ASSESSMENT OF REFRIGERATION METHODS FOR FRESH FISH

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ABSTRACT

Consumer expectations and market requirements are changing and the demand for healthy food with high quality increases. At the same time, the food industries face challenges due to pressure on resource utilisation, rational production and energy use. Chilling and freezing are the most important technologies for preserving food quality and reducing waste. The International Institute of Refrigeration (IIR) estimates that 25-30% of global food production is lost as waste due to lack of refrigeration. Additionally, refrigeration technologies are among the most energy-intensive technologies used in the food supply chain, accounting for about 35% of electricity consumption in the food industry. The need for research on energy efficient refrigeration technologies leading to increased shelf life and improved food quality is pointed out by several Norwegian organisations. There is a large and undisputed commercial potential inherent in more optimal and environmentally friendly food refrigeration.

The fish industry is one of the most important industries in Norway. Considerable amounts of fresh fish are transported from Norway to Europe every day. At present, most of this fish is chilled and packed in boxes with 25% ice. This paper covers a benchmarking between different refrigeration methods and their influence on product quality, production capacity, energy efficiency and raw material utilisation. The methods in question are ordinary chilling, superchilling and refreshing.

The key deliverable from this work is the development of new and improved technology for efficient refrigeration of fish, enabling the industry to compare different technological solutions. In turn this will enhance the implementation of the research results throughout the value chain.

INTRODUCTION

A better standard of living in most countries has led to an increasing demand for high quality food. Traditionally fish was regarded as non-status food and even as a low quality food in many countries. Today's focus on healthy food has now given fish products a unique possibility to change this image and take a large share of the well paying food markets all over the world. These markets, however, demand high quality, safe and healthy products and often prefer "fresh", i.e. unfrozen products.

The reason for the growth of fresh food sales seems complex and varied. Compared to frozen foods, two reasons are obvious: First of all, thawing takes time even in a microwave oven – and the end result varies. Secondly, the images of freshness, is easily related to newly harvested or produced food.

The family's choice of food is usually taken at the supermarkets display counters where fish products are scarce compared to other foods. The main reason for this is probably due to the lower shelf life for fish compared to meat products. To compete with i.e. meat products, fresh fish products require better chilling and lower storage temperatures. An analysis of the possibilities for improved shelf life is therefore very important for increased sales of fish products.

One important factor for predictable supply of high quality fish is the natural variations due to seasons, fishing grounds, feeding etc. Quality also depends on fishing methods, which may result in sea dead fish and quality loss. Besides, seasons, regulations and weather conditions may also stop the fishery. Shortage of certain species may occur, but can be met by use of pre rigor frozen and carefully thawed fish. Experiments have shown that this will give products of equal quality [1].

In contrast to many other foods, the sensory quality of fish will start to deteriorate very soon after harvest. This is shown in a large number of tests in laboratories all over the world, especially for iced codfish. However, the laps with time at a constant temperature vary between laboratories, partly due to methods used, criteria for quality, materials etc. This also results in large differences in shelf life of fresh fish, from 10 to 21 days. In Norway, both authorities and fish trade regards shelf life for well iced (0ºC) cod to be approximately 14 days. To safeguard the shelf life, all experiments show that storage temperature is of major importance. Some key figure on shelf life for different species, used in Norway, are given in Table 1, the variations dependent on seasons, fishing method, and handling [2].

Table 1*: Common shelf life for cod in Norway (100% RH)*

Product temperature	**0ºC**	**4ºC**	**8º**	**12ºC**
Shelf life	12-16	7-9	5-6	3-4

For fillets and processed fish, the shelf life is shorter than for unprocessed raw material, as the quality is influenced by the microbiological burden due to processing. During the last decades a large amount of research and experiments has been performed aiming at an increased shelf life for fresh fish products. The main focus has been given touse of Modified Atmospheric Packing (MAP), which may reduce bacterial growth. It should, however, be stressed that increase in shelf life requires proper chilling, and so the temperature is still the most important factor to increase the end product shelf life.

CHILLING

Chilling in boxes

National and international regulations require chilling of the raw material as soon as possible after catch. Practically, the period before chilling will depend on fishing year, vessel and working conditions. In the cod fisheries, most gear will give relative constant fish volumes during fishing, except in trawling where fish is taken onboard at certain intervals. However, fish caught by trawlers is normally chilled within 1-2 hours, and iced in boxes. The refrigeration capacity is “stored in the ice”, and chilling rate depends only on heat transfer between the fish and the ice.

Chilling of slaughtered fish

Poor chilling rate and expensive re-icing for box icing led to development of pre-chilling systems in mid 80’ties, based on experience from fish chilling in large containers with seawater and ice. To give effective chilling, ice must be placed in the bottom of the boxes to give effective thermal convection due to melted ice.

Increasing volumes in slaughter plants and need for more continuous and effective controlled chilling led to a research program for chilling systems. The work was focused on chilling in Refrigerated Sea Water (RSW) and brines with freezing point of -5ºC to -10ºC [3]. Figure 1 shows an experiment with different chilling levels and corresponding temperatures of equalisation. As expected, some variations in temperatures are found, mainly due to variations in thermocouple positions and fish size.

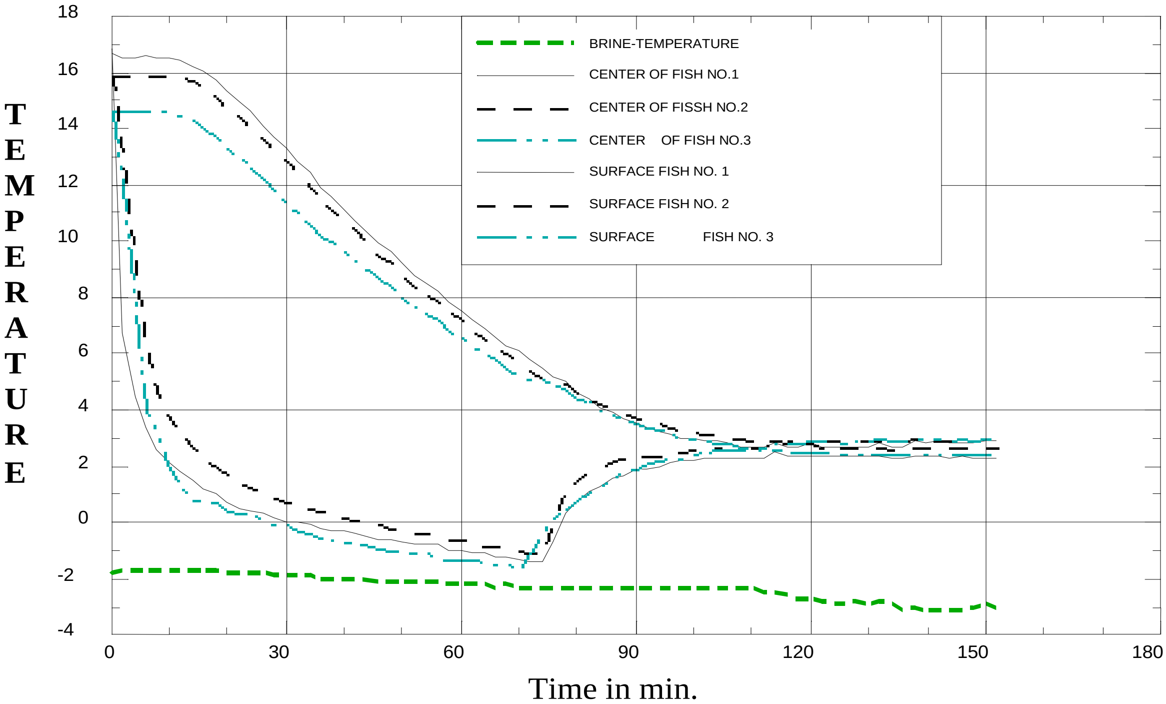

Figure 1: Chilling of 3 different batches of salmon in brine. After 75 minutes the fish is stored in insulated boxes in a cold store for temperature equalising and measurement.

Chilling of live fish

Experience with salmon at low sea temperatures has shown that the fish is calm and easy to handle. This led to the idea for chilling of live fish to reduce activity and need for anesthetization. The first experiments took place in containers where the temperature was reduced at a rate varying from 1,5 – 4 ºC pro hour. The fish showed no sign of stress during the chilling as long as the temperature did not fall below 0ºC. Even at the highest chilling rate the temperature difference between the water and the fishcore did not exceed 2 ºC.

To reduce the volume of chilled water and chilling time, experiments with transfer of fish to chilled containers were performed. Temperature drop from 4 to 14ºC was used with almost no sign of stress of the fish. Rapid chilling was obtained immediately after slaughtering for different chilling times, confer Figure 2. Currently, this chilling method is not used because of animal welfare regulations.

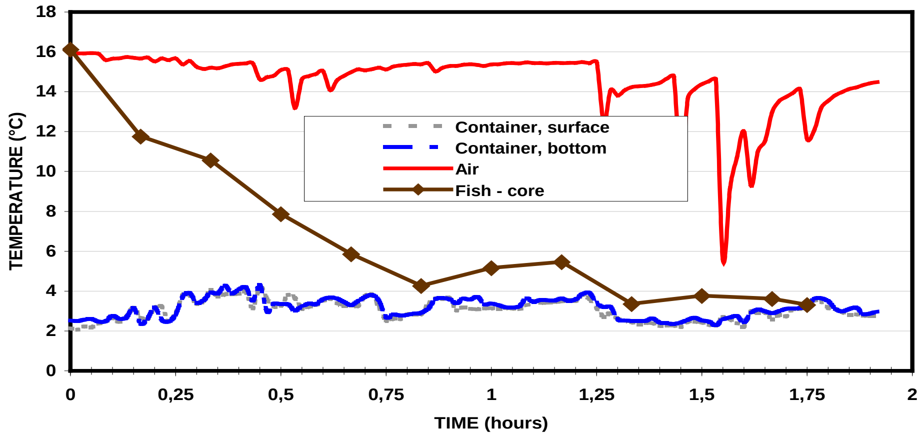

Figure 2: Temperatures during chilling of live salmon of approximately 4 kg.

SUPERCHILLING

Superchilling [4], described as early as in 1920 is a method for conserving foods by holding the product at a temperature between -0,5 and -4°C . For many food products, superchilling results in better quality compared to conventional chilling. It has been shown that the amount and distribution of ice in superchilled products prior to further processing greatly affects the process capacity and yield as well as the product quality, suggesting that an optimum ice content and distribution exists.

At superchilling temperatures, the microbial activity is drastically reduced. A comprehensive amount of studies on superchilling of fish conclude on a considerable extension of the microbiological shelf life for superchilled fish. Superchilling can extend the shelf-life of cod with about 7 days compared with traditional ice storage. It is showen that ice chilled reference fillets from farmed salmon of premium grade, maintained good quality up to 17–21 days. The storage time of vacuum packed salmon fillets can be doubled by superchilled storage at -1.4°C and -3.6 °C compared to ice chilled storage.

The difference in microbiological shelf life for superchilled and traditionally chilled salmon fillets is shown in Figure 3.

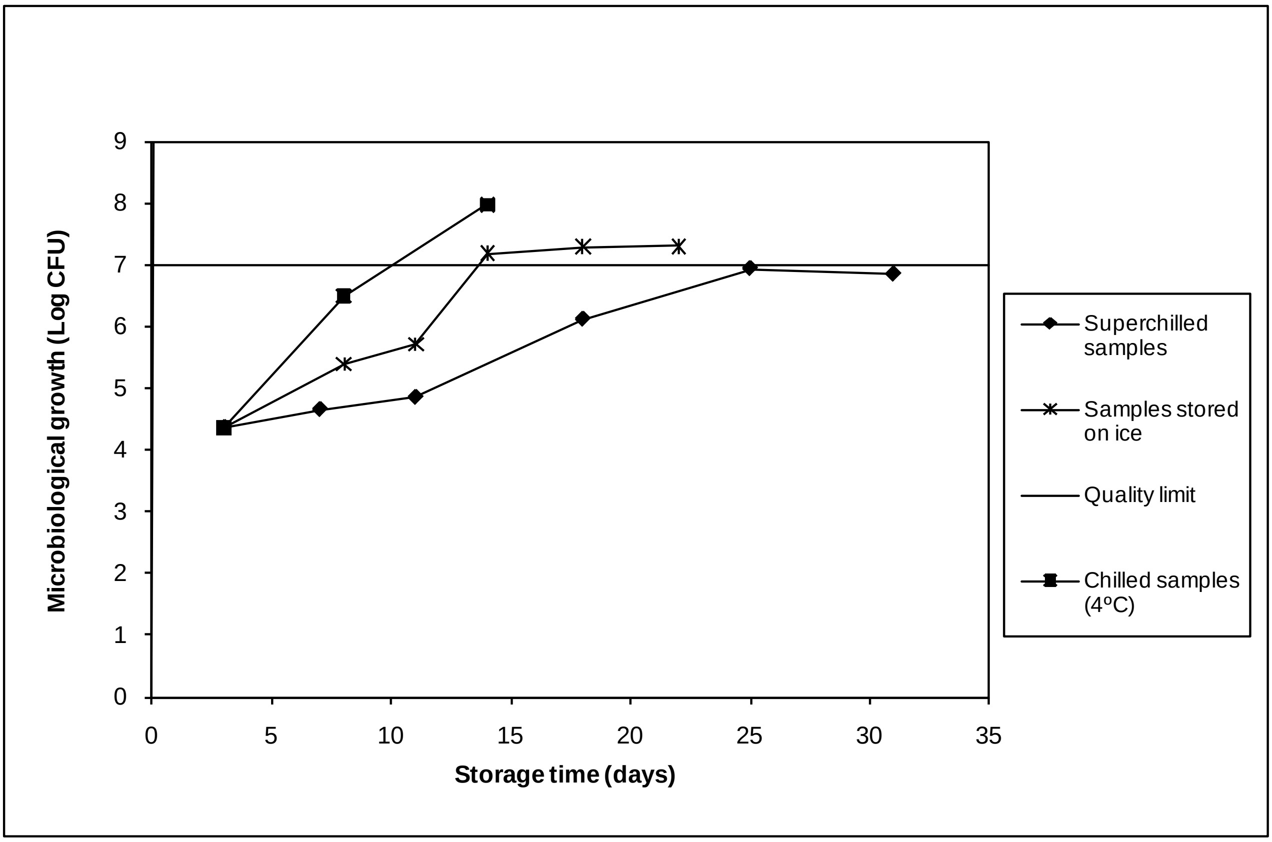

Figure 3: Microbiological shelf life for superchilled and chilled salmon.

In spite of the obvious benefits due to an extended shelf-life, the fear that the physical and sensory quality of superchilled products would be reduced compared to traditionally chilled products, has been deeply rooted in many communities. Cost- and energy efficiency questions and objections to the technology have also been raised. Recent research shows that the superchilling concept is indeed very competitive, both with respect to costs, energy efficiency and end product quality.

REFRESHING

In England, many supermarkets, offer refreshed fish together with fresh fish. Refreshed fish is fish that is immediately frozen after catch and carefully thawed at the supermarket or at a nearby plant. Results from a previously project [1] showed that this procedure can be applied also on farmed fish.

The total time for distribution from the fish farmers in Norway to the customer in Japan, including processing, freezing, cold storage during transportation, intermediate storing, and thawing, can take up to 3 months. It is a fact that the quality loss along this value chain is significant, especially with respect to colour changes in the products over time. Based on results from a recent study, refreshing can minimise reduction of quality during transport and storage [1]. In this context it is suggested that the following physical factors should be improved during the refreshed processing:

* Freshly killed salmon should be frozen to -30°C within 10-15 hours
* The storage temperature should be kept constant at -50°C during the distribution period to avoid decrease in colour quality
* The basis for a colour certificate to the customer can be based on the following concept:
    - Thawing in water between 5-10°C. The geometrical size of the product will determine the thawing time.
    - Adequate circulation of the thawing medium around the individual fishes.

- Immediate cooling down of the fish to $0^{o}C$ after the core temperature of $0^{o}C$ has been obtained

* This concept secures that the water content and water binding capacity is maintained at values close to the originals. In this way the drip-loss can be reduced and the texture will also be better preserved.

Discussion

At present most of the fresh fish caught or farmed in Norway are chilled with ice or by means of RSW. Export is done in boxes including approximately 25% ice/water (weight based). Recently a change to the traditional chilling chains has been implemented in the industry. A few plants has for instance included superchilling in their production, which in turn can eliminate the need for transport ice. In England, market changes implying a turn of consumer preference from fresh fish to refreshed fish has been registered. Such changes bring along new challenges to the distribution chain.

To benchmark different refrigeration methods with respect to energy efficiency, an enthalpy chart can be used. Comparing the different methods mentioned in an enthalpy chart, see figure 4, show the enthalpy difference for cod from 10°C, to chilled state, superchilled state and frozen state. In table 2 the exact enthalpy values are presented. As can be seen chilling only require 11,6% of the enthalpy change compared to freezing. Correspondingly superchilling requires 55,8% of the enthalpy compared to freezing.

Table 2: *Calculated enthalpy differences for different chilling methods applied on cod*

Method	Enthalpy change	Percentage
Chilling	37,4	11,6
Superchilling	166,5	51,8
Freezing	321,3	100

Figure 4: Enthalpy chart for cod.

These processes are only the start of the production line to the final costumer. Inadequate cold chains demand icing with approximately 25% ice/ water (weight based). For correctly superchilled fish icing is not necessary, but the distribution chain should hold superchilled conditions (-0,5 to -2°C. Frozen fish is transported at lower temperature, but heating is needed for the thawing process.

Even in the advanced fishing countries developments are needed to increase the value of the fisheries. Due to the low shelf life of fish, refrigeration play an important role. In the high cost market, fish has to compete with all types of food in the display counters in the supermarkets. This requires quality and pre-packed fresh and frozen food according to consumer demands.

Improved usage of the catch and reduced energy consumption will be important in the future. The ready to eat products are usually only 1/3 to 2/3 of the whole fish, depending on the raw material and end product. Hence safeguarding the exploitation of the raw material and production of by-products will therefore be an important challenge. Processing close to the place for catching will often give advantages. Figure 5 gives an example of what can be achieved, and illustrate how by-products can be taken care of in a sustainable way enabling the production of more food. This also reduces the amount of product for distribution and give cost and energy savings. Even larger volume reductions can be seen in export of iced fish.

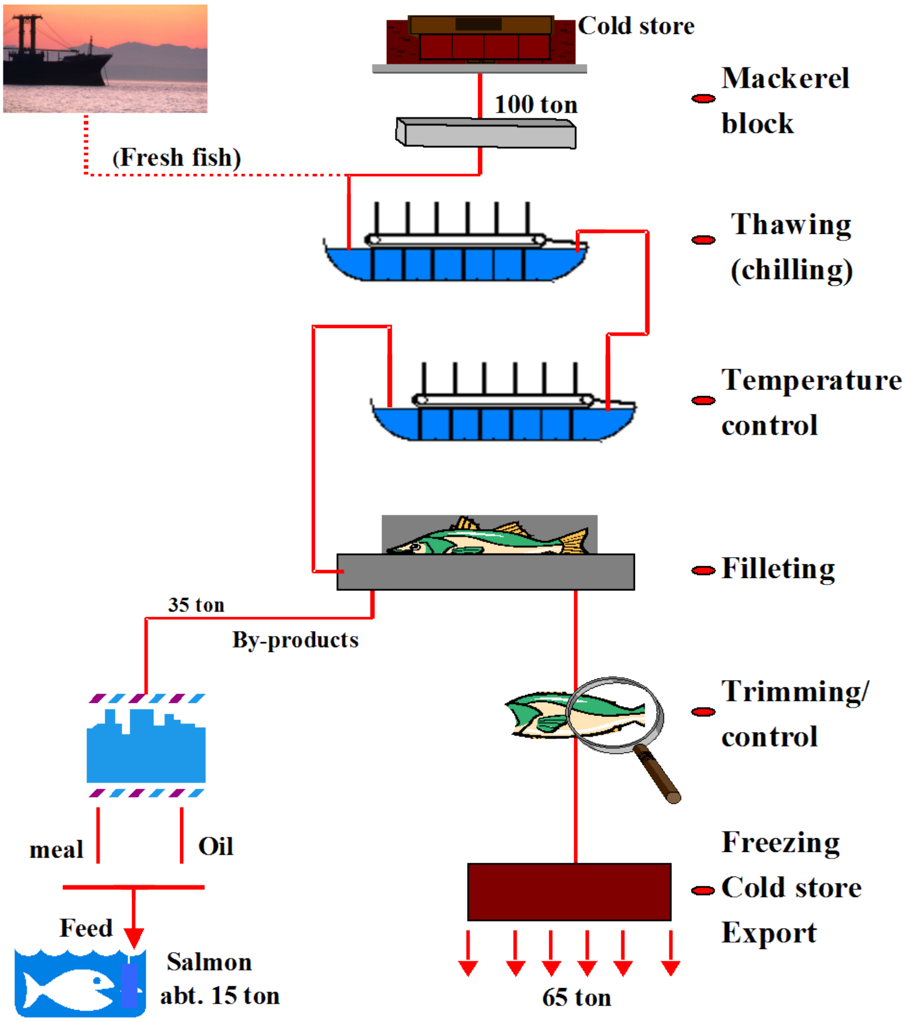

Figure 5: *Reduced transport volumes and use of by-products in a processing plant.*

As shown, the energy demand for chilling is less than for superchilling in the first phase of the cold chain However the demand for icing nearly equalize the difference in the end. Refreshed fish need a large amount of energy in the start for freezing and the same at the end for thawing. Compared to chilled fish products, superchilled fish products has an extended shelf life of 5-7 days, enabling less product spoilage because of a longer sale period. For refreshed fish the shelf life before thawing are many months, but as soon as the fish is thawed it has a shelf life as fresh fish or even less.

There are many advantages related to automated superchilled production with control of the most important raw material parameters. An increase of the microbiological shelf life of fish constitutes new possibilities with respect to production capacity and planning as well as benefits related to distribution and sale of the fresh product. The increased shelf life can open new fresh fish markets, extend the product portfolio and significantly reduce transport costs.

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RÉSUMÉ

Les espérances du consommateur et les besoins du marché changent et la demande de la nourriture saine avec la qualité augmente. En même temps, les défis de visage des industries alimentaires dus à la pression sur l'utilisation de ressource, la production raisonnable et l'utilisation d'énergie. Le refroidissement et la congélation sont les technologies les plus importantes pour préserver la qualité des produits alimentaires et réduire la perte. L'institut international de la réfrigération (IIR) estime que 25-30% de production globale de nourriture est perdu comme perte due au manque de réfrigération. En plus, les technologies de réfrigération sont parmi les technologies les plus grandes consommatrices d'énergie utilisées dans la chaîne d'approvisionnements alimentaires, expliquant environ 35% de consommation de l'électricité dans l'industrie alimentaire. Le besoin de recherche sur des technologies de rendement optimum de réfrigération menant à la durée de conservation accrue et à la qualité des produits alimentaires améliorée est précisé par plusieurs organismes norvégiens. Il y a un grand et incontesté potentiel commercial inhérent à une réfrigération plus optimale et ambiant plus amicale de nourriture. L'industrie de poissons est l'une des industries les plus importantes en Norvège. Des quantités considérables de poissons frais sont transportées de Norvège vers l'Europe journalière. Actuellement, la majeure partie de ce poisson est refroidie et emballée dans des boîtes avec de la glace de 25%. Cet article couvre benchmarking entre différentes méthodes de réfrigération et leur influence sur la qualité du produit, capacité de production, efficacité énergétique et utilisation de matière première. Les méthodes en question sont refroidissement ordinaire, surgélation et régénération. La clef livrable de ce travail est le développement de la technologie nouvelle et améliorée pour la réfrigération efficace des poissons, permettant à l'industrie de comparer différentes solutions technologiques. À leur tour ceci augmentera l'exécution des résultats de la recherche dans toute la séquence de valeurs.