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Superchilled Round Fish – Final Report

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Vinnsla, virðisaukning og eldi

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Ágrip á íslensku:	Meginmarkmið verkefnisins „Ofurkældur heill fiskur – fyrir dauðastirðnun“, sem hófst í júlí 2011, var að kanna hvort ofurkæling heils fisks um borð í veiðiskipi gæti lengt geymsluþol og aukið gæði afurðanna. Hæfilegra hita- og tímastillinga á roð- og snertikæli var leitað með fjórum kælitilraunum og bestu stillingarnar notaðar til ofurkælingar heilla fiska í geymsluþolstilraun. Niðurstöður geymsluþolstilraunar benda til þess að ofurkæld vinnsla á heilum þorski geti lengt geymsluþol hans um tvo daga. Samkvæmt skynmati var þó lítinn mun að finna á geymsluþoli mismunandi flakahópa. Geymsluþol var metið 16–18 dagar, sem er nokkuð langur tími fyrir þorskflök. Ferskleikatímabil tilraunahóps með ofurkældum flökum úr ofurkældum heilum fiski virtist þó vera heldur lengra en hinna hópanna. Líkt og fyrir heila þorskinn reyndist lítill munur milli flakahópanna m.t.t. örveruvaxtar, efna- og eðliseiginleika. Takmarkaðan mun milli tilraunahópa má mögulega skýra með stöðugum og ofurkældum geymsluaðstæðum. Með hliðsjón af því er ráðlagt að framkvæma aðra sambærilega tilraun þar sem hermt yrði eftir dæmigerðari umhverfishitaferlum í flutningi ferskfiskafurða (0–4 °C) en í þessari tilraun (–1.4 til –1.2 °C). Niðurstöður tölvuvæddrar varma- og straumfræði-líkanagerðar gefa til kynna að þess lags líkön gætu nýst til áframhaldandi hönnunar á roð- og snertikæli fyrir heilan fisk.		
Lykilorð á íslensku:	*heill hvítfiskur, ofurkæld vinnsla, geymsluþol, tölvuvædd varma- og straumfræði, varmaflutningslíkan*		

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Summary in English:	The main aim of the R&D project „Superchilled round fish – pre-rigor“, which was initiated in July 2011, was to investigate if superchilled processing of whole fish on-board fishing ships could increase the product quality and prolong storage life. The appropriate temperature- and time-settings for the superchilling equipment was studied in four cooling trials and the best settings applied when preparing samples for a storage life study. The results from the storage life study indicate that superchilled processing of whole cod can extend storage life by two days. However, differences in sensory scores between the fillet groups were small. Storage life was estimated between 16 and 18 days which is quite long storage life for cod fillets. However, the group with superchilled fillets from superchilled whole fish seemed to retain freshness a little longer than other groups. As in case of the whole cod, the differences in bacterial count, chemical and physical properties between the fillet groups were small. Very similar fish temperatures between both the whole fish and the fillet groups resulting from the superchilled storage conditions applied may be the main reason for the small differences obtained. Thus, another study with more common temperature conditions during transport and storage of fresh fish (chilled but not superchilled) should be performed. The results obtained in this study show that CFD modelling of fluid flow and heat transfer is a realistic and functional tool to simulate superchilling of whole fish in a CBC-cooler. In future work CFD-modelling can be used to determine optimal values for parameters such as holding time, chilling temperature and air velocity.
English keywords:	*whole whitefish, superchilled processing, storage life, computational fluid dynamics, heat transfer model*

Contents

1 Introduction

The purpose of this report is to review the most important results obtained in the R&D project "Ofurkældur heill fiskur" (e. Superchilled round fish – pre rigor). The main aim of the project was to experimentally investigate the effect that superchilling of whole fish has on product storage life and quality. The results could be used for designing a superchilling system on shore or on board fishing vessels.

Superchilling of fresh food implies that the food temperature is lowered to no more than 1–3 °C below the initial freezing point of the food.[1,2,3] The initial freezing point of cod is around –0.9 °C.[4] The term superchilling has also been used when chilling foods to a temperature only below the freezing point of water, i.e. 0 °C.[1] In order to avoid excessive surface freezing and ice crystal growth causing possible structural damage and negative texture changes to the fish flesh and increase drip loss[2,3], cod is normally superchilled to no lower temperature than –1 °C in modern industrial applications.[5,6]

In the current report, a limited emphasis is put on describing materials and methods used since these are described in each reference. The main results comprise cooling curves and computational fluid dynamics (CFD) models of superchilled processing of

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[1] Aune, E.J. 2003. Superchilling of foodstuff, a review. *In:* 21st International Congress of Refrigeration, International Institute of Refrigeration. 17–22 August 2003. Washington, DC, USA.

[2] Magnussen, O.M., Haugland, A., Torstveit Hemmingsen, A.K., Johansen, S., Nordtvedt, T.S., 2008. Advances in superchilling of food – Process characteristics and product quality, Trends in Food Science and Technology 19, 418–424.

[3] Kaale, L.D., Eikevik, T.M., Rustad, T., Kolsaker, K. 2011. Superchilling of food: A review. Journal of Food Engineering 107, 141–146.

[4] Rahman, M.S., 2009. Food Properties Handbook, 2nd ed. CRC Press, Boca Raton, FL, USA.

[5] Valtýsdóttir, K.L., Margeirsson, B., Arason, S., Lauzon, H.L., Martinsdóttir, E. 2010. Guidelines for precooling of fresh fish during processing and choice of packaging with respect to temperature control in cold chains. Tech. report 40–10, Matís, Reykjavík, Iceland. Available at http://www.matis.is/media/matis/utgafa/40-10-Guidelines-for-precooling-and-packaging.pdf.

[6] Stevik, A.M., Claussen, I.C. 2011. Industrial superchilling, a practical approach. Procedia Food Science 1, 1265–1271.

whole whitefish under different cooling conditions. The models can be used to predict product temperature variations and to cost-effectively investigate the effect of different cooling parameters such as air temperature, wind speed and cooling time. Finally, the effects of superchilled processing and storage on shelf life of both whole fish and fillets were investigated in a storage life study by means of temperature monitoring, chemical- and microbial measurements and sensory evaluation.

2 Materials and methods

In this section, the measurement- and numerical modelling procedures are briefly discussed. The detailed procedures of each study are described in each reference.

2.1 Temperature mapping

The aim of the temperature- and air flow measurements during superchilled processing of whole fish was to optimise the settings of the Superchiller from Marel (Garðabær, Iceland), formerly referred to as combined blast and contact (CBC) cooler by Skaginn Ltd., Akranes, Iceland, with regard to cooling time, air temperature and air velocity inside the cooler. Whole fish temperature, ambient air temperature and air velocity were monitored under different superchilling conditions in four trials. Fish specimens of different sizes were used in the trials ranging from around 1.5 to 4 kg and the main emphasis was put on optimisation with regard to cooling time and air temperature.

The specification of the different measurement devices used is presented in Table 1. Ibutton temperature loggers (type DS1922L) from Maxim Integrated Products (Sunnyvale, CA, USA) were used to monitor the fish and ambient temperatures. Its diameter is 17.4 mm and the thickness is 5.9 mm. All temperature loggers were factory calibrated and re-calibrated in a thick mixture of fresh crushed ice and water to ensure uniformity of the collected data. Air velocity was measured with Thermo-Anemometer Datalogger (model 451126) from Extech Instruments (Waltham, MA, USA).

Table 1. Specification of measurement devices.

Device	Resolution	Range	Accuracy
Ibutton	0.0625 °C	–40 to 85 °C	±0.5 °C between –15 and 65 °C
Thermo-Anemometer Datalogger	0.01 m/s	0.3 to 45 m/s	±(3% + 0.1) m/s

Figure 1. Temperature data logger inserted into a whole fish.

The temperature data loggers were inserted as shown in Figure 1. A cut was made through the flesh where the data loggers were to be placed. Three data loggers were inserted in cross section C (location of the cross section is shown in Figure 2) one above the spine and two below, closer to the belt, see the vertical placements of temperature data loggers in Figure 3.

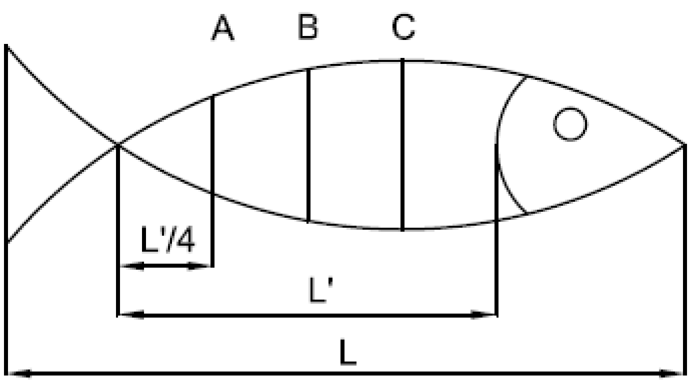

Figure 2. Schematic figure of the positions of cross-sections where data loggers were inserted.

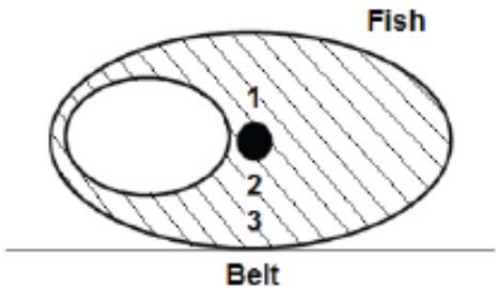

Figure 3. Vertical positions of temperature sensors in whole fish.

The air temperatures inside the CBC cooler ranged between –14 °C and –7 °C, the cooling time applied ranged between 6 and 30 min and the air velocity ranged between 2.2 m/s and 3.2 m/s with a mean value of 2.6 m/s. The superchilled process mapping has been described in more details by Bjarnason (2012)[7]. The results from this work were used to decide the settings used in the storage life study (Section 0).

2.2 CFD modelling of superchilled processing of whole fish

Two finite volume models, in two and three dimensions, were developed using the commercial Computational Fluid Dynamics (CFD) software FLUENT. The models were used to simulate the air flow and temperature behaviour inside a whole cod fish during superchilled processing and succeeding storage. The simulated results obtained with these models were compared with a part of the experimental results. The numerical modelling approach has been described in details by Bjarnason (2012)[7].

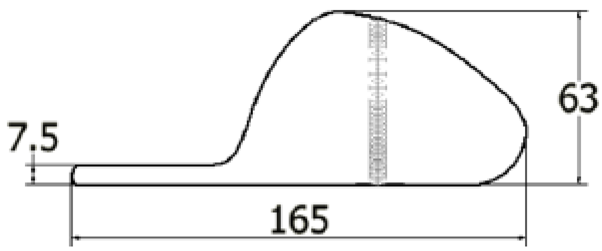

Figure 4. 2D-model of whole cod showing dimensions in mm and positions of temperature monitors.

[7] Valur Oddgeir Bjarnason, 2012. CFD Modelling of Combined Blast and Contact Cooling for Whole Fish. M.Sc. thesis, DTU, Department of Mechanical Engineering.

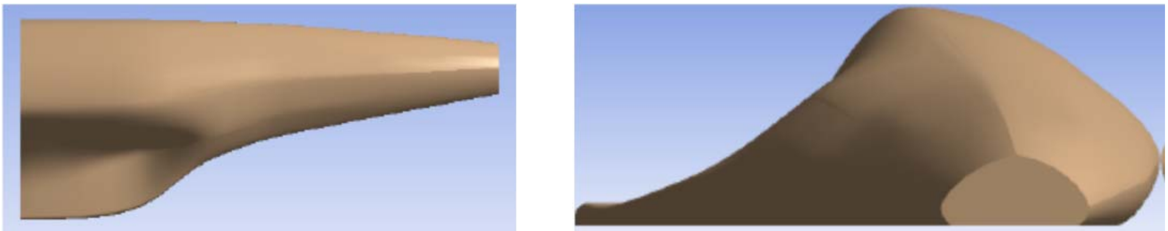

Figure 5. 3-D model of cod seen from above (left) and from the tail (right).

2.3 Storage life study

A storage life study was performed in order to study the effects of superchilled processing on storage life of both whole fish and fillets[8]. The following experimental groups were evaluated by means of temperature monitoring, chemical- and microbial measurements and sensory evaluation, which were stored at mean temperatures of –1.4 to –1.2 °C:

- NC: non-superchilled whole cod
- SC: superchilled whole cod
- NC-NC: non-superchilled fillets from non-superchilled whole cod
- NC-SC: superchilled fillets from non-superchilled whole cod
- SC-NC: non-superchilled fillets from superchilled whole cod
- SC-SC: superchilled fillets from superchilled whole cod

The experimental design, sensory evaluation, microbial and chemical measurements are described in detail by Ólafsdóttir et al. (2012).

[8] Ólafsdóttir, A., Margeirsson, B., Sveinsdóttir, K., Arason, S., Reynisson, E., Martinsdóttir, E. 2012. Effect of superchilled processing of whole whitefish - pre-rigor. Matís report 22-12.

3 Results and discussion

3.1 Temperature measurements during superchilled processing

The results from the four tests performed are presented in the following pages.

3.1.1 Test 1

Results of the tests obtained with the settings used when cooling fish fillets (ambient temperature –7.4 °C and cooling time 8 min) are shown in Figure 6. In the figure it is denoted with two vertical lines, marked with *In* and *Out*, when the fish is inserted into the CBC-cooler and when it is taken out, respectively. Obviously, not enough cooling was applied to these specimens.

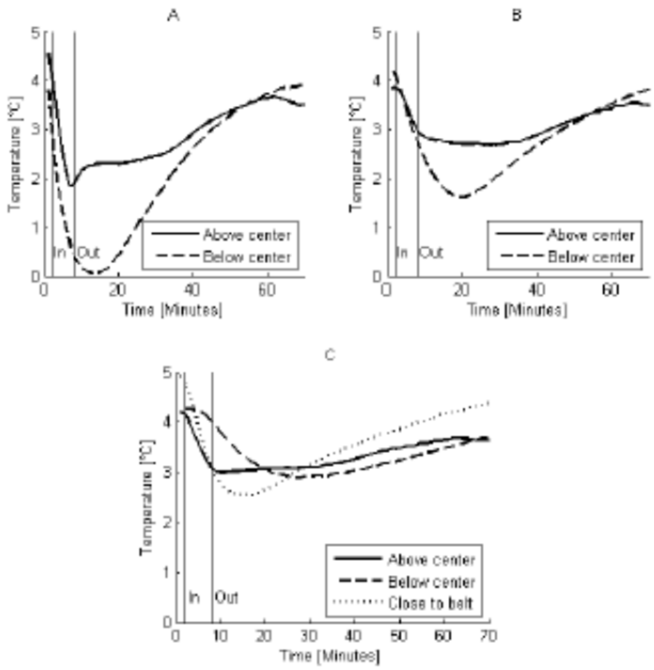

Figure 6. Whole fish temperature in test 1 with air temperature of –7.4 °C applied for 6 min to a fish weighing 2.36 kg.

Table 2 shows the lowest temperature values that were measured in the fish flesh during the CBC-cooling.

Table 2. Comparison of the lowest fish temperatures at different positions in the fish flesh after 8 minutes in the CBC-cooler in test 1.

Position		T_{min} [°C]
A	Above	1.9
	Below	0.1
B	Above	2.7
	Below	1.6
C	Above	3.0
	Below	2.9
	Belt	2.6

The temperature measured 80 minutes from the beginning of measurements, is shown in Table 3.

Table 3. Fish temperature after 80 minutes in test 1.

Position		T_{80} [°C]
A	Above	3.5
	Below	4.0
B	Above	3.6
	Below	4.0
C	Above	3.6
	Below	3.9
	Belt	4.6

3.1.2 Test 2

In this test the air temperature inside the CBC-cooler was set to –12 °C but according to measurements the mean ambient temperature turned out to be –13.0 °C.

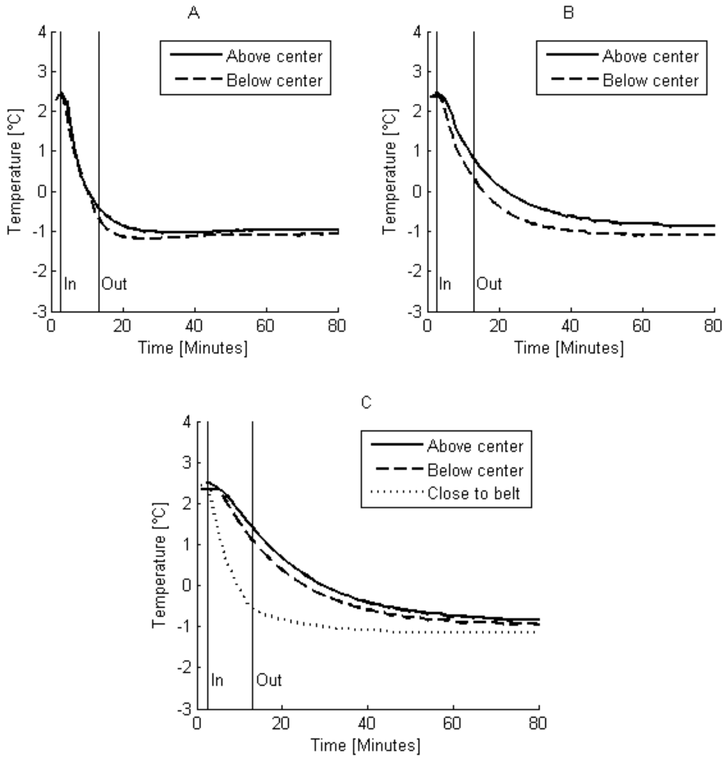

Figure 7. Whole fish temperature in test 2 with air temperature of –13.0 °C applied for 10 min to a fish weighing 1.45 kg.

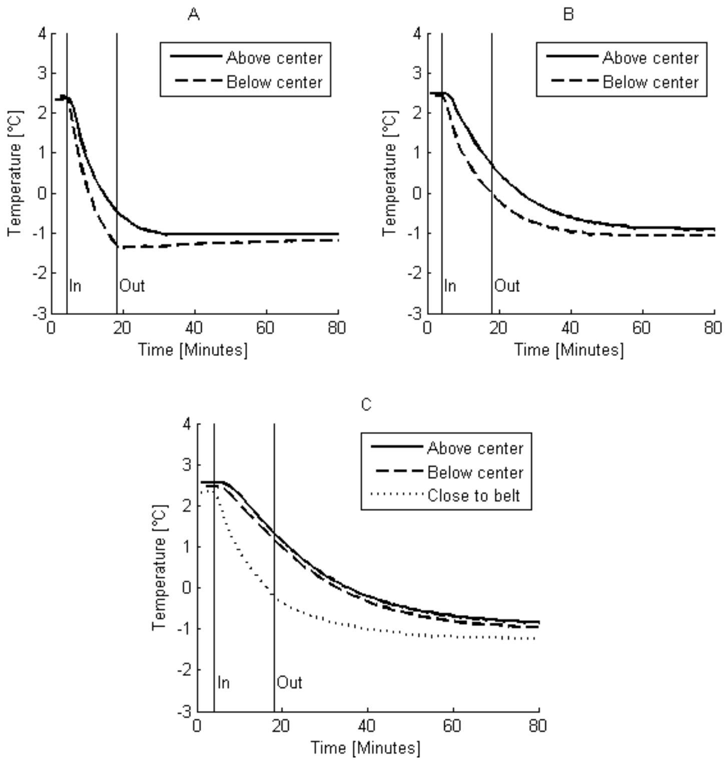

Figure 8. Whole fish temperature in test 2 with air temperature of –13.0 °C applied for 15 min to a fish weighing 1.67 kg.

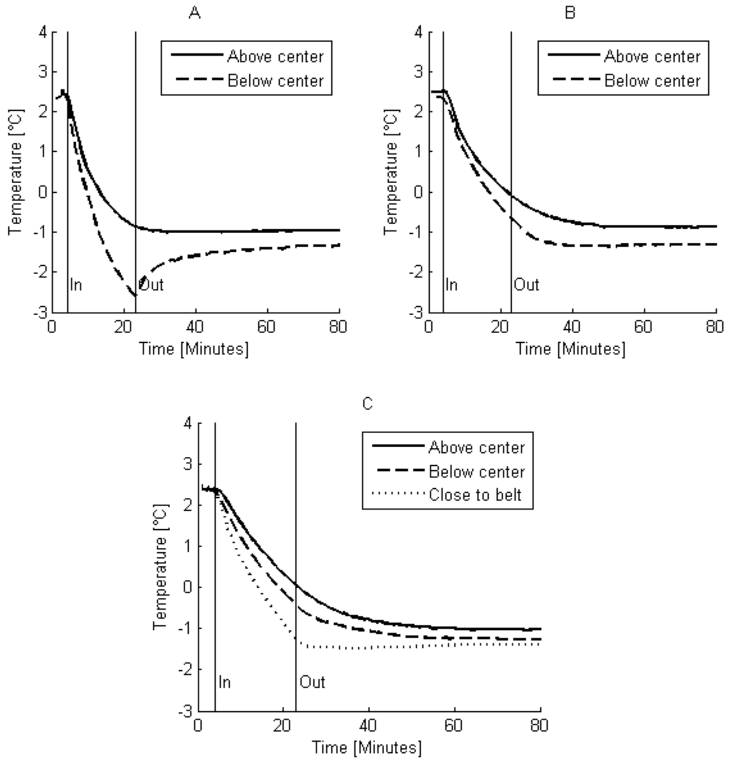

Figure 9. Whole fish temperature in test 2 with air temperature of –13.0 °C applied for 20 min to a fish weighing 1.49 kg.

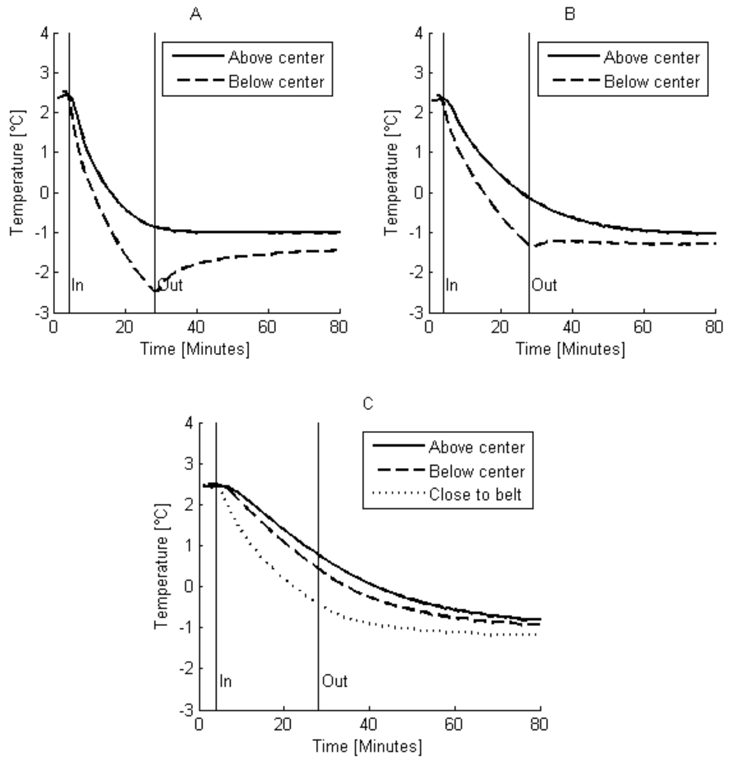

Figure 10. Whole fish temperature in test 2 with air temperature of –13.0 °C applied for 25 min to a fish weighing 2.87 kg.

Table 4 shows the lowest temperature values measured in the fish flesh during CBC-cooling in test 2.

Table 4. Minimum fish temperatures at different positions for the four cooling durations in test 2.

			Time [min]			
	Position		10	15	20	25
T_{min} [°C]	A	Above	−1.0	−1.0	−1.0	−1.0
		Below	−1.2	−1.4	−2.6	−2.5
	B	Above	−0.9	−0.9	−0.9	−1.0
		Below	−1.1	−1.1	−1.4	−1.4
	C	Above	−0.9	−0.9	−1.0	−0.9
		Below	−1.0	−1.0	−1.3	−1.0
		Belt	−1.1	−1.2	−1.5	−1.2

Table 5 shows the temperature in the fish flesh 80 minutes after the beginning of measurements.

Table 5. Fish temperature at t = 80 min at different positions for the four cooling durations in test 2.

			Time [min]			
	Position		10	15	20	25
T_{80} [°C]	A	Above	−1.0	−1.0	−1.0	−1.0
		Below	−1.1	−1.2	−1.3	−1.5
	B	Above	−0.9	−0.9	−0.9	−1.0
		Below	−1.1	−1.0	−1.3	−1.3
	C	Above	−0.9	−0.9	−1.0	−0.8
		Below	−1.0	−1.0	−1.3	−0.9
		Belt	−1.1	−1.2	−1.4	−1.2

3.1.3 Test 3

The temperature in the CBC-cooler was set at –14 °C but measurements revealed a mean air temperature of –14.1 °C.

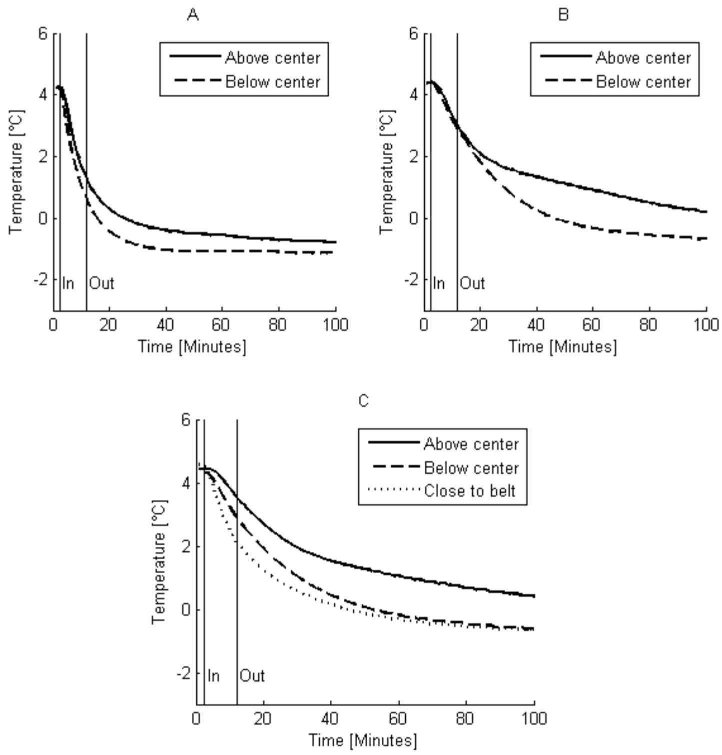

Figure 11. Whole fish temperature in test 3 with air temperature of –14.1 °C applied for 8 minutes to a fish weighing 2.51 kg.

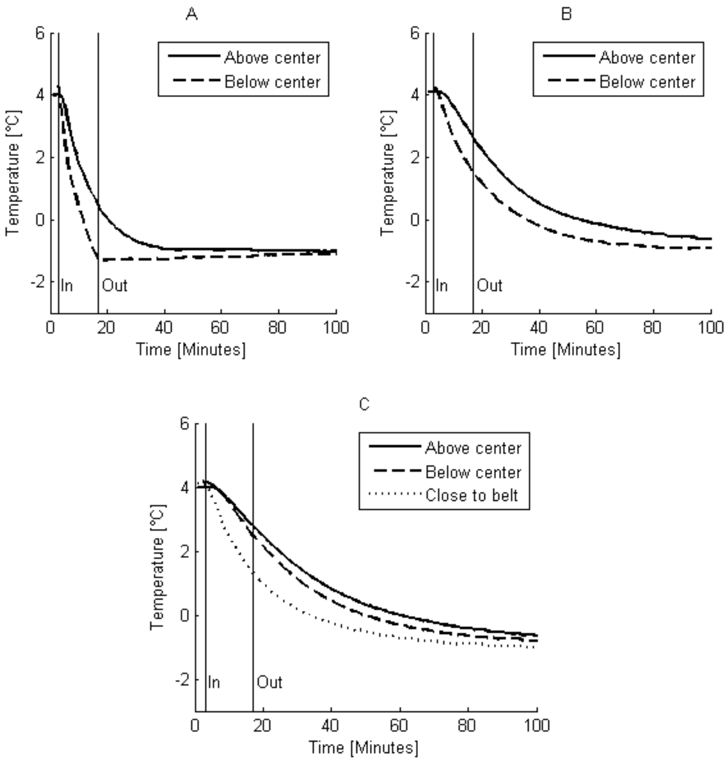

Figure 12. Whole fish temperature in test 3 with air temperature of –14.1 °C applied for 13 minutes to a fish weighing 2.82 kg.

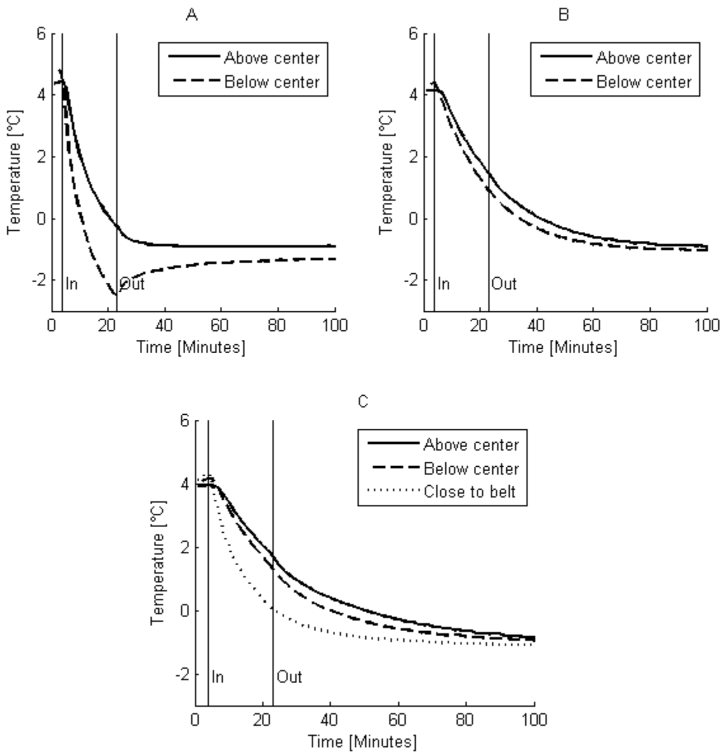

Figure 13. Whole fish temperature in test 3 with air temperature of –14.1 °C applied for 18 minutes to a fish weighing 2.72 kg.

Table 6 shows the lowest temperature values measured in the fish flesh during the CBC-cooling in test 3.

Table 6. Lowest fish temperatures at different positions for the three cooling durations in test 3.

			Time [min]		
	Position		8	13	18
T_{min} [°C]	A	Above	−0.9	−1.0	−0.9
		Below	−1.1	−1.3	−2.5
	B	Above	−0.4	−0.8	−1.0
		Below	−0.9	−1.0	−1.1
	C	Above	−0.2	−0.9	−1.0
		Below	−0.8	−0.9	−1.0
		Belt	−0.8	−1.1	−1.1

Table 7 shows temperature values in the fish flesh 80 minutes from the beginning of measurements. These values should give a focus on how cold the fish is after its temperature has balanced out.

Table 7. Comparison of the temperature values after t = 80 min at different positions for the three cases in test 3.

			Time [min]		
	Position		8	13	18
T_{80} [°C]	A	Above	−0.7	−1.0	−0.9
		Below	−1.1	−1.1	−1.4
	B	Above	0.5	−0.5	−0.8
		Below	−0.5	−0.9	−1.0
	C	Above	0.7	−0.4	−0.7
		Below	−0.5	−0.7	−0.8
		Belt	−0.6	−0.9	−1.1

3.1.4 Test 4

In this test, the fish samples were divided into five groups as shown in Table 8 where each group consisted of two samples. Four data loggers were inserted into each fish, at positions 1 and 2 at cross sections A and C, (see Figure 2 and Figure 3). The mean air temperature in the CBC-cooler during the cooling period was –13.6 °C.

Table 8. Experimental groups in test 4. Air temperature: –13.6 °C. Number of fish in each group: 2.

Group nr.	Mass [kg]	Cooling time [min]
1	1.5	15
2	1.5	30
3	3.4	15
4	3.7	30
5	1.7	0 (reference group)

The temperature of the fish in group 1, at cross sections A and C, during the CBC-cooling is shown in Figure 14. One possible problem with superchilling whole fish in the Superchiller (CBC-cooler) became clear during this test, i.e. immediate freezing of the fish skin to the conveyor belt as soon as the fish was laid on the belt. This could perhaps be solved by immersing the fish into weak brine/slurry ice, which was not done during any of the tests described in the current report.

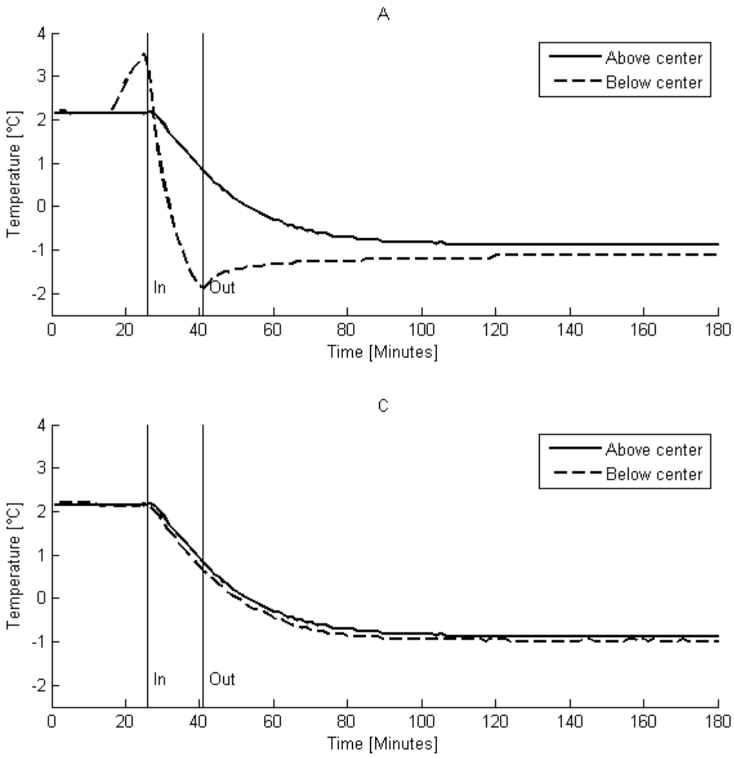

Figure 14. Whole fish temperature in test 4 with air temperature of –13.6 °C applied for 15 minutes to fish weighing 1.5 kg.

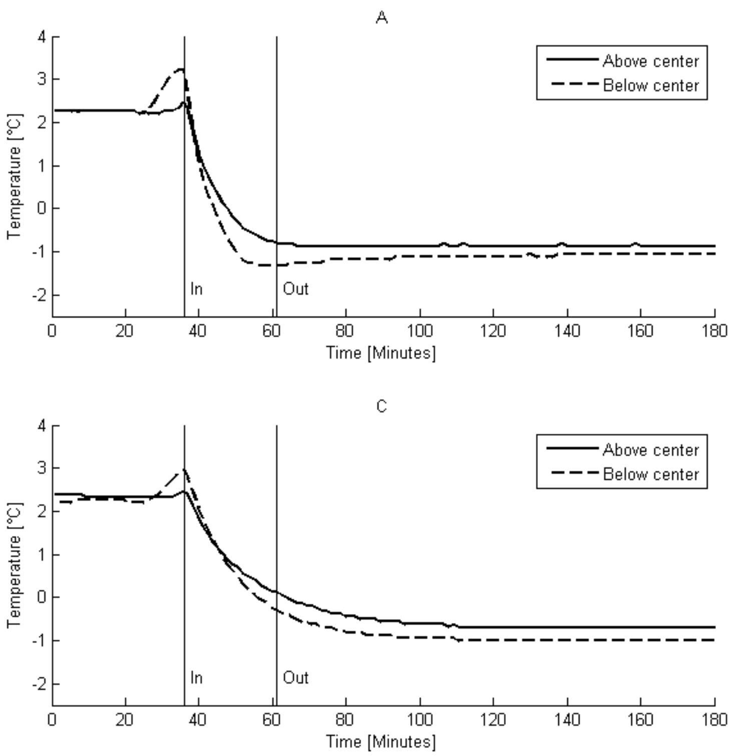

Figure 15. Whole fish temperature in test 4 with air temperature of –13.6 °C applied for 30 minutes to fish weighing 1.5 kg.

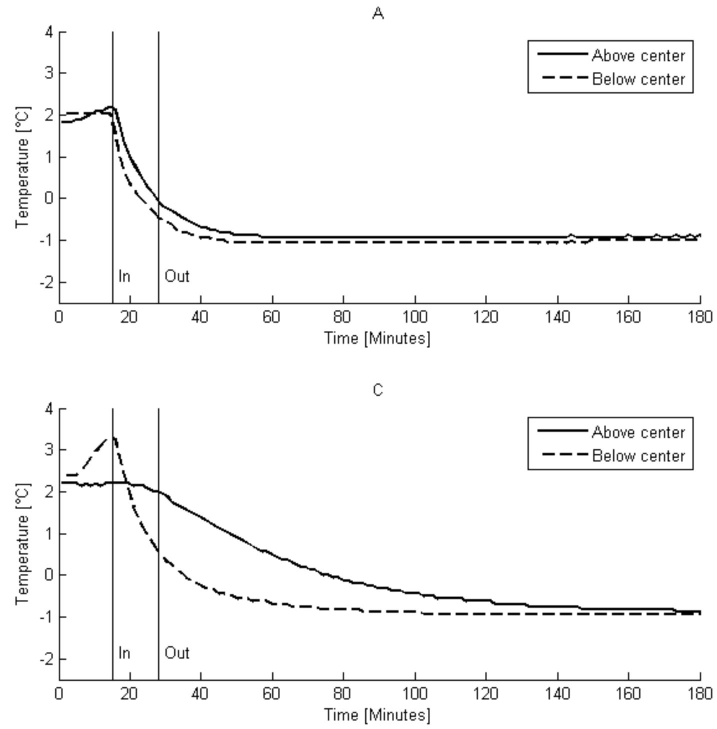

Figure 16. Whole fish temperature in test 4 with air temperature of –13.6 °C applied for 15 minutes to fish weighing 3.4 kg.

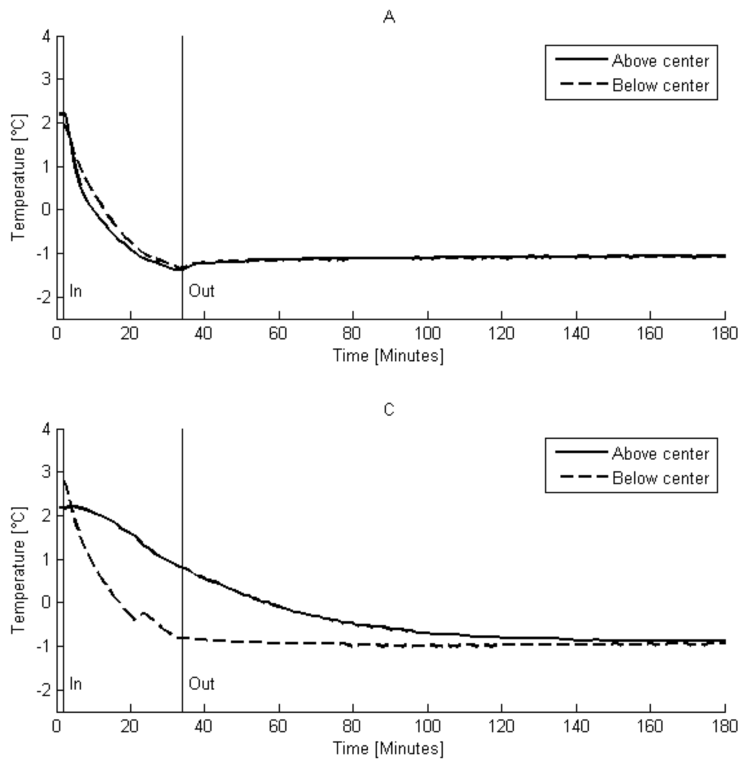

Figure 17. Whole fish temperature in test 4 with air temperature of –13.6 °C applied for 30 minutes to fish weighing 3.7 kg.

The lowest temperature values for each group during the CBC-cooling in test 4 are shown in Table 9.

Table 9. Lowest temperature values in groups 3 and 4 for 15 and 30 minutes of CBC-cooling, respectively, in test 4.

			Time [min] / Group nr.			
	Position		15 / 1	30 / 2	15 / 3	30 / 4
T_{min} [°C]	A	Above	−0.9	−0.9	−0.9	−1.4
		Below	−1.9	−1.3	−1.1	−1.4
	C	Above	−0.9	−0.7	−0.9	−0.9
		Below	−1.0	−1.0	−0.9	−1.0

3.2 Simulation results

Temperature decrease and air flow was simulated in ANSYS FLUENT in both 2-D and 3-D (Bjarnason, 2012). Results from the CFD simulations (see one example in Figure 18) were generally in good agreement with the experimental results. This shows that CFD modelling is a promising technique to predict, cost effectively, temperature changes during superchilled processing of whole fish and could be applied for designing superchilling equipment for whole fish. For further results on the CFD modelling and comparison to experimental results, a reference to Bjarnason (2012) should be made.

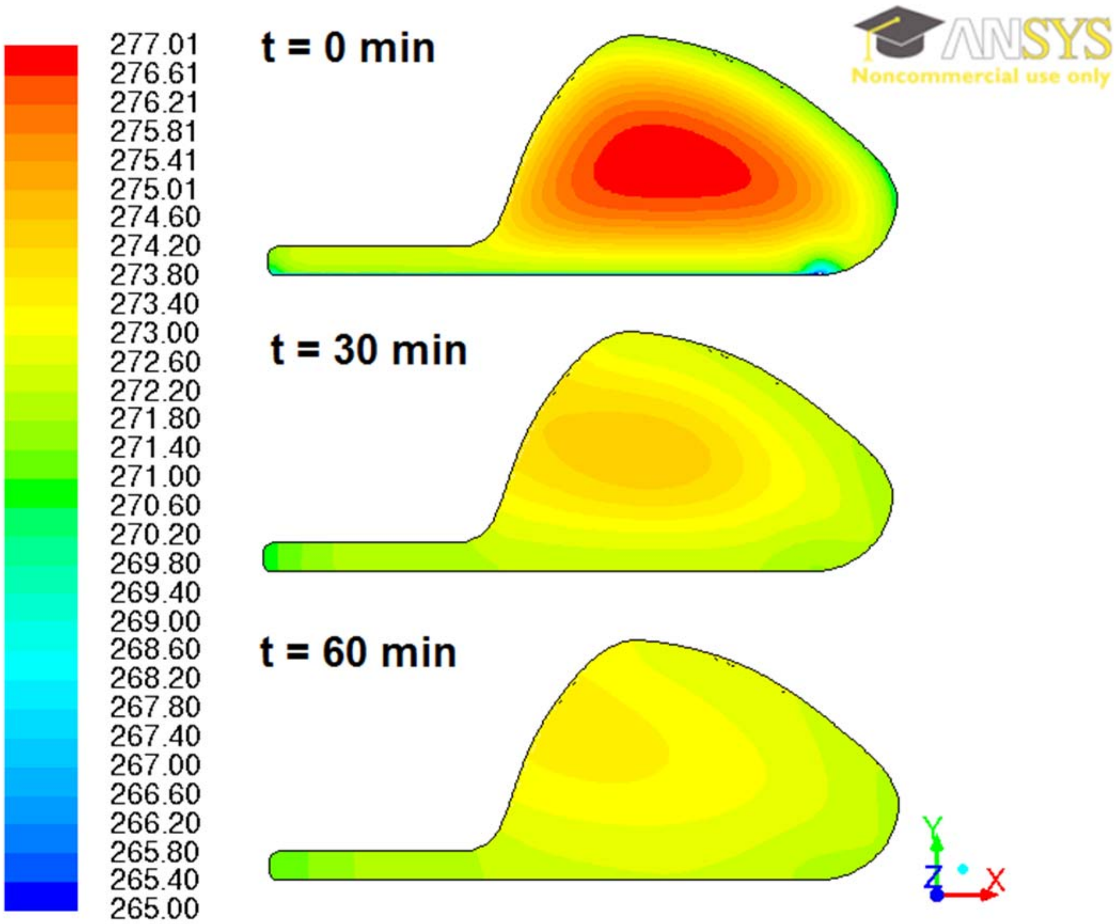

Figure 18. Temperature distribution (K) at the end of the CBC-cooling (top), 30 min post-CBC-cooling (middle) and 60 min post-CBC-cooling (bottom), predicted with a 2-D CFD model.

3.3 Storage life

The results from the sensory evaluation indicate that superchilled processing of whole cod can extend shelf life by two days.[8] Torry results indicated that the superchilled (SC) cod had two days longer shelf life than the non-superchilled (NC) cod (Figure 19). Differences between groups were minor during storage time until day 18 where the SC cod scored higher for Torry than the NC cod ($p < 0.05$).

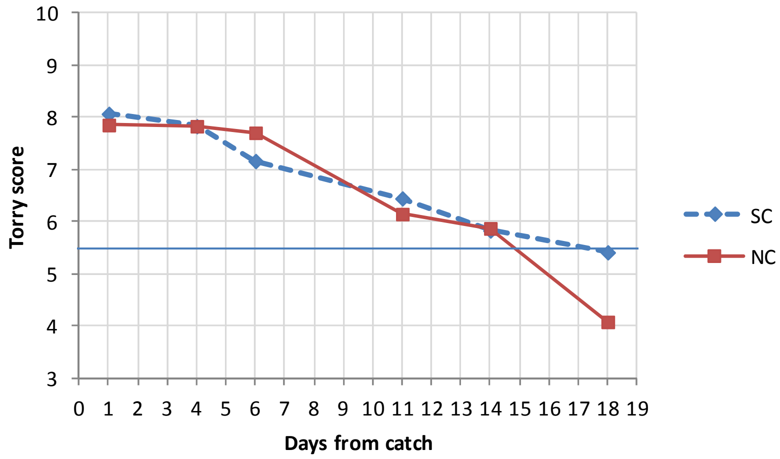

Figure 19. Mean Torry scores for whole cod; superchilled (SC) and non-superchilled (NC).

Differences in Torry scores between fillet groups were small (Figure 20). Shelf life was estimated between 16 and 18 days which is quite long shelf life for cod fillets.[9] Groups SC-NC and NC-SC might have a little shorter shelf life than groups SC-SC and NC-NC but group SC-SC seemed to retain freshness a little longer than other groups. It should be noted that the superchilled storage conditions (mean ambient temperature of –1.4 ± 0.9 °C and –1.3 ± 0.8 °C during 18-day storage for the NC and SC groups, respectively) resulted in the same mean product temperature (–1.2 ± 0.2 °C) in the two groups NC and SC. This made the two groups more similar and might have decreased the effect of the superchilled processing since both groups received the same superchilled storage treatment. Larger differences in chemical and physical properties, bacterial growth and shelf life could be expected in case of chilled storage conditions (0–4 °C) instead of the superchilled conditions in this study. For a more detailed coverage of the storage life study a reference to Ólafsdóttir et al. (2012) should be made.

[9] Olafsdottir, G., Lauzon, H.L., Martinsdottir,E., Oehlenschlauger, J., Kristbergsson, K. 2006. Evaluation of shelf life of superchilled cod (*Gadus morhua*) fillets and the influence of temperature fluctuations during storage on microbial and chemical quality indicators. Journal of Food Science 71(2), S97–S109.

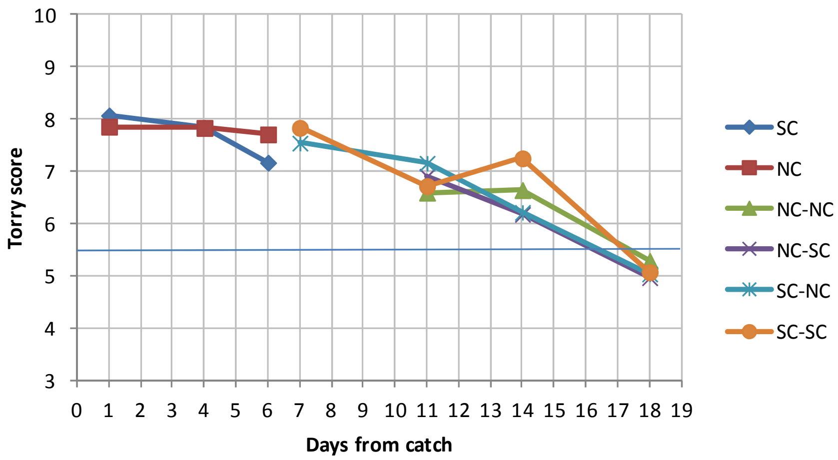

Figure 20. Mean Torry scores for whole cod on days 1, 4 and 6: Superchilled (SC) and non-superchilled (NC) and cod fillets on days 7, 11, 14 and 18: Non-superchilled whole, non-superchilled after filleting (NC-NC); non-superchilled whole, superchilled after filleting (NC-SC); superchilled whole, non-superchilled after filleting (SC-NC); superchilled whole, superchilled after filleting (SC-SC).

3.3.1 Importance of superchilling whole fish from catch to processing

Results from earlier studies[10,11,12] show that a Torry score of 7 (used for determining the freshness period) could be expected around 7–8 days post catch for whole cod on ice. Figure 20 implies that the superchilled processing and storage of whole fish in the current study would have resulted in around 0.5 higher Torry score compared to fish stored on ice 7 days post catch.

The Seafood Spoilage Predictor software (SSSP at http://www.dfu.min.dk/micro/ssp) allows for the calculation of storage life at any given temperature, ranging from –3 to +15 °C, based on a known storage life of the product at 0 °C. This model is applicable for aerobically stored, vacuum and modified atmosphere packed fresh seafood. Table 10 provides calculated storage life at defined temperatures based on a storage life of 12 to

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[10] Martinsdóttir, E., Schelvis, R., Hyldig, G., Sveinsdóttir, K. 2009. Sensory evaluation of seafood: methods. In: Fishery Products: Quality, Safety and Authenticity. Hartmut Rehbein, Jorg Oehlenschlager (editors). Chichester, Wiley-Blackwell, p. 425–443.

[11] Lauzon, H.L., Margeirsson, B., Sveinsdóttir, K., Guðjónsdóttir, M., Karlsdóttir, M.G., Martinsdóttir, E. 2010. Overview on fish quality research - Impact of fish handling, processing, storage and logistics on fish quality deterioration. Matís report 39–10, 70 pages.

[12] Seafish Industry Authority, 2011. Seafood Freshness Quality. Fact Sheet FS59-0111. Available at http://www.seafish.org/media/Publications/SeafishFactSheet_SeafoodFreshnessQuality_201101.pdf (accessed March 21, 2013).

15 days at 0 °C. It is observed that a larger difference in storage life variation is seen when going 1 °C below than above 0 °C.

Table 10. Calculated storage life at a predefined temperature based on a given storage life (SL) at 0 °C obtained from the square-root spoilage model of SSSP (adopted from Lauzon et al., 2010[13]).

SL at 0 °C	-1 °C	-0.5 °C	0.5 °C	1° C	2 °C
12	14.8	13.3	10.9	9.9	8.3
13	16.1	14.4	11.8	10.7	9.0
14	17.3	15.5	12.7	11.6	9.7
15	18.6	16.6	13.6	12.4	10.4

Table 11 shows that superchilled storage at –1 °C for 6 days can lead to a storage life extension of around 1 day compared to a 6-day storage at 0 °C (regular icing). This implies that valuable storage life is easily lost by a little temperature increase between –1 and 0 °C even though the time from catch to processing is limited to 6 days. However, due to influence on enzymatic reactions, care should be taken not to excessively superchill whitefish, which may lead to an altered spoilage process. For instance, a faster spoilage process has been observed for cod when stored at –1.8 °C in air than in ice at 0.6 °C.[14]

Table 11. Calculated remaining storage life at a predefined temperature based on a given storage life of 14 days at 0 °C obtained from the square-root spoilage model of SSSP.

Remaining storage life at	0 °C	5 °C
Stored at –1 °C for 6 days	9.1	4.1
Stored at 0 °C for 6 days	8.0	3.6

[13] Lauzon, H.L., Margeirsson, B., Arason, S., Martinsdóttir, E. 2010. Cooling technology report - Deliverable D3.12. EU-project CHILL-ON FP6-016333-2.

[14] Einarsson, H., Lauzon, H.L. 1996. Final report to the European Commission for the project AIR 2 CT93-1251, "Predictive modelling of shelf life of fish and meat products" (1993-1996), 26 pages.

4 Conclusions

The main conclusions from this study are the following:

- Superchilled processing and storage of whole whitefish could prolong both the freshness period and storage life of whole, fresh fish and products.
- CFD-modelling can be used to cost effectively simulate superchilling of whole fish in a CBC-cooler.

Further studies should consider the possible effects of superchilling on post-rigor whole fish and on processing yield both pre- and post-rigor. Also, future CFD-modelling can be used to optimise processing parameters such as holding time, temperature and air velocity as a function of fish size.

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6 Publications

The following has been published on the results of the current project.

1. Bjarnason, V.O. 2012. CFD Modelling of Combined Blast and Contact Cooling for Whole Fish. M.Sc. thesis, DTU, Department of Mechanical Engineering.
2. Ólafsdóttir, A., Margeirsson, B., Sveinsdóttir, K., Arason, S., Reynisson, E., Martinsdóttir, E. 2012. Effect of superchilled processing of whole whitefish - pre-rigor. Matís report 22-12.
3. Valur Oddgeir Bjarnason. CFD Modelling of Combined Blast and Contact Cooling for Whole Fish. Open MSc-presentation at Matís, 30 July 2012.
4. Bjarnason, V.O., Margeirsson, B., Walther, J.H., Arason, S., Bergsson, A.B. 2012. CFD Modelling of Combined Blast and Contact Cooling for Whole Fish. Poster presentation at the 4th Trans-Atlantic Fisheries Technology conference. Clearwater Beach, FL, USA, Oct 30–Nov 2, 2012.

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9. Martinsdóttir, E., Schelvis, R., Hyldig, G., Sveinsdóttir, K. 2009. Sensory evaluation of seafood: methods. In: Fishery Products: Quality, Safety and Authenticity. Hartmut Rehbein, Jorg Oehlenschlager (editors). Chichester, Wiley-Blackwell, p. 425–443.
10. Lauzon, H.L., Margeirsson, B., Sveinsdóttir, K., Guðjónsdóttir, M., Karlsdóttir, M.G., Martinsdóttir, E. 2010. Overview on fish quality research - Impact of fish handling, processing, storage and logistics on fish quality deterioration. Matís report 39–10, 70 pages.
11. Seafish Industry Authority, 2011. Seafood Freshness Quality. Fact Sheet FS59-0111. Available at http://www.seafish.org/media/Publications/SeafishFactSheet_SeafoodFreshnessQuality_201101.pdf (accessed March 21, 2013).
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14. Einarsson, H., Lauzon, H.L. 1996. Final report to the European Commission for the project AIR 2 CT93-1251, "Predictive modelling of shelf life of fish and meat products" (1993-1996), 26 pages.