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Guidelines for precooling of fresh fish during processing and choice of packaging with respect to temperature control in cold chains

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Icelandic Food and Biotech R&D
Report summary

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Ágrip á íslensku:	Tilgangur leiðbeininganna er að aðstoða við val á milli mismunandi aðferða við forkælingu ferskra fiskafurða ásamt því að aðstoða við val á pakkningum með tilliti til hitaálags sem varan verður fyrir á leið sinni frá framleiðanda til kaupanda. Fjallað er um eftirfarandi forkælingaraðferðir: vökvakælingu, krapaískælingu og roðkælingu (CBC, snerti- og blásturskælingu). Einnig er fjallað um meðferð afurða á meðan vinnslu stendur og áhrif mismunandi kælimiðla á hitastýringu, gæði og geymsluþol flaka áður en vörunni er pakkað. Leiðbeiningarnar taka mið af vinnslu á mögrum hvítfiski, s.s. þorski og ýsu. Niðurstöður rannsókna sýna að vel útfærð forkæling fyrir pökkun getur skilað 3 – 5 dögum lengra geymsluþoli m.v. enga forkælingu fyrir pökkun. Ófullnægjandi vökvaskipti við vökvakælingu með tilheyrandi krossmengun geta þó gert jákvæð áhrif forkælingarinnar að engu. Íslenskir ferskfiskframleiðendur notast einkum við frauðplastkassa (EPS, expanded polystyrene) og bylgjuplastkassa (CP, corrugated plastic) til útflutnings á ferskum flökum og flakabitum. Hér er því eingöngu fjallað um fyrrgreindar pakkningagerðir. Niðurstaðan er sú að ef hitastýring er ófullnægjandi og hitasveiflur miklar er æskilegt að nota frauðplastkassa sem veita betri varmaeinangrun en bylgjuplastkassar.		
Lykilorð á íslensku:	*Forkæling, kælimiðlar, magur hvítfiskur , hitaálag, pakkningar, frauðplast, bylgjuplast.*		

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Summary in English:	The aim of the guidelines is to provide and assist with choice of different precooling techniques for fresh fish fillets as well as assist with choice of packaging with respect to thermal abuse, which the product experiences during transport and storage from processor to customer. The following precooling techniques are discussed; liquid cooling (LC), slurry ice cooling (SIC) and combined blast and contact cooling (CBCC). In addition, the following is discussed; handling during processing and the effect of applying different cooling media before packaging on temperature control, quality and shelf life of fresh fillets. The guidelines are designed with lean white fish muscle in mind, such as cod and haddock. The results reveal that efficient precooling before packaging can prolong shelf life up to 3 to 5 days compared to no precooling before packaging. If the liquid exchange in the liquid cooler's circulation system is insufficient, cross-contamination can diminish the positive effects of precooling. Icelandic fresh fish processors mainly use expanded polystyrene (EPS) and corrugated plastic (CP) boxes for export of fresh fish fillets. The guidelines are therefore only focused on the above mentioned packaging types. The conclusion is that if temperature control is unsatisfactory and temperature fluctuations are great, then expanded polystyrene boxes are the preferred alternative because they provide better insulation.
English keywords:	*Precooling methods, cooling media, lean white fish fillets, thermal abuse, packaging, expanded polystyrene, corrugated plastic.*

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Symbols

α	proportion of frozen water in fish fillet
c	specific heat (kJ/kg/K)
CBC	combined blast and contact
CBCC	combined blast and contact cooling
CP	corrugated plastic
DI	dry ice
EPS	expanded polystyrene
fob	free on board
GP	gel pack
k	thermal conductivity (W/m/K)
LC	liquid cooling
NC	no cooling
PCMs	phase change materials
R-value	thermal resistance value (m^2K/W)
SIC	slurry ice cooling
T_f	initial freezing temperature (°C, K)

Introduction

The quality of fresh seafood depends on the characteristics and conditions, as well as factors such as hygiene and handling, during pre- and post-processing (from catch to on shore processing). Bacterial growth, enzyme activity, physical damage, dehydration, chemical reactions and contamination are the main causes of quality loss in fish. The importance of precooling and choice of packaging will be investigated with respect to temperature control during processing, storage and transport.

It is desirable to cool the product down to its intended storage temperature before packaging using some precooling techniques, resulting in an efficient and rapid cooling. Otherwise, cooling of an already packaged fish product in an insulated box will require a longer period to achieve the targeted product temperature. The cooling time is even prolonged by palletisation of boxes. A low product storage temperature can be achieved using e.g. one or a combination of the following precooling methods; combined blast and contact cooling (CBCC), liquid cooling (LC) or slurry ice cooling (SIC). Some processors apply extra cooling immediately before packaging in the form of ice/gel-packs, dry ice or water ice.

Experiments have shown that the cold chain from processing to market is discontinuous and therefore packaging plays an important role in keeping the fresh fish products safe from temperature fluctuations (Martinsdóttir et al., 2010, Mai et al., 2010). Since consistent quality is a critical factor to marketing fresh seafood, reliable temperature control is important, being reflected by the resulting shelf life.

The insulation property of a packaging will limit any heat transfer from the surroundings to the fish and vice versa. Heat transfer takes place through convection, conduction and radiation. The insulation value of the packaging is controlled by the physical properties and shape of the packaging, mainly thermal conductivity and wall thickness.

Numerical heat transfer modelling has proved to be an efficient tool for improving the thermal protection of such packaging (Moureh, 2002, Margeirsson et al., 2010a, Margeirsson et al., 2010b). The ambient temperature during transport and storage can fluctuate. Different transport methods e.g. land transport, air or sea freight, with different temperature profiles require different packaging solutions.

Icelandic fresh fish processors can choose between different precooling methods, packaging solutions and transport modes. The aim of these guidelines is to facilitate the decision making for fresh fish processors. In the following sections, the route of the fresh fish is tracked through processing, storage and transport from fresh fish processors in Iceland to wholesalers in Europe.

The research is limited to the following packaging types; i.e. EPS (expanded polystyrene) and CP (corrugated plastic). These packaging types dominate the Icelandic fresh fish products export.

1 Theoretical Discussion

The demand for efficient temperature control in cold chains for fresh fish products has increased for the last decades. An agreement (ATP) was concluded in the 1970, concerning the international carriage of perishable foodstuffs and the special equipment to be used for such carriage. In 2010, over 40 countries are parties to the ATP agreement including two, Morocco and Tunisia, from outside the UNECE region (ATP, 2010). Briefly, the agreement details conditions that have to be fulfilled in temperature control during transport of perishable foodstuffs. A full text of the ATP agreement can be downloaded directly from the UNECE (United Nations Economy Commission for Europe) website: http://www.unece.org/trans/main/wp11/atp.html. Research has shown that temperature control in cold chains of fresh fish products is insufficient compared to the requirements in the ATP agreement, i.e. that the temperature should be as close to 0 °C without crossing the initial freezing temperature (T_f) of the product (Giannakourou et al., 2005, Margeirsson et al., 2008, Mai et al., 2010).

The initial freezing temperature of a product refers to the temperature at which phase change (crystallisation) of water inside the tissue or muscle is initiated. According to Pham (1996), T_f for most fresh foods is -1 °C. Kolbe and Kramer (2007) state that the temperature at which fish muscle starts to freeze depends on the solutes in the tissue fluids and is -0.9 °C for cod with 82 % water content.

The main threats to optimal shelf life of fresh fish products during processing, storage and transport are high temperatures, temperature fluctuations and cross-contamination leading to higher loads of specific spoilage bacteria. At temperatures below 0 °C, there is a significant reduction in microbial growth rates and in the corresponding deterioration of the product due to microbial activity. Going beyond the initial freezing temperature of fish implies that some of the water freezes and the concentration of solutes in unfrozen solutions increase. This may lead to denaturation of the muscle proteins as well as structural damage of membranes, which can result in increased drip loss, loss of water holding capacity and textural changes. It has been demonstrated that the temperature of maximum activity is in the region of -2 to -1 °C (Johnston et al., 1994). If the product is cooled very close to its T_f during precooling, rapid cooling is necessary to ensure formation of small ice crystals within the product structure and minimise textural damages of the muscle (Singh and Heldman, 2003).

Export of fresh fish fillets (tons) from Iceland has increased for the last two decades as well as the free on board (fob) export value (million ISK), as Figure 1 and Figure 2 show. Around 15.4 thousand tons of with value of 15.3 milliard ISK were exported in 2009 according to the Statistics Iceland (2010). Export of fresh fish fillets via sea freight has increased at the expense of air freight. The reasons for this development can partially be explained by the different quality of temperature control in cold chains during transport from Iceland to Europe (Mai et al., 2010), the geographical position of some producers being remote to the international airport and differences in transport costs. The advantage of faster transport mode can be lost if the temperature control during transport is inadequate (Martinsdóttir et al., 2010, Magnússon et al., 2009). As a result the need for an efficient thermal performance of packaging is greater for air shipped fish than for fish transported by sea in refrigerated containers.

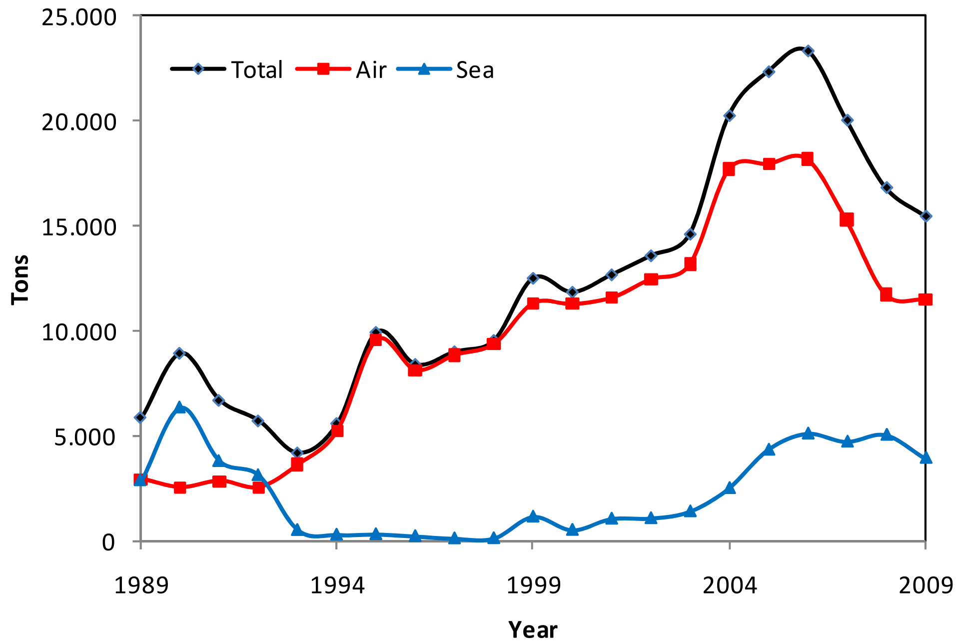

Figure 1. Export of fresh fish fillets (tons) by air and sea freight from 1989 to 2009 (Statistics-Iceland, 2010).

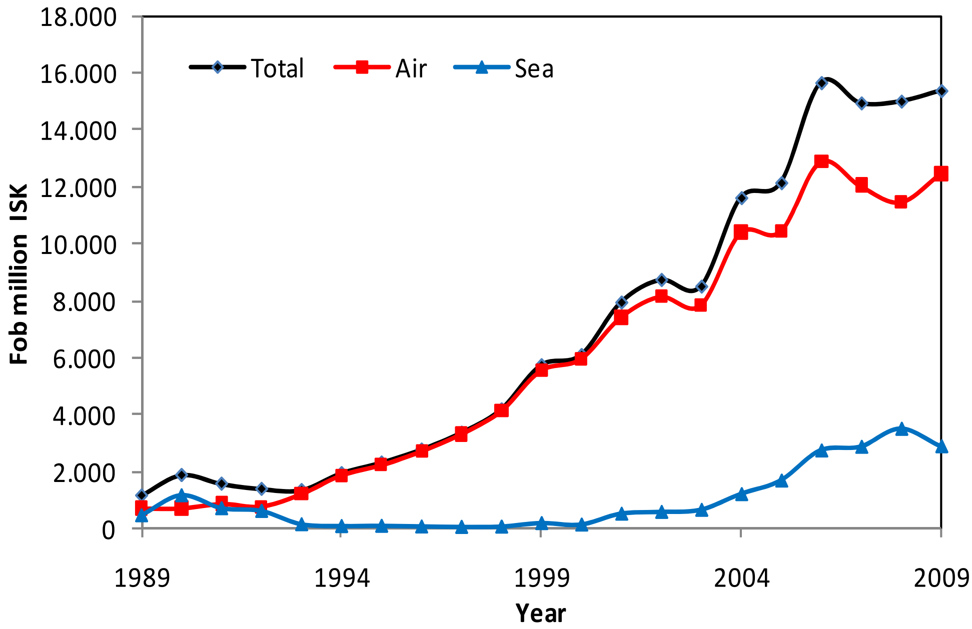

Figure 2. Export value of fresh fish fillets in Fob (Free on board) million ISK by air and sea freight from 1989 to 2009 (Statistics-Iceland, 2010).

According to Mai et al. (2010), the temperature control is rather insufficient during air freight shipping of fresh fish products compared to sea shipping. The lacking performance of air freight shipping is caused by frequent interruption of the cold chain during loading and unloading between different transport modes (e.g. land, air) which makes it difficult to keep the product at desired temperature. The negative effects of undesirable fluctuations in ambient temperature during transport and storage on fresh fish products are reduced to some extent by the thermal insulation of the packaging.

Expanded polystyrene (EPS) boxes are manufactured from moulded polystyrene beads and they comprise 98% air by volume, which makes them light and contributes to their insulation but makes them bulky to store when empty. They are usually white and the lid and box are manufactured in the same manner and designed to interlock, creating a tight seal. Expanded polystyrene is the most utilised packaging for export of fresh fish products during the last decades. Another type of packaging for fresh fish, which is particularly popular because of environmental aspects, is corrugated plastic (CP). The boxes are extruded twin wall plastic sheet products (about 2 – 3.5 mm thick) produced from high impact polypropylene resin. Corrugated plastic can easily be compacted in standard waste compaction equipment and are readily recycled, whereas expanded polystyrene requires specialised compaction equipment and the contaminated polystyrene material is difficult to recycle. The CP boxes can be folded, which saves storage space, but the strength and thermal performance are not as good as with the EPS boxes (Margeirsson et al., 2010a, Margeirsson et al., 2009, Anyadiegwu and Archer, 2002). Experiments performed by Archer (2007) revealed that the EPS box was most effective at maintaining a low average fillet temperature, followed by CP and other boxes.

Because the CP box is relatively new on the market, it has not received as much attention in the research field as the EPS box. Froese (1998) investigated the thermal performance of EPS boxes, which contained live fish in water. Burgess (1999) calculated and compared R-values (measurement of thermal resistance) for different packaging at a constant ambient temperature by using ice-melt test (because of the known physical properties of ice). Further comparison between packaging solutions was performed by Singh et al. (2008) by using the ice-melt tests. Not only was the R-value calculated for different packaging solutions, but the melting point and latent heat (and thereby the cooling ability) of twelve different gel packs and phase change materials (PCMs) were also evaluated. One of the research findings was that the thermal resistance (R-value) is not only dependent on the packaging but also its contents. This indicates that it is desirable to investigate the thermal resistance of different whole sale packaging for fresh fish by experimenting with fresh fish instead of ice.

The cooling ability of gel packs and other PCMs have been evaluated by Labranque and Kacimi (2007) as well as Elliott and Halbert (2005). Research performed by Zalba et al. (2003) provides a good overview of usage of phase change materials in the field of preservation of perishable products. Several authors (Margeirsson et al., 2009, Arnþórsdóttir et al., 2008, Margeirsson et al., 2010a) have demonstrated the importance of using ice packs during transport to maintain desirable product temperature. Icelandic fresh fish processors have shown great interest in further study in precooling techniques for fresh fish before packaging. By precooling fillets before packaging, their temperature is lowered considerably and better maintained or less increased following temperature fluctuations generally observed during transport and storage from processor to wholesaler.

The reason for the enhanced thermal performance of precooled fillets can be explained by Figure 3 which illustrates the relationship between energy, water content, temperature and percentage of frozen water in lean fish muscle. The water content of white fish (lean fish muscle e.g. cod and haddock) is approximately 80-82 % and therefore, it can be read from the figure that by precooling white fish down to -1 °C before packaging, 10-20 % of the water in the flesh is frozen. Since the latent heat of ice is high (around 335 kJ/kg), considerable amount of energy is needed from the environment to raise the temperature of the flesh from -1 °C to 0 °C or around 10 kcal/kg or 42 kJ/kg. Thereby, the shelf life of the fish fillet is generally prolonged because of the precooling process.

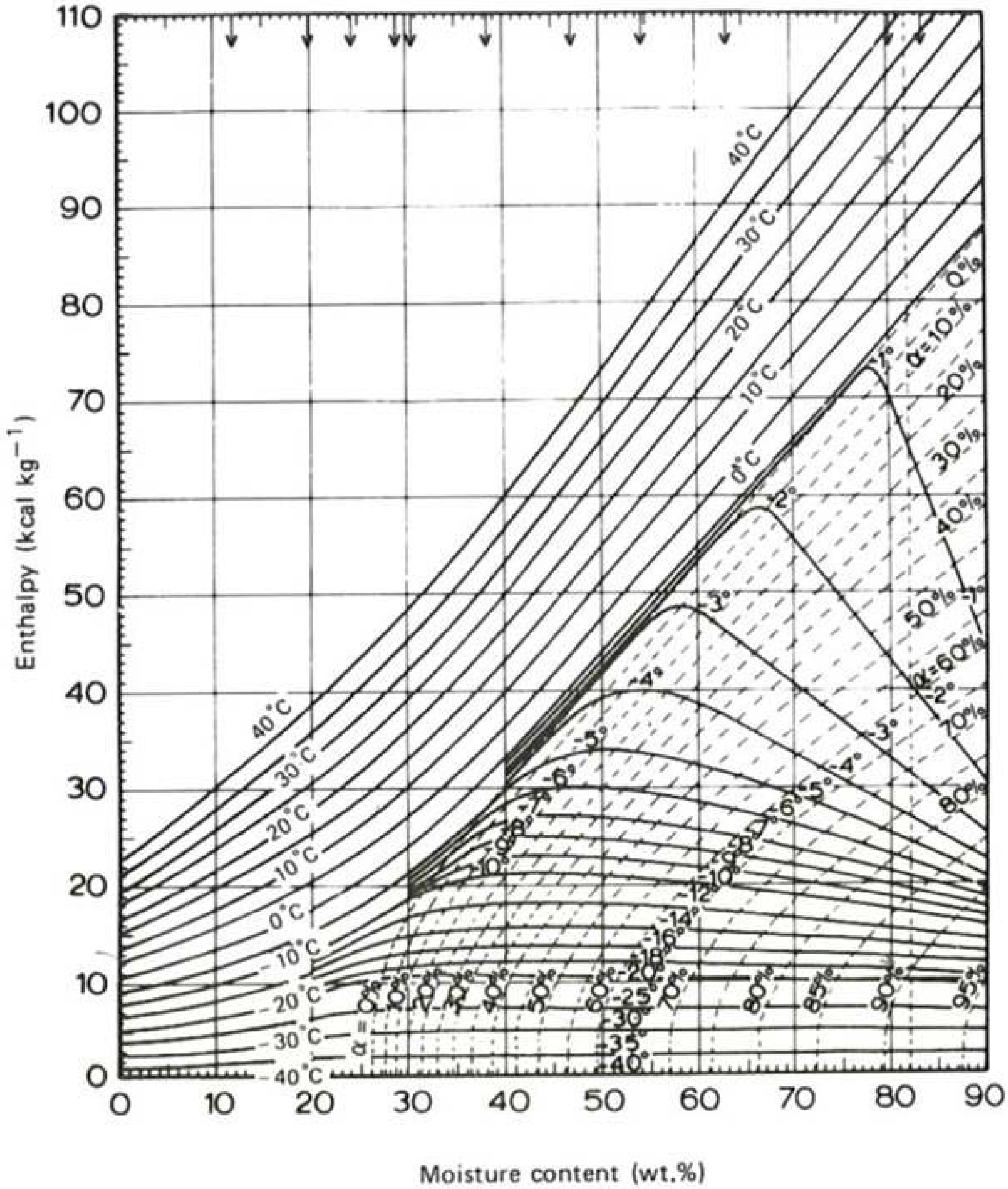

Figure 3. Enthalpy diagram for lean fish muscle (Rha, 1975), α is the proportion of frozen water in the fish fillet.

Both specific heat and thermal conductivity for white fish are temperature dependent, see Table 1 (Johnston et al., 1994). Specific heat is the amount of heat required to change a unit mass of a material by one degree. Notice the 'big jump' in specific heat from -1 to 0 °C, it emphasises even further the amount of energy needed to raise the temperature of fish from -1 to 0 °C.

Table 1. Temperature dependent thermal properties of white fish, thermal conductivity (k) in W/(m°C) and specific heat (c) in kJ/(kg°C)(Johnston et al., 1994) .

White fish							
T (°C)	-6	-4	-3	-2	-1	0	5
k	1.400	1.362	1.342	1.322	1.302	0.43	0.43
c	7.744	15.111	26.539	65.636	102.72	4.144	3.642

2 Processing

Among the factors, which need to be considered during each step of the processing are: hygiene, temperature control, relative humidity of air and handling. Since the main focus of these guidelines is on temperature control, hygiene and handling will not be discussed in details. There are two main tasks in cooling; the fast reduction of the product temperature down to the desired low temperature, and maintenance of the temperature over a longer period. The fast reduction of the temperature is achieved by cooling equipment, in connection to some processing operation or storage and the maintenance at a constant low temperature over a longer period during storage or transport. The aim of precooling is to slow down the process of microbial growth by lowering the temperature. Since all these factors are linked to the quality of the product, the failure of one of them may result in a shorter product shelf life. Precooling has proven to be necessary to ensure that the fresh fish products receive optimum handling. Figure 4 illustrates the factors that affect the quality of fresh fish products during processing. Other factors that are not controlled during processing, but are also known to influence fish quality, include intrinsic factors inherent to the fish at catch as well as extrinsic factors affecting further its condition.

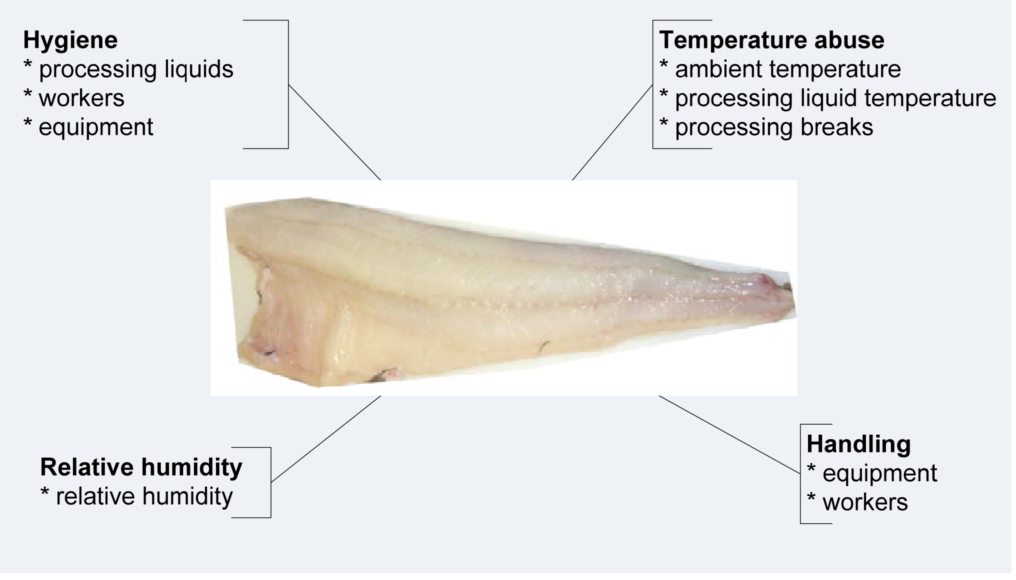

Figure 4. Factors that affect the quality of fresh fish during processing.

The Administration of Occupational Safety and Health in Iceland (AOSH) is responsible for enforcing legislation to prevent accidents and health damage at fish processing plants. According to regulations of the AOSH regarding work in cold rooms in food processing industry, the ambient temperature should be as close to 16 °C as possible on regular basis. The temperature should not drop below 10 °C. On regular basis means that continuous work cannot exceed 1 hour, or maximum 2 hours per day. For further information, see the 6th article regarding temperature for regulations in cold room working facilities in food production published by the Government Offices of Iceland (2005), http://www.reglugerd.is/interpro/dkm/WebGuard.nsf/key2/384-2005.

The flow chart in Figure 6 (on the next page) shows a typical fresh fish processing line. The processing line consists of different levels of processing as well as two-step precooling methods. Precooling before packaging (Step I) and cooling during packaging (Step II) to maintain the desired low temperature. Most fresh fish processors in Iceland use some kind of precooling techniques during processing, but if none is used, then the fish is skinned and trimmed right after filleting and stored in a cold storage, after packaging. The process is discussed in details in the following sections and afterwards, recommendations are given.

2.1 Cold storage

Fish is usually stored iced in tubs inside a chilled storage after it has been landed. The holding time before processing can vary from a couple of hours up to days, and since the cooling method on board differs between vessels, the temperature of the fresh fish can vary. The temperature distribution inside a storage room is often inhomogeneous. To ensure that the tubs experiencing the highest temperature load receive optimum handling, re-icing must take place.

2.2 Beheading, grading and filleting

The fresh fish experiences temperature load due to high ambient temperature during beheading, grading and filleting. Microbial growth accelerates when temperature is raised and, in addition, the fish muscle is no longer protected against cross-contamination after beheading and filleting. Figure 5 shows the fish after beheading and grading in tubs, where it is stored until processed.

Figure 5. The fish is immersed in slurry ice and stored in tubs until processing takes place in order to maintain temperature between -1 and 0 °C.

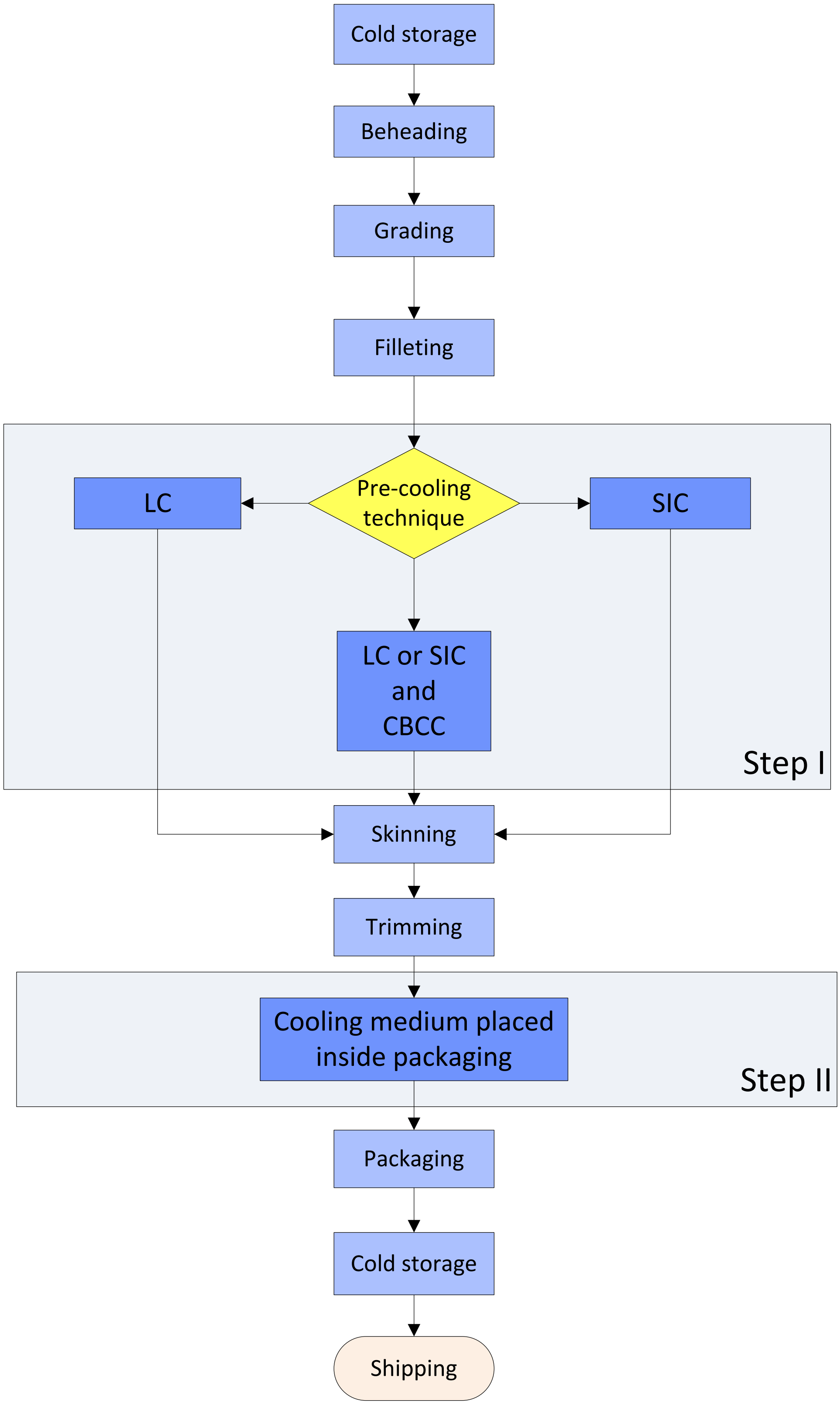

Figure 6. Flow chart displaying a typical fresh fish processing line including precooling. The precooling is twofold and highlighted in Steps I and II.

2.3 *Precooling*

There are mainly three methods of precooling used in the Icelandic fresh fish industry; liquid cooling (LC), slurry ice cooling (SIC) and combined blast and contact cooling (CBCC). Each method aims to effectively lower the temperature of the fresh lean fish to its T_f around -1 °C. The initial freezing point depends upon water and fat content of the fish. A number of experiments have been performed in the field of precooling. The focus of the experiments has been on the effects of the cooling media on the temperature of fresh fish as well as on microbial cross-contamination. The freezing point of water is 0 °C, but -1 °C is a desired cooling medium temperature. To achieve lowering of the fish temperature to its freezing point, cooling agents are added to the water. Salt is the most popular one, but despite its effect in lowering the freezing temperature of water, it may also accelerate growth of spoilage bacteria found in marine fish. Therefore one should use cooling medium with salt concentration as low as possible to reach an optimal cooling temperature. Increased temperature and contamination with spoilage bacteria will result in their rapid growth, hence reducing shelf life. Comparison between methods and a list of recommendations are discussed after the methods have been described.

2.3.1 Liquid cooling

Liquid cooling (LC) is a precooling technique which consists of immersing the fresh fish into cooled brine (NaCl < 5%). The fish is usually dropped from a conveyor belt into a liquid tank and transported via under water conveyor belt or a turning spiral.

An experiment (A) was performed in a processing plant in 2009 where the liquid temperature was recorded. Temperature was monitored with Ibutton DS1922L temperature recorders with an accuracy of ± 0.5 °C from -10 °C to 65 °C and AccuTuff Plus 330 thermometer with an accuracy of ± 0.5 °C from -40 °C to 260 °C, see Figure 7. For further details see:

AccuTuff Plus 330: http://www.technical-sys.com/Atkins%20Accutuff.htm
Ibutton DS1922L: http://www.maxim-ic.com/datasheet/index.mvp/id/4088

Figure 7. AccuTuff Plus 330 digital thermocouple thermometer (left) and iButton DS1922L temperature recorder (right).

The liquid temperature was recorded at the inlet (recorder 8a) and outlet (recorders 8b, 8c and 8d) of the liquid cooler. The experiment (A) revealed difficulties in liquid temperature control, see Figure 8. As the graph shows, the record spanned approximately 8 hours and the temperature fluctuations were considerable.

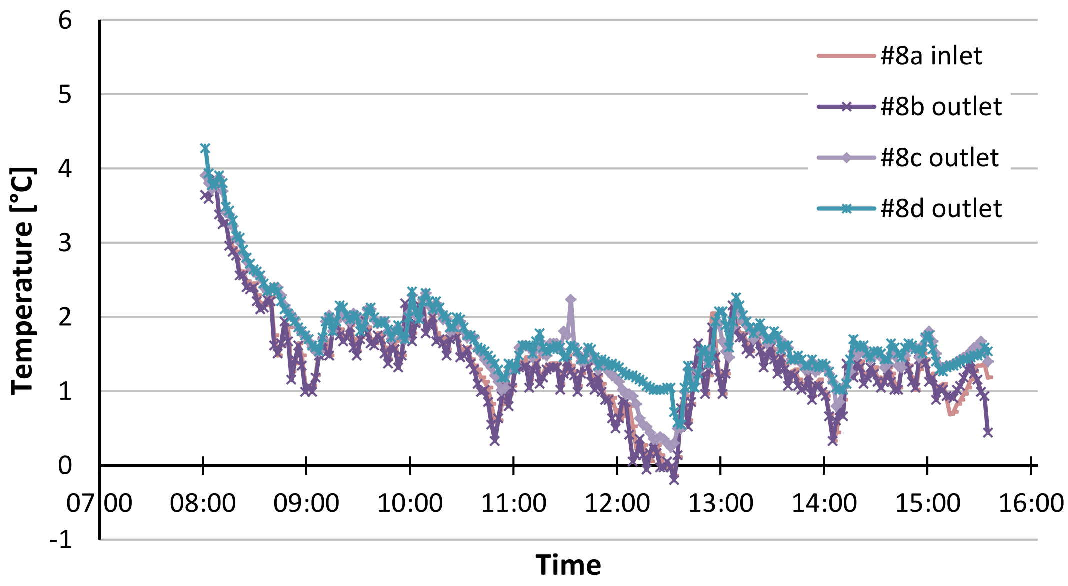

Figure 8. Temperature of liquid at the inlet and outlet of a liquid cooler (experiment A).

Another study (B) was performed where the liquid temperature was closer to T_f for white fish, see Figure 9. The temperature of the liquid was recorded for 40 minutes during which the experiment was performed.

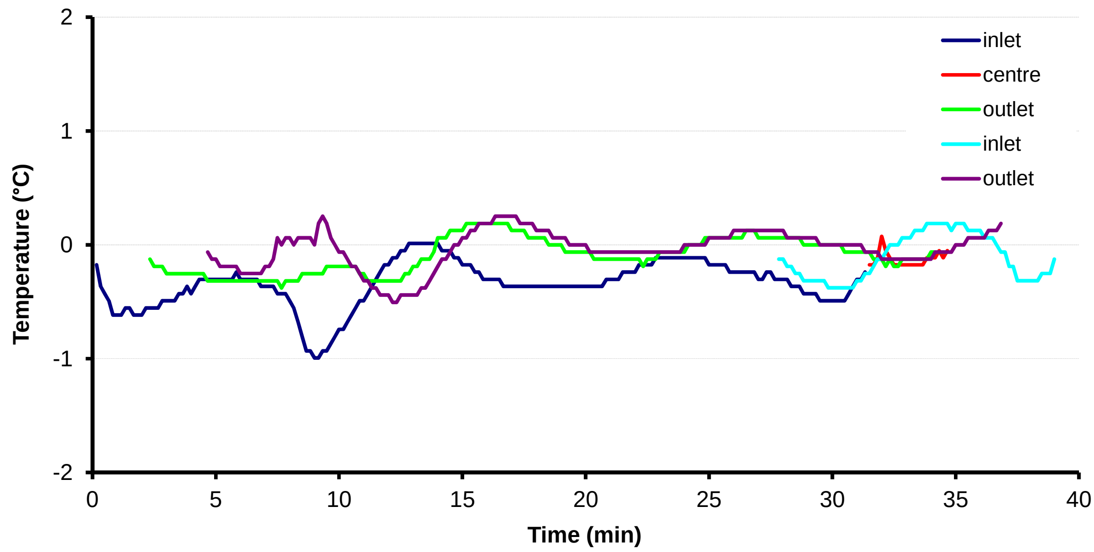

Figure 9. Temperature of liquid at inlet, outlet and centre of a liquid cooler (experiment B).

Three fillets weighing approximately 400 to 650 g were immersed in the liquid cooler for about 6 to 7 minutes. The red circles in Figure 10 show the position of the temperature recorders inside the fillets.

Figure 10. Position of temperature recorders inside fillets.

During immersion the threat of cross-contamination increases and consequently the number of bacteria increases. In addition to liquid contamination, fillets with higher bacterial loads will further increase the liquid contamination. Results from salt and water content measurements are shown in Table 2. The salt content of the liquid was 1.4%.

Table 3 shows the temperature results from the experiment. The temperature of the fish before immersion was approximately 1 °C but approximately -0.5 °C after cooling. The average cooling rate during immersion was 0.26 °C/min. Figure 11 illustrates the temperature of the fillets during immersion.

Table 2. Results from salt and water analysis measurements (experiment B)

	Salt, NaCl (%)	Water (%)
Fillet before LC	0.4	82.4
Fillet after LC	0.5	83.0
Brine	1.4	97.4

Table 3. Temperature data (experiment B)

Fillet weight (g)	630	460	630	**Average**
Temperature before LC (°C)	1.1	1.0	1.3	**1.1**
Temperature after LC (°C)	-0.6	-0.9	-0.4	**-0.6**
Cooling time (min)	6.0	7.0	6.5	**6.5**
Temperature drop (°C)	1.7	1.8	1.6	**1.7**
Cooling rate (°C/min)	0.3	0.3	0.3	**0.3**

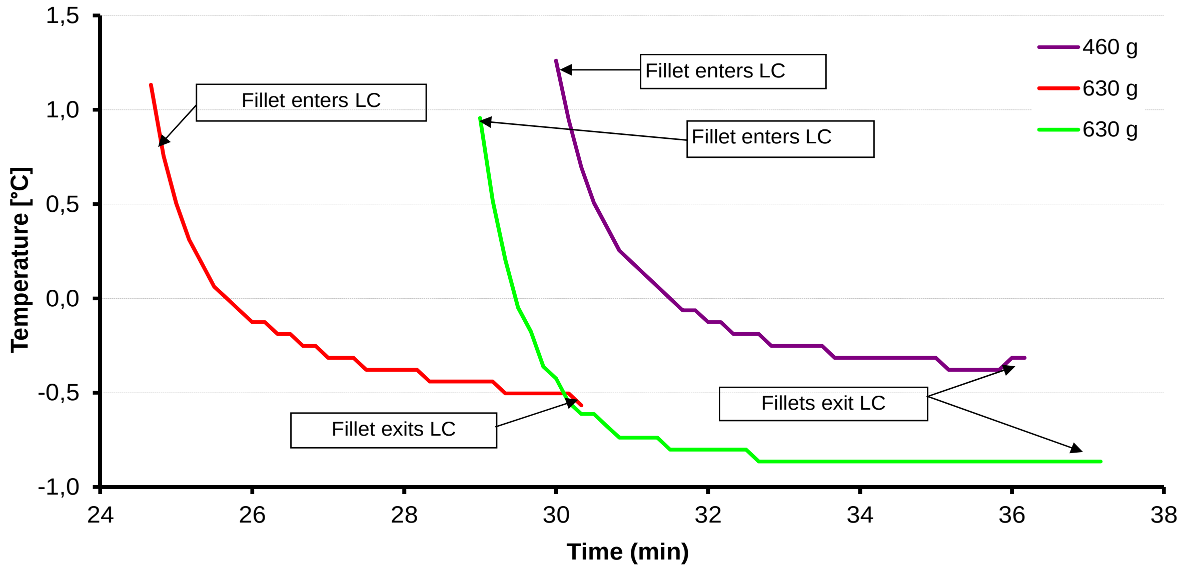

Figure 11. Temperature inside white fish fillets during liquid immersion in experiment B.

2.3.2 Slurry ice cooling

Slurry ice cooling (SIC) is similar to liquid cooling but instead of brine, slurry ice is used as the cooling medium, see Figure 12. The procedure most often consists of tubs with slurry ice and the fish is immersed into slurry ice. SIC can also be performed exactly the same way as LC, where the fish is dropped from a conveyor belt into a slurry ice tank and transported via under water conveyor belt or a turning spiral. Similar problems concerning cross-contamination are present as in LC. Liquid and slurry ice cooling are sometimes used before CBCC.

Figure 12. Slurry ice cooling tank, the inlet is visible to the left.

Figure 13 shows the properties of slurry ice; the relation between ice percentage, salinity (salt concentration) and temperature. The salt depresses the freezing temperature of water, e.g. mixture with 20% ice and 2% NaCl results in ice temperature of -1.4 °C. If the salt concentration is increased by 1 % to 3% NaCl with 20% ice then the ice temperature becomes -2.1 °C. Figure 14 shows the same relation for a wider salinity range.

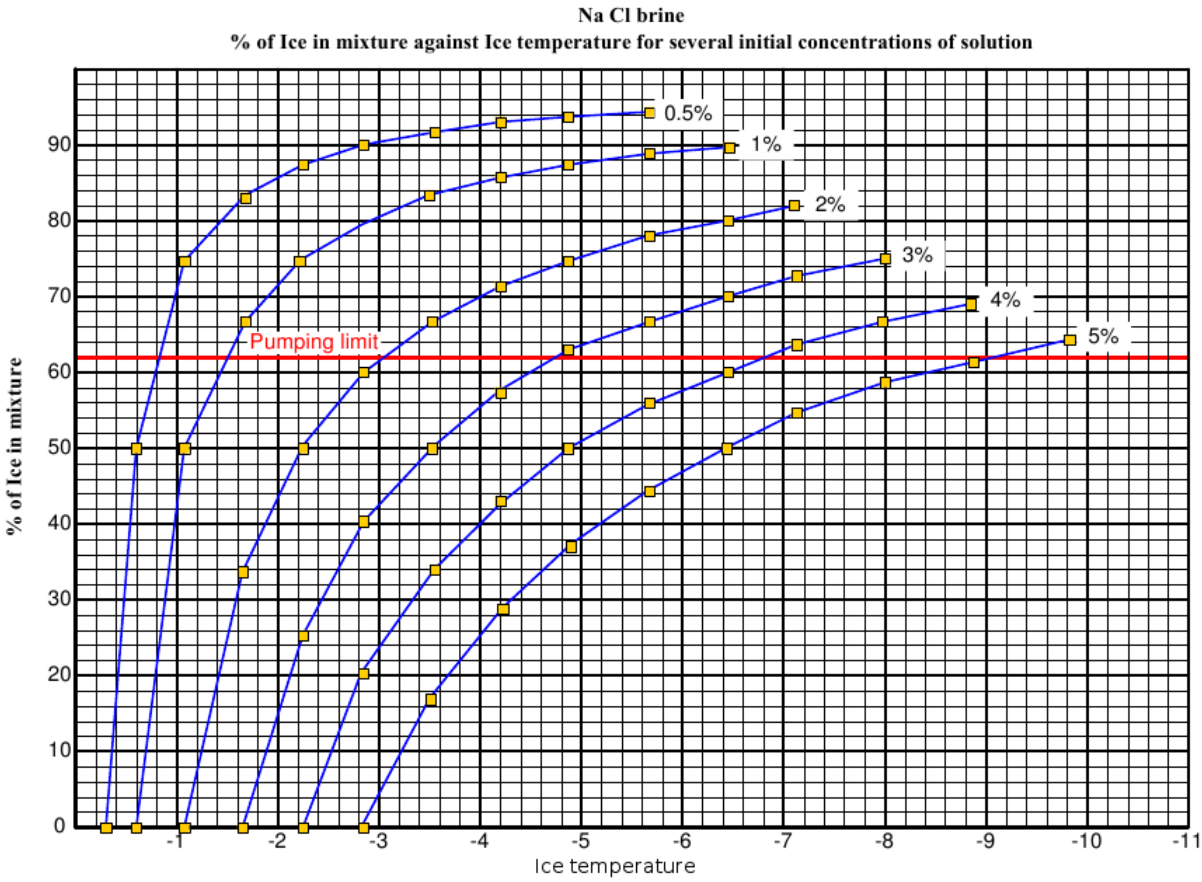

Figure 13. Relation between ice percentage, salt concentration and temperature of slurry ice (Crytec, 2007).

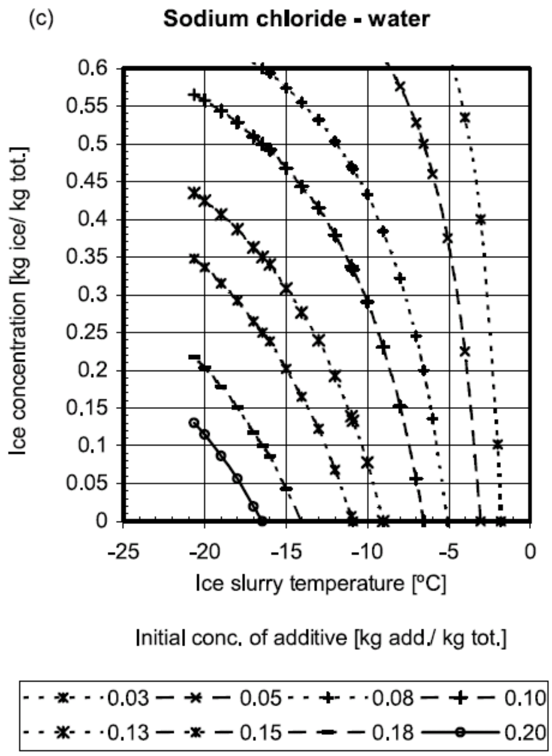

Figure 14. Relation between ice percentage, salt concentration and temperature of slurry ice for a wide range of salt concentration (Melinder and Granryd, 2005).

The cooling capacity (enthalpy) of ice slurries is shown in Figure 15.

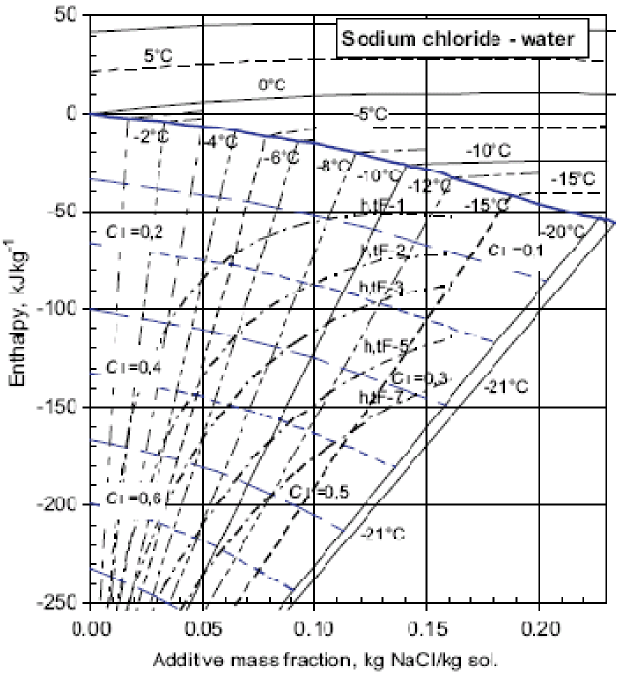

Figure 15. Enthalpy phase diagram of sodium chloride-water (slurry ice) as a function of additive concentration (Melinder, 2010).

2.3.3 Combined blast and contact cooling

Combined blast and contact cooling is a processing technique, which Skaginn hf. has developed and holds a patent for. The CBCC technique consists of a combination of blast and contact cooling. The technique is based on surface cooling after filleting and before or after trimming. A Teflon coated aluminium belt is used for the contact freezing. Before CBCC, the fish can be immersed in brine or slurry ice which lowers T_f for lean whitefish. The fillets lay skin-down on the belt and a fan is located above it, the configuration being displayed in Figure 16.

The temperature inside the cooler is approximately -8 °C and with cooling time is about 6-10 minutes. The size of the fillets controls the required speed of the conveyor belt inside the CBC cooler since small fillets require shorter cooling time than large fillets. Relying on the heat resistance of the fish, the core temperature of large fillets can continue to decrease after exiting the CBC cooler. This rapid cooling process freezes the skin without freezing the flesh.

The fillets exit the CBC cooler at temperature around -1 °C and are dropped on a conveyor belt which transports them to skinning and trimming, see Figure 17. The skinning has little effect on the fillets, since the fillets become stiff during the CBCC. This technique offers several benefits: the fillets are firm after the cooling which makes skinning easier, the fillets can withstand the necessary handling all the way through the processing, generally leading to valuable products with a built-in refrigeration.

Figure 16. Inside a CBC cooler, fillets are laid down on the skin and cooled with blast and contact cooling.

Figure 17. Fillets exiting a CBC cooler, the fillets are laid on a conveyor belt which transports them to skinning and trimming. Fillet temperature is around -1 to -0.5 °C after CBCC.

Martinsdóttir et al. (2004) analysed the effect of skin freezing on the physical properties of the fish muscle and concluded that no difference in microstructure was found between CBC cooled fillets and traditionally processed fillets which received no cooling (NC), see Figure 18 and Figure 19.

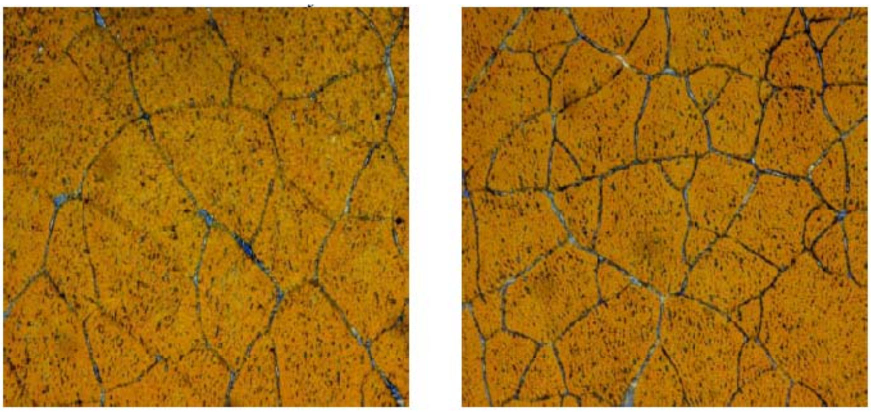

Figure 18. Microstructure of fish fillets 3 mm from the skin, fillets received NC (left) and CBCC (right), (Martinsdóttir et al., 2004).

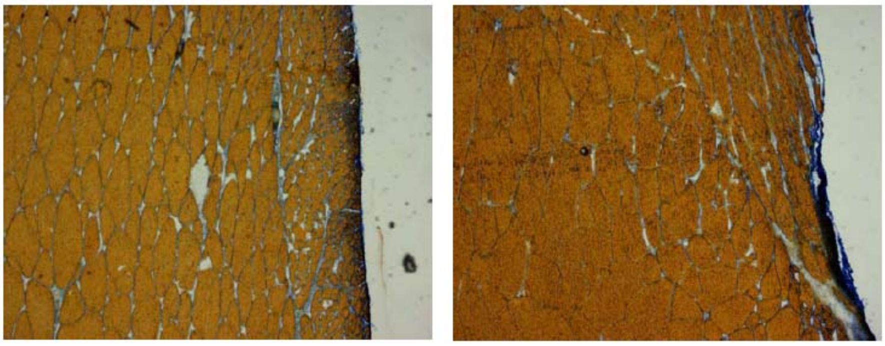

Figure 19. Microstructure of fish fillets next to the skin, fillets received NC (left) and CBCC (right), (Martinsdóttir et al., 2004).

Experiments have shown that the temperature of white fish fillets can be reduced from 1 to 5 °C down to -1.0 to -0.5 °C in only 6-10 minutes using the CBC cooler (Margeirsson et al., 2007). An experiment was performed in a processing plant in 2009 where temperature of fresh fish fillets was recorded during CBCC. Temperature was recorded with Ibutton DS1922L temperature recorders (see Figure 7) with an accuracy of ± 0.5 °C from -10 °C to 65 °C. The temperature of the fillets was measured in the centre of the thickest part of the fillet. Before entering the CBC cooler, the fillets were identified with plastic tags and temperature recorders were inserted in the fillets.

Variations in both ambient temperature inside the cooler and size of fillets were tested in an experiment in 2009. The ambient temperature varied from -9 to -6 °C, and the size of the fillets weighed around 300 to 1100 g. The placement of the fillets during transfer through the CBC cooler and position of ambient temperature recorders is shown in Figure 20. The fillets were located along the conveyor belt to observe if the fillets received similar cooling regardless of position. Ambient temperature was recorded at positions marked with orange circles (numbered #5a, #5b, #5c and #5d) about 10 to 20 cm above the conveyor belt.

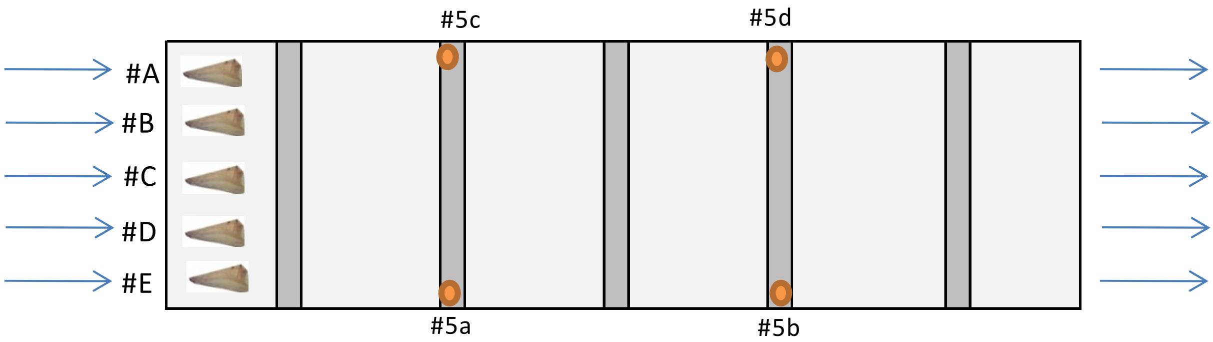

Figure 20. Position of five 400-600 g cod fillets (#A, #B, #C, #D, and #E) transferring through a CBC cooler. Ambient temperature was recorded at position marked with orange circles (#5a, #5b, #5c and #5d) about 10 to 20 cm above the conveyor belt.

Figure 21 illustrates the temperature inside five 400 to 600 g cod fillets (numbered #A, #B, #C, #D, and #E) transferring through a CBC cooler. Entering and exiting the CBC cooler took about 1 minute and the fillets were approximately 8-10 minutes inside the cooler. During insertion the temperature of the fillets rose up to 2.0 - 2.5 °C before entering the cooler.

The ambient temperature is shown in Figure 22 where the average temperature was approximately -8.0 °C but differs with position inside the cooler. The reason why the ambient temperature is not homogeneous can be explained by the powerful fans, which are located on one side of the cooler above the conveyor belt.

During the 10-min period inside the CBC cooler, the fillet temperature dropped by approximately 3.0 °C resulting in final temperature of around -0.8 °C. After the fillets exited the cooler, they continued to cool down at ambient temperature around 15 °C. The fillets maintained the optimum temperature for about 30 minutes when stored in an open plastic box at ambient temperature in the processing hall.

Other experiments have confirmed that CBCC is a successful method for decreasing the temperature of fresh fillets to the T_f, around -1 °C, quickly and effectively (Gao, 2007).

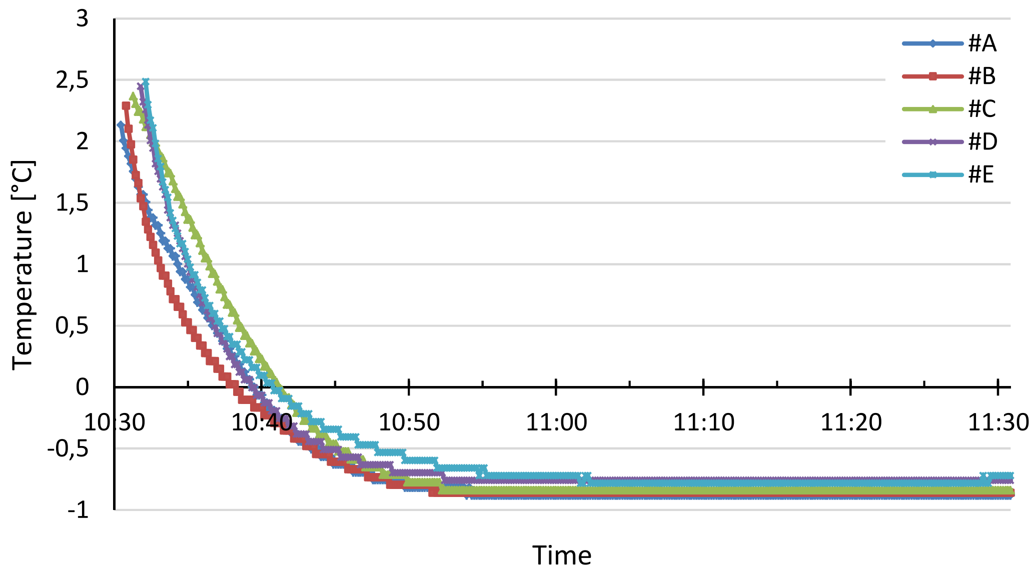

Figure 21. Temperature inside five 400-600 g cod fillets (#A, #B, #C, #D, and #E) transferring through a CBC cooler.

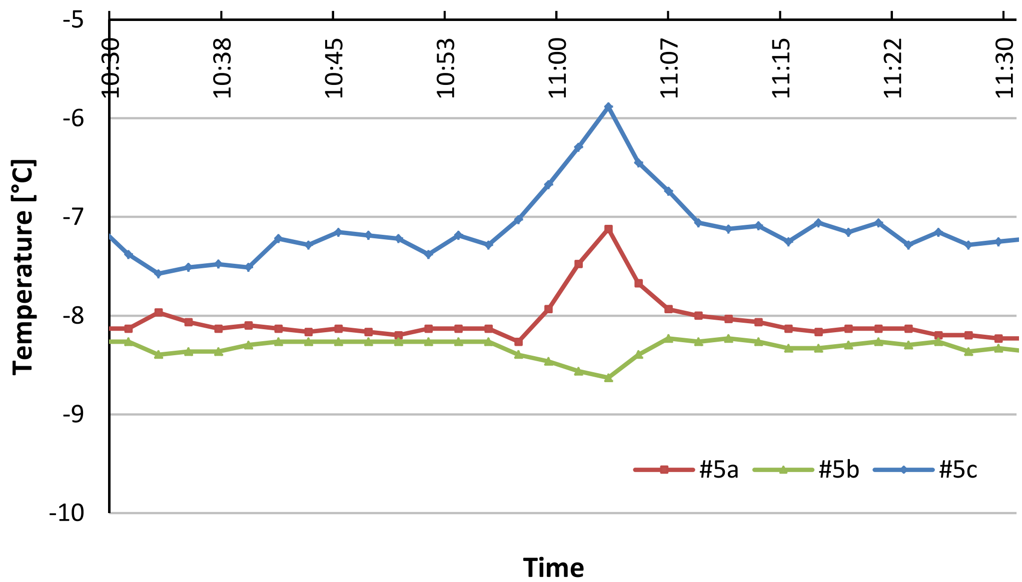

Figure 22. Ambient temperature inside the CBC cooler, each line represents a different position inside the cooler.

2.3.4 Comparison between LC, SIC and CBCC

Experiments have been performed to investigate the effects of LC versus SIC on quality and storage life of fresh cod fillets. In an experiment performed by Margeirsson et al. (2010c), the two cooling media were compared to no precooling during processing. The groups consisted of NC, LC and SIC. Samples were analysed with sensory evaluation, microbial and chemical methods for up to sixteen days from catch. The results showed that immersing the skinless cod fillets in brine (1.5 – 2.2% NaCl) prior to packaging resulted in a shelf life reduction of up to 2 days in comparison with fillets that were not immersed in liquid or slurry ice. This could be attributed to the fact that the cooling liquid carried considerable amounts of microbes including H_2S-producing bacteria and *Photobacterium phosphoreum* (Pp) which are active producers of trimethylamine (TMA). Highest microbial and chemical values and shortest shelf life were seen in the experimental groups where liquid cooling was applied after skinning. Results from temperature measurements from the same experiment indicated that slurry ice is recommended as a precooling medium during processing because of its higher cooling capacity than that of the brine.

In fact, the salt content required in a cooling medium to reach a suitable cooling temperature is higher for a one-phase brine compared to a two-phase slurry ice. As an example, a brine containing 2% NaCl cannot be cooled below around -1.1 °C without partially freezing the brine, while slurry ice with a common ice percentage of 20% only needs around 1.5% NaCl in order to reach the same temperature, see Figure 13. This fact alone makes slurry ice more appropriate than brine for precooling since a lower salt concentration will result in a lower salt uptake in the fish muscle. Further, it is easier to maintain the low temperature in a slurry ice than a brine cooling medium due to the higher latent heat of slurry ice. This is advantageous during cooling fish and ensures a better temperature control in process.

Two trials were performed by Arnþórsdóttir et al. (2008), a preliminary experiment (I) and a main experiment (II). In the preliminary experiment (I), water-holding capacity, quality and cooking yield were examined. In the main experiment (II) these same factors were examined, in addition to the superchilling effect on extended shelf-life of fresh and frozen haddock fillets.

The drip loss decreased in fillets in the superchilled state, which gave improved yield and quality. The final yield of the fillets after the CBCC was 100.3% to 101.2%. After skinning the fillets without precooling (traditional process) lost most weight. Fillets which were CBC cooled showed the best yield of the groups which indicates that the cooling process leads to a higher yield than the traditional process. Further, the process yield from whole gutted haddock was higher for the CBCC process than the traditional, 41.0% and 38.5%, respectively.

The CBCC increased the water holding capacity of the fillets, an important quality attribute which gives a juicier final product. The CBC cooled fillets had less gaping than the traditional ones. The traditional fillets had more ragged outlines, and the ratio of cut-offs after fine-trimming was therefore higher for the traditional fillets than the CBC cooled ones. Appearance of the traditional fillets (without precooling) showed a little yellow tinge which increased during the storage time. The CBC cooled fillets had a whiter colour. Examination of total bacterial counts, TMA and TVN content showed that CBCC can extend the shelf life of fresh haddock fillets.

The overall assessment of these two trials was that CBCC has more advantages than a traditional process without any additional refrigeration. CBCC led to better yields and therefore more valuable products with extended shelf life (Arnþórsdóttir et al., 2008). These results are in accordance with results from previous experiments performed by Martinsdóttir et al. (2004).

Martinsdóttir et al. (2010) investigated the effects of different cooling techniques during processing and temperature fluctuations during transport on the storage life of cod loins with and without gel packs. Both LC and CBCC (LC prior to CBCC) were used. The effect of real temperature simulation (RTS) during storage was compared to a steady storage temperature of -1 °C. The samples were analysed with sensory, microbial and chemical methods. The temperature was recorded with iButton temperature recorders and the CBC cooled fillets were transported to Bremerhaven via air and ship freight. The packaging used for this experiment was expanded polystyrene (EPS) boxes.

The experimental groups were as follows:

a) Liquid cooling and combined blast and contact cooling, with a cooling gel pack (GP) and stored under RTS conditions at Matís.
b) Liquid cooling and combined blast and contact cooling, stored under RTS conditions at Matís.
c) Liquid cooling, with a cooling gel pack and stored under RTS conditions at Matís.
d) No cooling during processing, with a cooling gel pack and stored under RTS conditions at Matís.
e) Liquid cooling and combined blast and contact cooling, with a cooling gel pack and stored at -1 °C (S) at Matís.
f) Liquid cooling and combined blast and contact cooling, stored at -1 °C at Matís.

The following abbreviations were used for the experimental groups:

A. CBCC-RTS-GP
B. CBCC-RTS
C. LC-RTS-GP
D. NC-RTS-GP
E. CBCC-S-GP
F. CBCC-S

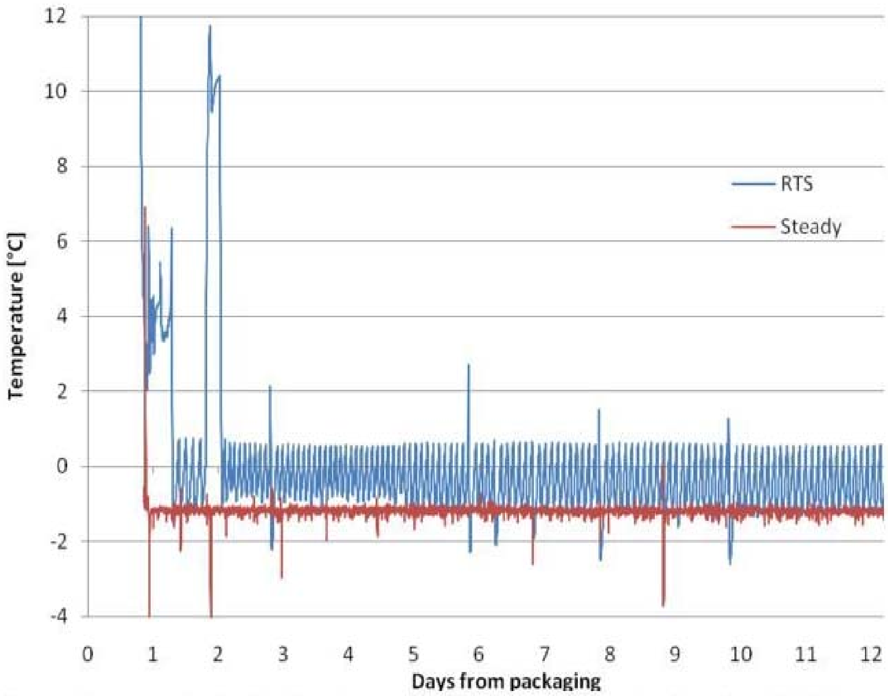

Figure 23. Ambient temperature in climate chambers which simulated real (air freight) temperature (RTS) and steady temperature (Steady) at -1 °C.

Figure 23 illustrates how the real (air freight) temperature simulation (RTS) and steady temperature simulation were performed. The boxes used for the RTS simulation were placed in a climate chamber with ambient temperature of 4.6 ± 3.0 °C. After 12 h the temperature was lowered to −0.6 ± 0.7 °C for 12 h and then raised again to 9.8 ± 2.2 °C for 6 h. Afterwards the temperature was kept at constant at -0.5 ± 0.5 °C for the remaining storage period (12 days). The boxes subjected to steady temperature were placed in a climate chamber with an ambient temperature of -1.2 ± 0.2 °C during the whole experiment.

Comparison of temperature among groups can be seen in Figure 24. Group D (NC-RTS-GP) reached the highest temperature, over 2.5 °C during the second thermal load period (9.8 °C for 6 h). A comparison between the two groups A (CBCC-RTS-GP) and C (LC-RTS-GP) revealed that CBCC was much more effective in maintaining a low temperature during periods of thermal load as it only reached a maximum temperature around 0.9 °C compared to 2.0 °C for liquid cooling. It should also be noted that all the groups receiving CBCC started with an initial temperature around -0.9 °C compared to about 2.2 °C for the groups receiving liquid cooling or no cooling.

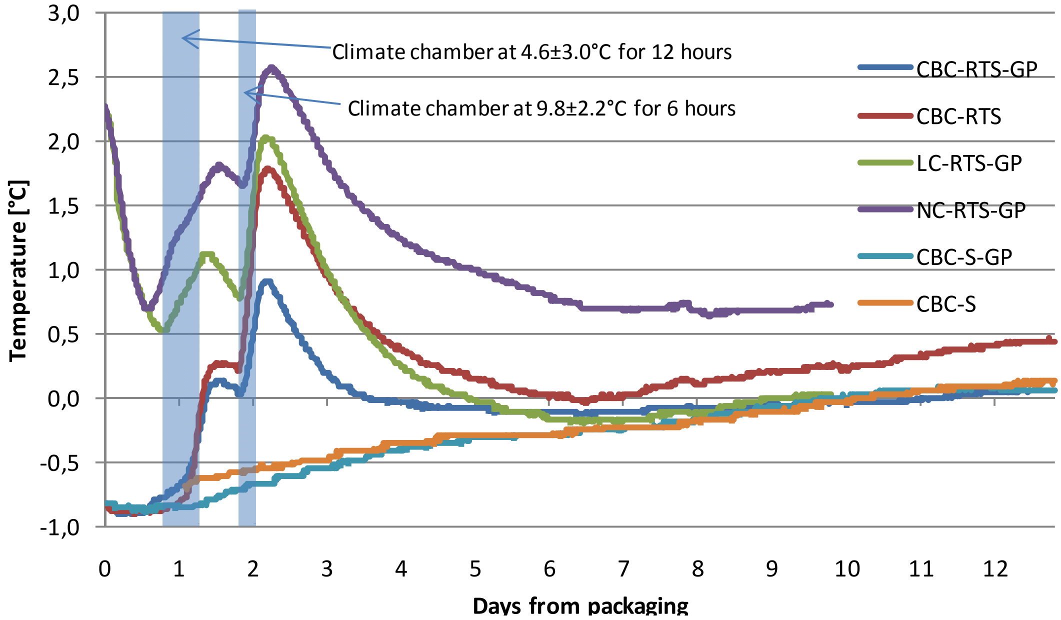

Figure 24. Average product temperature history of all groups during transport and storage at Matís.

CBCC resulted in a significantly lower product temperature profile during the thermal load applied for the first two days of the experiment. The use of gel packs slowed the temperature increase during periods of applied thermal load. Liquid cooling contributed to the maintenance of a lower temperature during the entire storage period compared to no cooling. According to sensory evaluation, immersing the fillets in liquid resulted in shorter freshness period and shorter maximum shelf life as compared to untreated fillets. Table 4 displays the freshness period (days) and shelf life (days) for all the groups. By using CBCC, and proper temperature control during storage and transport as well as gel packs, the shelf life was extended by 3-5 days compared to liquid cooling or no cooling (Martinsdóttir et al., 2010).

Table 4. Freshness period (days) and maximum shelf life (days) according to sensory evaluation (CBCC: Combined blast and contact cooling, RTS: Real temperature simulation, LC: Liquid cooling, NC: No cooling, GP: Gel pack, S: Storage at -1 °C)

Group	Freshness period (days)	Shelf life (days)
CBCC-RTS-GP	7-9	9-10
CBCC-RTS	7-9	9-10
LC-RTS-GP	6-7	8-9
NC-RTS-GP	7-9	10+
CBCC-S-GP	7-9	12-13
CBCC-S	8-9	12-13

2.4 Skinning

Skinning is carried out either before or after precooling. If the fresh fillets are superchilled using the CBC technique, skinning is carried out afterwards. Otherwise, it is a matter of choice for the processor. The fish tends to be more sensitive for the skinning process if it is not chilled properly and the chances of muscle deterioration increase. However, removal of the skin prior to liquid cooling may result in a lower microbial contamination of the cooling medium, and possibly, less cross-contamination to the fillets. Superchilling has both positive and negative effects on the skinning process. The positive effects is less gaping during skinning if it is well cooled, but the negative effects are present if the fish is cooled below -1.5 °C, which causes excessive ice crystals formation obstructing the skinning process.

2.5 Trimming

After the fresh fillets have been processed and precooled they go through final processing which involves trimming. Most processing flow lines operate in a continuous flow and individual worker statistics are collected at work stations. A common flow line, the Marel Basic Fish Flowline, see Figure 25, offers a short processing time, gentle product handling and good efficiency. A single conveyor is used for both input and output. Left and right fillets are processed separately and the line has a bin for untrimmed fillets. The fresh fish is exposed to additional thermal load during trimming because of handling and waiting time in the bin. If the fresh fish is put in the bin just before a break the temperature raises quickly, which has a negative effect on the shelf life of the product. The heat transfer consists of thermal conductance from conveyor belt to fillet, convection from surrounding air to fillet and even radiation from the surroundings.

Figure 25. Basic Fish Flowline from Marel (2010).

An experiment was performed in a processing plant in 2009 with the purpose of gaining a better understanding of how fast the fillet temperature rises during breaks. The fillets were removed from the processing line after entering the trimming area and placed in a plastic box on a plastic table next to the processing line, see Figure 26. The ambient temperature was recorded during the 2.5 hours thermal load period and is displayed in Figure 27. The temperature of the fillets increased by 3 - 4 °C during the first 30 minutes of the trial and the ambient temperature was around 20 °C. This gives a good idea of how important it is to keep a continuous material flow during fish processing.

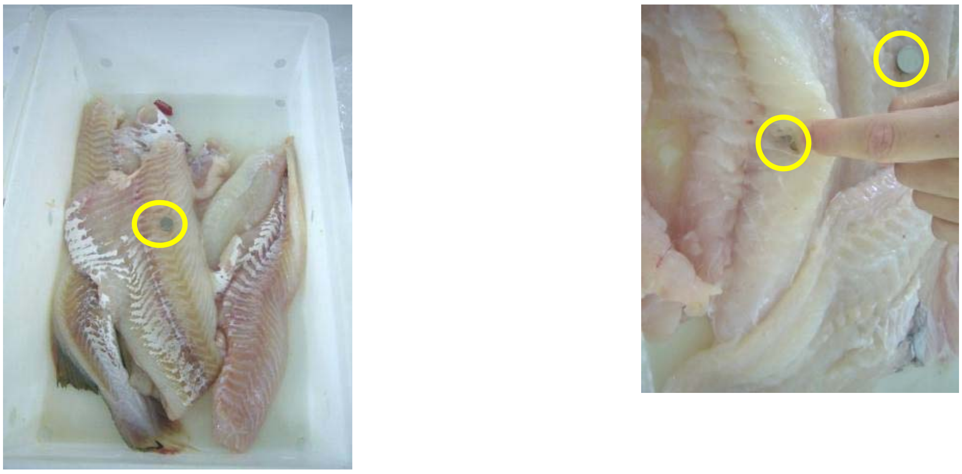

Figure 26. Fillets placed in a plastic box on a plastic table simulating the waiting period during breaks in trimming (left) and position of temperature recorder inside the fillet (right). The temperature recorders are marked with yellow circles.

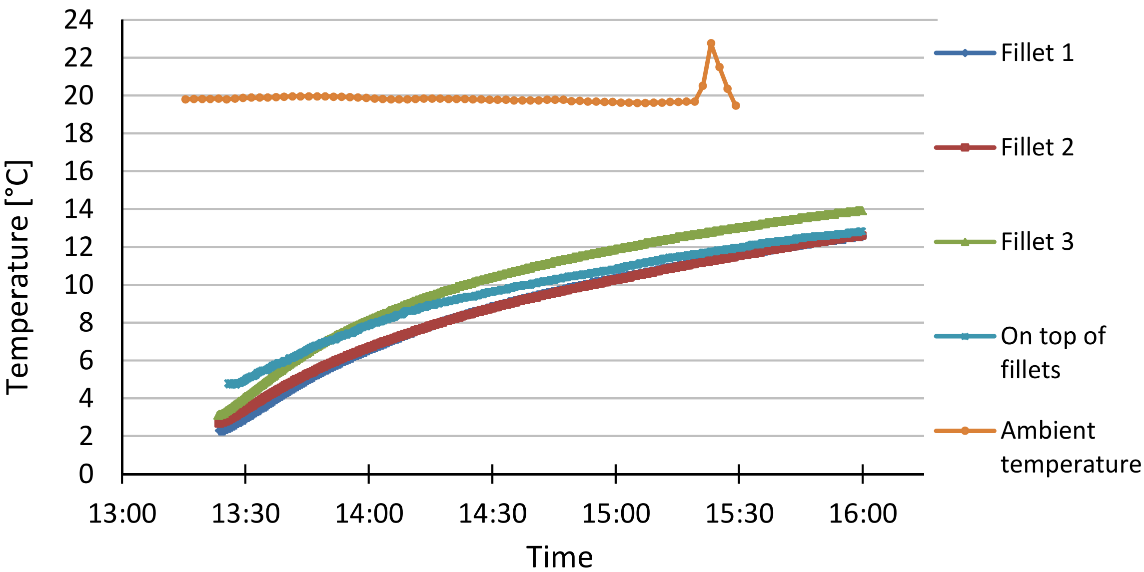

Figure 27. Fillet temperature increasing during break simulation in the trimming area.

2.6 Recommendations

- Tubs should be stored in a chilled storage with ambient temperature around 0 - 2 °C, avoiding ice formation inside the storage after beheading and grading.
- All time delays should be minimised, especially in case of high ambient temperature and exposure to direct sunlight.
- Fresh fish is sensitive to microbial contamination during immersion brine or slurry ice and therefore it is of great importance that the cooling medium is of high hygienic standard, properly cooled and renewed during processing. The possibility of adding a fillet rinsing

step prior to liquid cooling to reduce the introduction of a heavy microbial load to the cooling medium should be considered.

- One way to achieve a better microbial control of the cooling medium is by improving the circulation in the tank, ensuring homogeneous cooling.
- Temperature of the brine or slurry ice should be in the range between -1.5 to -0.5 °C and duration of cooling appropriately selected such that product temperature between -1 and -0.5 °C will be achieved after cooling.
- It has not been thoroughly investigated if immersing the fillets in cold brine is necessary in order to keep the fillets from sticking to the Teflon conveyor belt when using the CBC technique.
- Temperature control during processing must be efficient, especially during breaks.
- The time, which the fillets are exposed to high ambient temperature in the processing room, must be minimised as possible, e.g. by avoiding the accumulation of fillets at workstations during trimming.
- If possible, it is recommended that the all conveyor belts in the processing room carrying fish fillets are cooled down close to the product temperature.

3 Packaging, storage and transport

There are two main tasks in cooling fresh fish, the fast reduction of temperature down to a desired low temperature, about -1 °C for white fish (lean muscle), and the maintenance of the temperature during storage and transport. Packaging plays a very important role in maintaining a desired temperature of the product, especially if ambient temperature fluctuations are frequent. Expanded polystyrene (EPS) and corrugated plastic (CP) boxes are commonly used amongst Icelandic processors and exporters of fresh fish.

3.1 Cooling during packaging

After the fresh fish has been fully processed, it is packaged and usually, a plastic film is laid over the fish, see Figure 28. Before the fresh fish is placed inside non-draining boxes (in case of air transport), absorbent pads are used to avoid soaking of the product in the exudate water. To protect the fish against possible future thermal loads a cooling medium is often put on top of the plastic film before closing the box. This cooling medium is usually frozen when inserted into the packaging. It provides cooling after the lid has been put on and the packaging thereby closed. This is the second precooling step and afterwards the packaging will not be opened until in the hands of the buyer.

Figure 28. Fish placed in packaging (left) with a plastic film on top (middle), before a cooling medium, e.g. a combination of dry ice and ice pack (right) put on top of the plastic film.

The cooling media are referred to as phase change materials (PCMs). The melting point of the PCMs should be as close as possible to the desired product temperature, which is around -1 °C for white fish. As before, the aim of the cooling is to reduce quality degradation and microbial growth, which both increase with increasing temperature. The most common cooling media are dry ice, ice- or gel-packs and water ice. The choice of cooling media depends upon the required product temperature and duration of storage and shipment.

Water ice is solely used in land and containerised sea transport where the ice has a clear way out of the packaging after melting, see Figure 29. The other three types of cooling media are frequently used for transport via air freight and also containerised sea transport. Sometimes a combination of cooling media is used, such as dry ice in addition to ice packs, as shown to the right in Figure 28. An overview of phase change materials is found at:
http://www.coldchaininfo.com/papers/refrigerants.html.

Figure 29. Water ice placed on a plastic film on top of fish fillets in a box with drainage holes at the bottom.

3.1.1 Dry ice

Dry ice is made from liquid carbon dioxide by reducing pressure and temperature in a controlled manner. Liquid carbon dioxide is converted into clean white carbon dioxide snow. The snow is then compressed under high pressure to form blocks. The melting temperature of dry ice at 1 atm or 101.325 kPa is around -79 °C and when the temperature rises, dry ice sublimates from its solid form directly to gas without passing through a liquid phase (AGA, 2010). According to AGA (2010), the characteristics of dry ice are the following:

- Flavourless and odourless
- No residue due to sublimation
- Germ and bacteria-free
- Non-poisonous
- Non-flammable
- Easy to control because heavier than air
- Requires no electricity on-site when used for cooling
- More than three times colder than water ice

Dry ice is usually spread over a plastic film covering the fillets in order to lower the temperature of the fresh fish after it is placed in the packaging, just before the lid is put on. Commonly 300 - 600 g of dry ice is used for each 5 kg fresh fish package. More research is needed on the importance of the plastic film for protecting the fillets against possible cold spots.

3.1.2 Ice-or gel-packs

Ice- or gel-packs are available in different sizes and shapes, but they all have in common that they contain a frozen liquid. Gel-packs are very similar to ice-packs but instead of containing ice they contain a gel. Manufacturers can control the melting point of the packs by adding substances to the liquid. Singh et al. (2008) tested the melting points and latent heats of some gel packs and concluded that they were very similar to water. These authors also stated that the shape of the gel packs played a significant role. With large surface and small volume, gel packs melted faster but kept the product colder and with small surface and large volume, the gel packs lasted longer but the product was not as cold.

The position and number of ice- or gel-packs (and size) control the thermal performance of cooling packs. An experiment was performed at Matís, where 150 g ice-packs and 5 kg expanded polystyrene (EPS) boxes were used. The experiment consisted of four groups, see Table 5.

Table 5. Four experimental groups (A, B, C and D) with 150 g ice-packs placed on top and/or at bottom of 5 kg expanded polystyrene boxes, containing 5 kg of white fish (x indicates no ice-pack)

Box nr.	On top	At bottom	Total
A	*150 g*	*2 x 150 g*	3 x 150 g
B	*2 x 150 g*	*x*	2 x 150 g
C	*150 g*	*150 g*	2 x 150 g
D	*150 g*	*x*	1 x 150 g

Temperature was recorded at four different positions inside the boxes: at the bottom corner (#1), in the middle of the fish pile to the side (#2), at the top corner of the fish pile (#3) and in the middle of the fish pile in the centre of the box (#4). The duration of the trial was 24 hours with an ambient temperature of 18 °C. The positions are illustrated in Figure 30.

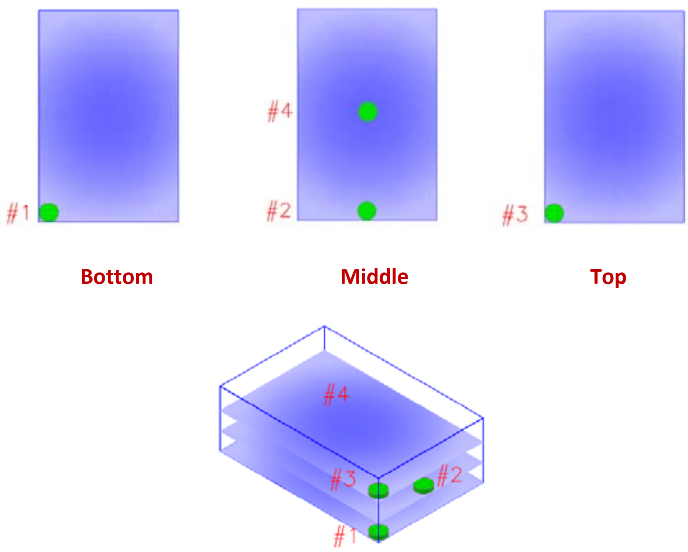

Figure 30. Positions of temperature recorders during the ice pack trial, recorders are represented by green buttons.

The results revealed that the position of the ice-pack inside the box matters, see Figure 31. The comparison between position of the ice-packs; two on top (B) compared to one on top and one at the bottom (C) showed that option C provided better cooling. This suggests that the cooling capacity of the ice-packs should be distributed throughout the box. The box with one ice pack located on top (D) received the poorest cooling during the 24 hours of temperature abuse at 18 °C.

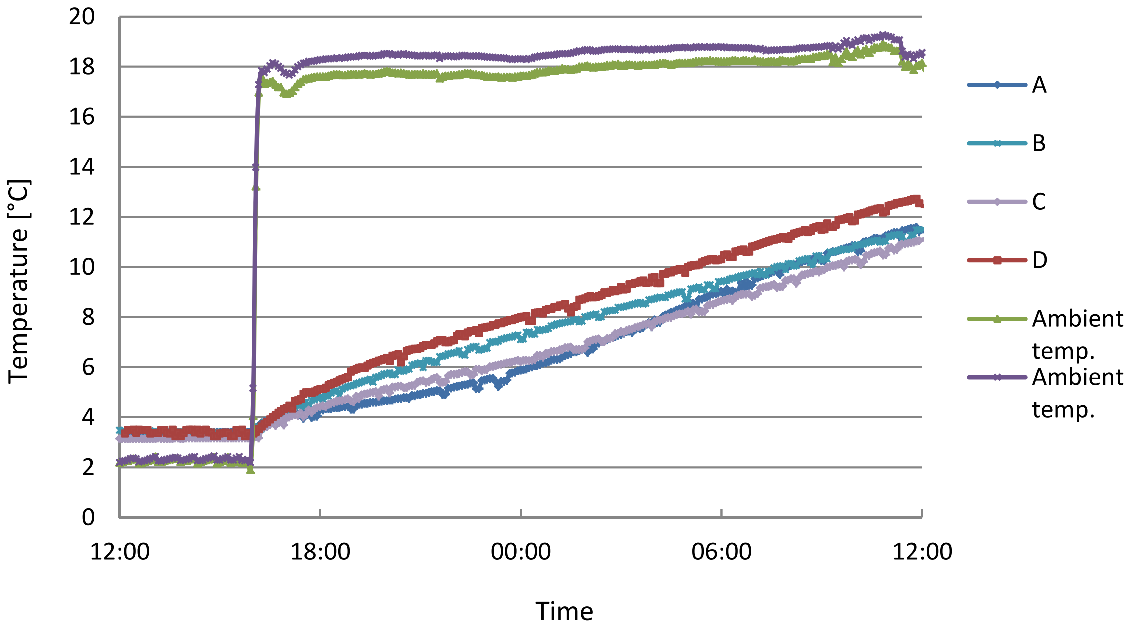

Figure 31. Comparison between position of ice-packs, average temperature inside boxes for the four cases (A – D) and ambient temperature during the trial. The cases are listed in Table 5.

An extended review on phase change materials (PCMs) is provided by Zalba et al. (2003). The melting temperature, heat of fusion and density of commercial PCMs available in the market are described.

3.1.3 Comparison between cooling media

An experiment was performed by Bao (2007) where the cooling capacity of dry ice and ice-packs was compared. The results showed that storage of *Arctic charr* fillets using dry ice can reduce temperature in fish boxes to below 0 °C. However, ice-packs were not able to perform adequately because they did not reduce the fish temperature below 0 °C, see Figure 32. The groups were stored at -2 °C. The temperature reduction rate of fillets packaged with dry ice was faster than the ones stored with ice-packs, despite an equivalent ratio of cooling medium. Using higher ratios of dry ice did not result in a faster product temperature drop, but maintained a lower product temperature for a longer period resulting in an extended shelf life. Absorption of carbon dioxide gas in the fish flesh did not cause a sour taste and cell destruction was not observed due to partial freezing.

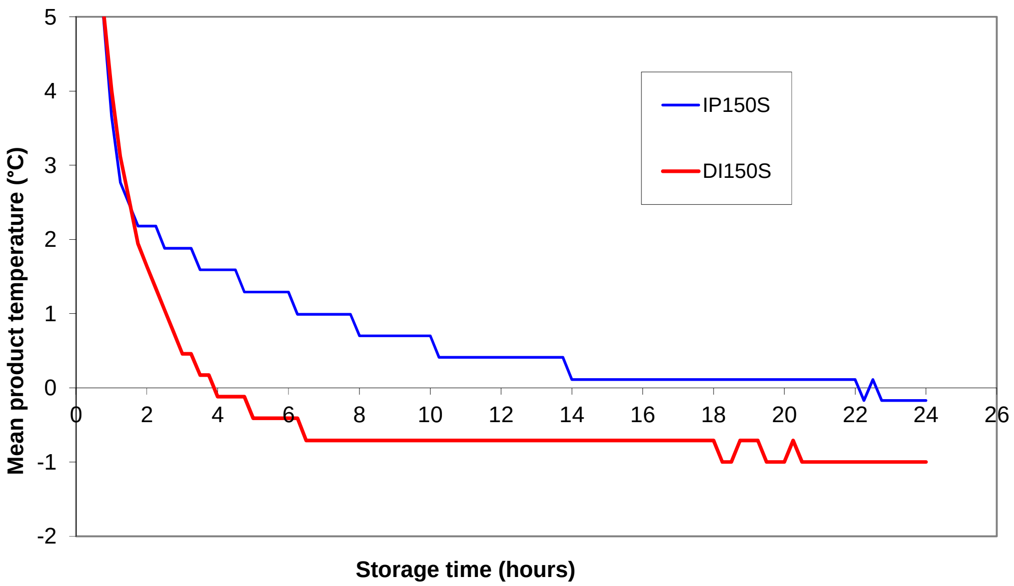

Figure 32. Temperature profiles during the first 24 hours in bottom of boxes with fillets packed with 150 g of dry ice (DI), 150 g of ice packs (IP) and then stored superchilled (S) at -2 °C (Bao et al., 2007).

According to Martinsdóttir et al. (2010), gel-packs play an important role in maintaining a low product temperature during periods of applied thermal load and temperature fluctuations (see Figure 24). Average temperature in groups A (CBCC-RTS-GP) and B (CBCC-RTS) reached maximum 0.9 °C compared to 1.7 °C, respectively. Although the need for gel-packs decreases if the ambient temperature during storage and transport is low and steady (below 1 °C), they have a significant impact during periods of applied thermal load and temperature fluctuations.

3.2 Packaging

Packaging acts as an insulating barrier between environment and product. Different methods can be applied in order to estimate the influence of dynamic environmental conditions (temperature, humidity, air velocity) on product quality. One way of estimating the effect of temperature abuse is to perform experiments in well controlled conditions. Another way, which is often less expensive, is to use numerical simulations and computational fluid dynamics (CFD) for analysis of the heat transfer. Numerical simulations and CFD analysis are one of the main engineering tools for optimisation of cold storages and packaging (Nahor et al., 2005, Hoang et al., 2000).

Thermal performance of different types of packaging, mostly CP (corrugated plastic) and EPS (expanded polystyrene) boxes, has been investigated both by experiments and numerical modelling by Margeirsson et al. (2009, 2010a).

Results from experiments performed by Margeirsson et al. (2009) show that the insulating performance of EPS containing 5 kg fish is significantly better than that of CP, independently of the usage of cooling packs. The average temperature inside EPS and CP boxes with and without ice-packs is displayed in Figure 33. The difference was exaggerated when cooling packs were used. In trial 1 (see Figure 33, left), the cooling fan was turned off but in trial 2 (right) the cooling fan was turned on resulting in faster cooling. Figure 34 shows the temperature distribution at different positions in four boxes with an average ambient temperature of 19.4 °C.

The experimental groups were as follows:

a) EPS with ice-pack (250 g)
b) EPS without ice-pack
c) CP with ice-pack (250 g)
d) CP without ice-pack

The boxes were free standing. The fish located in the corner of each box was more sensitive to temperature fluctuations than the fish positioned in the centre of the box.

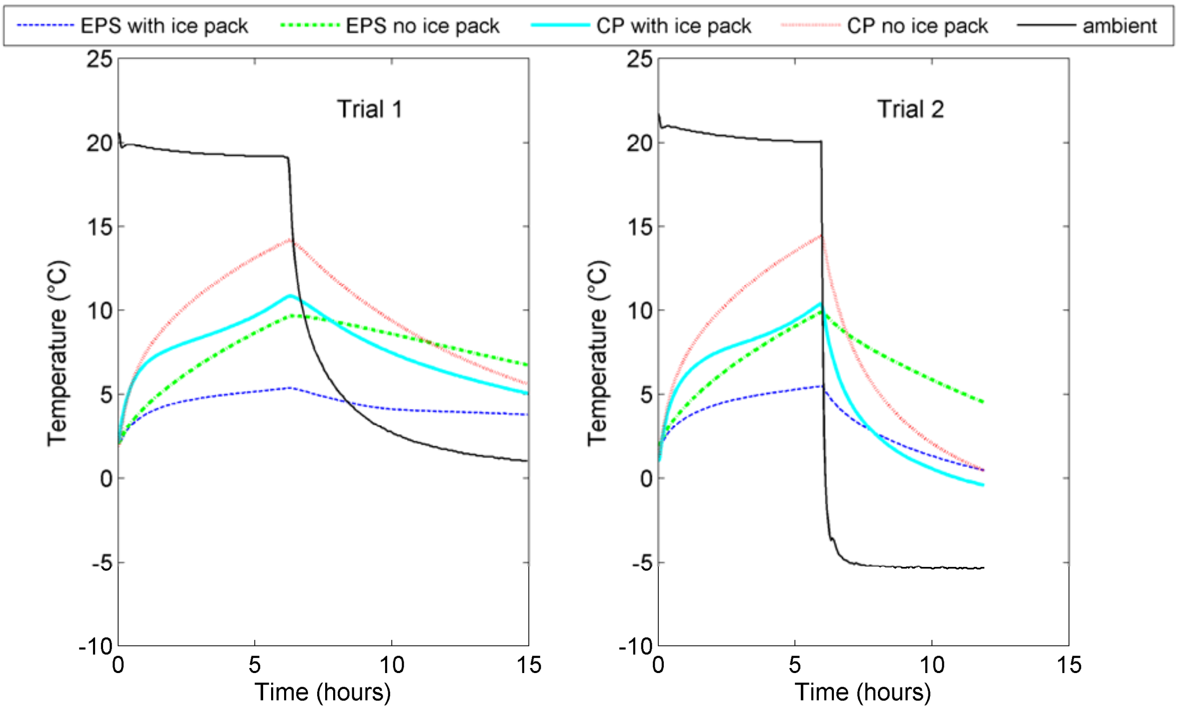

Figure 33. Average temperature inside EPS and CP boxes with and without ice-packs. Trial 1 (left), cooling fan turned off; trial 2 (right), cooling fan turned on.

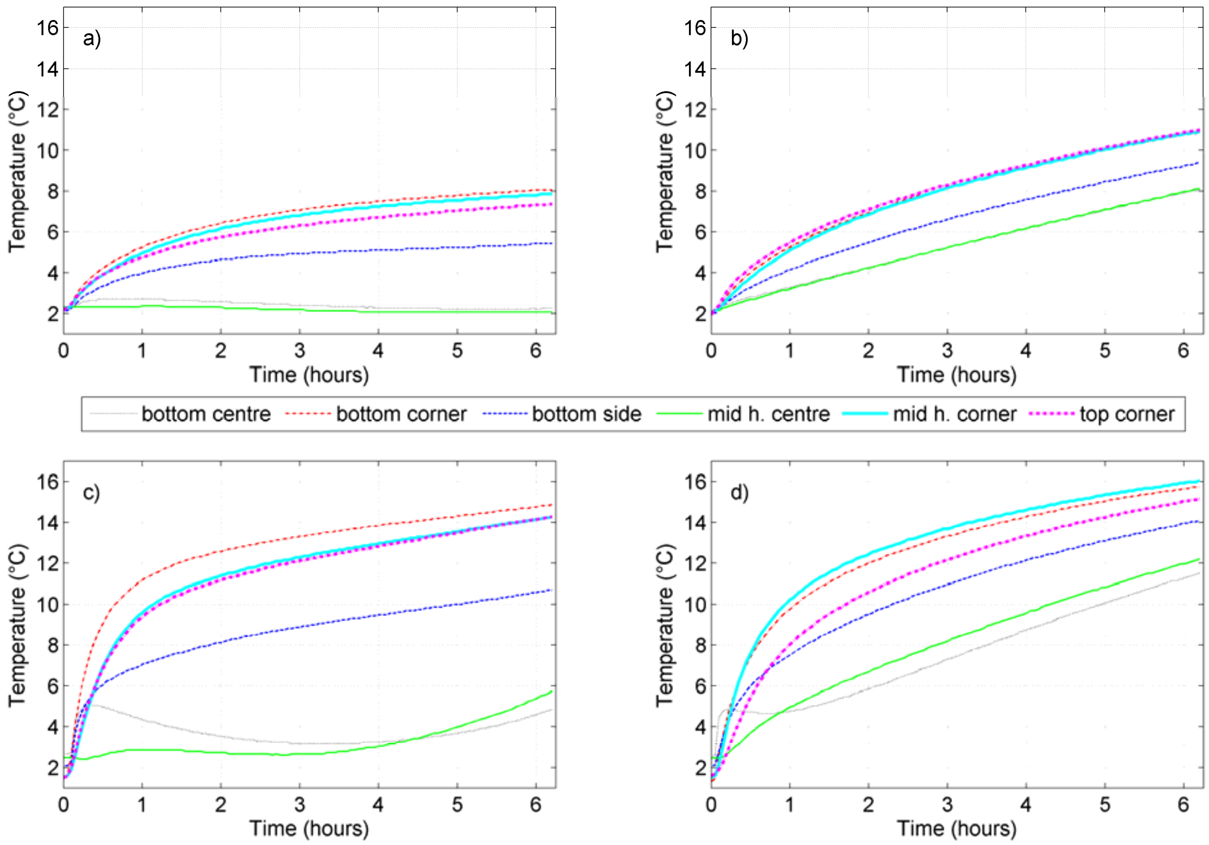

Figure 34. Temperature distribution at different positions in four boxes with average ambient temperature of 19.4 °C: a) EPS with ice-pack (250 g), b) EPS without ice-pack, c) CP with ice-pack (250 g), d) CP without ice-pack.

Experiments with pallets of either CP or EPS boxes were also conducted by Margeirsson et al. (2009), see Figure 35. As for the single boxes, the high ambient temperature more easily affected the product temperature in the CP boxes. As an example, the maximum product temperature in the CP boxes increased from 0.8 °C at 200 h to 8.7 °C at 225 h, i.e. almost 8 °C in 25 h. At the same time the maximum product temperature in the EPS boxes increased from 1.3 °C to 5.1 °C, i.e. almost 4 °C in 25 h. The ambient temperature was 10 °C during the trial and wind conditions were similar to those found at airports, with an air velocity ranging between ~ 0.5 – 9 m/s depending on the position inside the chamber.

Margeirsson et al. (2009) also found that under dynamic temperature conditions, the temperature distribution in a whole pallet of fish fillets under significant thermal load can be far from homogeneous. The product temperature difference can easily exceed 6-8 °C depending on the order of magnitude of the temperature fluctuations and their duration. Product temperature was more easily influenced by ambient temperature fluctuations at the bottom and top rows than in the middle rows on a pallet.

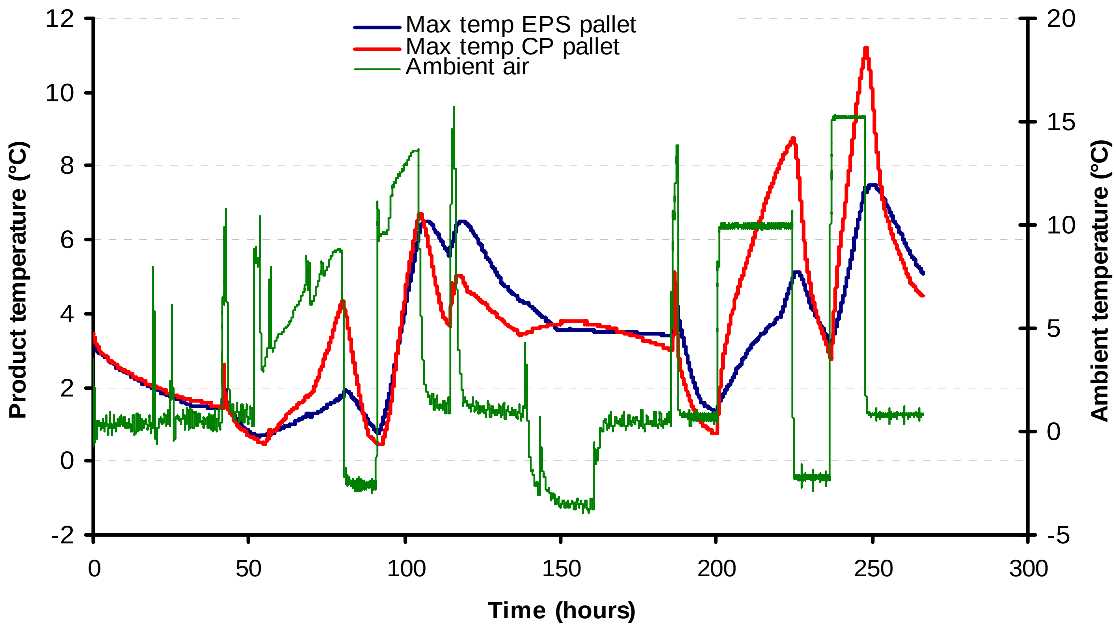

Figure 35. Maximum product temperature on two whole pallets (CP and EPS) along with the ambient air temperature during dynamic temperature storage (Margeirsson et al., 2009).

3.3 Storage and transport

In order to estimate the thermal performance of the packaging, the linkage between the processor to the wholesaler has to be examined. Fluctuations and high temperatures have very negative effects on the quality of fresh fish products. The ambient temperature during storage and transport is of main concern and its overall profile generally differs between transport via air and sea. Transport via sea offers relatively steady temperature compared to a fluctuating temperature during air transport (Mai et al., 2010). The duration of transport via sea is on the other hand much longer than via air. The selection of an appropriate transport mode will depend both on the product as well as choice of packaging.

Figure 36 and Figure 37 show typical profiles of ambient and product temperatures during transport from Iceland to Germany via air and sea, respectively (Martinsdóttir et al., 2010). The ambient temperature varies from -22 °C to 18 °C during the 42-h period of the air freight chain, while the 6 -day containerised transport via sea from Iceland to Germany varies from -9 °C to 1 °C.

Previous reports (Magnússon et al., 2009) have shown that temperature fluctuations and high ambient temperatures have very negative effects on fresh fish products and the cooling chain from processor to wholesaler and the chain needs constant observation.

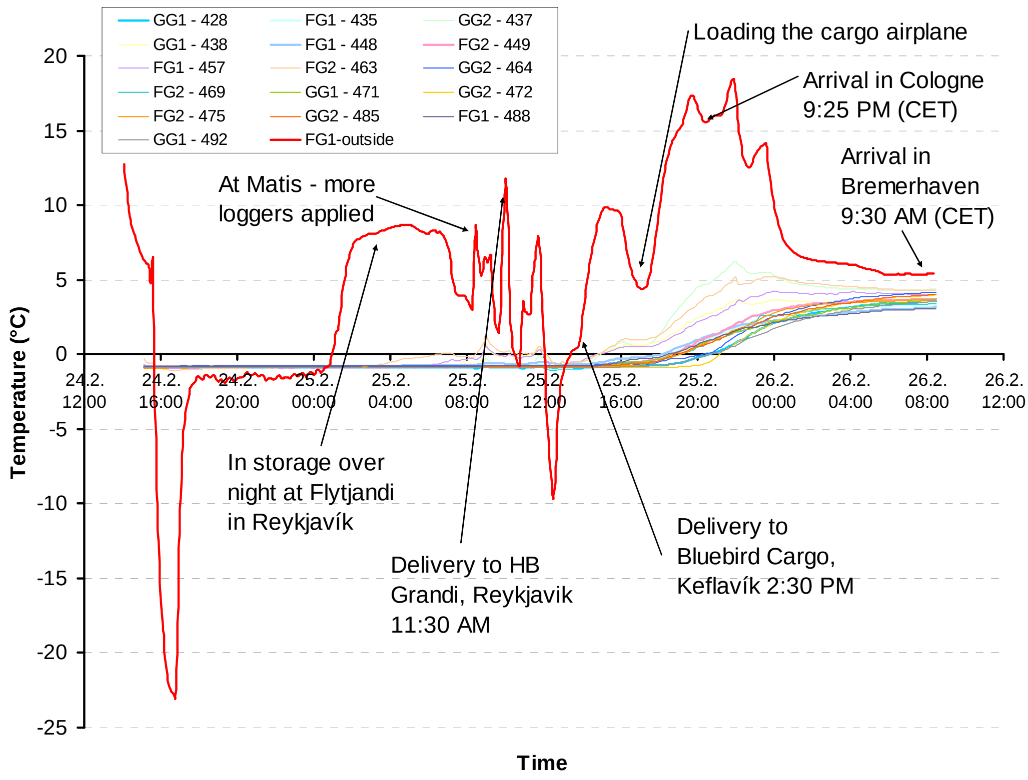

Figure 36. Ambient (red line) and product (other lines) temperatures for 5 kg EPS boxes, which contained precooled fresh cod loins, during air freight transport from Iceland to Germany (Martinsdóttir et al., 2010).

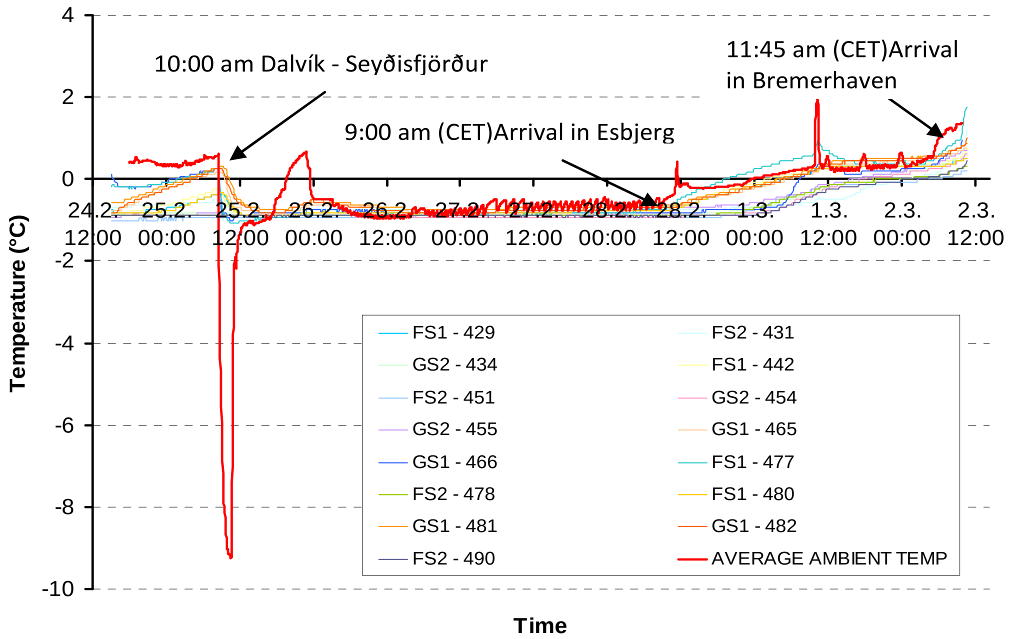

Figure 37. Ambient (red line) and product (other lines) temperatures for 5 kg EPS boxes, which contained precooled fresh cod loins, during containerised transport via sea from Iceland to Germany (Martinsdóttir et al., 2010).

3.4 Recommendations

- In non-draining boxes, sufficient absorbent pads should be used to prevent water from contacting the product.
- In non-draining boxes, the absorption capacity of absorbent pads should correspond to the expected amount of fish exudate accumulating during storage
- It depends upon the cooling requirement whether both ice- or gel-packs and dry ice are used together or not.
- If more than one ice- or gel-pack is used, particularly when exposed to high ambient temperatures, one should be located on top and another at the bottom of the packaging to effectively cool and maintain the fish temperature during storage.
- It has not been investigated whether it is necessary to place a plastic film on top of the fillets to prevent cold spot damages when dry ice is used.
- Packaging should be chosen with respect to its insulation properties and the thermal load expected during storage and transport.
- Product integrity and temperature control should be the most important factors when purchasing fish boxes. Other factors to consider include:
    - material disposal – can it be easily recycled? can it be compacted? etc.
    - cost
    - strength
    - sufficient headspace to fit ice or ice-packs with the seafood
    - weight – minimising weight helps with transport and disposal
    - storage – compact pack for easy storage
- Where fish is distributed in an uncontrolled cold chain, the use of boxes with greater insulation properties, such as EPS (expanded polystyrene) box, is advisable in order to maintain low product temperatures.
- Greater care to control the ambient temperature should be taken during warmer months, particularly if using boxes with less insulation.
- Where fish is distributed in a strictly controlled cold chain, it may be beneficial to use boxes with less insulation, such as CP (corrugated plastic) boxes, to allow chill temperatures to positively influence the product temperature.
- Processors and wholesalers must use the transport mode as a frame of reference for the selection of the appropriate packaging type.
- Expanded polystyrene (EPS) boxes provide better insulation than corrugated plastic (CP) under dynamic temperature conditions, hence the EPS boxes are recommended.
- Ambient temperature during storage and transport should be as close to 0 °C as possible.
- Temperature fluctuations during transport and storage should be minimised.

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