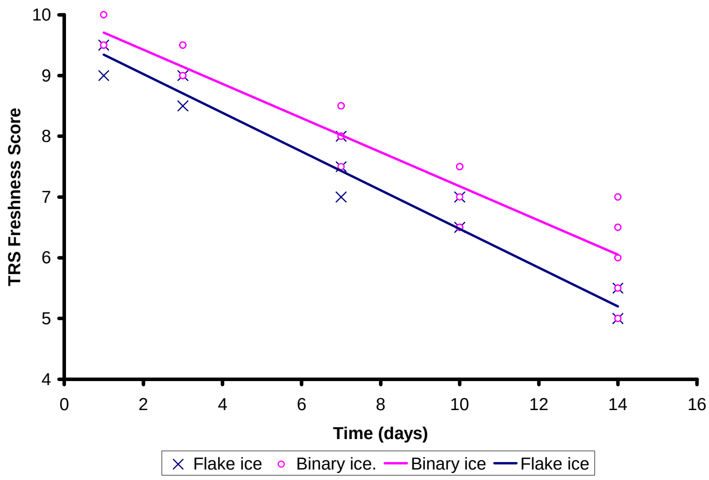


Figure 16. Cooked freshness scores of whole cod stored in binary and flake ice

Initially there was little raw freshness difference with ice type although there was a slight loss in 'seafresh' sheen with binary icing. There was a slower rate of loss of both raw and cooked freshness over chilled storage with binary icing. The sweet flavours desirable to the consumer, eg TRS cooked freshness score 7.5 and above, were retained for an additional 2 days with binary icing. Overall, the binary iced cod had a chilled storage life of 14 days, at which point it was at the limit of consumer acceptability at TRS 6. Whole cod stored in flake ice had a chilled storage life of just 12 days.

Cod fillets

There were no differences with ice type in the freshness of cod fillets, and their useful chilled storage life was about 12 days - similar to that for the flake iced whole fish. No salty flavours were found in the whole or fillet cod.

Nephrops

The raw and cooked freshness results for whole *Nephrops* are shown in figures 17 and 18.

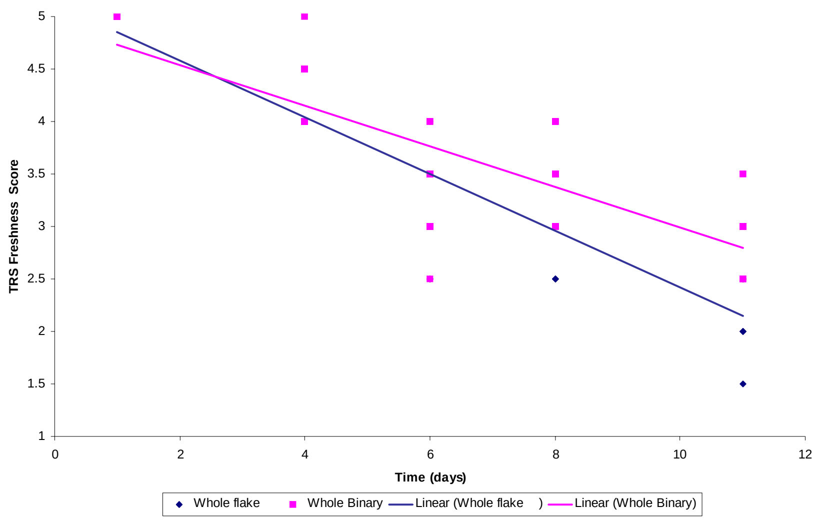


Figure 17. Raw freshness scores of whole Nephrops stored in binary and flake ice

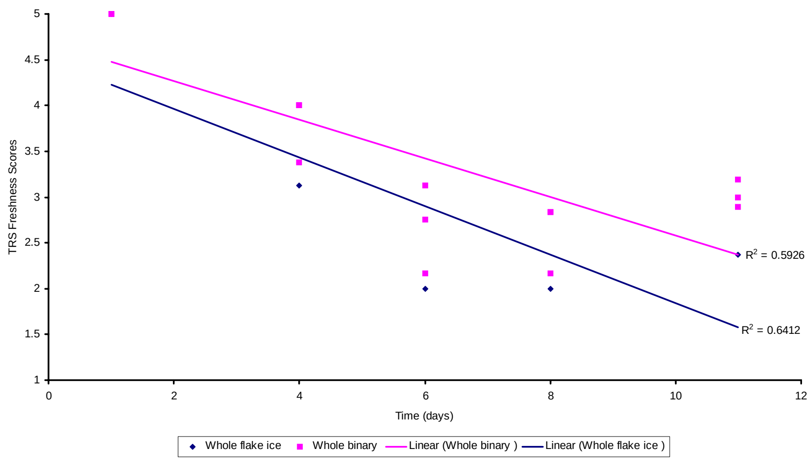


Figure 18. Cooked freshness scores of whole Nephrops stored in binary and flake Ice

Assuming a limit of consumer acceptability of TRS 2.5, binary iced *Nephrops* had a useful chilled storage life extension of about 2 days in comparison with those in flake ice. However the cooked freshness scores were more variable than the raw scores, and cooked whole *Nephrops* displayed a shorter chilled storage life than the raw equivalent.

It is possible that this was due to some animals being infected with Haematodinium or flesh necrosis disease, which has only recently been recognised commercially and have an adverse effect on eating quality. The disease is difficult to recognise visually and therefore did not affect raw TRS scores.

There was only a slight improvement in chilled storage life of *Nephrops* tails with binary icing, of about 11 days compared to 10 for those stored in flake ice.

No salty flavours were found in the whole or tail *Nephrops*.

Plaice

No appreciable differences in freshness, with ice type, were found for whole plaice. The freshness results for raw plaice indicated shorter useful storage lives, at about 13 days compared to 16 days for cooked freshness. Some loss of initial 'seafresh' sheen with binary icing was apparent in raw freshness assessment. However, this effect appeared to be limited to visual appearance of the skin of the fish.

Salty flavours developing towards the end of chilled storage may have had an effect on the cooked freshness scores of both binary iced whole and fillet plaice. Indeed fillet plaice in binary ice had a shorter chilled storage life of about 14 days compared with flake ice at about 16 days.

Mackerel

These fish were sourced from a Cornish handline boat. Icing did not happen until the fish were landed, allowing rigor to occur sooner than if the fish were iced shortly after catching.

There was a considerable loss of freshness, both in flake and binary ice, before the beginning of stage 2, probably due to the early onset of rigor. Raw whole mackerel in binary ice showed a 2 day longer chilled storage life than those in flake ice of 9 days compared with 7 days. However there was no sign of benefit with cooked freshness. This might have been related to the premature onset of rigor and hence spoilage.

Cooked assessment of whole and fillet mackerel showed a useful chilled storage life of 8 days and no saltiness in flavour was found.

3.4.3 Statistical analysis of the results of cod TRS scores

The significant results following GLM analysis of the TRS scores for Cod are summarised below.

Considering the TRS assessments carried out by the Seafish taste panel, these were found to be a series of well-designed experiments, producing some significant results.

In a comparison of the different assessors on the taste panel, one assessor was found (at p=0.014) to return different scores from the others. However leaving this assessor's results out of the analysis did not alter the conclusions outlined below. This assessor was involved in all the taste panels and thus the assessor's influence was evenly spread, so left in for subsequent analysis.

Combining the results for all fish (whole and filleted), the TRS scores produced a significant difference between the flake and pumpable ice treatments at better than p=0.001, with binary ice preserving freshness better than flake ice

There were also significant differences between binary and flake ice, and between particulate ice and flake ice. However there was not a significant difference between binary and particulate ice.

It is interesting and significant that whole fish lasted half a day longer than filleted fish, irrespective of ice treatment.

Considering the relative influence on freshness of type of ice used vs presentation of the stored fish as either whole or fillets, presentation was found to have a bigger influence than ice type. Storage of whole fish rather than fillets is thus a more significant factor than type of ice in preserving freshness.

Table 4. Linear regression equations of TRS scores of cooked cod in binary and flake ice

A	Whole Fish - Flake Ice	$Y = 0.29X + 9.40$
	Whole fish - Binary Ice (combined results of 3 types)	$Y = 0.29X + 10.00$
B	Fillets - Binary Ice (combined results of 3 types) plus Flake Ice	$Y = 0.3 + 9.55$
	Whole Fish - Binary Ice (combined results of 3 types) plus Flake Ice	$Y = 0.3 + 10.05$

4 Discussion and Conclusions

Binary ice was seen to cool fish much faster than flake ice, and also enabled fish to reach lower temperatures. Fish stored in flake ice were held at approximately -0.5^{o}C while samples held in binary ice were at temperatures between -0.8 and -1.7^{o}C, and mostly below -1.0^{o}C. The temperature depended on the original ice temperature and the time in storage.

White fish held at temperatures below -1.0^{o}C showed signs of partial freezing such as dulling, but these effects mostly diminished with slight warming, as seen in previous trials.

For fish stored whole, the raw and cooked TRS scores during storage were variable, but for binary iced fish, the scores were slightly better than flake iced equivalents, indicating an extension to chilled storage and thus shelf-life. Statistical analysis of the data showed a significant improvement in fish quality using binary compared to flake ice, although storing whole fish rather than fillets had a more significant effect in preserving fish quality. The main point to be drawn from the results is that binary icing had a positive affect on the freshness quality and clear advantage was found with cod and *Nephrops*.

Cooked freshness results indicate a 2-day extension in chilled storage life of cod to around 14 days, compared with 12 days for flake icing.

There was little difference in the chilled storage lives for the binary and flake iced whole and fillet plaice or mackerel.

Previous Seafish work, mainly on whole cod and *Nephrops*, showed greater chilled storage life improvement with binary icing. However the associated flake iced fish storage temperatures were around 0.3^{o}C warmer than in the trials reported here, and it is thought that this may have reduced to the difference. The inference is that if storage is above 0°C then use of binary ice can make significant improvements to maintaining quality by storage at slightly sub-zero temperatures.

There were appreciable and similar increases in salt content with binary iced storage of all whole and fillet fish compared with those held in flake ice. This was particularly noticeable with binary iced plaice, mackerel and *Nephrops*. The thickness of the fish was probably a factor in the different salt content changes between species, ie the plaice were much thinner than the cod and became saltier.

Whilst only the plaice held in binary ice showed discernible salty flavours towards the end of storage, in previous work cod had exhibited an increased salty flavour over time, but in those trials, fish were re-iced more frequently which may account for this effect.

Although total numbers of bacteria (TVCs) on the fish were initially between 10^2 and 10^5/g, the *Pseudomonad* spoilage bacteria tended to predominate during storage.

Binary icing compared to flake icing retarded the growth of *Pseudomonad*s on whole fish by a factor of about 10 by the end of storage. However there was less of an effect with fillets. This slowing of growth of spoilage bacteria is likely to be factor in the potential for binary ice to reduce the rate of loss of fish freshness in chilled storage.

The mackerel freshness results indicated the considerable loss to fish quality caused by a delay in controlling the temperature of the fish. Not taking ice to sea is quite normal for day boats, which land ‘fresh’ one-day old fish. These trials show that potential shelf-life of their fish can be reduced by a number of days through early onset of rigor and associated production of autolytic enzymes.

Appendix II

Observations and Trials in Commercial Conditions

Appendix II. Observations and Trials in Commercial Conditions

1 Introduction

The previous laboratory trials undertaken by Seafish on pumpable icing of fish as detailed in Seafish Report SR 518 and Appendix 1of this report, demonstrated fish chilling and quality advantages compared with use of solid ice such as flake, plate or tube ice.

Having established potential benefits under laboratory conditions, a series of trials was planned and carried out between 1998 and 2003 to assess use of pumpable ice in commercial operations. Where appropriate, these trials assessed fish cooling, storage, quality and processing effects and the practicalities of using pumpable ice were considered at every stage.

Trials were carried out at sea and onshore using plaice, cod, mackerel and *Nephrops*. At sea the work was mainly observational and assessed the efficiency of pumpable ice in cooling fish, whilst onshore trials concentrated on comparisons between pumpable and solid ice.

The sea and shore trials are reported separately in this Appendix, with an overall consideration of the results at the end.

For each commercial trial, pumpable ice was obtainable on-site. To enable direct comparisons to be made between use of pumpable ice and solid ice, standard commercial practices and equipment were used throughout.

The trials are outlined in Table 5 and reported in the same order.

Table 5- Sea and shore observations and trials programme

Trial	Type of site	Location	Nature of work
1	33 M flatfish trawler	North Holland	Pre-cooling of fish and icing in boxes at sea
2	44 M pelagic purse seiner	West Norway	Fish cooling and fish quality assessment
3	60 M roundfish trawler then chilled fish processing factory	N West Iceland	Pre-cooling and pumpable ice storage of fish at sea, followed by quality assessment during processing
4	Fish Market	Grimsby	Fish re-icing before sale
5	Frozen fish processing factory	Hull	Chilled storage of defrosted fish and assessment during subsequent processing
6	15 M *Nephrops* trawler	Clyde	Cooling, salt, quality and processing yields

Factors assessed across the range of trials, where possible, were fish temperatures, quality, salt content, microbiological count and product yield.

A handheld digital thermometer was used to measure individual fish and ice temperatures. Temperature records during fish cooling were obtained by inserting thermocouples into the thickest part of the fish and recorded with a data logger. The temperatures in a container or box were monitored at the centre of the mass of fish.

2 Trial 1. Pumpable Icing on a Flatfish Trawler

2.1 Introduction

The purpose of this trial was threefold:

- to monitor the use of pumpable ice for fish cooling
- to experiment with fish box icing technique
- to obtain pumpable and flake iced samples of plaice for subsequent chilled storage and quality assessment trials at the laboratory.

The lab trials are reported in Appendix 1.

The opportunity was taken to work with the newly built 33m trawler TUNIS VAN LUUT (UK 224). RIVO, the Dutch Fisheries Research Institution, contributed to the design of the vessel and was pleased to help with arrangements for the trial. This vessel boasts a fully-integrated fish handling system, incorporating pre-cooling with pumpable ice. The system supports good handling of fish including elevator/conveyor arrangements and semi-continuous fish washing.

A 5 day seatrip was undertaken from the North Netherlands to fish the southern North Sea grounds. Trawl tows were about 4 hours in duration, with catches varying between 5 and 25 boxes. Plaice was targeted and was the main species caught.

2.2 Methodology

2.2.1 Vessel and Equipment

The vessel was fitted with a nominal 5 tonnes per day binary ice plant and 2 ice storage tanks. The larger 2,000L tank was installed in the fishroom and held 20% fraction binary ice for pre-chilling fish, and the smaller 600L tank held 30% fraction ice for use in boxing the fish. A pipework and manual valve system supplied binary ice from the separate tanks to the pre-cooling and boxing points.

Pre-cooling of the fish took place in vertical tanks, whose tops were on the working deck and bottoms in the forward part of the fish hold, fitted with gates. The gates enabled the release of fish for boxing and stacked storage in the after part of the hold. Icing of fish in boxes was via a hose leading from the small binary ice holding tank.

The vessel used 60L stacknest boxes of the type widely used on the Continent. Some 200kg of flake ice was taken to sea to compare storage effects with binary ice.

Figure 19 Binary ice flowing onto top of fish in a pre-cooling tank on the vessel

2.2.2 Fish cooling

At three points after capture, fish temperatures were taken: directly from the sea; after pre-cooling in the tanks; and after periods of up to 4 hours storage in the hold. Monitoring of fish temperatures after longer periods was not feasible due to the way in which the catch was stowed in the hold.

2.2.3 Fish box icing technique

Two trials were carried out on fish box icing technique: the first compared binary icing with top and bottom solid icing; and the second compared drainage characteristics of binary iced fish in Continental and Scottish style fish boxes.

Fish required for subsequent laboratory trials was boxed with binary or solid ice in the ratio 1:1, then stored in insulated containers for delivery to the laboratory . The results were given in Appendix 1.

Figure 20 - Dispersing binary ice throughout a box of fish in the fish room of the vessel

2.3 Results

2.3.1 Fish cooling

Seawater and initial fish temperatures ranged between 14.2^{o}C and 15.2^{o}C. During application, binary ice temperatures were between –2.8^{o}C and –3.2^{o}C depending on the ice concentration. The -3.2^{o}C ice had a higher ice concentration and was used for boxing the fish.

Fish temperatures in Table 2 reflect the commercial practices used. Pre-cooling for less than one hour occurred when the fish were boxed directly after the haul, whereas pre-cooling for 2.5 - 3 hours was possible if the fish were left in the pre-cooling tanks until the next haul. Boxed fish temperatures were taken after approx. 3 hours of storage in the hold.

Table 6. Fish temperatures achieved after 1 or 3 hours in the pre-cooling tank

Time Period	Fish Temperatures (^{o}C) Average (range)
1 hour	4.5 (-1.0 to 10.0)
3 hours	3.6 (-1.6 to 9.2)

It was noted that smaller and thinner fish and possibly those nearer the top of the pre-cooling tanks cooled the most. The brine gradually leaked away through the bottom doors of the tanks and this may have slowed down the rate of cooling after 3 hours.

Temperatures of fish stored in boxes in the hold 3 hours after leaving the pre-cooling tank averaged 2^{o}C, however there were a range of temperatures (-1.6 to 9.2^{o}C). This indicates that the practice of applying binary ice only to the top of boxes does not adequately disperse ice through the mass of fish and therefore does not efficiently cool the fish. The highest temperatures were found at the bottom of the fish box.

2.3.2 Fish box icing technique

The results of a trial which compared cooling rates between binary and solid ice applied to 35kg fish in boxes, are shown in Table 7.

Table 7. Comparative icing of 35kg of fish in boxes

Box icing technique	Fish temperatures (°C)	
	0 hours (before icing in box)	3 hours storage in box
	Average (range)	Average (range)
Flake ice to top and bottom of fish	4.1 (3.6 to 5.3)	2.8 (2.5 to 3.3)
Binary icing to top of fish only	4.3 (3.4- to 5.8)	3.1 (0.1 to 4.1)
Binary icing throughout fish *	3.2 (0.1 to 4.1)	-1.0 (-1.7 to 1.1)

***** the binary ice hose was inserted in to the mass of fish to disperse ice throughout the box.

Top and bottom flake icing slowly cooled the fish, whereas binary top icing did not chill all the fish in the box. However, binary ice dispersed throughout the box effectively chilled all the fish to an average of -1°C.

A further one-off trial was conducted to compare the performance of binary icing of fish in the Continental stacknest type of box, with the typical 70L stack only box used in Scotland, which has drainage slots in the base.

Both boxes were filled with 35 kg red gurnard and were binary iced into the mass of fish. Binary ice at about 30% ice fraction flowed amongst the fish easily. The stacknest box filled quickly and surrounded the fish with ice, whereas the ice kept draining through the bottom holes of the stack only box and would not fill.

Although the initial temperature of the pumpable ice was between –2.8°C and –3.2°C, the fish in the commercial catch did not show signs of partial freezing such as stiffness and dulling of external appearance on landing to shore. This may be attributable to the temperature of the fish room in which they were held, or the relatively inefficient top icing being used.

2.4 Discussion

Although binary ice enables rapid cooling of fish and good chilled storage temperatures, its use on this vessel at that time was not as effective as it could have been. Pre-cooling did reduce the temperature of some fish to as low as –1.0^{o}C within an hour, but other fish remained as high as 8.3^{o}C after pre-cooling and 3 hours iced storage in boxes. This problem was partly due to equipment design and partly due to icing technique.

A contributory factor was leaky pre-cooling tank gates, which allowed the brine to drain, causing ineffective mixing of fish and ice. Also, as seen from the comparative icing trials on the vessel, to apply pumpable ice only to the top of the box is not sufficient to ensure adequate icing and chilling. The trials showed that the type of box used and the box icing technique both need be suitable.

There did not appear to be any partial freezing effects to the catch and this may have been due to the relatively inefficient chilling involved. The vessel's reputation for catch quality at market was reported to be good.

The binary ice manufacture and storage system itself appeared to work satisfactorily. Further, the integrated design and constructional quality of the fish handling and storage system were impressive. However the trials showed that ice application techniques need to be effective, ensuring thorough ice dispersion around all the fish.

3 Trial 2. Pumpable icing on a Pelagic Purse Seiner

3.1 Introduction

The purpose of this trial was twofold;

- to monitor use of pumpable ice for cooling pelagic fish
- to assess the effects of pumpable ice on fish quality

Seafish was invited by the Norwegian Herring Oil and Meal Research Institute to attend trials of mackerel chilling on a pelagic purse seiner. The Fisheries Research organisation 'More Research' of Aalesund was also involved.

The trial took place on the vessel TORBAS, which had a pumpable ice plant fitted in conjunction with its refrigerated seawater (RSW) system. Fish cooling performance was monitored during the on-board trials, and fish was followed to a processing factory for commercial feedback on quality, and for chemical analyses of fish held in pumpable ice for an extended period of time.

The vessel sailed from Aalesund to fish near to the Norwegian/EU sector line west of Bergen. Due to poor fishing and weather, the 170 tonne catch of mackerel was not made until three nights into the trip and the vessel landed to a pelagic fish factory near Maloy approx 24 hours after capture.

3.2 Methodology

3.2.1 Vessel and Equipment

The TORBAS (ex 'Ocean Way' of Peterhead) is a purser/trawler with a total RSW tank volume of 700m^3 and a 40 tonne per day binary ice plant. This was used to produce pumpable ice of around 20% ice fraction, distributed to the RSW tanks to await loading. There was no means of quantifying the amount of ice in the tanks.

3.2.2 Fish cooling

One RSW tank was specially fitted with thermocouples to measure ice slurry temperatures in the top, middle and bottom. A number of mackerel had individual thermocouple temperature recorders inserted into them. These fish were placed in the middle and top of the tank and their temperatures measured during cooling. As the vessel was operating and fishing commercially, it was not possible to compare the fish cooling properties of pumpable ice/ RSW with RSW only.

Ice was produced during the 3 days prior to the fish haul, although problems with the plant reduced the anticipated quantity. Some 45 tonnes of mackerel were added to the trials tank with a fish:ice/seawater mix of 50:50. The quantity of fish was assessed using the vessel's normal tank dipping procedures.

To provide a comparison to the fish stored in ice slurry in RSW tanks, some 300Kg of mackerel was held in un-drained binary ice in a 660L insulated bin with a fish: pumpable ice ratio of 50:50. This was stored for 7 days, including 6 days in a chill-room ashore. Normally the catch is frozen on the day of landing.

3.2.3 Fish Quality

Fish from the binary ice/RSW storage were sensory assessed at the processing factory by Japanese fish quality inspectors, whose assessment procedure carefully graded appearance, belly condition and meat texture, including softness and bruise marking.

Fish held in binary ice in insulated tubs was analysed by measurement of nitrogenous spoilage indicating compounds, using the Conway Diffusion Analysis method in the flesh. These fish were also sensory assessed at the end of storage by the factory manager and analysed for salt content.

3.3 Results

3.3.1 Fish cooling

The initial temperatures of the mackerel and RSW/pumpable ice were about 12^{o}C and –1.5^{o}C respectively, as can be seen in Figure 21 below.

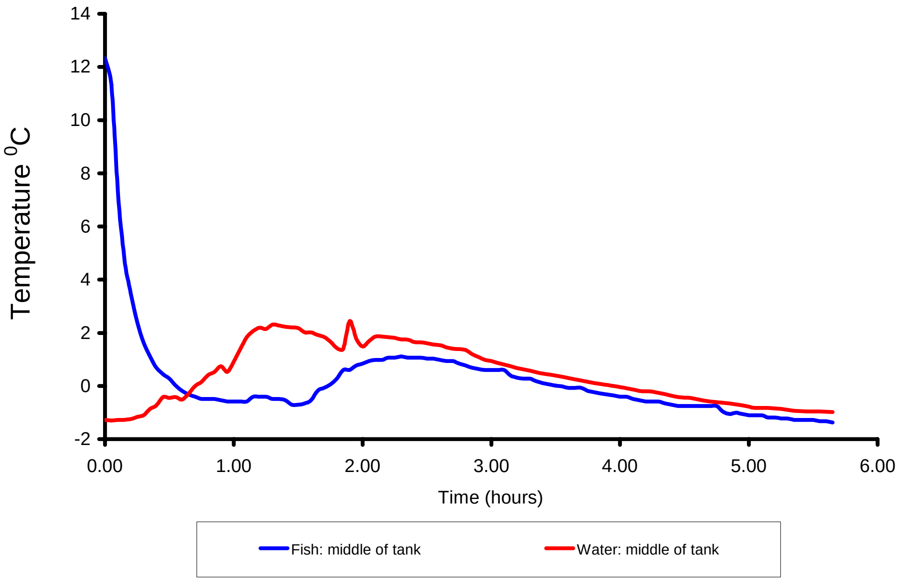


Figure 21. Temperature of water and mackerel during cooling in RSW/binary ice in an onboard tank

Whilst Figure 21 shows a rapid cooling of the fish containing the thermocouple from around 12 °C to 0 °C in around half an hour, there was some variability in the temperatures recorded, with one fish chilling quickly and another taking 6 hours to reach -0.5 °C. This may have been due to poor mixing in the tank. The temperatures of fish on landing, 24 hours after capture, varied between -1.2 and +0.4°C.

Mackerel held in pumpable ice in the insulated bin cooled very rapidly. The small mackerel (0.4KG) cooled from about 12°C to 0°C within 35 minutes, whereas the large mackerel (0.9KG) took 60 minutes to cool to 0 °C. The temperature of the fish during the 7 days storage was approximately -1.4°C.

3.3.2 Fish Quality

The quality of fish from the binary ice/RSW tank was assessed by the Japanese technicians at the factory. They concluded that the quality was good and there were no signs of partial freezing.

The results of the nitrogenous spoilage related compound analysis carried out on mackerel stored in the insulated bin are shown below in Table 8.

Table 8. Content of nitrogenous spoilage compounds in mackerel flesh at the start and end of a period of 7 days storage in binary ice

Storage time (days)	Total volatile nitrogen (TVN) mg N/100g	Trimethylamine-oxide (TMAO) mg N/100g	Trimethylamine (TMA) mg N/100g
0	9.4	20.4	0.0
7	10.2	20.7	0.0

The results indicate that the mackerel quality changed little during storage as the levels of TMAO remained similar. TMAO levels would be expected to fall as spoilage progresses, whilst levels of TMA would be expected to rise. This indication of quality agrees with the sensory results of the fish after 7 days, where the appearance, gut condition and flesh texture were assessed to be equivalent to fish which had been kept in RSW for 2-3 days.

The salt content of the mackerel after 7 days was 0.3g/100g of flesh but fish were not analysed for salt at the beginning of storage, so scientific comparison is not possible. However, see Appendix I for further information on salt uptake.

3.4 Discussion

The pumpable ice installation enabled fish to be landed at the processing unit at chilled temperatures, which the vessel's RSW alone could not have achieved, given the short steaming time involved. However, the supply of binary ice to the tanks prior to fish being loaded, led to floatation of ice to the top, with possible loss of fish cooling efficiency. This probably resulted in the ice and fish not mixing properly within the tank.

It should be noted that engineers were called to repair the ice generator during the trials, due to failures in the ice scraper assemblies in 2 ice generating cylinders. This was thought to be due to wear and tear as a result of using low salinity inshore seawater.

The prompt and rapid chilling of fish, as well as near freezing storage temperatures, was seen to be important in achieving best quality pelagic fish. For the fish stored in binary ice only, the extension to chilled storage life was exceptional, albeit from a one-off trial, and this was achieved in ideal conditions of pumpable ice storage for 7 days, instead of the 2-3 days normally expected with RSW.

Meeting the strict temperature and quality requirements for the high value Japanese market is a powerful incentive for pelagic boats to focus on effective chilling. The combination of RSW/binary ice to chill fish is particularly effective, because the ice in the tank quickly extracts heat from the fish, while RSW refrigeration pre-chills the water and keeps the mixture at chilled storage temperatures. The EU/Nordic pelagic fleet has already invested in very powerful RSW systems hoping to rectify fish chilling inefficiencies, with resultant high capital and running costs.

4 Trial 3. Use of Pumpable Ice on a Large Whitefish Trawler with Associated Primary Processing Trial

4.1 Introduction

The trial aimed to do the following:

- Obtain pumpable and plate iced cod, stored in commercial containers, for assessment of effects in primary processing ashore
- monitor fish temperature during iced storage
- assess the effects of pumpable iced storage of cod on processing yield
- assess the effects of pumpable iced storage of cod on quality

The sea trials took place onboard the 20 year old 60m whitefish trawler **PALL PALLSON,** while the processing trials were carried out at the HG Hf factory at Isafjordur, NW Iceland. Vessel and factory are owned by the same company.

Trials were carried out on the Pall Pallson because no vessel with a pumpable ice installation was available in the UK fleet at that time.

The vessel used binary ice to pre-cool the catch before stowage, with final stowage in flake ice. Typically the vessel fished for up to 5 days before landing directly to the factory.

A 4 day seatrip was undertaken from Isafjordur. Tows were typically 3-4 hours in duration and catches, mostly of cod, were between 1 and 3 tonnes per haul. All fish used for iced storage and processing trials were handled as per standard UK practice.

Trials work at the processing factory was carried out following the seatrip. A major part of the HG Hf factory operation is primary processing of fish for a range of markets including fresh and frozen products for the UK multiple retailing sector. Yields of prime fillet product depend on freshness and quality, thus these attributes are vital to profitable processing operations.

4.2 Methodology

4.2.1 Vessel, Equipment and Fish Handling

The **PALL PALLSON** was fitted with 2 binary ice plants with a combined nominal ice production of 8 tonnes per day. The binary ice system supplied a fish pre-cooling tank directly, with no dedicated ice storage tank. As the vessel normally used flake ice for fish storage, a temporary pumpable ice supply hose was rigged to the fish hold to facilitate binary icing of cod in bins. The ice fraction used was about 20%.

It is normal practice in Iceland to allow the fish to bleed in water before icing and storage and fish are gutted by hand before entering the pre-cooling tank. The vessel's elongated pre-cooling tank (approximately 8m^3) was a novel development which combined fish bleeding/washing and cooling, using pumpable ice and seawater.

The pre-cooling tank operated by conveying fish in a circular cycle from top to bottom, then onto an electronic fish grading and weighing system. Pumpable ice entered the top of the tank and mixed with fish as they moved through the tank. Fish were conveyed onward by batch, into the hold, for iced stowage in 660L bins.

Figure 22 - Binary ice being pumped onto cod on the conveyor at the top of the cooling tanks

4.2.2 Fish cooling

Observations and fish temperatures were taken to gain an overall picture of the performance of the system. Fish temperatures were taken at two points; directly from the sea and after pre-cooling. Detailed temperature profiles of fish in stowage had been planned, but were not obtained due to equipment failure.

4.2.3 Onboard: Binary and flake icing of fish

Small-medium cod were used for the iced storage trials and were gutted and washed without pre-cooling. These were iced in bins according to good practice. Approximately 400kg fish plus ice filled a 660L bin, and approximately 270kg fish plus ice filled a 460L bin.

Binary ice was bucketed onto the fish as the bins were filled, layer by layer, with fish. The brine was allowed to drain to leave a residue of drained snow ice around the fish in similar proportions to solid ice in bins. The solid iced bin of fish was also filled layer by layer with fish and ice. 1 x 400kg and 1 x 270kg bin was binary iced and 1 x 400kg and 1 x 270kg bin was flake iced, all with fish from the same haul. This was done three times, at 3, 5 and 9 days before processing.

As the sea trip was 4 days long, the trials fish was held ashore for up to 9 days in a chill, to achieve storage periods similar to UK short, medium and long trips. The fish hold and chill room ashore were set to 1^{o}C.

4.2.4 Shore Factory: Processing and Yields

After 3, 5 and 9 days storage, fish temperatures were taken from each bin, then fish were filleted using normal factory processes, and the final fillet yield recorded. Samples were also assessed for freshness, salt content and total numbers of bacteria (TVC) by the Icelandic Fisheries Laboratory at Reyjkavic and Isafjordur.

4.2.5 Fish Quality

To compare the effects of pumpable vs. plate ice for storing fish in bins, after the 3, 5 and 9 days one fish from the top, middle and bottom layers of each of the

400kg bins, were assessed for raw freshness by the Quality Index Method. Samples from the 9 day old fish stored in binary and flake ice in 400kg bins were also assessed for cooked freshness using the TRS scheme for cod. This was carried out by the Icelandic Fisheries Laboratory at Reykjavic.

The Icelandic Fisheries Laboratory at Isafjordur analysed skin off fillet flesh after each storage period for total bacteria numbers using a total plate count, and for salt content using the Volhards Method.

4.3 Results

4.3.1 Fish cooling in the onboard cooling / bleeding tank

Fish temperatures after gutting but before pre-cooling were found to be between 4.9°C and 5.3°C. Some binary ice was supplied to the tank before, as well as during the pre-cooling cycle and some 1.5 tonnes of fish, mostly 2-3kg cod, passed through the tank in 20 minutes. The temperature of cod coming out of the tank was 1.6°C average, with a range of 0.3 °C to 2.6°C. This low average temperature after only 20 minutes indicates rapid cooling in the pre-cooling tanks.

4.3.2 Storage, processing and quality assessment

4.3.2.1 Fish temperatures during storage

A profile of fish temperatures during storage was obtained by measuring individual fish temperatures directly on removal from 400kg bins after 3, 5 and 9 days. The results are shown in Figure 23.

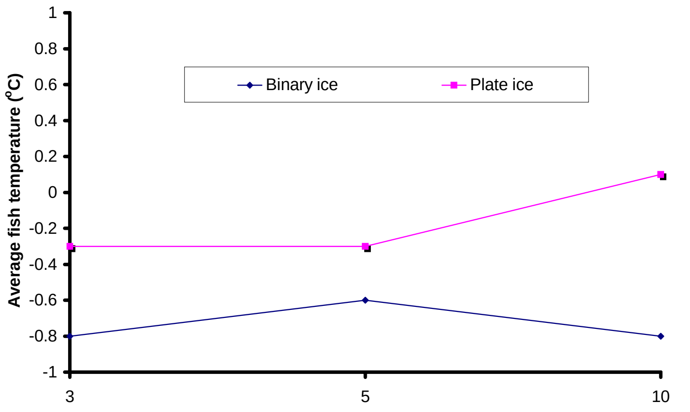


Figure 23. Average storage temperatures of cod in binary and plate ice

The temperatures of binary iced fish were appreciably lower than those in solid ice. The lowest temperature reached by fish in binary ice was -1.1°C and these fish showed signs of stiffening due to partial freezing, although these effects disappeared before processing

4.3.2.2 Fish processing and yields

Fillet yields in Table 8 show little or no difference between ice type and storage time after 10 days. The average fillet yield for binary iced fish was 52.8% compared with 52.5 % for solid iced fish

Table 9. Fillet yields from binary and solid iced whole fish, stored in bins

Ice Type	% fillet yield from whole cod		
	3 days stored	5 days stored	10 days stored
Binary	52.8	52.4	53.3
Plate	48.9	53.5	55.3

Average yield for binary iced fish = 52.8%; for plate iced fish 52.5%

4.3.2.3 Fish Quality

The raw freshness scores of the binary and solid iced fish after storage are shown in Figure 24.

The scores for fish samples from the solid iced 400L and 270L bins were combined, as were those for the binary iced equivalents.

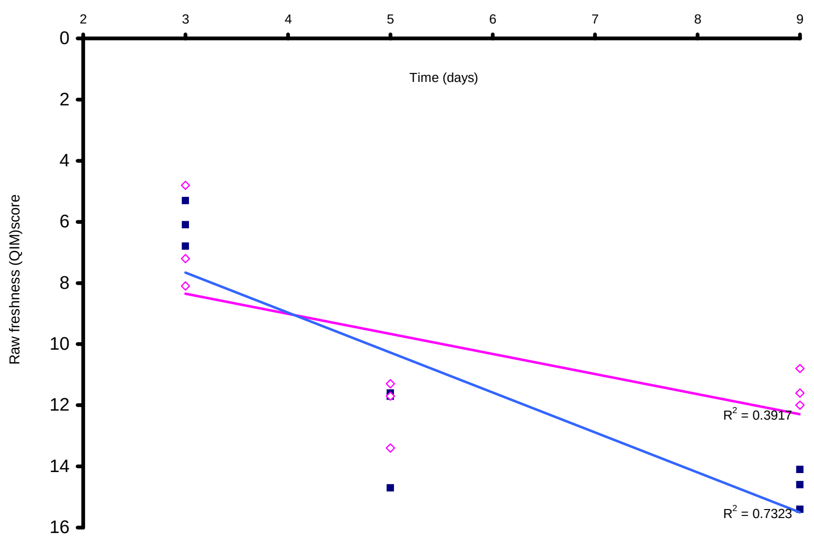


Figure 24. Raw freshness scores (QIM) of cod during storage in binary and plate ice

Because QIM scores equate high freshness with a low score, ie the opposite of the Torry system, the y-axis is inverted to show a downward trend representing a loss of freshness with time similar to a Torry freshness chart.

For both types of ice the raw freshness scores indicated a slightly higher, ie less fresh score than would have been expected from the length of storage of the fish. This was probably due to the softness of the fish as a result of heavy feeding on capelin. However, by day 9 of storage the binary iced fish were significantly fresher than their solid iced equivalents, with a 95 % confidence level.

There was also a significant freshness difference between icing treatments according to TRS cooked scores, by day 9 of storage. The average score for binary iced fish was 7.5 compared with 6.9 for solid iced fish, which is equivalent to a 1 to 1.5 days increase in chilled storage life with binary icing.

Measurement of salt content during storage as shown in Table 10, shows no appreciable difference between binary and solid ice treatments, but a general tendency to increase over time.

Table 10. Salt content of cod after storage in binary and solid ice

Ice Type	Salt contents of cod flesh g/100g or % by weight		
	3 days stored	5 days stored	10 days stored
Binary	0.10	0.10	0.25
Plate	0.15	0.15	0.25

Analysis of numbers of bacteria in cod flesh also showed no appreciable difference between icing type.

4.4 Discussion

The binary ice pre-cooling system was found to significantly reduce the temperature of the fish in a short period of time. However there was some variation in temperature after pre-cooling, which indicates either that there was not enough ice, or that mixing with the fish was not fully effective.

There were small but significant advantages in freshness with binary iced storage of fish in the 660L bins, although no advantage was found for either type of ice with fish held in shallow bin storage (270kg of fish) compared with deep bins (400kg fish). However, it is interesting to note that the Icelandic fishing fleet tends to use shallower bins for perceived quality reasons.

The performance of the binary ice plants during the trial was affected by mechanical problems which indicate possible frailties with this type of machinery, at that time. The technology has improved since then.

At the time of the trials, fish technologists at the Icelandic Fisheries Laboratory were investigating cooling of fish immediately post-catch, potentially to extend the rigor process for a few days. Their aim was to facilitate landing of whitefish at about TRS 9, from 4-5 day wet fish trips. Their efforts were welcomed by the processing factory, which reported high quality scores for pre-cooled fish.

Fillet yields from binary and solid iced fish were very similar and did not appear to be affected by the storage capacity of the bins. However binary iced fish tended to increase slightly in weight in storage, whereas solid iced fish tended to slightly reduce in weight. Binary icing of fish would therefore be expected to give a greater overall fillet yield.

There was a small but significant chilled storage life benefit with the binary iced fish which were 9 days old before processing. This was equivalent to an extra 1 to 1.5 days chilled storage life compared with solid icing. There was no marked increase in salt contents of cod fillet with storage in binary ice as compared with solid ice.

Similarly there was no particular difference in the total numbers of bacteria on fish with icing type. However, Seafish laboratory trials (App. I) have shown that binary icing tends to reduce the rates of growth of *Pseudomonad* spoilage bacteria during storage.

5 Trial 4. Pumpable Icing of Fish in a Fish Market

5.1 Introduction

This trial looked at use of pumpable ice technology in a market environment and had three purposes:

- to assess fish cooling and temperature control
- to monitor operation of a crushed-ice slurry machine
- to assess icing affects on fish

The work was carried out at the request of Grimsby Fish Dock Enterprises (GFDE) in Grimsby Fish Market Hall, which is a modern but unchilled building, where fish are prepared overnight for auction sale in the morning. Normally on landing fish are de-iced, graded for size and weighed into boxes, then top iced with solid ice. Boxes are laid out on the hall floor overnight and up to 7 hours can elapse before auction.

A ground/crushed pumpable (particulate) ice machine was made available for the trials by Frost HF of Iceland and fish was donated by Premier Fish Handling and Jubilee Fishing Co.

The work was carried out over 3 days and compared top flake icing with top pumpable icing techniques through temperature monitoring and assessment of appearance.

5.2 Methodology

5.2.1 Ice supply and trials equipment

The ground/crushed pumpable ice maker consisted of a 600L tank in which solid ice was ground and mixed with brine, to make pumpable ice by the batch. A small silo/conveyor supplied solid ice to the grinding mechanism, and a brine making system continuously fed brine to the unit. A batch of crushed ice took approximately 5 minutes to make depending on the temperature and ice fraction required.

Figure 25 - Trials of ground/crushed ice system on market (brine maker to left, ice maker at front on right , with ice silo behind

Standard 75L stacknest fish market boxes were used for the trials and temperature monitored by handheld thermometers and a data logger. Because of the surrounding commercial activities, the trials boxes were placed in unlidded 660L bins to protect the temperature monitoring equipment. This is not representative of actual market conditions but all boxes were treated the same. Both flake and plate ice were made available during the trials and where necessary distinctions have been made in the text.

5.2.2 Trials Procedure and Assessments: Fish cooling

Boxes of de-iced round and flat fish were cooled with particulate ice and left in ambient conditions for up to 9 hours.

Brine and ice inputs to the particulate ice machine were measured, to control delivery of known quantities of ice to boxes through a handheld hose. The pumpable ice was made from a 2% strength sodium chloride brine with a 40% ice fraction.

Figure 26 - Top Icing of Plaice

The resultant particulate ice slurry was about -1^{o}C. The quantity of solid ice typically used per box was 4-6kg, and the particulate ice equivalent was 10-14L per box. Table 11 outlines the trials undertaken.

Table 11. Icing Trials on Grimsby Fish Market

Fish icing trial	Icing Treatment	Amount of ice used	Temperature measurements
Trial 1 (I Kg sized haddock; iced and held for 9 hours)	Top solid icing	4 KG of solid ice or 10L pumpable ice	Temperatures monitored by one thermocouple placed in the centre of the middle layer of fish in the box. Temperatures also taken of individual fish at the end of the trial.
	Top particulate icing		
Trial 2 (Small-medium cod and plaice; iced and held for 7 hours)	Top solid icing	4 KG of solid ice or 10L particulate ice	Temperatures monitored by one thermocouple placed in the centre of the middle layer of fish in the box
	Top particulate icing		

5.2.3 Trials Procedure and Assessments: Fish quality

In addition to the temperature trials, pumpable and solid iced fish: cod, haddock and plaice were presented to buyers for their feedback on the appearance of the fish. The fish were presented both in iced boxes and individually, to remove the possibility of bias.

5.3 Results

5.3.1 Fish cooling - Trial 1 (1kg Haddock)

Figure 27 shows that particulate ice cooled some of the fish from 7.5°C to 3°C in less than an hour, whereas solid top icing took 9 hours to achieve the same temperature. For the first 4 hours of holding, the solid top iced fish were held at over 4°C, which could potentially lead to loss of quality and consequent lower fillet yields.

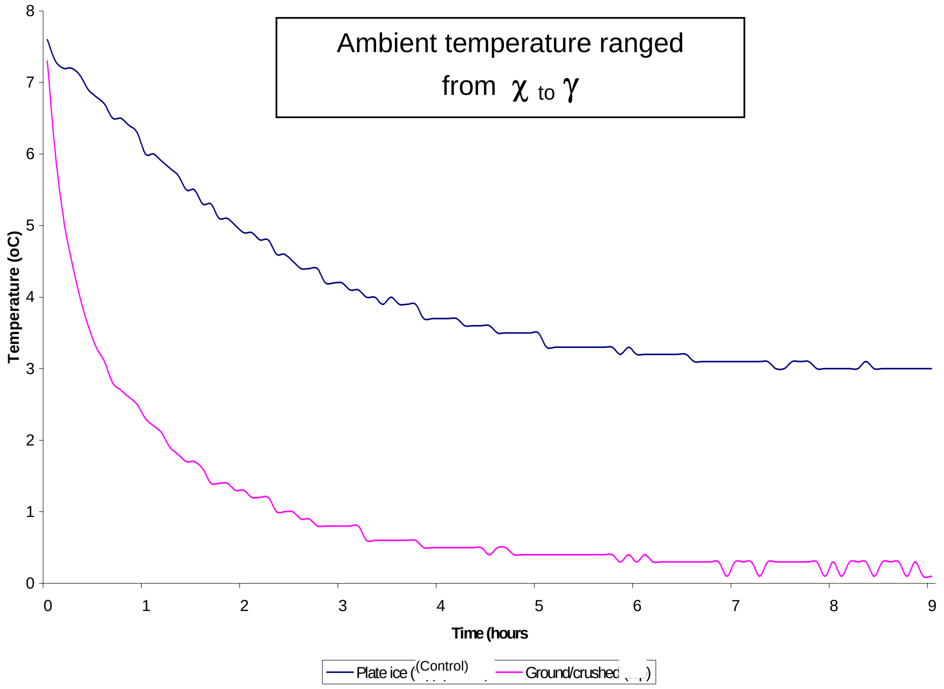


Figure 27- Temperatures of haddock during cooling in ground/crushed and plate ice (Trial 1)

Table 12 below shows fish temperatures at the end of the trial, at three different levels, in the centre and sides of the boxes.

Table 12. Temperature of fish at the centre and sides of fish boxes after cooling in binary and solid ice for 9 hours in trial 1

Icing Treatment	Layer in box	Temperature oC	
		Centre of layer *	Side of layer**
Top flake icing	Top	1.9	3.6
	Middle	3.0	3.8
	Bottom	4.9	5.6
Top particulate icing	Top	2.7	2.6
	Middle	0.3	1.4
	Bottom	0.4	2.4

*** temperature taken by thermocouple**
**** average of temperatures taken by thermometer**

Fish in the centre of the top, middle and bottom layers of the flake iced box, showed cooling from 7^{o}C to 3^{o}C. However, cooling to the bottom of the box was only to 5^{o}C. By comparison, the particulate top iced treatment achieved fish temperatures of 0.5^{o}C in the middle and bottom of the box. However fish at the top of the box only cooled to 3^{o}C, which was probably due to loss of ice. Fish in both types of ice suffered from warming to the sides of the boxes, although the effect appeared to be less marked with pumpable icing. Overall, pumpable ice gave the best cooling performance.

5.3.2 Fish cooling - Trial 2 (small – medium cod and plaice)

Figures 28 and 29 show the temperature of cod and plaice taken in the middle and bottom layers of boxes top iced with pumpable ice and flake ice.

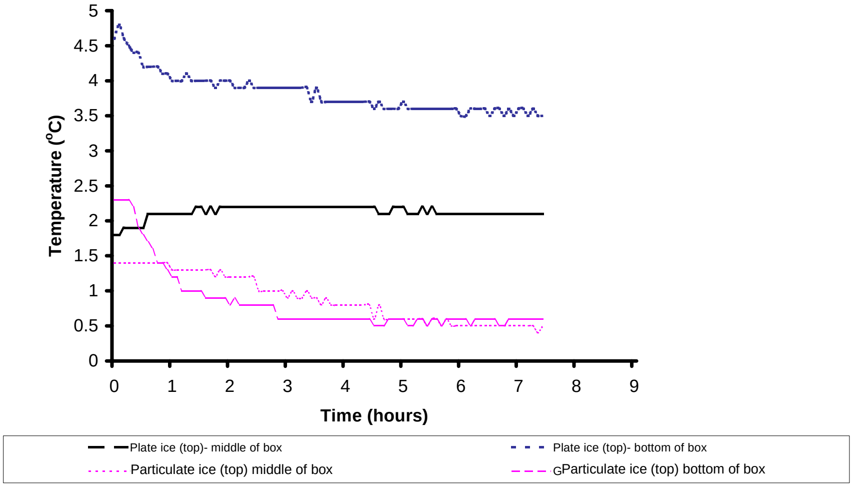
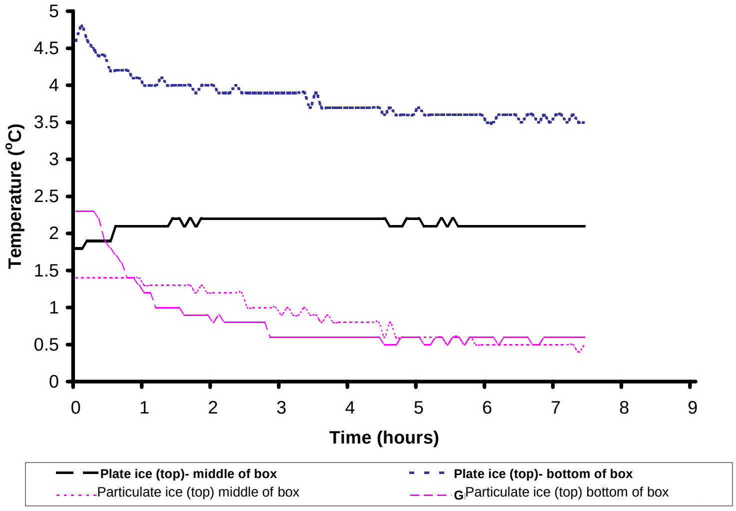


Figure 28 - Temperature of cod during cooling in particulate and plate ice (Trial 2)



as well as roundfish. As there was no ice left in the boxes at the end of the trial.
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Figure 29 - Temperature of plaice during cooling in particulate and plate ice (Trial 2)

5.3.3 Fish Quality - appearance

Two freshness categories of fish were particulate and flake iced. Ice was applied to the top of the boxes and the fish assessed 9 hours later. This enabled comparisons to be made between bright and colourful 'seafresh' fish, and fish several days older, ie 'less fresh' fish, that were dull in both sheen and colour. Two buyers and Seafish technologists participated in the assessment and were presented with fish iced in boxes and as samples without identification of the icing treatment used.

In the view of the assessors, there appeared to be no difference between the appearance of 'seafresh' and 'less fresh' cod and haddock with icing type. However one buyer detected a slime/sheen loss with the fresh plaice at TRS raw score 9 that had been in contact with particulate ice. Such an effect could possibly influence perceptions of freshness and hence quality. There were no signs of stiffening of the fish due to partial freezing.

5.4 Discussion

It was clear that in the warm ambient conditions of the market hall, effective chilling of fish by icing alone is only feasible for a relatively short period of time, whatever type of ice is used.

Particulate top icing was more effective at fish cooling than conventional top icing because of the percolation of cold brine and ice crystals through the mass of fish. It appeared to be effective with both round fish and flat fish. For effective temperature reduction and chill control and to negate problems with the sides of boxes warming up, ice needs to be distributed throughout and around the fish in the box

The use of particulate ice made from 2 % brine and 40% ice fraction meant that fish freezing was avoided. Further, the ice flowed well enough for effective top icing of fish, yet the loss of ice through the box drain holes appeared to be limited with this thickness of ice slurry. Although the ice particle size with particulate ice is substantially coarser than with a binary pumpable form, the trial demonstrated that there was no particular disadvantage with this type of pumpable ice in this application.

Bearing in mind that buyers' perceptions of quality are instinctively influenced by appearance, the temperature of the particulate ice used in the trials aimed to minimise possible effects. However there was an effect with very fresh plaice, but it may be that there can be subtle slime/sheen effects with any fresh fish, if the slime has been frozen. If this is found to be the case in a future trial, then an adjustment of ice slurry temperature closer to 0^{o}C might be advantageous This is more easily achieved with particulate ice than binary pumpable ice, as the salinity of the former can be adjusted to give a wider range of temperatures.

6 Trial 5. Trials of Pumpable Icing of Defrosted Cod prior to Processing (Frozen Fish Factory)

6.1 Introduction

The purpose of the trial was:

- to assess the use of particulate ice for cooling and chilled storage of defrosted fish
- to assess the effects of iced storage on the processing of the fish

This work was undertaken in collaboration with Glenrose (Hull) Ltd who produce block frozen fillet products from defrosted frozen-at-sea fish. The frozen at sea fish are defrosted in warm air defrosters, then held overnight in pallet bins for processing the following day.

Two separate trials were carried out. In the first trial, defrosted cod were stored in binary pumpable ice and solid top ice, to allow comparative assessment of fish temperature, freshness, weight and salt content. The second compared fish held under the same conditions, but followed them through the filleting and skinning processes where temperature, weight change and process yields were monitored.

In addition, the practicalities of using both forms of pumpable ice ie binary and crushed pumpable ice were also compared in this trial. Binary pumpable ice was supplied from the Seafish Laboratory and the crushed pumpable ice from an ice machine on trial at the factory.

6.2 Methodology

6.2.1 Trial1: Icing effects on fish during storage

This trial was undertaken at the Seafish Laboratory for an extended period of 48 hours, to investigate the effects of pumpable ice on fish during storage.

Approx. 350kg of newly defrosted, gutted head-on and head-off cod were delivered by the processor, then iced and stored in standard 660L insulated pallet bins in a chillroom set at + 2^{o}C. The icing treatments are shown in the table 13 below.

Table 13. Icing Trials of Defrosted Cod Stored in Bins

Trial	Form of fish	Icing Treatment
1.	Gutted head on and head off	Top- iced using 10 Kg flake ice (as in normal factory practice)
		Fish immersed in 120L of binary ice (3% brine/20 % ice crystals) (flake ice equivalent = 24 Kg)
		Fish immersed in 120L of binary ice (1.5% brine/20 % ice crystals) ** (Flake ice equivalent = 24Kg)
2	Gutted head off only	Fish iced using 10 Kg flake ice as in normal factory practice

		Fish immersed in 180L binary ice (3% brine / 20 % ice crystals)slurry at –2.5^{o}C flake ice equivalent 32Kg

** This was achieved by dilution with chilled fresh water

Figure 30 - Trials - bins of binary and flake iced defrosted cod in the chill

Temper … n a number of fish in each … ial fish tempera … nt for … ch … ng the Volhards method. Fillets from fish stored for 24 and 48 hours from each icing treatment were also sensory assessed according to the TRS cooked freshness scheme for cod.

The weight of fish in each bin was recorded at the start and end of the chilled storage period. Additionally, a sample batch of 6 fish of each type were strung together and placed in each bin for monitoring of weight after 4, 8, 12, 24 and 48 hours. After each check weighing, these fish were replaced in the bin.

6.2.2 Trial 2: Effects of icing on processing

To compare the effects of binary and flake ice on stored, defrosted cod at processing, approx. 340 Kg of defrosted head–off cod were kept in 660L bins overnight in the processor's chill set at 3^{o}C. These were kept in flake ice, binary pumpable ice and crushed pumpable ice, the latter two both at 3%brine:20% ice

At the start of the trial and after 10 and 15 hours, the weight of fish in each bin was recorded. The weight of skin-on and skin-off fillet from each icing treatment was also recorded to provide yield data.

Individual fish temperatures were also taken after defrosting and chilled storage, and during processing. Salt content and freshness assessment was not undertaken.

6.3 Results

6.3.1 Trial 1

Figure 31 shows the average temperatures of defrosted fish held in storage for 48 hours in flake and binary ice.

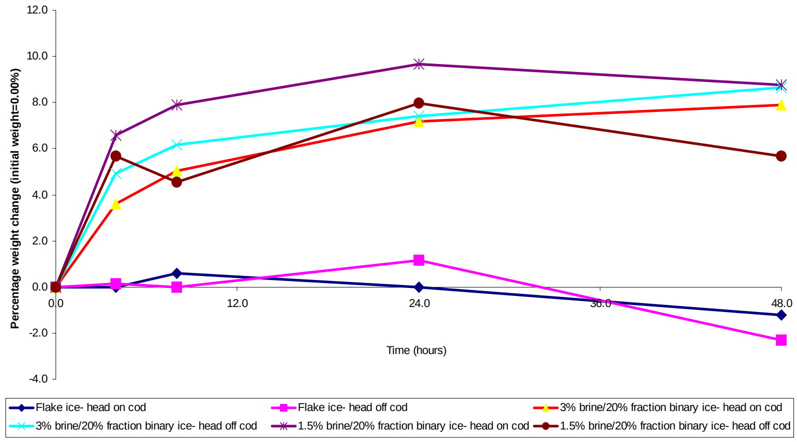

Figure 32. Percentage weight change of a sample batch of head on and head off cod during iced storage in Trial 1

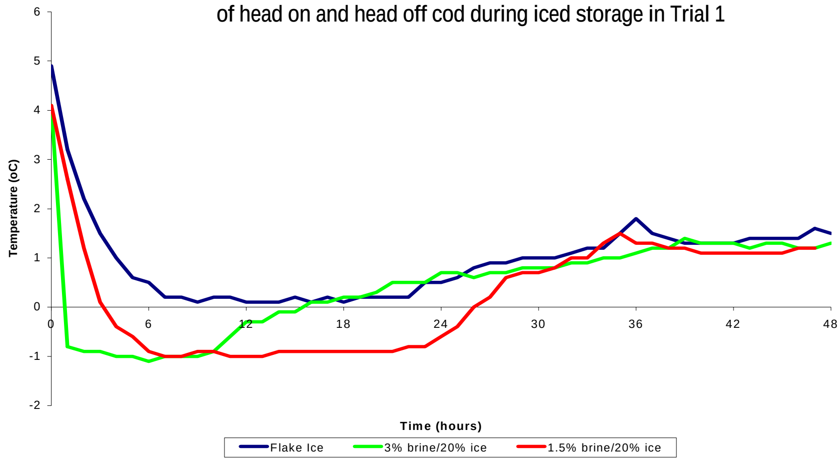

Figure 31. Temperature of defrosted cod during binary and flake iced storage in bins in Trial 1

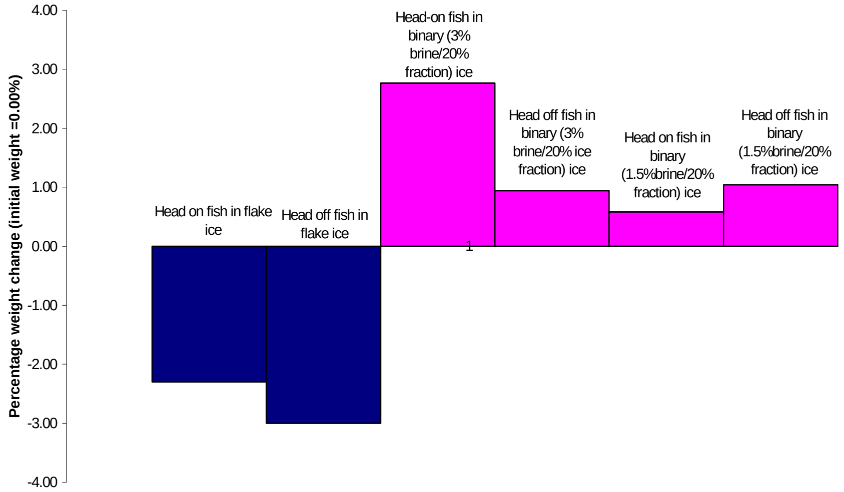

Figure 33 - Percentage weight change of defrosted cod after 48 hours in binary and flake ice in bins (Trial 1)

The sample batch of fish held in pumpable ice appeared to gain weight quickly, by between 5% and 8% over the first 8 hours, then stayed at similar weights for the remainder of the 48 hour storage period. By comparison, the flake iced fish weight did not change with time. Figure 33 shows the overall weight change pattern of fish held in different icing treatments over the 48 hours storage period.

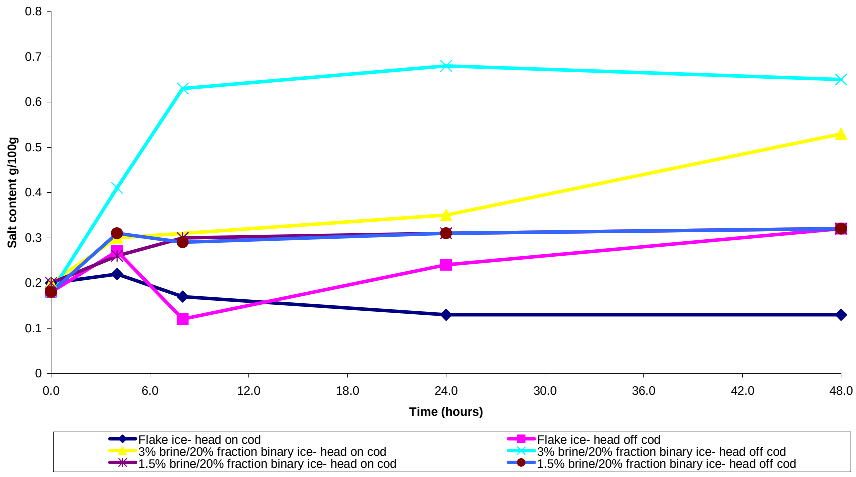

Figure 34. Percentage salt content change in defrosted cod flesh during storage in binary and flake ice in bins

those held in binary ice. The overall difference was smaller than with the sample batch of fish, and was between 3 and 5.5 percentage points, due to a weight loss with flake icing, and a weight gain with binary icing. As with the sample fish results, there was no pattern of weight change with fish type or binary icing treatment, only between pumpable and flake ice, ie the two ice types. Figure 34 shows the change in salt content of defrosted cod flesh during storage.

There was variability within the results but there was a pattern of salt content increase with binary icing. This was mainly during the first 24 hours and to fish in the higher brine content ice, starting at 0.2g/100g and rising to 0.6g/100g. There was a smaller increase in salt concentration in the fish in the least salty binary ice.

The TRS cooked flavour scores for fish from different icing treatments showed that while head-off fish reduced from flavour score 9 to 8 during storage, there was no pattern of freshness change difference between icing treatments.

However slight salty flavours developed during storage in the (saltiest) 3% brine binary ice and this agrees with the increase in salt content found in those fish.

6.3.2 Trial 2

The fish temperatures after defrosting and after icing in the bins, for both trials batches, are given in Table 14.

Table 14. Fish temperature after defrosting and after iced storage in bins

Ice type	Time in storage (hrs)	Fish Temperatures. after defrosting (^oC)		Fish Temperatures after iced storage (^oC)	
		Av.	Range	Av.	Range
Flake	10	5.0	- 0.1 to 12.1	3.0	2.0 to 4.2
	15	3.9	1.0 to 7.0	0.7	- 0.1 to 3.4
Binary	10	6.7	- 1.2 to 12.5	1.4	- 1.1 to 4.1
	15	4.2	- 1.4 to 12.8	-0.7	- 1.6 to 0.2

After 15 hours, the first batch bins had only small amounts of ice remaining at the top. Apart from the binary ice bin, the second batch bins after 10 hours had more ice remaining. Binary icing clearly gave better chilled temperature control than solid top icing.

The binary ice treatments used more ice than the standard factory procedure. However, this would not have been the only reason that cooling using binary ice was more effective than top icing, as top icing relies on inefficient conduction of heat through the depth of fish.

Fish in binary ice tended to remain slightly cooler during filleting than that held in flake ice, but by the point of skinning were at similar temperatures – typically between 4^{o}C and 6^{o}C. The change in fish weight during iced storage for both trial batches, are given in Table 15 below.

Table 15. Fish weight change during iced storage

Ice Type	Storage time (hours)	% Weight Change in storage
Flake	10	- 0.7
	15	- 9.4
Binary	10	0.0
	15	+ 3.0

The weight change to fish held in flake ice were quite marked, with a near 10% loss after 15 hours, compared to weight gains of 3% to 5% for fish held in pumpable ice. There was relatively little change in weight of fish held in binary ice for 10 hours, and it is thought that storage time could be the main factor here. Fillet yields for skin-on and skin-off fish are shown in Table 16 overleaf.

Table 16. Yields of skin-on and skin-off fillets from iced and stored, defrosted cod

Trial	Form of fish	Icing Treatment
1.	Gutted head on and head off	Fish solid iced to the top using 10 Kg flake ice (as in normal factory practice)
		Fish immersed in 120L of 3% brine/20 % fraction binary pumpable ice (flake ice equivalent = 24 Kg)
		Fish immersed in 120L of 1.5% brine/20 % fraction binary pumpable ice (Flake ice equivalent = 24Kg)
2	Gutted head off only	Fish solid iced using 10 Kg flake ice as in normal factory practice
		Fish immersed in 180L of 3% original brine / 20 % fraction binary pumpable ice at –2.5^{o}C flake ice equivalent 32Kg)

The fish filleted as would normally be expected, except those held in binary ice for 15 hours, which were considered to be a little awkward to cut due to slight partial freezing and hence giving slight difficulties in filleting close to the bone. However this did not appear to affect the yields which were similar for both binary and flake iced fish. This indicates that any weight change benefit with binary iced storage of fish should feed through to final yield, ie weight.

6.4 Discussion

Defrosted cod (head on and head off) stored in bins using binary ice showed better temperature control compared to top-icing with flake ice. Binary iced fish were typically found to be between -0.4°C and -0.7°C after storage. However there were some signs of partial freezing of fish, some of which were as cold as -1.6°C. Although flake icing of the fish through the depth of the bin would be better than top icing only, this would not be as easy to achieve or as effective as using pumpable ice.

Fish in binary ice slightly increased in weight during storage compared with no weight change or even a loss of weight with top solid iced fish after about 15 hours.

Overall the filleting yields from binary iced fish were similar to those of flake iced fish. There were, however, some instances where the binary iced fish were slightly frozen, with consequent awkwardness in filleting close to the bone. The likelihood is that any weight change benefit with binary iced storage of fish would enhance final yields of fillet product for block re-freezing.

The salt content results were variable, but with a pattern of increase with binaryicing during the first 24 hours, and to fish in the binary higher brine content. Salt content increase in these fish was reflected by slight salty flavours. There was no difference in the pattern of fish freshness during storage with any type of ice although storage was limited to 48 hours.

A demonstration of a particulate, pumpable ice machine was installed at the factory of one of the trials. Particulate ice appeared to perform satisfactorily but the factory staff were of the opinion that this type of ice separated more quickly that binary ice.

The factory went on to install a binary ice system for icing of the defrosted fish and fillet prior to freezing.

7 Trial 6. Pumpable icing of Nephrops - Trials of salt content effects and use on a Nephrops Trawler

7.1 Introduction

The purpose was to :

- Investigate the effects of different pumpable icing techniques on the salt and water content of *Nephrops*

- Investigate the quality and processing effects of icing *Nephrops* at sea on a day boat trawler

Day boat trawlers typically do not use ice except in the summer months, when quality is particularly at risk. Previous Seafish icing trials of *Nephrops* on small trawlers showed a significant loss in yield to whole product when processing after 2 days. This was considered to be the result of poor cooling with typical top icing only practice. Pumpable icing now offers better cooling than with best solid icing practice.

As pumpable ice can be used in drained or un-drained forms, some initial investigation was needed of salt/water content effects on *Nephrops* to guide the techniques to be used in the sea trials. Keeping *Nephrops* in un-drained ice potentially eases the handling of these fragile animals. Pumpable ice made from 2.0% and 3.5 % (seawater strength) brine was used.

The initial trial of salt/water content effects was carried out in July on *Nephrops* at the Seafish Laboratory and the at-sea icing trials were carried out in July/August from Troon on FV AEOLUS with processing at Scotprime Ltd, Ayr.

7.2 Methodology

Binary ice was supplied from the Seafish Pumpable ice system for both the trials was temporarily installed at Scotprime for the sea trials.

7.2.1 Vessel, equipment and quality assessment

The AEOLUS is a modern 12 m steel day fishing trawler with a fish room, and takes on ice during the summer months.

Insulated boxes and containers were used as appropriate to transport and store, ice and *Nephrops*. Temperature was taken using handheld digital thermometers.

Quality assessment was undertaken at the Seafish Laboratory by a panel of 2- 3 assessors using the TRS scoring scheme for raw and cooked freshness. Salt and water content assessment was by external laboratory analysis of samples of shelled tail flesh. External microbiological analysis was carried out for total viable counts (TVC) and *Pseudomonad* spoilage bacteria.

7.2.2 Salt/water content trial

Whole and tailed shell on small *Nephrops* were collected from the AEOLUS within 2 hours of catching. The samples were packed in sealed polythene bags, and held on ice in insulated containers for transport to Seafish Laboratory at Hull. The whole and tail *Nephrops* were subjected to different ice treatments as follows:

- Flake ice control, top and bottom ice, drained as per normal practice
- Binary (2%brine/30% fraction ice), drained and undrained
- Binary (3.5 % brine/30% fraction ice), drained and undrained

It should be noted that the *Nephrops* were not dipped in sodium metabisulphite solution.

After catching, *Nephrops* were held in insulated boxes in a chill set at 0^{o}C for 6 days. Sampling for salt/water content was on days 0, 1, 2, 3 and 6 of storage, with freshness assessment at days 0, 3 and 6.

7.2.3 Icing at sea trial

Solid flake ice and binary ice was taken to sea in 220L insulated containers which were loaded on the vessel when it landed at night.

The trials *Nephrops* were taken from the same haul and split between icing treatments. Therefore handling prior to icing was not a variable. Whole small *Nephrops* were used because these were main part of the catch and the factory does not process tails. In all, 3 one day trips were carried out.

The control was typical top only flake icing, with the binary ice treatments (3.5% brine ice being the main treatment) being as follows:

– Binary (2% brine/30% fraction) ice, un-drained
– Binary (3.5 % brine/30% fraction) ice, un-drained and drained

A trial using one of the above binary ice treatments, each with a control, was carried out on each trip. The trials batches weighed around 60kg, with the drained iced *Nephrops* held in ordinary fish boxes and the undrained *Nephrops* in 220L insulated containers.

The *Nephrops* were landed at night and stored in their original containers in the factory chill, until processing (on the second day after capture). The control flake iced at sea *Nephrops* were lightly re-iced to the top before storage at the factory. This is normal practice.

Samples for salt/water content and microbiological counts were taken before the *Nephrops* were dipped in sodium metabisulphite.

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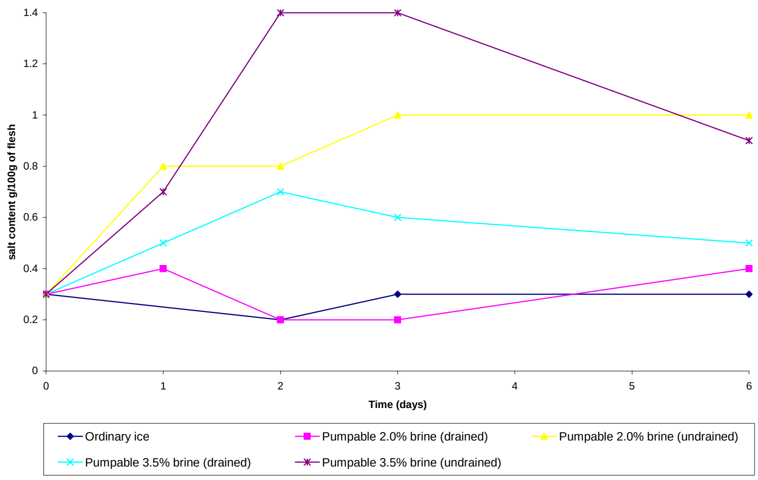

Figure 36 - Salt content of tail Nephrops during storage in binary and flake ice

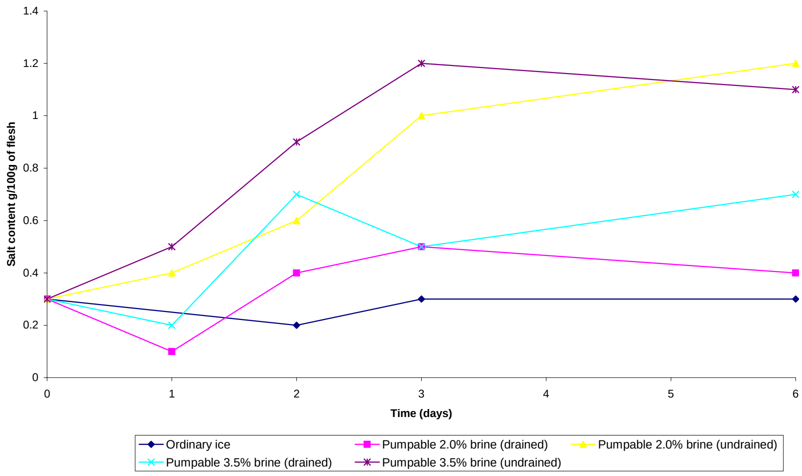

Figure 35 - Salt content of whole Nephrops during storage in binary and flake ice

Both the whole and tail *Nephrops* had an initial salt content of about 0.3g/100g of flesh. There was relatively little change through storage with flake icing or the 2.0%brine / 30% fraction drained binary ice.

The salt content of both whole and tail *Nephrops* in 3.5%brine/30% fraction drained ice doubled to about 0.6g/100g after 6 days of storage. Most of the increase occurred within the first two days.

The greatest increase in salt content was in whole and tail *Nephrops* in undrained pumpable ice. These showed 3 to 4 fold increases within 3 days, and remained at high levels between 1.0g/100g and 1.2g/100g by the end of storage.

There was a relatively steady increase in the water content of whole *Nephrops* in solid and drained pumpable ice. This was from 78% to between 80% and 81.5 % during storage. The increases with these ices was similar for tails, rising from 78% to between 79% and 81%, and occurred mostly during the first day of storage.

The greatest overall increase was to whole and tail *Nephrops* in 3.5 % brine undrained ice.

7.3.1.3 Quality

On reception at the laboratory, *Nephrops* were scored at TRS 4.5 raw freshness, (TRS 5.0 is maximum freshness).

The main focus was on cooked quality. There was little difference in cooked freshness of whole and tail *Nephrops* between ice treatments after 2 days, except for those in undrained 3.5% brine/30% fraction ice, which were unacceptably salty in flavour.

Assuming a TRS score of 2.5 as the limit of consumer acceptability, only the *Nephrops* in drained pumpable ice were acceptable after 6 days storage. These, albeit starting to become salty in flavour, had a TRS count of 3, whereas those held in solid ice scored TRS 2. This result is equivalent to a 1-2 day extension of chilled storage life.

7.4 Icing at sea trial

7.4.1 Temperature

The temperature logger used for measuring temperatures during cooling failed, but previous trials showed very rapid cooling of *Nephrops* in pumpable ice to –0.6 within an hour. They also showed that *Nephrops* with solid top iced only, did not cool to 0^{o}C by the time they reached reception at the factory.

The top flake iced *Nephrops* were at 1.3 oC average on removal from iced storage. The binary iced *Nephrops* were at -1.6 oC average, with those in 3.5% brine ice being colder than in 2.0% brine ice. There were no signs of partial freezing of *Nephrops*. All *Nephrops* warmed to about 12 oC after dipping in sodium metabisulphite.

7.4.2 Salt and water content

There appeared to be no salt content increase in *Nephrops* after day 1 of storage in flake and binary ice. The salt contents were about 0.7 %/100g. Salt contents of *Nephrops* held in undrained ice increased after 1 day to 0.8%/100g for the 2% brine ice and 0.2g/100g for the 3.5% ice after 2 days. The exception was tose held in 3.5% brine drained ice.

Binary iced *Nephrops* generally increased in water content by about 0.5% after 1 day, compared to flake iced.

After 2 days it appeared that the pumpable iced *Nephrops* had decreased in water content, and registered levels only a little higher than those held in flake ice, which had not changed.

7.4.3 7.4.3 Microbiological change

The results for each of the different ice treatments were averaged as they were similar for each ice type, and are shown in Table 17.

Table 17 - TVC and Pseudomonad bacteria counts on flake and binary iced Nephrops after 48 hours in storage after capture

Bacteria Type	Icing Treatment			
	Flake	2.0% brine undrained	3.5% brine drained	3.5% brine undrained
TVC	4870	330	220	600
Pseudomonads	1640	40	100	340

Although the period of iced storage was only 48 hours, there was clear pattern of reduced numbers of bacteria with binary icing.

7.4.4 Freshness quality

There were slight signs of relative loss of freshness, eg an increase in odour, with the flake iced *Nephrops* prior to processing.

Table 18 shows the raw and cooked TRS freshness scores of *Nephrops* held in flake and 3.5% drained and undrained ice for 2 days as raw material, and for a further 6 days as chilled, packed, flake iced whole product. Therefore a of total 8 days chilled storage after capture.

Table 18. Raw and cooked freshness of whole Nephrops product 6 days after processing (total 8 days storage after capture)

. Condition	TRS scores of chilled whole Nephrops product 6 days after processing (total 8 days storage after capture)		
	Top flake ice	Pumpable 3.5% brine/drained ice	Pumpable 3.5% brine/undrained ice
Raw	2.5	2.5	2.5
Cooked	1.5	2.5	2.5

Assuming a TRS score of 2.5 as the limit of consumer acceptability, all but the cooked top flake iced *Nephrops* were still acceptable. The metabisulphite treatment to reduce blackening to *Nephrops* was probably the reason for the appearance of a better raw freshness quality than justified by the cooked assessment.

7.4.5 Whole Nephrops Product yield

The *Nephrops* are size graded and packed and iced into small polystyrene boxes as fresh chilled product. There was little difference between yields for the different binary iced treatments and they are combined in table 19.

Table 19 Yield of whole fresh Nephrops product from Nephrops stored in binary and flake ice at sea

Type ice	Weight of Nephrops (Kg)	% Yield
Top flake ice	191	95.3
Binary ice 3.5% (drained and undrained)	169	95.9

Assessment of the reject *Nephrops* for claw loss, softness and general damage, also showed little difference as a result of ice type.

7.5 Discussion

Salt and water uptake

There was relatively little difference between the salt and water content changes to whole and tail *Nephrops* in each ice treatment in the salt/water content trial.

Little salt water effect was found with flake and undrained 2.0% brine ice. However there was a trebling of salt contents in *Nephrops* held in undrained 3.5% brine. Two days storage in these ices would appear to be the limit, as salty flavours started to develop.

The water content of *Nephrops* in this trial generally increased by a few % points during storage, and mostly during the first day. The least water uptake was with the flake and drained binary ice. Most uptake was in the un-drained binary ice, where water content rose from about 78% to 83% during the six days storage.

Icing at sea trail

There was little or no salt increase to whole *Nephrops* in flake or drained binary ice after 48 hours storage. However, there was a slight increase with undrained 3.5% brine ice. These salt content changes were similar to those found in the salt/water content trials. There was a slight general increase in water content in the iced at sea *Nephrops*. Again this was similar to the salt/water content trial result for storage of around 2 days.

Although bacteria numbers on the iced at sea *Nephrops* after 48 hours were low, there was a pattern of least growth on binary iced *Nephrops*.

This advantage with suitable binary icing of *Nephrops* was equivalent to an increase of about 1-2 days chilled storage life compared with flake icing. Binary ice enhanced the freshness and chilled storage life of *Nephrops*. Provided that storage in undrained ice was less than 2 days.

Assessment of whole chilled product from flake iced at sea *Nephrops* 6 days after processing, showed that the raw freshness condition was misleading as to freshness quality. This was probably because of the effect of the sodium metabisulphite treatment on the appearance of *Nephrops*. The eating quality or cooked freshness, was appreciably worse than raw appearance indicated.

There was no improvement of whole chilled product yield with binary icing. This was contrary to the results of previous summertime trials of improved icing where a 6% increase in product yield was obtained after 48 hours. Perhaps this reflects a lower standard of product acceptability, now that trip caught North Sea catches are a major source of supply to processors.

Appendix 3

Torry and QIM Freshness Schemes for Cod, Flat fish, Mackerel and Nephrops

Torry Freshness Score Sheet for Raw Cod

Score	Eyes	Skin	Texture and Effect of Rigor Mortis	Flesh and Belly Flaps	Kidney and Blood	Gills: Appearance	Gills: Odour	Score
10	Bulging, convex lens, black pupil, crystal-clear cornea	Bright, well-differentiated colours, glossy, transparent slime.	Flesh firm and elastic. Body pre-rigor or in rigor.	Cut surface stained with blood. Bluish translucency around backbone. Fillet may have rough appearance due to rigor mortis contraction	Bright red blood flows readily	Glossy, bright red or pink mucus	Initially very little odour increasing to sharp, iodine, starchy, metallic odours changing to less sharp seaweedy, shellfish odours.	10
9	Convex lens, black pupil with loss of initial clarity.		Flesh firm and elastic. Muscle blocks apparent. In or just passing through rigor.	White with bluish translucency, may be corrugated due to rigor mortis effect.	Bright red, blood does not flow.			9
8	Slight flattening or plane, loss of brilliance.	Loss of brilliance of colour	Firm, elastic to the touch.	White flesh with some loss of bluish translucency. Slight yellowing of cut surfaces of belly flaps.	Slight loss of brightness of blood.	Loss of gloss and brightness, slight loss of colour.	Freshly cut grass. Seaweedy and shellfish odours just detectable	8
7							Slight mousy, musty or caprylic,	7
6	Slightly sunken, slightly grey pupil, slight opalescence of cornea.	Loss of differentiation and general fading of colours; overall greyness. Opaque and somewhat milky slime.	Softening of the flesh, finger indentations retained, some grittiness near tail.	Waxy appearance of the flesh, reddening around the kidney region. Cut surfaces of the belly flaps brown and discoloured.	Loss of brightness, some browning.	Some discoloration of the gills and cloudiness of the mucus.	Bready, malty, beery, yeasty	6
5							Lactic acid, sour milk or oily.	5
4	Sunken, milky white pupil, opaque cornea.	Further loss of skin colour. Thick yellow knotted slime with bacterial discoloration. Wrinkling of skin on nose.	Softer flesh, definite grittiness.	Some opacity, reddening along backbone and brown discoloration of the belly flaps	Brownish kidney blood	Slight bleaching and brown discoloration with some yellow bacterial mucus.	Lower fatty acid odours (e.g. Acetic or butyric acids), composted grass, 'old boots', slightly sweet, fruity or chloroform like.	4
3							Stale cabbage water, stale turnips, 'sour sink', wet matches.	3

Torry Freshness Score Sheet For Cooked Cod

Score	Odour	Flavour	Texture, Mouth Feel and Appearance	Score
10	Initially weak odour of sweet, boiled milk, starchy followed by strengthening of these odours	Watery, metallic, starchy. Initially no sweetness but meaty flavours with slight sweetness may develop.	Dry, crumbly with short tough fibres.	10
9	Shellfish, seaweed, boiled meat, raw green plant.	Sweet, meaty, creamy, green plant, characteristic.	Succulent, fibrous. Initially firm going softer with storage. Appearance originally white and opaque going yellowish and waxy on storage.	9
8	Loss of odour, neutral odour	Sweet and characteristic flavours but reduced in intensity.		8
7	Woodshavings, woodsap, vanillin.	Neutral		7
6	Condensed milk, caramel, toffee-like.	Insipid		6
5	Milk jug odours, boiled potato, boiled clothes like.	Slight sourness, trace of 'off' flavours.		5
4	Lactic acid, sour milk, 'byre-like'.	Slight bitterness, sour 'off' flavours		4
3	Lower fatty acids (e.g. Acetic or butyric acids), composted grass, soapy, turnipy, tallowy.	Strong, bitter, rubber, slight sulphide.		3

Torry Freshness Score Sheet for Raw Flatfish

Score	General Appearance
5	Eyes full, bright or very slightly cloudy; gills bright red or very deep pink, with slight clear slime; slime on body clear to slightly silky.
4	Eyes slightly sunk, some opacity; gills pale pink, bleached, with thick opaque slime; slime on body thick and opaque; edge of gill cover slightly bleached and pinking in regions on under-side of body.
3	Eyes sunk and opaque; fills bleached with thick grey or brown slime; slime on body yellow and watery; bleaching on back, particularly in head region and gill cover, pinking on underside.
2	Eyes completely sunk or bloated and opaque; gills very bleached with dirty grey or brown-yellow slime; slime on body watery with yellow bacterial discoloration; marked bleaching and pinking on body.
1	Eyes totally collapsed; gills badly bleached and badly discoloured with bacterial slime; body slime watery or scarce with marked bacterial discoloration, particularly in head region; gill covers very bleached; marked pinking on the underside.

Score	Flesh Including the Body Cavity
5	Translucent with blue or pink tinge. Dark purple blood in backbone.
4	Loss of translucency; bluish or pinkish white; slightly waxy. Backbone still purple.
3	Waxy, slight yellowing, slight discoloration of body cavity. Backbone still well coloured (red-blue to purple).
2	Some opacity, yellow or brownish discoloration extending in from fin rays. Reddening on backbone.
1	Marked opacity, yellow or brown discoloration and marked reddening in backbone.
0	Marked discoloration, particularly in body cavity. Blood almost completely diffused in backbone.

Score	Texture
5	Firm, smooth and slimy.
4	Loss of slime but no marked grittiness.
2	Grittiness towards the tail.
1	Marked general grittiness.

Score	Odours of Gills and Belly Cavity
10	Fresh oil, metallic, roses, freshly-cut grass ("lawn mower")
9	Metallic, oily, earthy, peppery.
8	Oily, seaweedy, aromatic.
7	Oily, citric, musty, mousy.
6	Oily, bready, biscuity, malty, cut-flower stems
5	Sour beer, slight rancidity, painty, cod-liver-oil.
4	Muddy, grassy, meaty, stale vegetables, "old boots", fruity, sweaty, lower fatty acids.
3	Rotten cabbages, sour sink, wet matches, rotten meat, rancid butter.
2	Byre-like, singed hair, ammonia
1	H_2S, strong ammonia, sulphides.
0	Faecal, nauseating, indole.

Freshness Score Sheet for Cooked Flatfish

Score	Odour
10	Meaty, oniony, fresh butter or margarine, Worcester sauce, slight caramel.
9	Oily, slightly aromatic, slightly peppery, boiled clothes.
8	Curry, still oily, peppery, damp clothes, "baked" smell.
7	Caramel, boiled potatoes, musty, butterscotch.
6	Metallic, slightly sour, acrid, slightly sweaty, boiled string.
5	Sour bread, lower fatty acids, rancid butter, singed milk, smoky.
4	Slight amines, slight ammonia, sour beer, spoiled cheese.
3	Ammonia, very sour, slightly faecal.
2	Strong ammonia and amines, faecal.
1	Very strong ammonia, strongly faecal, putrid cheese

Score	flavour
10	Meaty, very slightly bitter, shellfish, slightly garlic flavoured.
9	Oil, rather herring-like, metallic, but still meaty.
8	Curry, seasoned meat, oniony, spicy, peppery, canned meat.
7	Neutral flavour, only slightly sweet and meaty.
6	Slightly rancid, slightly sour, slightly bitter.
5	Rancid oil, rancid butter, fish meal.

4	Bitter, "woody", sour, little flavour.
3	Very bitter, rotten fruit.
2	Very bitter and sour.
1	Nauseating: difficult to taste.

Score	Texture
5	Firm and dry.
4	Crumbly, short and firm.
3	Soft but dry.
2	Soft and moist.
1	Very soft, sloppy.

Torry Mackerel Scoring Scales

(Revised April 1986)

Raw Fish

Appearance of Skin and Body

Score	Description
8	Firm body with silky smooth skin, lateral line and reticulations on upper surface well-defined. Body colours iridescent with strong royal blue and turquoise colours on upper surface and blue violet colours on ventral surface with a silvery sheen. Passing into *rigor mortis.*
7	Loss of colour definition, some blood stains apparent. Passing our, or out of *rigor mortis.*
6	Colours of dorsal surface paler, reticulations grey, ventral surface white with golden tinge. Patchy iridescence
5	Washed out colours, definite golden tinge to skin, patchy iridescence. Body soft with blood red/brown slime oozing from gill-covers. Skin wrinkles on flexing.
4	Fish limp and floppy with distinct ice marks. Washed out colours with mottling of golden tinge.
3	Little distinction between upper and lower surfaces. Skin very wrinkled with distinct ice marks. Body very soft.
2	Yellow slime apparent with belly burst of ungutted fish.
1	Thick knotted yellow slime, gritty skin with wrinkling on the nose.

Appearance of the Eyes

Score	Description
8	Bulging convex eye with protruding lens. Shiny jet black/blue pupil with metallic brown iris. Eye-cap water clear.
7	Convex eye, lens plane with cornea. Pupil less shiny, iris green/brown. Slight clouding of eye-cap.
5	flattening of eye but still convex, wrinkled pupil with slight clouding of the lens. Silvery iris, starting to wrinkle. Yellowing of eye-cap.
4	Eye-ball plane with eye socket. Cloudy lens with silvery iris showing black specks. Golden yellow eye-cap.

Mackerel Scoring Scales continued.

Score	Description
2	Concave or flattened eye with cloudy pupil. Yellow eye-cap.
1	Sunken eye covered in thick yellow slime, bleached eye-cap with peppered appearance.

Appearance of Gills

Score	Description
8	Uniformly dark red/purple in colour with free blood and water-clear slime present.
7	Dark purple/maroon in colour with paler edge. Congealed blood present with opaque slime.
5	Loss of colour with red/brown slime.
4	Browning of gills with patchy bleaching, increase in quantity of slime resulting on blood red/brown slime oozing from gill cover.
3	Marked bleaching of gills with pink/brown viscous slime.
1	Gills completely bleached or washed out pink colour and starting to disintegrate.

Odour of gills

Score	Description
8	Weak, delicate odours, cloying sweet, sharp, pepper, halogens, seaweed, blood.
7	More definite odours as above, also fragrant, fresh grass, fruity, metallic, shellfish.
6	Dull muddy odours, musty, mousy, malty, cardboard, linseed oil, cod liver oil, biscuits, blood.
5	Stale odours as above, also butterscotch, wet cardboard, wet dogs.
4	Mixture of 5 and 3 odours.
3	Sweet, rotten odours, oily, sweet rotten fruit (grapefruit), old grass cuttings, sickly sour.
2	Sour and sweaty odours, rancid, slight sulphury, yeast, slight ammonia.
1	Sulphury odours, rotten turnips, sour sink, wet matches, compost heap, sour cheese.
0	Strong faecal and ammoniacal odours

Mackerel Scoring Scales continued.

Cooked Fish Odours

Score	Description
8	Shellfish, fresh seaweed, halogens (iodine), fresh blood, fresh lemons/chicken, sweet oil, muddy.
7	Fresh lamb stew, boiled potatoes, washing soda solution, onions, biscuits, sweet oil.
6	Earthy, slight spicy, curry, white chicken meat, fresh mushrooms, cardboard.
5	Waxy, new leather, wet paper, cardboard, dried meat extract, curry, just detectable rancidity.
4	Slight rancidity, caramel, yeasty, stale, musty, malty, greasy stale chicken fat/chicken skins.
2	Sweaty, sour, rancid, stale cheese, sulphides, pickled herring, rotten fruit (sweet odour), charred.
1	Sulphides, burnt/acrid, rotten meat, vomit.
0	Strong ammoniacal, faecal, nauseating.

Cooked Fish Flavours

Score	Description
8	Sweet, starch, astringent, metallic, blood, meaty (cold lean beef), green plant, spicy lemons, muddy, strong sweet oil. Red meat : Strong meaty, sweet.
7	Sweet, oily chicken (white meat), blood, herbs (e.g. Parsley), roast meat (cold lamb, pork), starch, astringent, insipid, earthy, mushrooms, onions/lemons. Red meat : Strong meaty.
6	Sweet, earthy, cardboard, slight curry, bland sweet oil, onions/lemons. Red meat : Strong meaty.
5	Slightly sweet, weak meaty, just detectable rancidity, musty, wet paper, cardboard, neutral bland oil, new leather. Red meat : Strong meaty, slightly rancid.
4	Neutral bland oil, greasy cold chicken, slight rancidity, sweet/sour, caramel, acidic after-taste. Red meat : Strong meaty, rancid, sulphury.
3	Slightly sour, rancid, stale roast meat, cold mutton stew, yeast, burning sensation on sides of tongue, "coin in the mouth" sensation, acrid. Red meat : Strong rancidity, sulphury.
2	Sour, rancid, rotten fruit (sweet sensation), chicken skins, charred paper, sulphides. Red meat : Strong rancidity, sulphury, tasted with difficulty.
1	Strong rancidity, bitter, burnt, acrid, strong sulphides, rotten cabbages, rotten meat. Red meat : Nauseating rancidity and sulphury.
0	Nauseating, ammoniacal, very strong sulphides, tasted with difficulty.

Torry Score Sheet for Development of Blackening on Whole Nephrops - Raw Fish

Appearance of the Eyes	
Score	Description
5	Heads clean, bright colour. Slight intrinsic greyness on dorsal surface from hopatopancreas. Claws rosy pink. No discolouration on tail, telson or at the junction of segments. Ventral surface translucent white.
4	Some darkening of dorsal surface. No marked blackening of sides of carapace. Some dulling of the colour of the claws and tail and slight discolouration appering at the joints of the segments and damaged areas. Loss of translucence of ventral surface. Darkening of swimmerets.
3	Some blackening of the dorsal surface of the head, spreading down the sides of the carapace. General loss of brightness of the shell. Some discolouration and blackening at the joints of the segments and telson. Ventral surface opaque white, black discolouration becoming apparent around the area of the vent.
2	General blackening of the dorsal surface of the head, spreading to the sides of the carapace. Discolouration apparent on claws, extending to the first segment of the tail. Blackening apparent on the telson sides of the shell and beginning to extend from the intersegment joints. Ventral surface discoloured.
1	General blackening of all the carapace spreading down to the segments and telson. Blackening appearing on the claws. Dark line apparent on the ventral surface, discolouring the tail meat.

Freshness Score Sheet for Nephrops - Cooked Tail Meat

Score	Odour	Flavour	Texture, Mouth Feel and Appearance	Score
5	Milky-sweet, seaweed, slightly sulphurous, characteristic shellfish	Intensely sweet, metallic	Very firm, crisp	5
4	Milky, creamy, slight ammonia.	Very sweet, creamy, milky	Firm	4
3	Slight ammonia, loss of milkiness	Sweet	Slightly soft	3
2	Ammonia	Loss of sweetness, neutral	Soft	2
1	Strong ammonia	Sour, off, creamy-sour	Very soft	1
0	Strong ammonia, sour	Strong, off-flavour, bitter, very sour	Sloppy, little texture	0

Quality Index Method (QIM) Scheme for Cod

Quality parameter		Description	Score
Appearance	Skin	Bright, iridescent pigmentation	0
		Rather dull, becoming discoloured	1
		Dull	2
	Stiffness	In rigor	0
		Firm, elastic	1
		Soft	2
		Very soft	3
Eyes	Cornea	Clear	0
		Opalescent	1
		Milky	2
	Form	Convex	0
		Flat, slightly sunken	1
		Sunken, concave	2
	Pupil	Black	0
		Opaque	1
		Grey	2
Gills	Colour	Bright	0
		Less coloured, becoming discoloured	1
		Discoloured, brown spots	2
		Brown, discoloured	3
	Odour	Fresh, seaweedy, metallic	0
		Neutral, grassy, musty	1
		Yeast, bread, beer, sour milk	2
		Acetic acid, sulphuric, very sour	3
	Mucus	Clear	0
		Milky	1
		Milky, dark, opaque	2
Flesh, fillets	Colour	Translucent, bluish	0
		Waxy, milky	1
		Opaque, yellow, brown spots	2
Blood	Colour	Red	0
		Dark red	1
		Brown	2
Quality Index			0-23

