Drying of salted fish

Comparison between different methods and species

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Faculty of Industrial Engineering, Mechanical Engineering and Computer Science
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Abstract

Dried salted fish is a popular seafood product in Southern Europe and South America. Large quantities of the salted fish from Iceland are further processed into dried salted products in Portugal before they are sold to the consumer in Portugal or exported to Brazil. By drying the salted fish in Iceland an added value could be achieved in the country before the fish is exported. In this thesis experiments were performed to gather knowledge of drying of salted fish in Icelandic conventional tunnel dryer. Products from different fish species, salting methods and treatments before and during drying were compared. The results showed that there was a great difference in drying rate between ling, tusk and cod. Comparison also showed difference between cod that has been pickle salted, brine salted and injected with Carnal phosphate. Still, no difference in weight loss was observed in drying between brined cod, with and without phosphate, from the same producer. Some advantages can also be achieved by compressing the fish during drying which speeds up water removal and reduces energy cost. All the salted fish had fully saturated brine in the water phase of the muscle and for that reason the fish does not follow normal drying theory. There is no constant drying rate in drying of salted fish, or at least it is very short and therefore the drying curve is different from drying of fresh fish. The humidity and temperature measurements were quite homogeneous through the drying tunnel and no difference could be seen in drying of fish in different locations of the drying tunnel. Results from chemical measurements conducted showed variance in water content and salt content between locations inside the split fish. The surface layer dried fast but inside the fish muscle the water content was still high after drying. Water content measurements using spectroscopic analysis with Near Infrared (NIR) technology showed positive results which have already been shown in an earlier research.

Útdráttur

Þurrkaður saltfiskur er vinsæl neysluvara í Suður-Evrópu og Suður-Ameríku. Töluvert magn af þeim saltfiski sem fluttur er út frá Íslandi er þurrkaður í Portúgal áður en hann er seldur til neytenda þar í landi eða fluttur áfram til Brasilíu. Áhugi er fyrir því að skoða fýsileika þess að flytja þurrkunarferlið hingað til lands og fá því virðisaukann af því vinnsluferli hingað heim. Í þessu verkefni voru tilraunir á þurrkun á saltfiski framkvæmdar til að afla þekkingar á þurrkun saltfisks í hefðbundnum íslenskum grindaklefa (pýramídaþurrkara). Fiskur af mismunandi tegundum, söltunaraðferðum og meðhöndlun fyrir þurrkun og á meðan þurrkun stóð var borinn saman. Niðurstöður sýndu að munur var á þurrkhraða milli löngu, keilu og þorsks og einnig milli þorsks sem var pækilsaltaður, sprautaður með Carnal fosfati og þorsks sem var pæklaður. Samt sem áður mældist enginn munur á þyngdartapi í þurrkun milli pæklaðs fisks, með og án fosfats frá sama framleiðanda. Nokkur ávinningur í formi hraðara þyngdartaps í þurrkun náðist með því að fergja fiskinn á meðan á þurrkferlinu stóð. Saltfiskurinn mældist allur með fullmettaðan saltpækil í holdi og fylgdi því ekki hefðbundnum þurrkferlum. Þegar ekkert laust vatn er í holdinu verður stöðugur þurrkhraði mjög stuttur, ef nokkur, og því er þurrkferillinn frábrugðinn þurrkun á ósöltuðum fiski. Hita– og rakastig var mjög einsleitt í þurrkklefanum og var ekki greinilegur munur á þurrkhraða í fiski sem staðsettur var á mismunandi stöðum í þurrkklefanum. Niðurstöður efnamælinga sýndu að yfirborð fisksins þornaði mest, en innan í fiskholdi er ennþá hátt vatnsinnihald eftir þurrkun. Niðurstöður á vatnsmælingum með litrófsgreiningu með innrauðu ljósi (Spectroscopic analysis using near infrared technology) gáfu til kynna að aðferðin væri möguleg við að meta vatnsinnihald saltfisks en það er í samræmi við eldri niðurstöður.

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Nomenclature

a	Top part of the loin (with or without the surface) in chemical measurements.
A	Surface area [m^2]
a_w (aw)	Water activity
b	Middle part of the split fish loin in chemical measurements.
c	Lowest part of the split fish loin, next to the skin, in chemical measurements
c_p	Specific heat capacity [J/kg/K]
d	Middle part of the split fish from the pelvic fins to the anal fins (with or without the surface) in chemical measurements.
e	Tail of the split fish (with or without the surface) in chemical measurements.
G	Mass flow of air [kg/s]
i	Enthalpy of air [kJ/kg]
L_S	Mass of dry solid [g]
m	Mass [kg]
m_l	Weight loss [kg]
p	Partial pressure of water in product [kPa]
p_0	Partial pressure of pure water [kPa]
q	Energy [kJ/kg]
R	Rate of drying
T	Temperature of air [°C, K]
t	Time
V	Air flow [m^3/h]
v_{air}	Air velocity [m/s]
w	Water
W	Weight [kg]
W_s	Weight of solid material [kg]
X	Moisture content of fish [%]
x	Amount of water in air [kg water / kg air]
X^*	Equilibrium moisture content (solid basis) [%]
X_C	Critical moisture content [%]
X_l	Relative weight loss in drying [%]
X_s	The proportion of solid material
$X_{s\ a.d}$	Proportion of solid material of the weight after drying [%]
$X_{s\ loss}$	Relative loss of solid material in drying [%]
$X_{s.\ b.d}$	Proportion of solid material before drying [%]
X_w	The proportion of the weight loss that is water [%]
$X_{w\ a.d}$	Water content of fish after drying [%]
$X_{w\ b.d}$	Water content before drying [%]
Z^{NaCl}	Salt concentration of water in fish. [%]

φ	Relative humidity (RH) [%]

Subscripts

Brine	Salted fish that is brine salted before kench salting
Brine + inj	Fish that is injected with brine and phosphate before brine salting and then kenching.
HSD	Tukey's honestly significant difference
LSD	Fisher's LSD method
NIR	Near Infrared
PCR	Principal Component Regression
PLS	Partial Least Square Regression
PORT	Quality specification of salted fish sold to Portugal.
SPIG	Quality specification of salted fish sold to Spain, Italy and Greece.
Std	Standard deviation
S	Small
L	Large
XL	Extra - large
WHC	Water Holding Capacity [%]
NBMS	Small ling nearest to air inlet, Middle height
NBML	Large ling nearest to air inlet, Middle height
NBUS	Small ling nearest to air inlet, Top
NBUL	Large ling nearest to air inlet, Top
MMMS	Small ling in the middle of center of the tunnel, Middle height
MMML	Large ling in the middle of center of the tunnel, Middle height
MMUS	Small ling in the middle of center of the tunnel, Top
MMUL	Large ling in the middle of center of the tunnel, Top
MVMS	Small ling at the left side in center of the tunnel, Middle height
MVML	Large ling at the left side in center of the tunnel, Middle height
MVUS	Small ling at the left side in center of the tunnel, Top
MVUL	Large ling at the left side in center of the tunnel, Top
MHMS	Small ling at the right side in center of the tunnel, Middle height
MHML	Large ling at the right side in center of the tunnel, Middle height
MHUS	Small ling at the right side in center of the tunnel, Top
MHUL	Large ling at the right side in center of the tunnel, Top
NHMS	Small ling next to door, Middle height
NHML	Large ling next to door, Middle height
NHUS	Small ling next to door, Top
NHUL	Large ling next to door, Top

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1 Introduction

Salting is an ancient method for preservation of food products. Salted fish products have been one of Iceland's most important export items through the years. Drying of seafood is a method that has been known for centuries which prolongs shelf life even more. Drying of salted fish is not a new production method but it has been developing through the years. In drying of salted fish in the past, fish was hung out to dry but today indoor drying is used exclusively. Today, no company in Iceland is producing dried salted fish in large quantities. Due to changes in the market there is an interest to study the possibility of starting a production and export of dried salted fish to current and new markets. Large quantity of Icelandic salted fish is exported to customers in South Europe where it is dried before it is sold to consumers there or exported to South America, where Brazil is one of the largest markets. In this project, different factors affecting drying of salted fish were analyzed with the objective of gathering knowledge on efficiency and quality of the products, focusing on factors such as air velocity, temperature and humidity. Drying rate was measured for different fish species, sizes and salting methods. The effects of compressing the material during the drying process were also examined. The water content and salt content was measured at different locations in the split fish both before and after drying along with water holding capacity and water activity. Finally the fish was rehydrated and sensory analysis conducted. Samples were sent to the markets for inspections and review at potential customers.

1.1 Motivation

Cod is a very popular fish in Southern Europe and South America. Even with development of other preservation techniques, the market for dried salted cod is still very strong.

In recent years, Icelandic seafood producers have been exporting great amounts of salted cod to southern parts of Europe, mainly to Spain, Italy, Greece (SPIG) and Portugal (PORT). The Portuguese have been drying salted cod, or "bacalao" as it is known in the European and South American market, and exporting it to Brazil. That includes some of the salted fish that the Portuguese import from Iceland. As the Icelandic cod quotas have been decreasing the past decades and competition hardening, the emphasis is becoming more and more on quality rather than quantity. More emphasis is being put on full processing in order to add value in Iceland and get the highest possible share of the value remaining in the country. Due to financial crises in Europe and increased cod quotas in North Atlantic Ocean the market price for Atlantic cod (*Gadus Morhua*) have been decreasing so it is necessary to look at new markets with new products to get the highest possible value for all seafood products caught and processed in Iceland. Fuel for heating air in air dryer is the main economic factor in production of dried fish and by using geothermal energy, Icelandic companies could have a competitive advantage in dried salted fish markets where the price is important.

1.2 Objectives

The objectives of this thesis are to analyze the current methodology for drying of salted fish and explore whether there are differences in drying rate and physical properties between different species, salting methods and size grades. In addition, the goal is to gather knowledge about drying salted fish in Icelandic designed tunnel (pyramid) dryers (see Section 3.2 “Drying facilities”) and evaluate the most suitable drying conditions.

Some questions or bullet points are presented and attempts made to answer or touch on the following. Explanation of some of the terms will be introduced in the following chapters.

- Is it possible to dry different species and sizes of salted split fish together or are the requirements different between groups?
- How long is the drying process of different groups at different drying conditions?
- Does phosphate injection affect the ability to dry salted fish?
- Is there any difference in drying of brine salted fish and pickle salted fish?
- Is it possible to use mass balance to calculate the final water content of dried split fish from the weight loss?
- Is there any difference in water content, water holding capacity, salt content and water activity between different locations in the split fish?
- Is there any difference in drying rate between locations in the drying tunnel?
- Are there benefits in compressing the fish during or before drying?
- Is there any difference in rehydration yield between different salting methods and species?
- Does the salt crystalize inside the fish muscle when the water evaporates?
- Is it necessary to wash the salt of the surface of the split fish before drying?

1.3 Salted fish

The Egyptians were the first to use salt in order to preserve food prior to the year 2,000 B.C. Salting and drying methods to preserve food, together with fish catching techniques have been reflected in wall paintings that reveal the daily life of ancient Egypt (Gallart-Jornet *et al*., 2006). Since then, different methods have been used for salting of fish even though the basic functionality has stayed the same. The quality and characteristics of the salted products are believed to be influenced by the salting method used (Thorarinsdottir *et al*., 2004). The traditional way of salting is brine or pickle salting followed by kench salting (dry salting; also called kenching).

Curing of salted fish in Iceland has developed through the years (Figure 1) and it can be roughly categorized into four methods: Kenching, pickling, brining and injecting. Kench salting was the method used in the beginning. The fish was butterfly split before it was stacked up and each layer of fish was covered with salt. The fish takes up salt while liquid diffusing from the muscle is allowed to drain away. The fish was stored like that for 10 to 12 days and then packed or stacked again with new layers of salt to dry the fish even more.

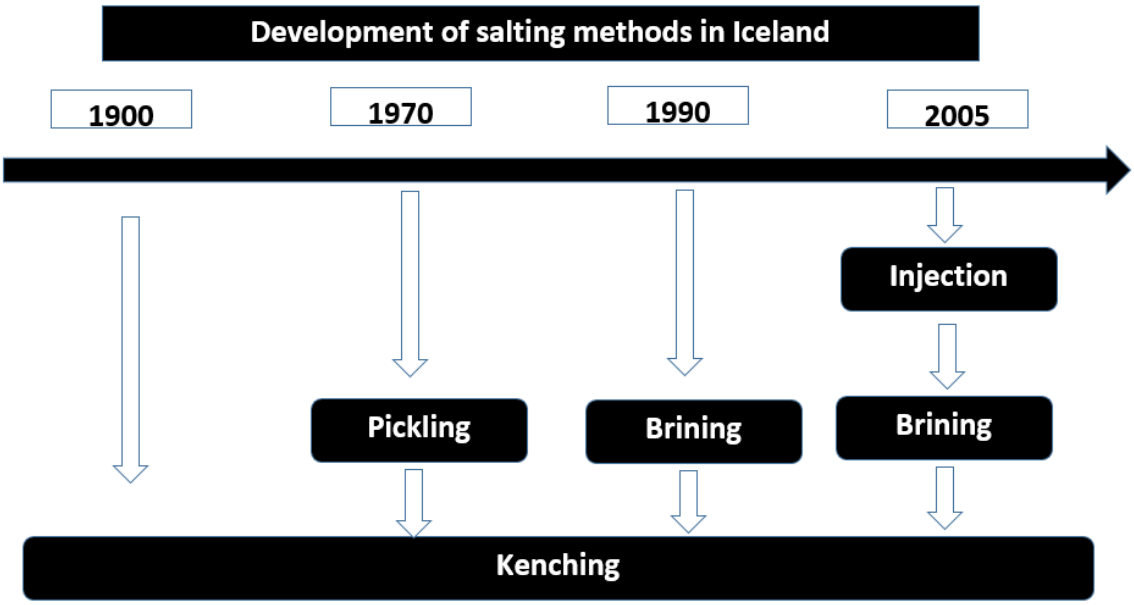


Figure 1 Development of salting methods in Iceland (Palsson et al, 2012)

In pickling, the split fish is put into a closed plastic tub and salt spread over each layer. Fully saturated brine is formed when the water flows out of the fish and dissolves the salt. The fish stays in the fully saturated brine for 3 to 5 days. The reason why pickling process was added before kenching was that the salt absorption of the fish was much faster and the color of the product lighter. The downside of the kenching and pickling is that the surface is burned because of the direct contact with the salt resulting in closing of the surface. That leads to much decreased absorption of salt and makes it harder for it to reach all the way through the fish muscle. The parts of the muscle that do not get sufficiently salted are then exposed to bacteria growth and enzyme activity which facilitates spoilage. Furthermore the salt burning causes denaturation of proteins. To decrease this surface burning and denaturation of proteins the third salting method, brining, was developed. In brining, the split fish is put into milder brine (about 18 %) for 24 to 48 hours. That way quicker salt uptake is achieved without burning the fish surface. In Iceland the method of brining has become more popular than pickle salting. Brining result in better yield and lighter color of salted and dried salted fish because of stronger water retention of the fish muscle compared to pickle salting and kenching (Barat *et al*., 2003; Brás & Costa, 2010; Thorarinsdottir, 2010)

The most recent method is to add brine injection to the process. The fish muscle is injected with brine to speed up the salting absorption and prevent spoilage from bacteria and enzyme. Brine injection also helps to get salt into thicker parts of the muscle, which tend to be left out, and the salting becomes more homogeneous. The risk of contamination is highest in injection salting and therefore hygiene is very important, both with the needles and the salt. In Iceland the salting process today normally consists of injection, brining and then kenching. In that way fast and effective salting is ensured in all parts of the fish muscle. Water activity of fish with fully saturated brine in the muscle is about 0.75 to 0.78. In those cases prevention of almost all bacteria has been ensured (Aberoumand, 2010).

Figure 2 Kench salted and stacked split fish. Catch from Gardar GK in the summer of 1935 (http://solir.blog.is/blog/solir/?offset=710)

Icelandic companies have been using polyphosphates to reduce the oxidations of lipids in salt fish that causes yellow discoloration of the products. In the past years polyphosphates have not been allowed in production of salted fish in Europe, however phosphate is allowed in salted fish in Brazil and from January 2014 it might be allowed in Europe. Therefore in this thesis, the effects of polyphosphate in drying of cod was examined and compared to drying of cod without polyphosphate. Cod that has been injected with polyphosphate will be referred to as "injected" cod and cod without polyphosphate will be referred to as "non-injected" in this thesis..

1.4 Drying of salted fish

Years back production of dried salted fish stopped in Iceland, mainly because of high labor cost. That part of the processing is now mainly done in Portugal (Palsson *et al*., 2012). Today majority of the exported salted fish from Iceland is wet salted fish that is salted fish that is not dried after salting. In fact, in 2010 wet salted cod amounted for the highest exporting value from individual seafood products from Iceland (Hagstofan, 2011). In Portugal, salted fish is considered to be dry when it stays straight when held by the loin (Figure 3). If the fish stays straight the water

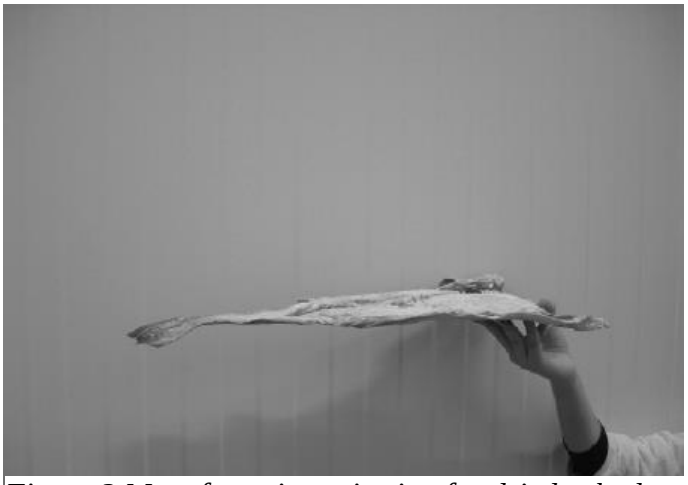


Figure 3 Manufacturing criterion for dried salted fish is that it stands straight when held by the loin (Brás & Costa, 2010)

content is below 47 %, which is a requirement for the Portuguese market. Even though the water content is below 47 % the drying is considered insufficient if the fish bends in the test as it might present different characteristics for the consumer, for example in terms of texture (Brás & Costa, 2010). According to Rui Costa at ESAC, Higher School of Agriculture in Combria, Portugal, the method of holding the fish by the loin is an empirical technique used for centuries and no studies about the relation of the curvature with other parameters are known by him (Costa, 2013). Drying is not only a method to increase shelf life of the product and reduce transportation cost, it also gives a specific taste and texture that is desirable in many countries.

1.5 Markets for salted fish

Iceland is a large exporter of salted fish. In 2011 about 28.1 % of caught cod was salted (Hagstofan, 2012a). In 2011 the export value of salted fish products was about 29,000 million ISK or about 11.6 % of the total export value of Icelandic seafood products that year. Of the 29 billion ISK, the value of the wet salted fish was about 15 billion ISK (Hagstofan, 2012b).

The quantity of salted products from Iceland have been quite stable for the last few years, about 20 to 40 thousand tons and about 20,000 – 30,000 million ISK (Figure 4 and 5).

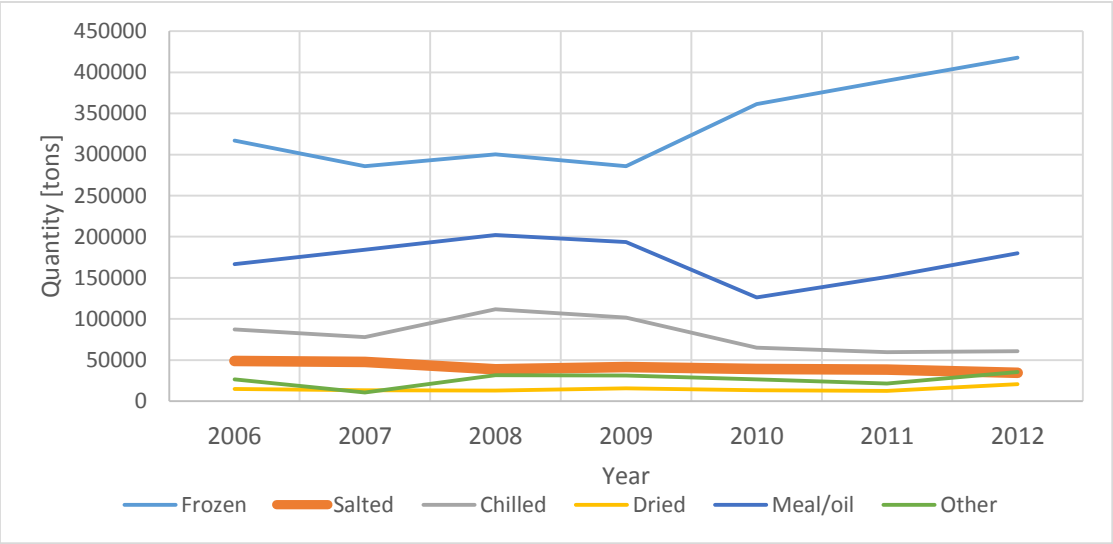


Figure 4 Export quantity of different seafood products from Iceland 2006 - 2012 (data from Statistics Iceland)

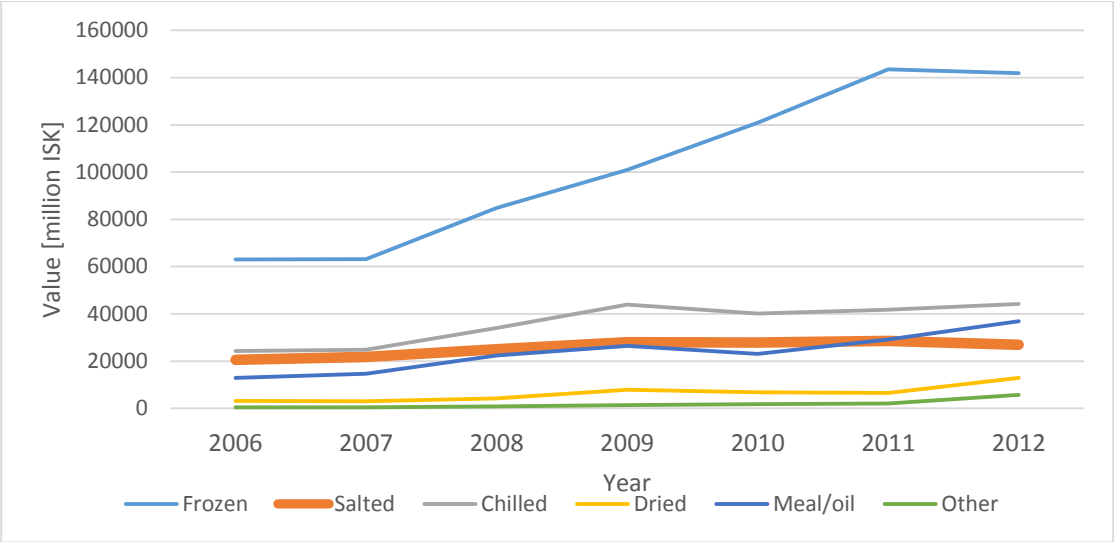


Figure 5 Export value of different seafood products from Iceland 2006 - 2012 (data from Statistics Iceland)

Portugal and Spain are the largest importer of Icelandic salted cod products. In Figure 6 the export of salted and "dried and salted" cod to Portugal from different countries can be seen from Haagensen's presentation at Marin Samhandlingsarena in 2011. According to him, Norway is the largest exporter of salted fish to Portugal and Iceland the second largest.

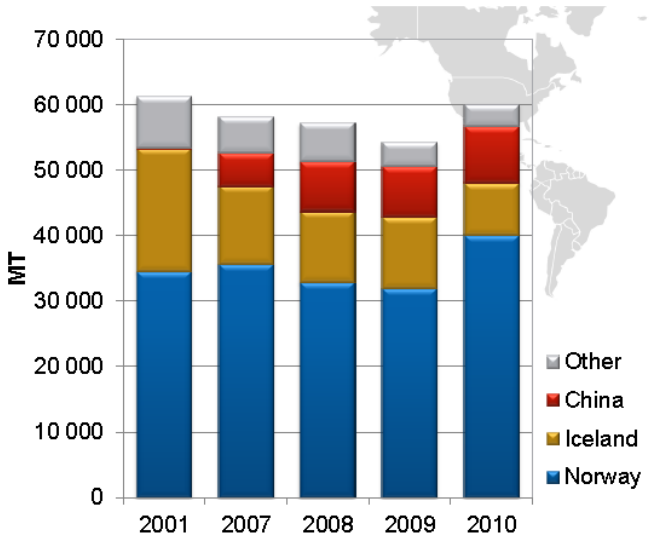


Figure 6 Export of salted and "dried and salted" cod to Portugal (Haagensen, 2011)

Together with dried and salted cod, Norway exports wet salted cod to Portugal where it is dried for domestic consumption. The advantages of drying the material in Portugal have been lower production cost. Portugal also dries parts of their salted fish imported from Iceland. Even though the Atlantic cod (*Gadus Morhua)* is preferred and accounts for almost all the dried salted fish consumption in Portugal (Nystrand, 2011), they also import dried salted products from other species like, saithe (*Pollachius virens*), tusk (*Brosme brosme*) and ling (*Molva molva*).

According to Statistics Iceland some quantities of dried salted fish have been exported from Iceland in recent years, mainly cod or about 2000 to 3000 tons (Figure 7 and 8). Still when asked around no one knows who is drying the fish in this quantity so the exporting figures might not be accurate.

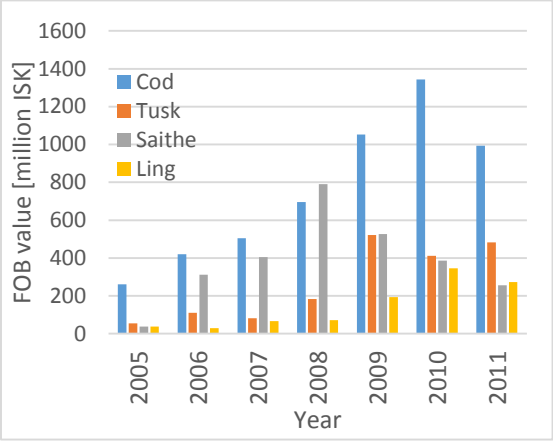


Figure 7 Value of exported dried salted fish from 2005 - 2011 (data from Statistics Iceland)

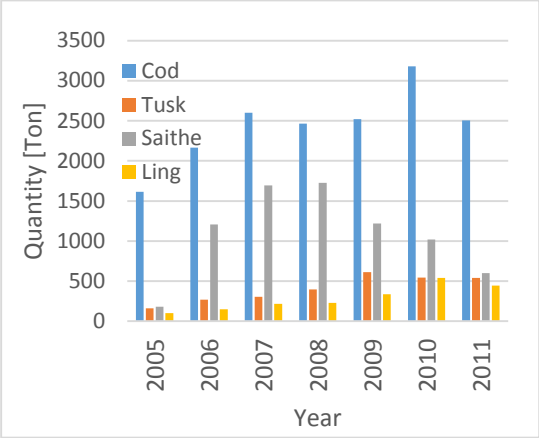


Figure 8 Export of dried salted fish from Iceland 2005 – 2011 (data from Statistics Iceland)

A related objective of this thesis was to analyze the possibility for Icelandic seafood producers to dry the salted fish sent to Portugal and therefore adding extra value to the product before it ends up in Brazil.

As a Catholic country, Brazil is influenced by traditions that once were recognized in Southern European countries. There is a rich tradition to consume fish in Easter time and especially on Good Friday, where salted fish or dried salted fish is usually the number one alternative. Salted fish consumption over the Easter holiday is about 35 % of the total annual consumption of salted fish in Brazil (Gardar, 2013).

In recent years new seafood products have entered into the Brazilian market, competing directly with traditional salted and dried bacalao from Norway. In an article based on a research project financed by the Norwegian Seafood Research Fund, the Norwegian Fishermen‘s Sales Organization Nordea and the Norwegian Seafood Council, it is stated that the main competition to Norwegian dried salted split fish is from dried and salted fish in smaller pieces and frozen desalted bacalao. The market share of Norwegian bacalao has decreased from 86 % to 61 % in the last five years. In 2011 Brazilian consumer purchased about 45,000 tons of frozen desalted cod. That is about 10 % of the total bacalao market. The results of consumer surveys have shown that desalted fish is preferred to avoid the time consuming process of desalting the product. People seem to be willing to pay higher prices for desalted products (Egeness, 2012).

1.6 Previous experiments

Norway is the largest exporter of salted and dried cod products with about 30 % of the world export. In the years of 2005 to 2008 a big project of drying of salted fish was run in Norway in collaboration between SINTEF, which is the largest independent research organization in Scandinavia, COWI, consulting group in Tromsö and FHL, The Norwegian Seafood

Federation. The results from their studies showed that when salted cod was dried in a tunnel dryer the surface was completely dry after few hours and then the drying rate dropped. After 24 to 48 hours the drying rate was uninfluenced by high air velocity and low relative humidity. Other factors, such as water transport inside the fish, salt transport and salt accumulation in the drying, had bigger effects (Magnussen & Walde, 2008).

In the same research results showed big difference in drying rate between cod and saithe and between size grades. The span of drying was also big between fishes with similar weight and length.

It is also stated that big difference in air velocity from the top and bottom of each rack in the drying tunnels and also between locations in the tunnel caused uneven drying (Jonassen & Walde, 2006a).

In a different report Jonassen and Walde stated that burning of the surface of the fish occurred if the air temperature went above 26 to 28 °C and because of that it is very conservative to have the temperature limit up to 23 °C (Jonassen & Walde 2006b). They also found out that the drying time could be reduced by 30 % for cod by increasing the temperature from 21.9 °C to 26.5 °C (Jonassen & Walde 2006c).

In another research in Norway, pausing the drying of the fish in the drying process was tested. Fish that was paused in the drying process dried much faster in a short interval after the pause but it never got as dry as the fish that was dried continuously. Measurements of initial water content and water activity gave reproducible results, but measurements during the drying process where difficult to interpret. Both water content and water activity seemed to be dependent and varying with which layer of the fish the measurements were made, but there was a good agreement between the measured water content and water activity (Stevik *et al*., 2007).

Only cod (*Gadus morhua*) and saithe (*Pollachius virens*) were dried in the Norwegian research as in this following research ling (*Molva molva*) and tusk (*Brosme brosme*) were also dried. The drying cabins used in the Norwegian research have 10 to 12 racks in the length of the tunnel while in this research the Icelandic pyramid driers had shorter tunnels, only six racks in the length of the tunnel. Therefore less difference in drying rate between front and back of the tunnels should be obtained. The salting methods were also different as the Norwegian fish was pickle salted while the Icelandic fish was brine salted. In this thesis pickle salted fish was compared with the traditional Icelandic brine salted fish and fish injected with phosphate.

In 2010 a drying research was made in Portugal, with the object of studying the influence of brining before pickling in terms of yield, drying time, color and texture. The fish that was studied was Alaska Pollack (*Theragra chalcogramma*), Pacific Cod (*Gadus Macrocephalus*) and Atlantic Cod (*Gadus Morhua*) (Brás & Costa, 2010).

In 2007 drying research was conducted in Iceland where cod salted with different salting methods was dried for ten days in a drying cabin identical to the one used in this study. Water and salt content were also measured before and after drying but not in as systematic way as in this current study (Thorarinsdottir *et al*., 2007).

In the nineties, drying research was conducted in Iceland where weight loss was measured at different drying conditions in terms of humidity, temperature and air velocity (Arason, 2012). The research was limited to 1 - 2 kg cod split fish as in this study both larger cod split fish was used together with other species and also drying of fish that was washed prior to drying and not washed was compared. In the previous research only washed cod was dried.

What is also different from the experiments made in this current study and previous researches is that chemical measurements where made from samples in five different locations of the fish to examine chemical content in different places instead of only one or two samples from the fish. Author has not found results from experiments with drying for ling or tusk or comparison of washed and not washed split fish.

1.7 Structure of the thesis

In the first chapter the motivation for the thesis is introduced, some definitions of salted fish and drying of salted fish explained, focusing on the market trends for dried salted fish in Southern Europe and Brazil. Previous researches on drying of salted fish, both in Iceland and Norway, are then reviewed. In chapter two, drying theory will be explained and methods for analyzing different parameters in drying and spectroscopic analysis using NIR technology will be introduced. In chapter three the drying experiments made in this research are described and in the following chapter the results are presented and analyzed. Thereafter discussion and conclusions are made, followed by future work.

2 Theory

2.1 Physical properties of fish

The water content of fresh cod is about 80 - 85 %, the protein content about 17 – 20 % and the fat content 0.4 – 0.9 %. Nutrition is not homogenous in the fish muscle. For example in fresh cod the water content is highest in the tail and lowest near the head but the protein content is lowest in the tail and highest in the loin. The fat content is relatively higher in the tail than in the middle part and the loin (Pálsson *et al*., 2012).

The season is not the biggest factor when it comes to producing high quality salted fish even though the fish is little bit different depending on the time of year. There are small changes in water content and protein content between seasons but it is mainly between April and June, during spawning where the protein content is low and the water content high. Still the variations in fat content are much smaller in white fish like cod than in fatty fish like herring or mackerel where the fat content changes from 5 % to 30 % in a few months over the summer (Thorarinsdottir *et al*., 2011). Attributes of the fish and nutrition can vary depending on the catching grounds. The water content, salt content and fat content of cod, ling and tusk can be seen in Table 1. That are the species that are dried in the experiments in this study.

Table 1 Nutrition of fresh fish (Arason, 2010)

Species	**Tusk (*Brosme brosme*)**	**Ling (*Molva molva*)**	**Cod (*Gadus morhua*)**
Protein [%]	19.1	19.8	17 – 19.9
Fat [%]	0.8 - 2.2	0.2	0.44 - 0.73
Water [%]	80.4	79.2	79.9 - 87.5

2.2 Drying theory

2.2.1 Drying techniques

Drying processes can be classified into three categories. The first is air and contact drying, where the heat is transferred through the product from heated air or surface and the water vapor is removed with the air. The second is vacuum drying where low pressure is used to facilitate evaporation and the heat transfer is usually made with conduction or radiation. The third category is freeze drying where the water evaporates and is removed from the product in frozen state by conducting the process below the triple point (Mujumdar, 2006) . Freeze drying has the benefits of preserving the quality of the food very well but it is an expensive process and has not been used much for drying of salted fish even though some experiments have been made. Also laboratory-scale experiments have been made in Norway using

vacuum drying and the result indicate that drying can be shortened by those means compared to air drying (Jonassen & Walde, 2007).

The present study is limited to air drying which is the method that is used today in drying of various seafood products in Iceland. The drying facilities are available and it is the traditional method for drying of salted fish. Freeze drying might become more popular in the future but one of the reasons it has not been used before in drying of salted fish is that the process is considerably more expensive than conventional air drying and is used for more expensive products.

During drying of food in an air dryer, water is removed by blowing dry hot air over the surface of the product. The product warms up, and the water evaporates and is carried away with the air. There are two main factors in the process that make the drying possible, that is transfer of heat necessary for the evaporation and the movement of water through the food material and away from it. When drying in rack cabins dry air is heated up, blown through the tunnel where the product is located and goes out as colder and more humid air. While the surface of the product is wet, the drying rate is constant. When the surface of the product has become dry the water from within the fish muscle starts to transfer to the surface to balance out the difference in moisture content. Temperature, relative humidity and air velocity are of importance in the beginning of the drying period for the rate of drying but in later stages it is the friction of steam flow inside the product that has most influence on the drying rate. It takes much shorter time to get the surface dry than the inner parts (Earle & Earle, 2004). The drying rate also decreases when the free water decreases and the bound water is removed. The difference in water activity inside the product and the relative humidity in the surrounding air is the driving force in drying.

Equation (2.1) is used to calculate constant rate drying

$$\frac{\Delta w}{\Delta t} = \text{constant} \tag{2.1}$$

where Δw is the weight loss on a time interval Δt.

The constant drying rate ends when free water on the surface has been removed, that is when the moisture content X has reached X_c, the critical free moisture content. Then there is insufficient water on the surface to maintain a continuous film of water and the drying rate falls (from time B to C in Figure 9). At time C the surface is completely dry and the drying rate falls more. The drying curve in Figure 9 is of same nature as presented in the book *Transport processes and separation process principles* (Geankoplis, 2003).

In the falling rate period diffusion through the fish and changes in energy-binding patterns of the water molecules affect the drying rate. In the book *Unit operations and food processing* it is also mentioned that there are very little theoretical information available for drying of food in falling rate period and experimental drying curves are the only sufficient guide to designing of drying processes (Earle & Earle, 2004).

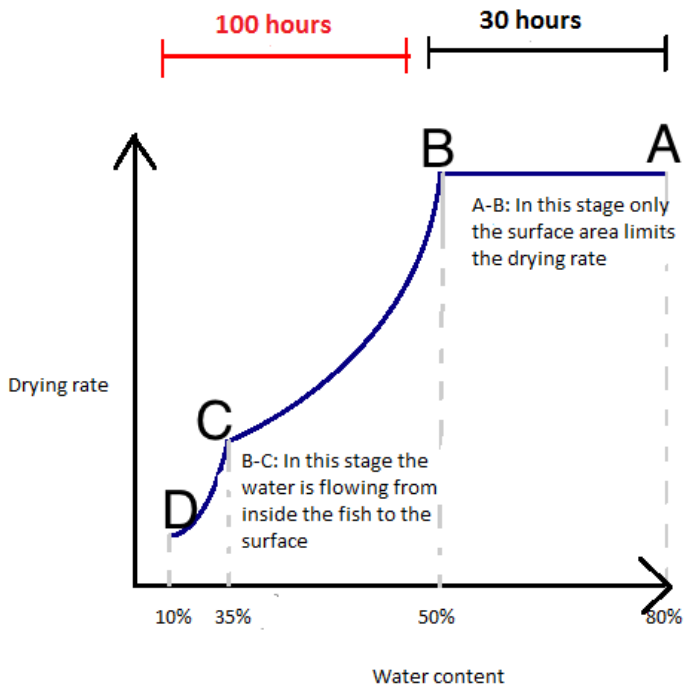


Figure 9 Theoretical drying rate of a product (Earle & Earle, 2004)

2.2.2 Water activity

There are three forms of water all of which are presented in some quantity in food products. Type 1 is water that is bonded to the fish by strong hydrated chemicals, or structured water. The second type is bound water that is tied up by the presence of soluble material such as salts, vitamins and proteins and the third type is free water that can be easily removed from the product (Mathlouthi, 2001). The water activity is a measurement of how much of free water is in the product,, that is how much water is available in a product for chemical reaction and microbial growth.

Water activity is defined as the ratio between the partial pressure of water vapor in product, p, and the partial pressure of pure water, p_0.

$$a_w = \frac{p}{p_0} \tag{2.2}$$

Equation (2.2) above assumes that the product is in equilibrium with the surrounding atmosphere (Lewicki, 2004).

Pure water without any solutes is 100 % available for microorganisms. Salt, sugar and other substances that dissolve in water decrease the water activity as part of the water becomes bound in the substances. So by salting the fish the water activity decreases, which reduces spoilage.

Most methods for measuring water activity were originally designed for measuring relative humidity in the atmosphere (Troller & Christian, 1978). In equilibrium, water activity equals the relative humidity in the surroundings and for that reason, being aware of the humidity in storage is very important as it can have great effects on the quality of the product. If the relative humidity in the surroundings is lower than the water activity, the product dries up

trying to get to equilibrium and if the surroundings have high humidity the product takes up water and increases water available for microorganisms and spoilage. If water activity is higher than the humidity of the environment, water flows out of the product and vice versa (Figure 10).

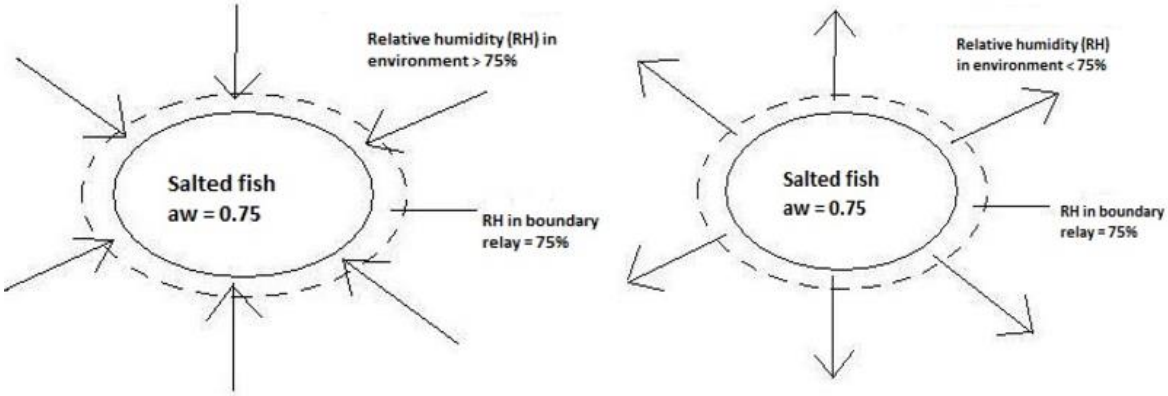


Figure 10 Relationship between relative humidity and water activity in drying of fish

Lowering of water activity is the reason why salting and drying increases preservation of fish. One of the reasons for drying salted fish for the Brazilian market is to crystalize salt inside the fish so when the fish is put out on street markets in 80 to 90 % humidity, it might absorb some water from the environment but enough of salt crystals are available in the muscle to keep fully saturated brine in the fish even though some water is added.

2.2.3 Drying rates of salted fish

The goal of drying salted fish is both to increase shelf life and decrease transportation cost. The drying also gives special taste and texture which is desirable in some markets where the product is very popular commodity.

Washing the wet salted fish before drying is recommended. The fish is washed in a machine that brushes the fish in continuously flowing water. The salted fish is washed before drying to remove salt from the surface of the fish (Beatty & Fougere, 1957). The black membranes on the belly flaps should be peeled of and that is done manually (Figure 11).

Figure 11 Salted cod split fish placed on a drying tray - the black membranes can be seen on the belly flaps

Before, drying was usually divided into 2 to 3 steps and the fish was restacked between steps depending on the desired final water content (Table 2).

Table 2 Steps in drying of salted fish (Arason, 2010)

Step	Temperature	Humidity	Water reduction	
			From	To
1	18 °C	65%	52%	46%
2	21 °C	55%	46%	40%
3	25 °C	45%	40%	35%

Since Icelandic companies started brine salting instead of pickle salting split fish, the initial water content before drying became 57 to 58 % instead of the original 52 %. The reason for the increased water is that with brining, the denaturation of proteins are less than in pickle salting which results in increased water holding capacity of the muscle (Thorarinsdottir *et al*., 2004). There are many different definitions of salted fish depending on the curing states, where both salt content and water content varies (Thorarinsdottir *et al*., 2010).

2.2.4 Drying calculations using Mollier-diagram

With Mollier diagrams, it is easy to visualize the most common air condition processes in air drying. That is heating of air, humidifying air by adding water to it, cooling and dehumidifying air and mixing air. Mollier diagram provides a graphical representation of the physical properties of the air, which helps to understand the behavior of air in the drying process (Figure 12).

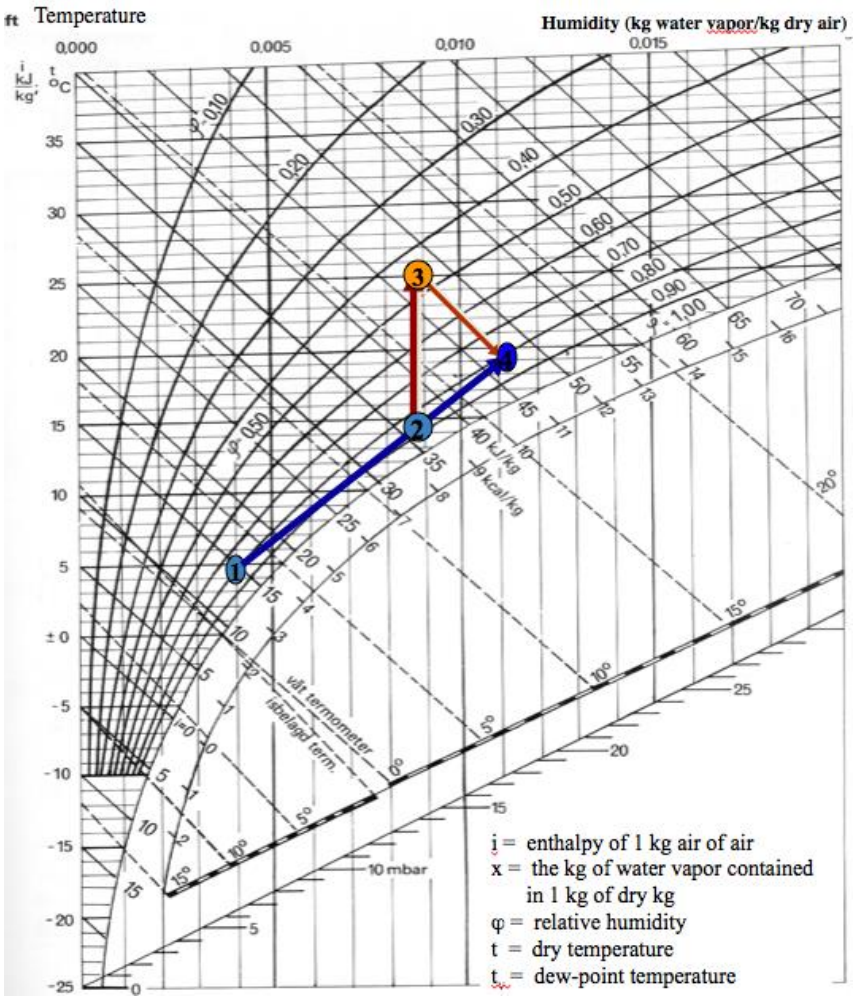


Figure 12 Mollier diagram (Arason, 2012)

To locate a state on a Mollier digram, two variables need to be known. The possible variables are:

Temperature *T*:
Temperature of the air can be seen on the vertical axes where the temperature lines lie perpendicular out from the axes.

Enthalpy *i*:
Enthalpy of the air is also on the vertical axes but the energy lines lie diagonally down.

Water content *x*:
Parameter for how much water the air can hold. The amount of water in each kilogram of air. It is located on the horizontal axes above the chart and the lines lie vertical down from the axes.

Relative Humidity *φ*:
The humidity of the air is located on the curved lines starting from the bottom left to the top right corner.

In Figure 12, the conditions of the air at different locations in the drying tunnel can be seen. Input air, coming into the facility is in condition 1. Condition 2 is a mix of the air coming in from the environment and air that is circulated from the tunnel. The process of heating air is expressed from point 2 to point 3 on the diagram. Heating of the air moves the air condition from 2 to 3 along a constant humidity line and the increase in heat [kJ/kg] can be read from the chart (Arason, 2008).

Mixing air of different conditions is done in air drying when the output air is recirculated. Input air at condition 1 and humid air carrying water from the fish out of the tunnel in condition 4 is mixed and the mixing point will be on a straight line between those conditions, depending on the volume of air 1 and air 3.

The heat balance for the mixture can be expressed as:

$$m_1 * i_1 + m_4 * i_4 = (m_1 + m_4) i_2 \tag{2.3}$$

Where *m* is the mass of the air and *i* is the heat enthalpy of the air in condition 1, 4 and 2.

The moisture balance for the mixture can be expressed as:

$$m_1 * x_1 + m_4 * x_4 = (m_1 + m_4) x_2 \tag{2.4}$$

Where *x* is the water content of the air in condition 1, 4 and 2.

When the heated dry air is blown over the wet fish, water is added to the air from the fish because of the humidity difference. In other words, the water is added to the air without any heat supply and then the air condition changes adiabatically along a constant enthalpy line and the temperature of the air decreases from point 3 to point 4. These characteristics of the air in drying can be used when designing an air dryer.

The energy needed can be calculated with Equation (2.5). It depends on the mass of air *G* that has to be heated in the heating elements. The heat is the difference between the enthalpy *i* in points 2 and 3 on the Mollier diagram.

$$q = G * \Delta i_{2-3} = m_w * c_{pw} * \Delta T_w \tag{2.5}$$

The volume flow of air *V* that is needed in the drying depends on how much water m_w from the fish is evaporated on a time unit and the water capacity of the air. The amount of water carried away equals the humidity difference between the air into the drying tunnel and out of it, which is point 3 and point 4 in the Mollier diagram. Using Equation (2.6) for calculation of water evaporated on a time unit, Equation (2.7) can be used to calculate the volume flow of air (Arason, 2011).

$$m_w = \frac{m}{\Delta t} \tag{2.6}$$

$$V\left[\frac{\mathrm{m}^3}{\mathrm{klst}}\right] = \frac{m_w\left[\frac{\mathrm{kg\ water}}{\mathrm{klst}}\right]}{\rho\left[\frac{\mathrm{kg}}{\mathrm{m}^3}\right](x_4 - x_3)\left[\frac{\mathrm{kg\ water}}{\mathrm{kg\ air}}\right]} \tag{2.7}$$

By using simple mass balance the amount of water that has to be removed from the fish can be calculated, which is a precondition for all other calculations above regarding temperature, humidity and air velocity in the drying.

Knowing the cross sectional area of the drying tunnel and the air velocity, the volume of air that can flow through the tunnel and remove water from vapor on a time unit can be calculated with Equation (2.8). Optimization of that area and air velocity could minimize energy consumption.

Volume velocity of the air can be expressed as

$$V\left[\frac{m^3}{s}\right] = v_{\text{air}}\left[\frac{m}{s}\right] * A'[m^3] \tag{2.8}$$

where v_{air} is the air velocity and A' is the tunnel cross section area available for air flow

$$A' = A * \varepsilon \tag{2.9}$$

where A is the total cross sectional area of the tunnel and ε is the proportion that is not occupied by racks and fish.

As stated before, the difference in relative humidity between the fish (water activity) and the surrounding air is the main drying force in the beginning of the drying process.

2.2.5 Drying formulas

Different equations are used in calculations of drying curves depending on the drying conditions. For constant drying conditions, the drying rate is calculated with Equations (2.10 to 2.12) from the book *Transport processes and separation process principals* (Geankoplis, 2003) as follows:

$$X_t = \frac{W - W_s}{W_s} \tag{2.10}$$

where W is the weight of the fish before drying and W_s is the weight of the solid material. The free moisture content X in kg free water/kg solid is calculated at each time t as

$$X = X_t - X^* \tag{2.11}$$

where X^* is the equilibrium moisture content $\left(\frac{\text{kg equilibrium moisture}}{\text{kg dry solid}}\right)$ on a solid basis.

Boeri *et al.* (2013) studied the equilibrium moisture content isotherms of codfish at various conditions and according to their results, when drying at constant conditions, the equilibrium moisture content for salted cod with water content 55.6 % at 40 % relative humidity is about 6 to 11 % (wet basis) which equals 6.3 to 12.4 % on a solid basis depending on temperature. At 60 % relative humidity the equilibrium moisture content is between 10 and 20 % on wet basis. That is well below the 47 % wet basis water content that the aim is to dry the fish to. Knowledge of the equilibrium moisture content is necessary to use Equation (2.11) to calculate the free moisture content and determine the drying rate.

The rate of drying R, is calculated at each point in time as follows

$$R = -\frac{L_S}{A}\frac{dX}{\Delta t} \tag{2.12}$$

where L_S is the kg of dry solid used, and A exposed surface area for drying in m^2.

2.3 Material and energy balance

Material and energy balances are important in the food industry. Both in processing control and designing of processes it can be a useful tool. The law of conservation of mass states that mass can neither be created nor destroyed. One of the objectives of this thesis examine the accuracy of using simple mass balance calculations to determine the final water content of the fish by looking at the weight loss in the process, compared to actual water content measurements after drying.

Roughly the estimation of the material balance in the process of drying fish is:

$$m_m = m_v + m_p \tag{2.13}$$

where m_m, is the mass of material, that is salted fish, m_p is the mass of product which is the dried salted fish and m_v is the mass of water vapor removed from the fish (Figure 13).

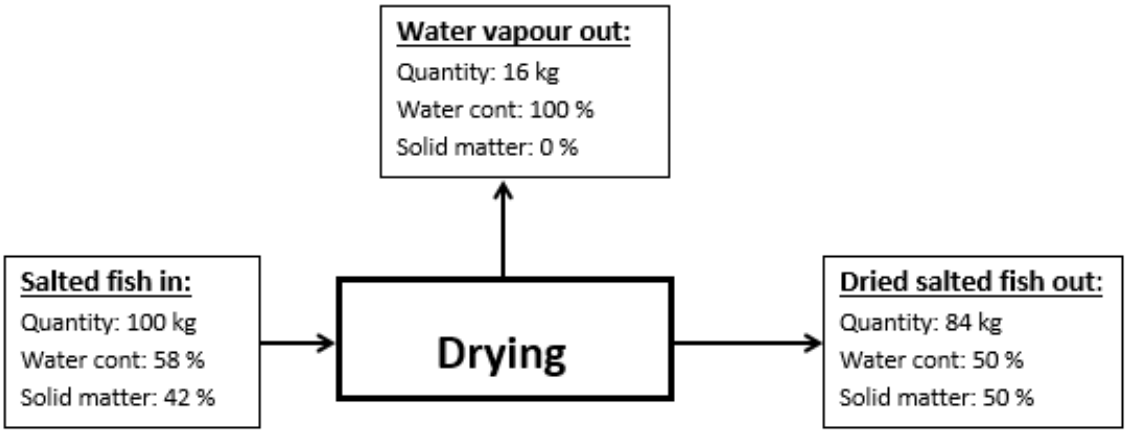


Figure 13 Example of mass balance in drying of salted fish.

If water content of fish is predicted by using mass balance based on the weight loss in drying the calculations are as follows in Equation (2.14)

$$m_{\text{salted\_fish}} * X_{\text{solid\_before}} = m_{\text{driedfish}} * X_{\text{solid\_after}} \tag{2.14}$$

Where $m_{\text{salted\_fish}}$ is the mass of the salted fish before drying and $X_{\text{solid\_before}}$ is the proportion of the weight that is solid material. $m_{\text{driedfish}}$ is the weight of the fish after drying and $X_{\text{solid\_after}}$ is the proportion of solid material after drying.

Measuring the weight before and after drying and the water content before drying should be sufficient for estimating the water content after drying using Equation (2.14).

Calculations of water content after drying $X_{\text{w a.d}}$ considering the weight loss X_{l} and the water content before drying $X_{\text{w b.d}}$ is as follows in Equation (2.15).

$$X_{\text{w a.d}} = \frac{X_{\text{w.b.d}} - X_{\text{l}}}{1 - X_{\text{l}}} \tag{2.15}$$

Also the weight loss X_l can be calculated if the water content before and after drying is known.

$$X_l = \frac{X_{\text{w.b.d}} - X_{\text{w a.d}}}{1 - X_{\text{w a.d}}} \tag{2.16}$$

2.4 Spectroscopic analysis (NIR)

With the increasing demand in the food industry for documentation and traceability of food and emphasis on nutrition and health, new quality measurements for process and product control were necessary. For some years usage of spectroscopic analysis has been examined and are used more and more as an effective tool in food research (Wold, 2010) .

Spectroscopic methods provide valuable insight into the chemical nature of various sample types and can provide information on physical characteristics specific to the sample. Spectroscopic methods can be highly multivariate and require powerful visual and analytical tools to unlock important information. Most commonly used with Near Infrared (NIR) spectroscopy. The benefits of NIR-technology compared to conventional chemical measurements are that it is nondestructive. Therefore samples could be taken from the same fish both before and after drying. NIR reflection measures the surface and forces infrared light into the product. Water and other molecules have specific amount of energy. NIR spectroscopy has a wavelength between 700 and 2500 nm and by applying the infrared energy on the salted fish, the molecules of the fish will undergo wavelength specific transitions. NIR energy causes molecular overtones and combination of vibrations which produces a spectral output that can contain information on chemical contents of products (Nilsson, 2007). Multivariate calibration methods like Partial Least Square Regression (PLS) and Principal Component Regression (PCR) are then used to obtain chemical information from the spectra data. For it to be possible to measure chemical values spectroscopic data, information has to be gathered about chemical values of samples into a database. There have been positive results from using NIR technique in water content and water holding capacity measurements of cold water shrimp (*Pandalus borealis) (*Gudjonsdottir et. al, 2011). On-line fat measurements with NIR infrared technology have also already been implemented in the salmon industry (Aursand, 2009). Salt fish producers in Norway have looked at NIR-spectroscopic analysis as a good way of measuring the water content of dried salted fish, as the water content is a big quality factor for the product. Consumers do not want to pay for water when they buy dried salted fish. Experiments that have been conducted in Norway using NIR technology to measure water content of salted fish have showen positive results (Wold *et al*., 2001).

2.5 Rehydration

Dried salted fish needs to be rehydrated (desalted) before consumption. Rehydration is a process where the fish is soaked in water where the fish absorbs water and loses salt. In rehydration the salt content of the fish goes from about 17 to 21 % to 1 to 3 % (Pálsson, 2012). The process must take place in a cooled area as microorganisms increase as soon as the water activity rises. Rehydrated dried salted fish can spoil in less than 10 days stored in 4°C cooling storage (Bjørkevoll *et al*., 2003).

The thickness of the portion that are to be rehydrated is important as rehydration process goes faster for thinner fish and smaller portions (Pálsson *et al*., 2012).

According to Gunnar Tómasson, production and sales manager at Thorfish hf., the method of rehydration of dried salted fish in Portugal is to divide the fish into portions and put it in 3 to 4 liters of water for every kg of salted fish. The water is replaced every eight hours for three days. Somewhere more water is used and the water changed every 12 hours. The thinnest portions are removed from the water after two days (Tómasson, 2013).

In Iceland, different variations of rehydration processes have been used, for example, changing water every 24 hours and with longer intervals and more water per kg fish (Thorarinsdottir *et al*., 2007).

2.6 Statistical methods used

In this study statistical methods are used to analyze the data. That is to compare drying rates, weight change and chemical content in different groups and locations of fish.

2.6.1 Analysis of Variance (ANOVA)

Two way ANOVA is a statistical method to analyze the difference between means of groups. It is especially useful to compare three or more mean groups for statistical significance. The hypothesis for ANOVA is

$$\mathrm{H}_0: \beta_1 = \beta_2 = \cdots = \beta_k = 0$$
$$\mathrm{H}_1: \beta_j \neq 0 \text{ for at least one j}$$

"The ANOVA is a method of decomposing the total variability in a set of observation, as measured by the sum of the squares of these observations from their average, into component sums of squares that are associated with specific defined sources of variation" (Montgomery & Runger, 2006).

2.6.2 Multiple comparison methods

If the null hypothesis in the in ANOVA is rejected, it means that some of the treatment or factor level means are different. However it is not clear which means are different. Multiple comparison is then commonly used to determine which means are different. Number of procedures are available and two of them are Fisher's least significant difference (LSD) method and Tukey's HSD (Honestly significant difference). Both methods are pairwise comparison and compare the mean of each group with the mean of all other groups (Montgomery & Runger, 2006).

Fisher's LSD method

The LSD method compares the means for all the groups with the null hypotheses $H_0: \mu_i = \mu_j$ for all $\mathrm{i} \neq \mathrm{j}$ using the t-statistics as defined in *Applied Statistics and Probability for Engineers* with Equation (2.17).

$$t_0 = \frac{\bar{y}_{i\cdot} - \bar{y}_{j\cdot}}{\sqrt{\frac{2MS_E}{n}}} \tag{2.17}$$

The pair of means: $\mu_i$and $\mu_j$are significant if

$$\left|\bar{y}_{i\cdot} - \bar{y}_{j\cdot}\right| > LSD$$

where the least significant difference (LSD) for multiple comparison is found by Equation (2.18).

$$LSD = t_{\alpha/2,a(n-1)}\sqrt{\frac{2MSE_E}{n}} \tag{2.18}$$

(Montgomery & Runger, 2006)

Tukey's honestly significant difference (HSD)

When many comparisons are made, that is if the mean groups are numerous, the probability of type I error increases. Rejecting the null hypothesis H_0 when it is true is defined as a type I error. The benefits of HSD test is that it keeps the error rate of each comparison as a constant and prevents cumulative type I error. All differences are evaluated using the same sampling distribution used for the largest difference. Therefore the HSD method is often said to be conservative (Hauksdóttir, 2003). The HSD value is calculated using Equation (2.19) (Salkind, 2010)

$$HSD = q\sqrt{\frac{MS_{With}}{n}} \tag{2.19}$$

where the q is a table value from studentized range q distribution. And similar to the LSD method, the null hypothesis is rejected if

$$\left|\bar{y}_{i\cdot} - \bar{y}_{j\cdot}\right| > HSD.$$

3 Experiments and data

In January and February 2013, three drying experiments were conducted using a full scale rack drying cabinet at Haustak hf. Haustak hf. is the biggest fish drying company in Iceland and specializes in drying of various fish stocks (www.haustak.is, 2013). About 25 tons of fish were dried in total in the experiments. Fish of different species, size grades and salting methods were examined. In July of 2013 the fourth experiment was conducted with cod, using different salting methods.

All dryers are nonlinear and scale-up of dryers is generally not an easy task. Therefore experiments in full scale dryers are very important along with laboratory scale dryers for designing of a new dryer application (Mujumdar & Devahastin, 2000). In the experiments in this study, full scale dryers were used solely.

The main objectives of the drying experiments were to compare the drying rates of cod, ling and tusk in different size grades. Furthermore to compare drying between phosphate injected and non-injected cod and observe the effects of compressing the cod in the drying process. With chemical analysis it was also the goal to analyze the drying in different parts of the split fish. Other goals of the experiments where to map the temperature, humidity and air velocity dynamics in the drying tunnels and what effect it has on drying of fish in different locations of the tunnels. To summarize, the main goals of the experiments were following:

Experiment 1: Drying rate of different species, size grades, salting methods and effects of compressing. Temperature and humidity measurements in tunnel.

Experiment 2: Comparing drying rate between tunnels and difference between ling and cod. Temperature and humidity measurements in tunnel. In the first experiment the ling and the cod were dried in different tunnels and a slight difference in temperature and humidity values between tunnels. For that reason the second experiment was made to assure that the drying was identical in both tunnels.

Experiment 3: Analyzing drying rate in different locations of drying tunnel. Temperature and humidity measurements in tunnel.

Experiment 4: Drying rate of cod produced with different salting method and both washed and not washed before drying. Also the drying conditions were different from the first three experiments. Temperature and humidity measurements in tunnel.

3.1 Experimental design

In the production of the salted fish used in the drying experiment, the fish was headed and gutted, washed and butterfly split. Some of the fish was then injected with brine and phosphate before brine salting. After brine salting for 1 - 2 days the fish was kench salted and kept like that until drying. Some of the cod used in the experiment was not injected with brine or phosphate but only brine salted and then kench salted (Figure 14). That was done to examine the effects of brine and phosphate injection in the salting process. All the fish in

Experiment 1 to 3 was long line caught at Visir hf.'s fishing vessels and processed in the companies processing plant in Grindavik (Table 3).

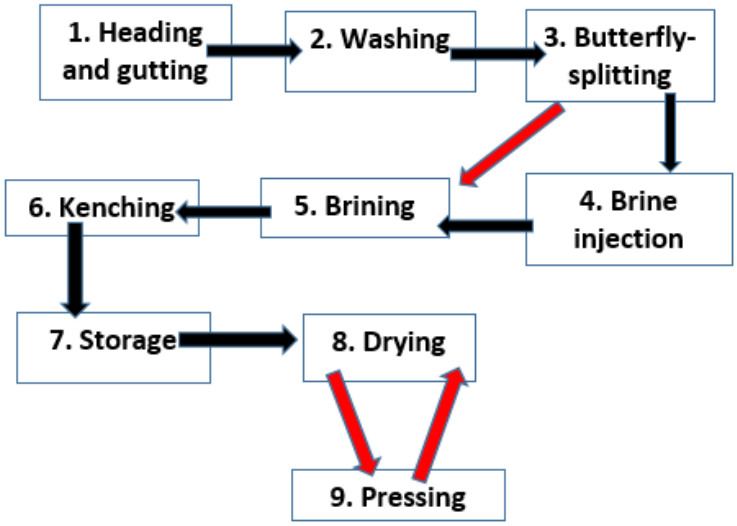


Figure 14 Flow chart of fish processing from catching until drying

Table 3 Specifications of raw material in Experiment 1 to 3

Species	Catching time	Catching area	Salting method
Cod	30/9 - 5/10 2012	672D and 671C	Brine salted for 24 hours and then kench salted for 3 weeks.
Cod	25/11- 5/12 2012 From two vessels	614B, 718C, 668B and 620B	Injected with Carnal phosphate before 24 hours in brining and then kench salted for 3 weeks.
Tusk	29/11- 11/12 2012 Three separate fishing trips	672B, 718C, 668B - 474D - 424B - 372C - 321C and 321A	Injected with Carnal phosphate before 24 hours in brining and then kench salted for 3 weeks.
Ling	6/10 - 26/11 2012 Three separate fishing trips	576A - 576B - 576C and 626C.	Injected with Carnal phosphate before 24 hours in brining and then kench salted for 3 weeks.

3.2 Drying facility

The same drying cabinet was used for the first three experiments. The cabinet has two drying tunnels with the air coming down in the middle between them. A pyramid panel in the middle directs the air through both the tunnels.

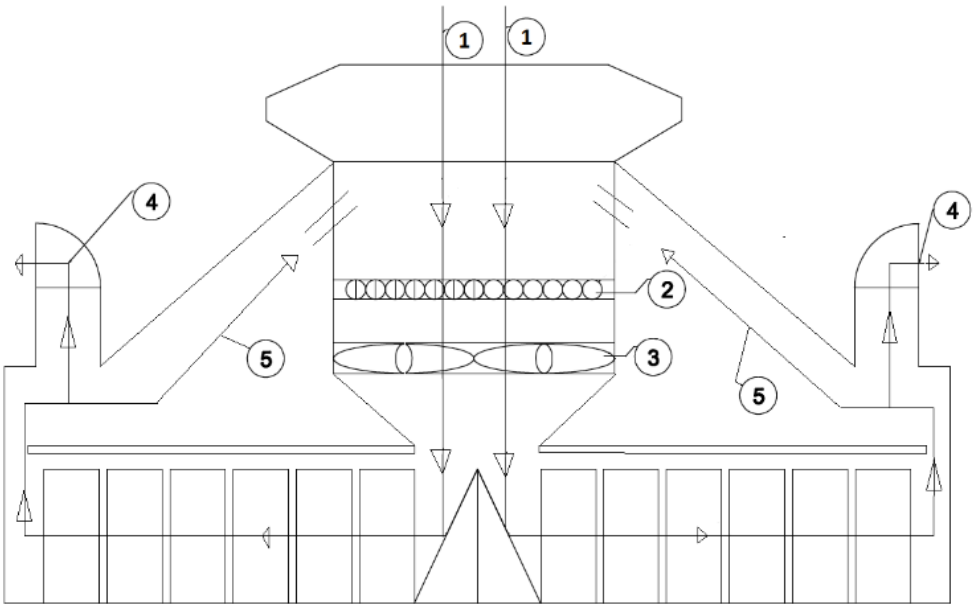


Figure 15 Drawing of rack drying cabin used in the drying experiments (Arason & Árnason, 1992)

The air comes in (1), goes through a heating element (2) and then fans (3) blow the air down to the tunnels. The hot air blows through the fish located on racks in the tunnels and carries vapor away and cools down. Some of the air goes out of the cabinet (4) and some of the air is recirculated (5), the air cools and the water condenses (Figure 15).

The fish is placed on trays in the cabinet. Two to five split fishes on each tray, depending on size (Figure 17). The area of each tray is approximately 1 x 1 m and 17 trays go on top of each other to form one rack (Figure 18). The rack height is about 220 cm and the gap between trays about 12 cm. The width of the tunnel is four racks and the length is six racks (Figure 16). One rack cabinet like the one used in the experiments in this thesis has a capacity of 2 x 24 racks. Heated air is recirculated by a fan over and parallel to the surface of the trays.

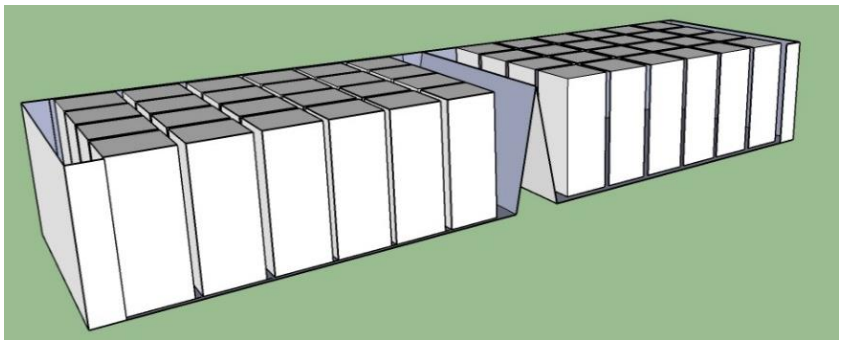


Figure 16 Drawing of rack position in the two drying tunnels

Figure 17 Salted cod placed on a tray

Figure 18 Four racks with 17 trays each are in the width of the cabinet

3.3 Temperature measurements

Temperature was measured at different locations in the drying with 3 x 3 x 3 or 3 x 2 x 3 grid of temperature loggers (Figure 19). Ibutton temperature data loggers with accuracy of ± 0.5 °C were used and set to record the temperature with 5 minutes interval.

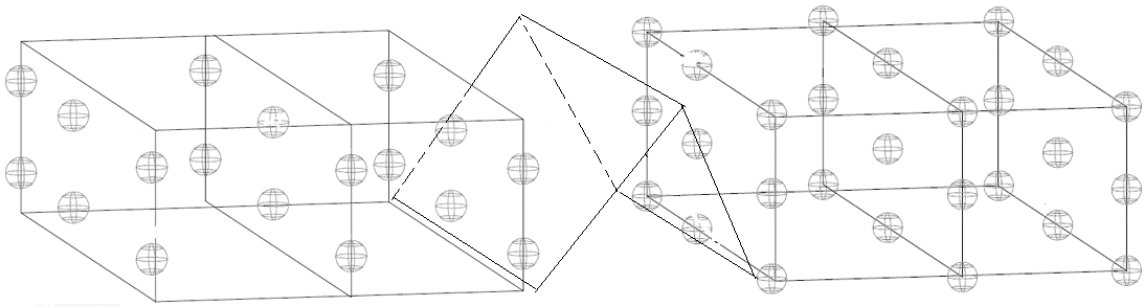


Figure 19 Locations of temperature loggers in the two drying tunnels

The temperature loggers where attached to the racks. The highest logger on tray 16, the middle logger on tray 11 and the lowest one on tray 3. In the tunnel where there were only two loggers in each position the higher one was attached to tray 14 and the lower one at tray 6.

The locations of the temperature and humidity loggers are identified on temperature and humidity graphs in the results chapter in the following way; at the the air inlet, (I,x,x) center of the tunnel (C,x,x) or at the door (air outlet) (D,x,x). On the horizontal axes the logger is identified as at the right side (x,R,x), at the left side (x,L,x) or in the middle (x,M,x). The

height of the logger is then identified as at the bottom (x,x,B), middle height (x,x,M) or at the top (x,x,T)

3.4 Humidity measurements

Humidity at different locations in the drying cabinet was measured with HOBO U12-013 external channel humidity data logger with accuracy of ± 2.5 % (Figure 20). The data loggers measured the humidity with a 5 minute interval. The humidity loggers were attached at the same heights as the temperature loggers.

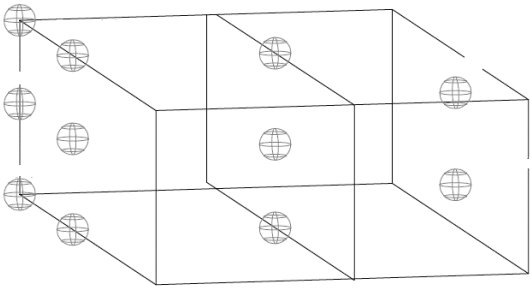


Figure 20 Location of humidity loggers in drying tunnel

3.5 Air velocity measurements

Air velocity in the drying tunnels was measured with handheld measuring device (Figure 21)

Figure 21 The air velocity measuring device used in the experiments

The air velocity was measured in nine different places at the cross section at the end of the drying tunnels. At three different heights; top, middle and bottom, in three different locations; left side, center and right side. In the experiments the aim was to keep the air velocity about 1.5 m/s. The reason why air velocity should be 1 to 2 m/s between the trays is that air velocity over 3 m/s causes case hardening which closes the surface and inhibits

water flow out of the fish (Arason, 2011). Magnussen and Walde (2008) also imply in another research that even less air velocity might be sufficient to remove the water that evaporates because it happens so slowly with salted fish.

3.6 Weight measurements and yield estimation

Split fish was weighed using a M1100 portable scale from Marel with accuracy of ± 5g.

Figure 22 The scale used for weight measuring in the experiments

Yield (%) was determined as the ratio between the total mass of the fish after drying and the mass before drying. The weight loss was calculated at each time as using Equation (3.1).

$$\Delta m_0^t = \frac{m_t - m_0}{m_o} \tag{3.1}$$

where *m* is the mass of the fish at time *t* and *0* respectively.

3.7 Chemical analysis

Three fishes (*n* = 3) of each group where analyzed in terms of water content, salt content and water holding capacity before and after drying. Sample from five different locations were taken from each fish. The purpose was to examine chemical properties in the fish. Three samples were taken from the loin, below the surface (a), in the middle of the loin (b) and lowest, nearest to the skin (c). One sample was taken from the middle part of the split fish, below the surface (d) and one from the tail, below the surface (e) (Figure 23). The chemical analysis were done with accredited chemical methods at the laboratory at Matis ltd. in Reykjavik. All fish samples were shredded before the chemical measuring.

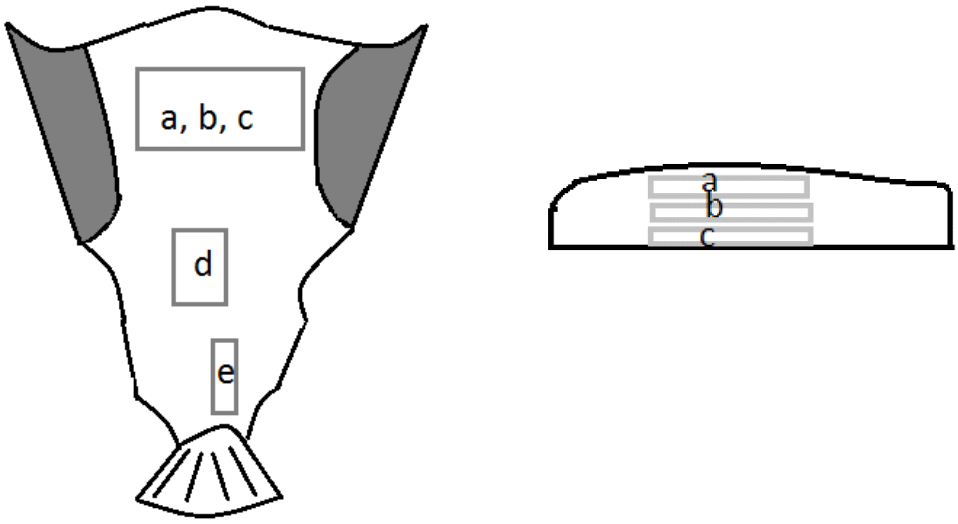


Figure 23 Sample locations - overview of split fish (left) and cross section of loin (right)

In this thesis the average water content, salt content and water holding capacity of the fish was calculated as the average of the values from each location according to Equation (3.2).

$$X_{ave\_value} = \frac{\sum_{i=1}^{n} X_{ai}+X_{bi}+X_{ci}+X_{di}+X_{ei}}{5*n} \quad (3.2)$$

X_{*i} is the measured value of water content, salt content or water holding capacity in each location (a, b, c, d, e) and *n* is the number of fish samples from each group.

3.7.1 Water content

The procedure of the water content measurement was that sample of fish was dried at 104 °C and the weight loss calculated as water loss (ISO, 1999). The method from Matis ltd. laboratory is certified and the water content measurement were always wet basis.

3.7.2 Salt content

When determining the salt content, soluble chloride was extracted from the sample with water. The solution was titrated with silver nitrate upon addition of nitric acid and the end point was determined. The results have accuracy of ± 1 % (AOAC (2000). 17th Ed no.976.18). The method from Matis ltd. laboratory is certified.

3.7.3 Water holding capacity (WHC)

One of the factors that consumer look at in their salt fish is juiciness of the fish and that is affected by the water holding capacity of the fish (Andrés *et al*., 2005). Water holding capacity (WHC) is defined as the particular ability of the sample to hold water. Sample was minced right before measuring. 2 g ± 0.1 g of the sample was put into special cylinders which were then put into a centrifuge for five minutes with 1350 rpm at 4°C. When the filtration was over the cylinders were weighed and then the water loss divided by water content was given as water holding capacity (Aske *et al*., 1993; Ofstad, 1996). The method from Matis laboratory is not certified.

3.7.4 Water activity

Water activity was measured using Aqua lab water activity meter. A small amount of shredded sample (7 g) was put in a plastic container and into the meter which measured the water activity (Figure 24 and 25). Samples were taken from the loin, location a, b and c from both injected and non-injected cod.

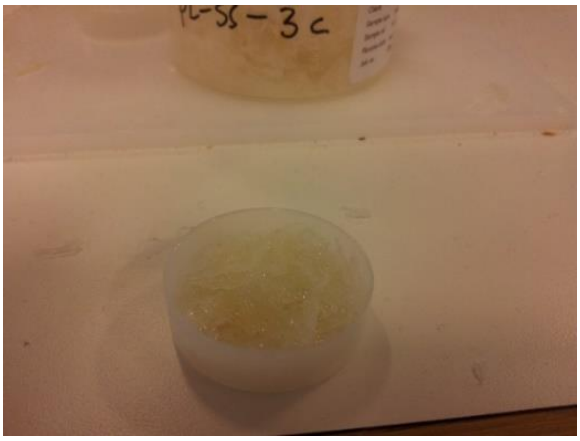


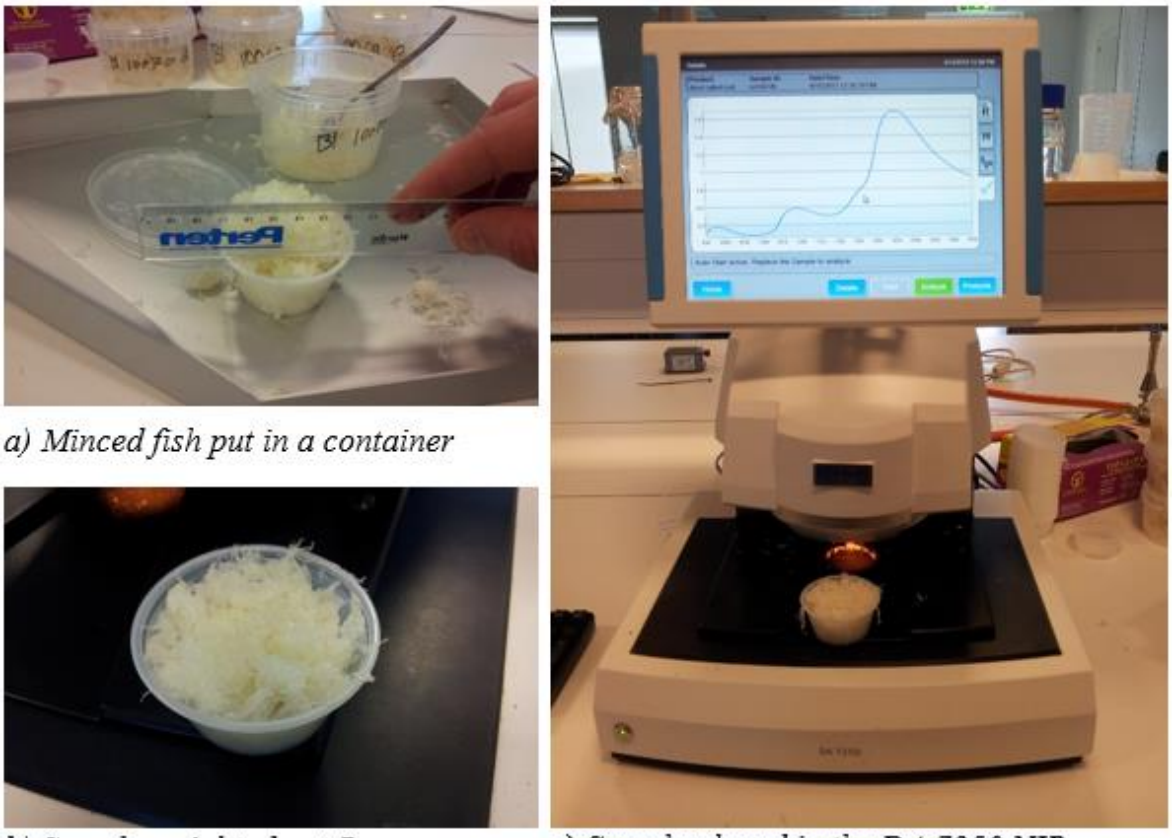
Figure 25 Shredded sample is placed in a plastic container

Figure 24 Sample is placed in a dock in the water activity meter

3.8 Near Infrared (NIR) Measurements

NIR technology was tested to see if it could be applied to measure the water content of salted fish and dried salted fish. Spectroscopic data was gathered and the data compared to water content results from the laboratory from the same sample. From that data a prediction model for the water content could be made.

The spectrum was measured with DA 7250 instrument from Perten. The spectrum was measured from the same sample cuts that had already been measured in Matis ltd. laboratory. About 2 g of samples were put in a plastic box and measured in the device (Figure 26). Both dried and not dried salted fish samples from cod, ling and tusk were analyzed. The spectrum was then calibrated using partial least squares regression (PLS) which is the most important linear calibration method (Balabin *et al*., 2007). The calibrated results were then used to make a prediction model and the results compared to the lab values of water content for the same samples. The Unscrambler X 10.2 from Camo software was used for these calculations.



a) Minced fish put in a container

b) Sample weight about 7 g

c) Sample placed in the DA 7250 NIR instrument

Figure 26 NIR measurements on shredded salt fish sample

3.9 Experiment 1

3.9.1 Description

Eleven different groups of split fish were dried in the experiment. Three species of fish, cod, ling and tusk in two to three size grades; small (S), large (L) and extra-large (XL). The groups had been salted with one of the two following salting methods, injected with brine and phosphate before brine salting and kench salting (Brine + inj) or without phosphate (Brine). Two groups were taken out of the rack cabinet after two days of drying and compressed under 800 kg for two days before being transferred back to the rack cabinet (Pr) (Table 4).

Table 4 Sample groups in Experiment 1

Group no.	Species	Size grade	Size	Salting method	Compressing	Int. ave. weight [g]
1	Tusk	S	< 1,7 kg	Brine + inj	No	1100±100
2	Tusk	L	> 1,7 kg	Brine + inj	No	2000±300
3	Ling	S	2 - 4 kg	Brine + inj	No	3700±300
4	Ling	L	4 - 6 kg	Brine + inj	No	5200±500
5	Ling	XL	> 6 kg	Brine + inj	No	7300±1000
6	Cod	S	2,7 - 4 kg	Brine + inj	No	3400±300
7	Cod	L	> 4 kg	Brine + inj	No	5100±700
8	Cod	S	2,7 - 4 kg	Brine	No	3500±400
9	Cod	L	> 4 kg	Brine	No	4800±500
10	Cod	L	> 4 kg	Brine + inj+ Pr	Yes	4700±400
11	Cod	L	> 4 kg	Brine + Pr	Yes	4700±700

About 8 tons of raw material were used in the experiment and the drying time was about 136 hours from January 15th to January 21st 2013. The aim was to keep humidity about 40 %, the temperature between 15 - 20 °C and the air velocity 1.5 m/s.

3.9.2 Drying preparation

Before drying, 20 fishes from each of the eleven sample groups were weighed and marked with a numbered plastic mark (Figure 27). Total 220 fishes. As stated before there are two tunnels in each rack cabinet. The five groups of labeled ling and tusk where placed on trays in Tunnel A and the six groups of labeled cod were placed in Tunnel B (Figure 28).

Tunnel B was filled with 19 racks of cod and five racks of tusk. The 120 marked cod samples were placed on four racks, two racks in the middle nearest to the door and two racks behind that. The marked fish were on trays 6 to 15.

Tunnel A had eight empty racks and 16 racks filled with ling and tusk. The marked ling and tusk, 100 split fishes total, where placed on three racks. Two in the middle nearest to the door and one rack behind those two.

Figure 28 Fish was labeled and

Figure 27 Racks with fish are rolled into the tunnel

The marked fish was weighed before drying, after approximately 24 hours, 48 hours, 96 hours and after 136 hours when the drying process finished. Individual trays in different locations of the drying cabinet where also weighed before and after the drying (Figure 29 and 30).

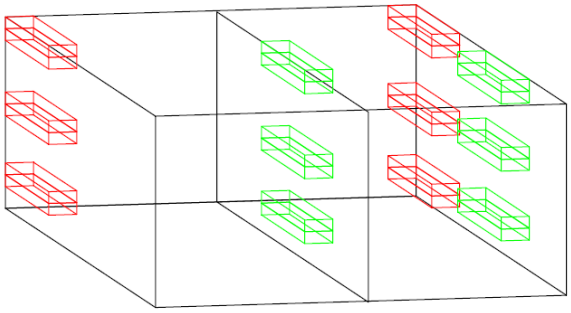


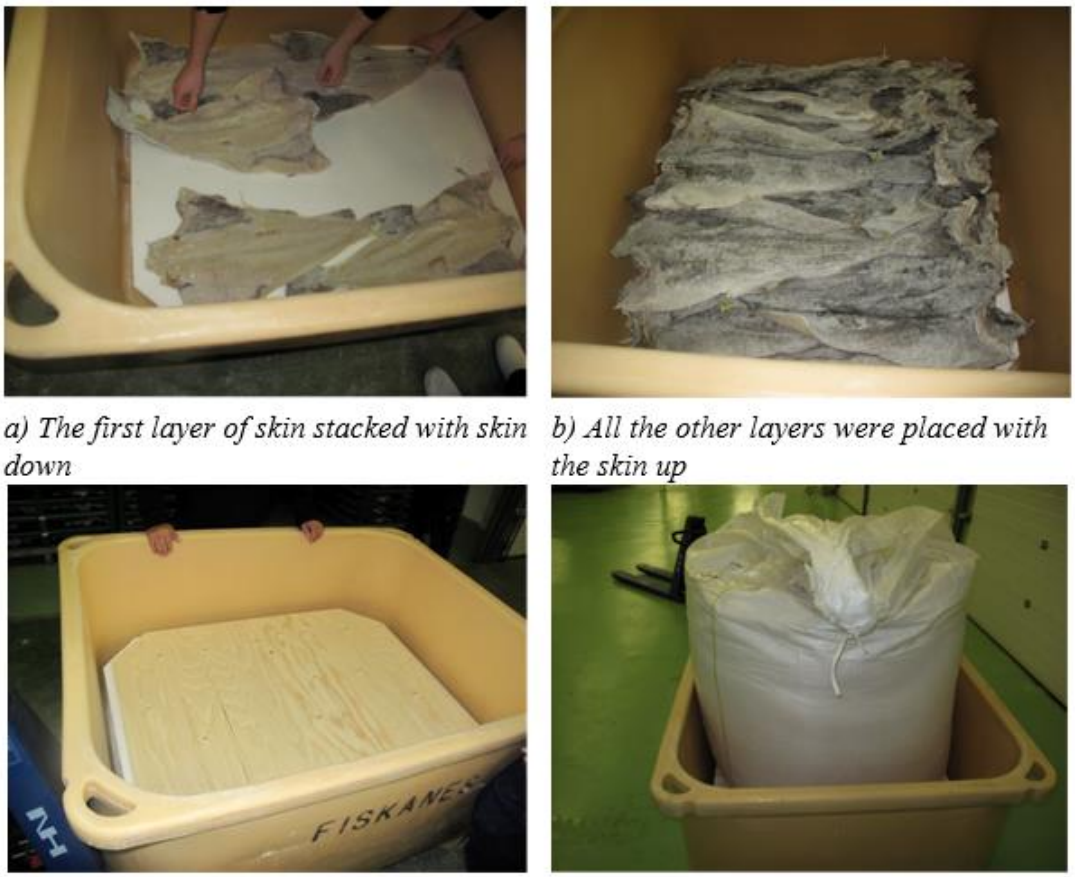
Figure 29 Location of trays that were weighed before and after drying

Figure 30 Tray on the scale

3.9.3 Compressing

When fish is dried, the drying rate is high in the beginning while the surface is wet and the rate is dependent on the temperature, humidity and air velocity (see section 2.2.1). If there is enough dry air to carry the vapor from the fish away, then maximum drying rate for those conditions is accomplished. When the surface has been dried completely, the water from inside of the fish needs to flow out to the surface to be carried away. That usually takes longer time and therefore the drying rate decreases and as has been mentioned earlier, studies have shown that the humidity and air velocity has less effect after the surface has become dry. The purpose of compressing the fish after two initial days of drying was to force the water quicker out on to the surface and see if it has any effect on the drying rate. Drying time should be shorter if the fish is press piled in the drying tunnel instead of drying the fish in one stage (Waterman, 1976). Samples of large injected cod and large non-injected cod where used in the compressing experiment. About 35 to 40 split fishes or about 200 kg of each group. The fish was removed from the rack cabinet after about 45 hours of drying. The 40

fishes of injected cod where put in one plastic tub and the 40 fishes of non-injected cod where put in another. A styrofoam plate was put on the bottom of the tub and the first layer of fish on top of that with the skin facing down. The next layers of fish were placed with the skin facing up. On top of the fish was another styrofoam plate and a wooden plate on top of that. A salt bag weighing about 800 kg was put on top of each tub (Figure 31). After about 48 hours in the tub, the fish was put back into the drying cabinet with the rest of the fish that had been inside the dryer the whole time. The compressed fish went again into the drying tunnel about 93 hours after the drying process was started.



a) The first layer of skin stacked with skin down

b) All the other layers were placed with the skin up

c) Styrofoam plate and a wooden plate on top of the fish

d) Salt bag was used to press the fish for 48 hours

Figure 31 Compressing procedure

3.10 Experiment 2

3.10.1 Description

In Experiment 2, the objective was to confirm results of drying rate of ling and injected cod from Experiment 1. Another objective was to compare drying rate of different size grades and compare drying in the two tunnels of the rack cabinet. About 8 tons of ling and cod where dried in total in the two tunnels (Table 5). All the fish was injected with carnal phosphate before brining and then kench salted.

Table 5 Sample groups in Experiment 2

Group no.	Species	Size	Size grade	Tunnel	Initial ave. weight [g]
1	Ling	S	< 4 kg	B	3500±300
2	Ling	L	4 - 6 kg	B	4800±300
3	Cod	S	< 4 kg	B	3300±300
4	Cod	L	> 4 kg	B	6200±1500
5	Ling	S	< 4 kg	A	3300±300
6	Ling	L	4 - 6 kg	A	4500±200

The drying took place from 23rd to 28th of January 2013. The ling in Experiment 2 was the same as before in Experiment 1 but the cod was caught between 10/12 and 15/12 2012 in fishing areas 366B, 366D and 367C. The aim was to keep the same drying conditions as in Experiment 1, humidity about 40 %, the temperature between 15-20 °C and the air velocity 1.5 m/s.

3.10.2 Drying preparation

Five split fishes from each group where marked with plastic labels and weighed before drying. Five fishes from groups 1 to 4 were placed on the two middle racks nearest to the door in Tunnel B. In Tunnel A, five fishes from groups 5 and 6 were placed on one rack in the middle nearest to the door. Tunnel B was filled with fish (24 racks) and in Tunnel A eight racks, located nearest to the door were empty along with the samples.

The marked fish was weighed before drying, after approximately 24 hours, 48 hours and then after 113 hours, when the drying was finished.

3.11 Experiment 3

3.11.1 Description

In Experiment 3 the objective was to examine the drying rate at different locations in the drying tunnel. Only one of the two tunnels of the rack cabinet was used in this experiment (Tunnel B) and only ling was dried. The size grades were small (< 4 kg) and large (4-6 kg).

3.11.2 Drying preparation

The ling was placed in five places. In the middle, nearest to the fans (air inlet). In the center of the tunnel, in the center at the right hand side, the center at the left hand side and at the door (Figure 32). The sample groups were also in two different heights on the racks, in trays 14 through 16 [HIGH] and in trays 7 through 9 [MIDDLE]. All in all, there were two different size grades of ling, in five different locations at two different heights. There were five split fishes in each group. a total of 100 fishes. The fish was marked with plastic marks and weighed before the drying and then it was weighed again after approximately 24 hours, 48 hours and then after about 130 hours when the drying was stopped.

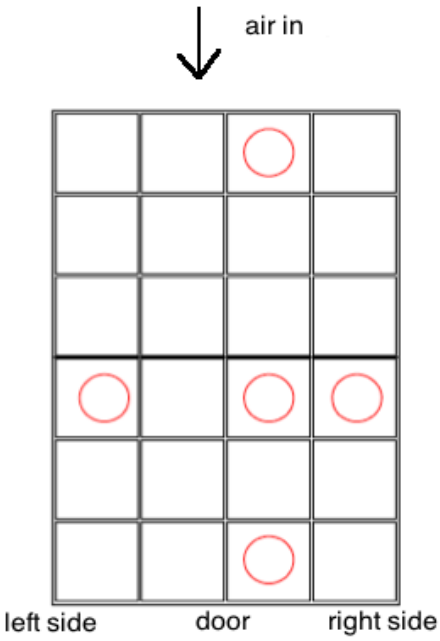


Figure 32 Location of labeled fish in drying tunnel

3.12 Experiment 4

3.12.1 Description

After results from Experiment 1 to 3 had been analyzed, Experiment 4 was planned. It was decided to dry the same type of injected cod as before together with pickle salted fish, which is the salting method used in Norway. It was also decided to wash the fish before drying which had not been done in the previous experiments.

In Experiment 4 the aim was to keep humidity of the air about 50 to 60 % to observe the difference in drying from the 30 to 40 % humidity in the first three experiments.

In Experiment 4 injected cod from Visir hf., identical to the one used in previous experiments, was dried, together with injected cod that was washed before drying. Also cod from different producer was dried which was brine salted and not injected. The difference between the fish from the other producer and the „not injected“ fish from Visir h.f. in previous experiments is that the fish from the other producer is put into 1 % brine for 24 to 48 hours before going into 17 to 20 % brine. The fish goes through rigor mortis in the weak brine and that is supposed to give whiter color of the flesh. The fourth group was pickle salted and the fifth group was injected cod from Visir that was soaked in water for 10 minutes before drying (Table 6).

Eighteen fishes from groups 1 to 4 were weighed and labeled and five fishes from group 5. In total 77 split fishes.

Table 6 Sample groups in Experiment 4

Group no.	Species	Method	Salting method	Int. ave. weight [g]
1	Cod	Not washed	Brine + inj	3500±300
2	Cod	Washed	Brine + inj	3500±400
3	Cod	Washed	Brine	3100±600
4	Cod	Washed	Pickle salted	4700±500
5	Cod	10 min in water	Brine + inj	3200±100

All the fish was stacked on trays. Three to four fishes on each tray, using trays 6 through 15 on the racks. All the fish was on two racks in the middle closest to the door of the tunnel. Together with the salted fish the drying cabin was filled with lute fish.

The humidity in the tunnel was aimed at 50 to 60 % and the temperature about 17 to 20 °C. The fish was dried under those conditions and air velocity about 2 to 2.5 m/s for 6 days. The samples were weighed before the drying, after 19 hours, 24 hours, 45 hours, 116 hours and when the fish was removed from the drying after 138 hours.

3.12.2 Chemical measurements

Samples were taken from fish before and after drying in five locations: a - e. (Figure 33)

a) Surface of loin about 0,5-1 cm.
b) Middle of the loin.
c) Loin at the skin.
d) The middle part of the fish below the belly flaps down to the anal fin. From middle of the middle part from surface and down to skin.
e) Sample taken under the bone in the tail and also from the surface of the tail.

Figure 33 Samples taken from the middle of the loin in three layers; the surface, the middle part and the tail

Salt was brushed of all the surface samples. Samples were taken from three fishes in each group in each location and pooled together. So in total there was one measurement from each group in each location (n = 1).

3.12.3 Washing

All the fish was washed before drying, by dipping it three times into water and brushing the salt of with a brush in between (Figure 34), except for the control group, injected cod from Visir hf. (group 1) which was not washed. Then the fish was put on trays for about 30 minutes to let the water drip off before it was weighed and stacked on trays again for drying.

Figure 34 Fish covered in salt dipped in water and brushed. Afterwards, most of the surface salt had been removed.

3.12.4 Drying preparation

The pickle salted fish (4) and the brine salted fish (3) was weighed before washing and again after washing, before drying. The injected fish (1-2) wash weighed after washing, before drying. The injected cod that was soaked in water for ten minutes before drying (5) was weighed before going into the water and again before drying. All the fish was weighed again after 19, 24, 45 and 116 hours and finally when the fish was removed from drying after 138 hours.

3.13 Rehydration

Two rehydration experiments were conducted. First a pre experiment and then the main rehydration experiment.

3.13.1 Preliminary rehydration experiment

In the pre experiment washed and dried, injected fish from Visir hf. (Group no. 2 in Experiment 4) was rehydrated, using two different versions of rehydration.

1. Fish and water ratio 1:6 – water changed every 24 hours.

2. Fish and water ratio 1:5 – water changed every 12 hours.

Both versions were conducted for 72 hours with some of the samples put again in water for another 24 hours, total of 96 hours. The tail was cut of the fish and then the fish was cut in half so one piece was the middle part and tail and the other piece was the loin with belly flaps (Figure 35 and 36). In total 6 pieces in each group. The fish was then weighed when the water was changed, every 12 and 24 hours.

Figure 36 The sample pieces before rehydration in the pre experiment

Figure 35 The two rehydration recipes in identical plastic containers

3.13.2 Primary rehydration experiment

After getting the results from the pre experiment, another rehydration experiment was conducted where the fish:water ratio was 1:4 and the water changed every 24 hours for 96 hours. Each fish was cut in four to six, 6 cm wide pieces (Figure 37). The dried salted fish is often prepared in piecese like that in restaurants in Spain and Portugal and therefore it was decided to cut the fish this way. False bottom was on the rehydration container for the salt to fall to the bottom. Other than that, the containers were the same as in the pre-experiment.

Figure 37 Fish cut into pieces before rehydration in the primary experiment

Seven groups were rehydrated (Table 7). One fish was used from each group.

Table 7 Sample groups in rehydration experiment

No. of Group	Species	Salting method	Sample from drying Experiment
1	Cod	Injected	(Group 1 from Experiment 4)
2	Cod	Not injected	(Group 8 from Experiment 1)
3	Cod	Brined	(Group 3 from Experiment 4)
4	Cod	Pickled	(Group 4 from Experiment 4)
5	Cod	Inj + 10 min wash	(Group 5 from Experiment 4)
6	Ling	Injected	(Group 3 from Experiment 1)
7	Tusk	Injected	(Group 2 from Experiment 1)

The reason why the water was changed every 24 hours instead of every 8 or 12 hours like is done in some places in Portugal is that it was not thought practical to spend that much time changing water.

3.14 Statistical analysis

Difference between weight losses of different sample groups (species, salting methods, sizes and locations) and chemical analysis (water content, salt content and water holding capacity) were compared using two way analysis of variance (ANOVA). The post hoc tests, Fisher's least significant difference (LSD) and Tukey's honestly significant difference (HSD) methods were used when the results from the ANOVA showed difference in mean. MATLAB and SPSS 20.0 statistical software were used in the calculations and a 5 % significance limit (p = 0.05) was used. In the Results chapter the significant differences between groups are displayed in tables where each group is compared to each other individually.

Green cell with a "+" in it means that the group in the row lost significantly more weight or has significantly higher water content, salt content or WHC than the group in the column. Yellow "–" cell means that the group in the row is significantly lower than the column. White cell with "0" means that there is no significant difference between the group in the row and the column. As the Tukey's HSD method is more conservative than the LSD method there is not as often a significant difference using that method. To draw attention to that, the cell that has significant difference in LSD method but not in HSD method has a red color in the HSD table. An example of a significance table where the HSD method is used can be seen in Figure 38. Group 3 has significantly lower value than group 2 and 5. Also there is a significant difference between group 1 and 4 when using the LSD method but not for the HSD method.

	1	2	3	4	5
1		0	0	0	0
2	0		+	0	0
3	0	-		0	-
4	0	0	0		
5	0	0	+	0	

Figure 38 An example of significant difference table

4 Results

4.1 Experiment 1

In Experiment 1 the weight loss between fish species, salting methods and size grades were examined in addition to the effects of compressing the fish during the drying process.

4.1.1 Yield and drying rate

All the groups lost the same amount of water in the first 21 hours, about 5.5 to 7.5 %. After about 45 hours the difference in weight loss between groups grew bigger. Small fish had lost around 2 % more weight than large fish and the ling had lost about 2-3 % more weight than the tusk and cod. After 93 hours there was a great difference between small and large tusk or about 4 % and the ling had lost about 5 % more weight than the other groups. In the last two days the cod and the tusk lost about 3 % of the weight and the ling about 5 %. The compressed cod that went back into the drying cabinet the last two days lost about 6 to 7 % of the weight during that time (Figure 39 and 40 and Table 8).

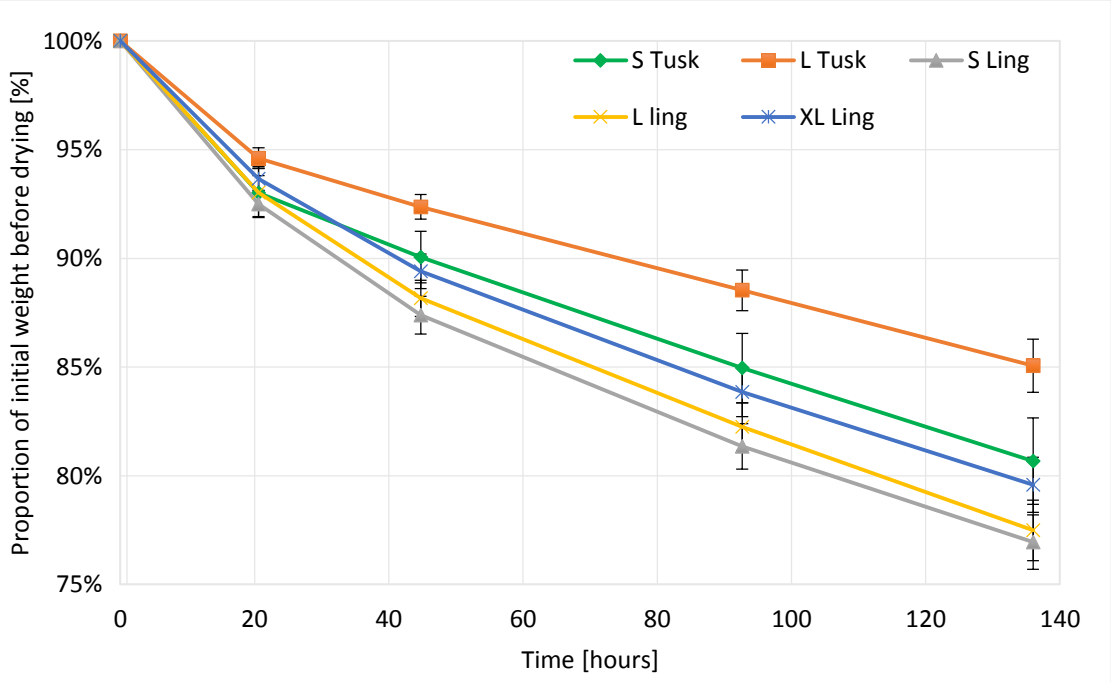


Figure 39 Weight loss during drying of ling and tusk of different sizes in Experiment 1. (ave ± std)

When the weight loss of the compressed fish is compared to the uncompressed fish (Figure 40), it can be seen that during the two days of compressing, the fish loses less weight than the not compressed fish that is in the drying at the same time. It still seems that the injected and compressed cod is losing the same weight as the fish that is in the drying. After the

compressed fish is put back into the drying tunnel the drying rate is much higher than for the fish that has been in the drying the whole time. It can be assumed that taking the fish out of the drying and compressing it is not giving worse results than drying it the whole time with regards to weight loss.

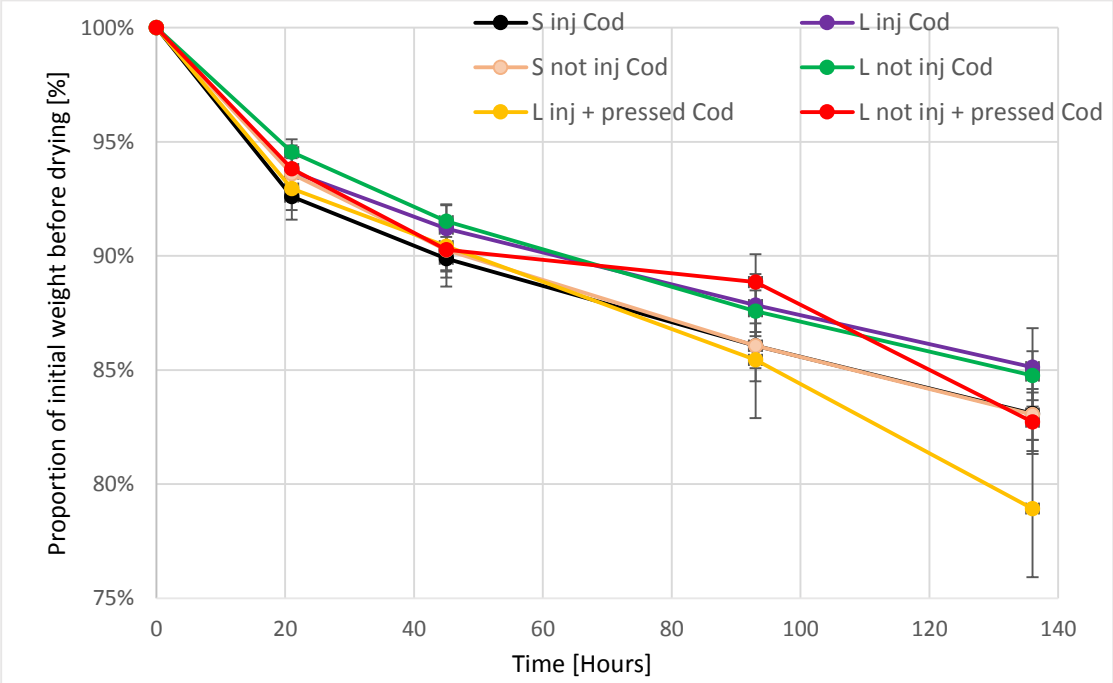


Figure 40 Weight loss of cod of different sizes and salting methods, compressed and uncompressed in drying Experiment 1 (ave±std)

Table 8 Initial weight and proportion of initial weight at different times during drying in Experiment 1 (ave±std)

		Average Weight Before	Proportion of initial weight [% ± 1 std] over time [hrs] (n=3)			
No.	Group	Drying [g ± 1 std]	21 hrs	45 hrs	93 hrs	136 hrs
1	Small tusk	1100±100	93.0 ± 0.8	90.1 ± 1.2	85.0 ± 1.6	80.7 ± 2.0
2	Large tusk	2000±300	94.6 ± 0.5	92.4 ± 0.6	88.5 ± 0.9	85.1 ±1.2
3	Small ling	3700±300	92.5 ± 0.6	87.4 ± 0.9	81.4 ± 1.0	77.0 ± 1.3
4	Large ling	5200±500	93.0 ± 1.1	88.2 ± 0.8	82.3 ± 1.1	77.5 ± 1.4
5	X-Large ling	7300±1000	93.7 ± 0.6	89.4 ± 0.8	83.9 ± 1.1	79.6 ± 1.3
6	Small injected cod	3400±300	92.6 ± 1.0	89.9 ± 1.2	86.1 ± 1.6	83.1 ± 1.8
7	Large injected cod	5100±700	93.7 ± 0.8	91.2 ± 1.1	87.8 ± 1.4	85.1 ± 1.7
8	S not injected cod	3500±400	93.6 ± 0.7	90.3 ± 0.9	86.1 ± 1.0	83.1 ± 1.1
9	L not injected cod	4800±500	94.6 ± 0.6	91.5 ± 0.7	87.6 ± 0.9	84.8 ± 1.1
10	L inj+ pressed cod	4700±400	93.0 ± 0.9	90.4 ± 1.1	85.4 ± 2.6	78.9 ± 3.0
11	L pressed cod	4700±700	93.8± 1.0	90.3 ± 1.2	88.9 ± 1.2	82.7 ± 1.3

Number of groups are I = 11. Number of individuals in each group i is n_i = 20 for all i. Number of individuals all together is n = 220.

After the first 20 hours there was no significant difference in weight loss between any groups when HSD method was used with 5 % significant limit. When LSD method was used, large

non-injected cod had lost significantly less weight than the other groups except for the XL ling, large injected cod, small non-injected cod and the compressed non-injected cod.

In day two, all the groups had lost significantly more weight than the large tusk except for large non-injected cod. The ling had lost more weight than all the other groups.

The significant difference in weight loss after drying between groups can be seen in Figure 41 and 42 below. Red cells in the figure for the Tukey's HSD method show where there was a significant difference between groups when the LSD method was used but not with the HSD method (explanations of colors and signs in Section 3.14). Where group in the row has significantly higher value than the group in the column there is a green cell with a plus sign and a yellow minus sign if the row has significantly lower value. If there is not a significant difference the cell is white (or red) with a zero in the middle. As can be seen, HSD method was not as sensitive for difference, which is consistent with the text about the methods in Section 2.6.2.

	1	2	3	4	5	6	7	8	9	10	11
1		+	-	-	0	+	+	+	+	0	+
2	-		-	-	-	-	0	-	0	-	-
3	+	+		0	+	+	+	+	+	+	+
4	+	+	0		+	+	+	+	+	0	+
5	0	+	-	-		+	+	+	+	0	+
6	-	+	-	-	-		0	0	0	-	0
7	-	0	-	-	-	0		-	0	-	-
8	-	+	-	-	-	0	+		0	-	0
9	-	0	-	-	-	0	0	0		-	-
10	0	+	-	0	0	+	+	+	+		+
11	-	+	-	-	-	0	+	0	+	-	

Figure 41 Results of significance test in weight loss between groups in Experiment 1 - HSD method with 5 % significance level (Definition of groups in Table 4)

	1	2	3	4	5	6	7	8	9	10	11
1		+	-	-	0	+	+	+	+	-	+
2	-		-	-	-	-	0	-	0	-	-
3	+	+		0	+	+	+	+	+	+	+
4	+	+	0		+	+	+	+	+	+	+
5	0	+	-	-		+	+	+	+	0	+
6	-	+	-	-	-		+	0	+	-	0
7	-	0	-	-	-	-		-	0	-	-
8	-	+	-	-	-	0	+		+	-	0
9	-	0	-	-	-	-	0	-		-	-
10	+	+	-	-	0	+	+	+	+		+
11	-	+	-	-	-	0	+	0	+	-	

Figure 42 Results of significance test of weight loss between groups in Experiment 1 - LSD method with 5 % significance level (Definition of groups in Table 4)

The order of the groups from most weight loss to the least was as follows 3 ≥ 4 > 10 ≥ 5 ≥ 1 > 11 ≥ 8 ≥ 6 > 9 ≥ 2 ≥ 7. The compressed fish lost more weight than uncompressed fish. No significant difference was between weight loss of cod injected with phosphate and non-injected cod.

4.1.2 Species and sizes

The results show that the small and large ling dries significantly faster than the cod and the tusk with over 40 % higher weight loss. Also the extra-large ling is drying slower than small and large grade. The small cod dries faster than large cod. The small tusk is drying faster than the large tusk and all the cod, while the large tusk is drying similar to the large cod.

It is logical that small fish would dry faster as it has proportionally larger surface area-to-weight ratio than larger fish and therefore the water has more area to leave the product. When the average initial weight of the fish is considered it can be seen that the difference in weight between groups is not very great between cod and ling, while the large tusk is almost twice the weight of the small tusk.

The weight of large tusk is about 2000 g and of the small tusk 1000 g before drying, while the small ling and cod weighs about 3500 g and the large 5000 g. The average weight of the extra-large ling was about 7200 g. As seen in the significance testing (Figure 41 and 42) there is not a significant different between small and large ling and when the HSD method was used there was also not a significant difference between small and large cod. That might be because the size difference is not that great. On the other hand the small and large ling dried significantly faster than extra-large ling and small tusk did also dry faster than large tusk.

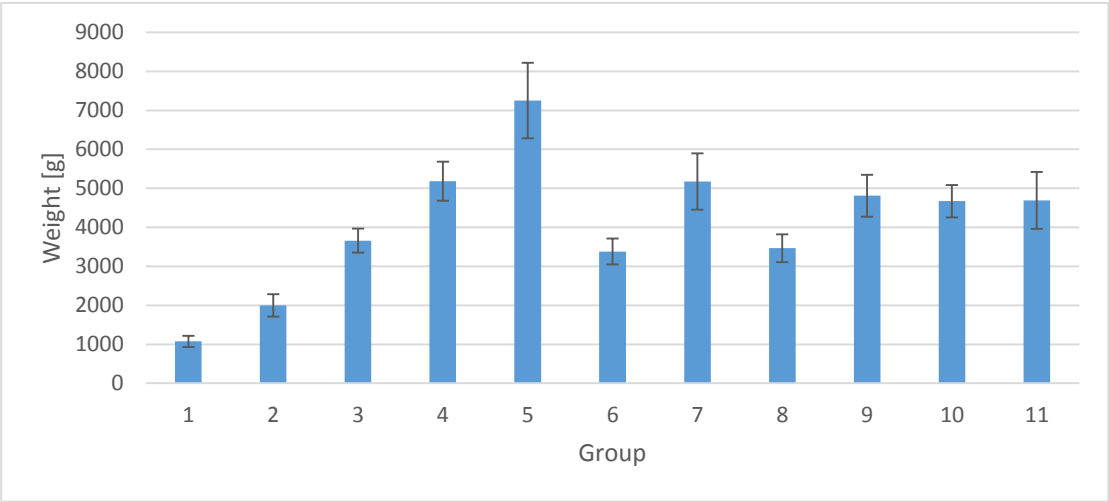


Figure 43 Average weight before drying of sample groups in Experiment 1 - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9), pressed cod (10-11) (further information of groups in Table 4)

The surface area-to-weight is also similar for cod and ling and the tusk is not that different either (Figure 44).

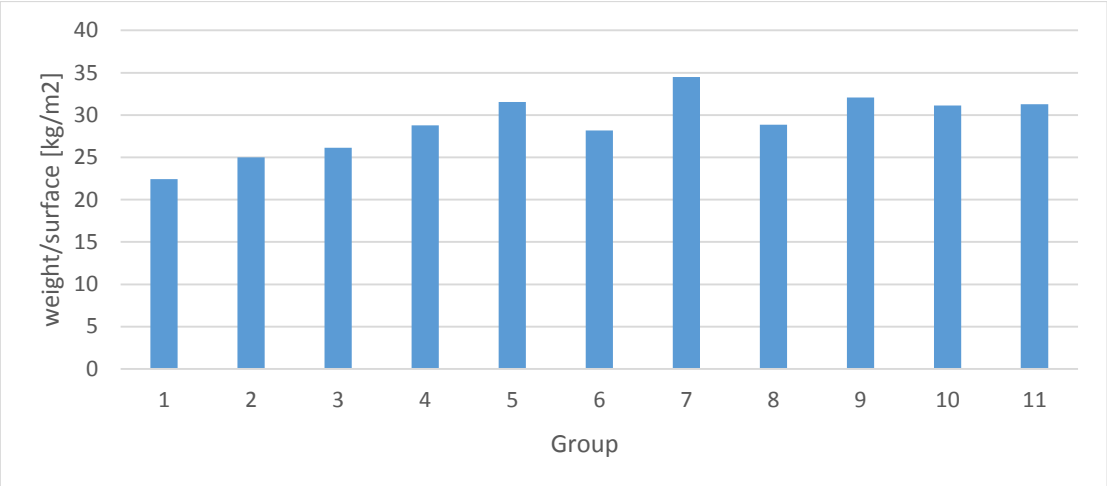


Figure 44 Weight on square meter of sample groups before drying in Experiment 1 - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9), pressed cod (10-11) (further information of groups in Table 4)

The ling lost significantly less weight than both tusk and cod, but there was not a significant difference between tusk and cod.

4.1.3 Salting methods

All the ling and tusk was injected with phosphate and as the difference between species has been shown the salting methods were compared using only cod. The order of the groups from most weight loss to the least was as follows; injected + compressed > not injected + compressed > not injected ≥ injected.

The injected cod that was compressed lost significantly more weight than all the other cod groups but no other difference was significant when the HSD method was used. If the LSD method was used the compressed non-injected cod also lost significantly more weight than the not compressed fish (Figure 45). Still the difference between injected and non-injected cod is not nearly as much as between cod and ling.

	Inj	Not inj	Inj+P	Not inj + P
Inj		0	-	0
Not inj	0		-	0
Inj+P	+	+		+
Not inj + P	0	0	-	

	Inj	Not inj	Inj+P	Not inj + P
Inj		0	-	-
Not inj	0		-	-
Inj+P	+	+		+
Not inj + P	+	+	-	

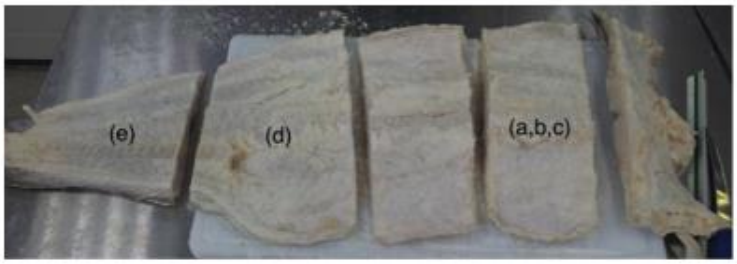
Figure 45 Results of significance test for weight loss between salting methods of cod in Experiment 1 (HSD method to the left and LSD method to the right) with 5 % significance level

4.1.4 Water content, Salt content and Water Holding Capacity (WHC)

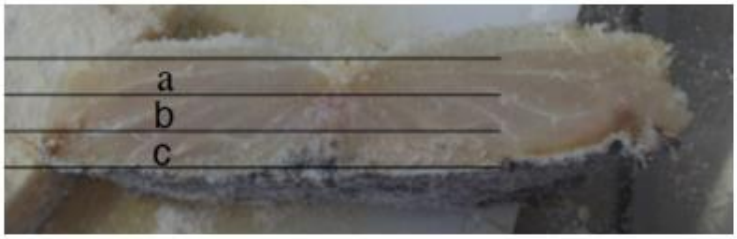
Chemical analyses were performed on samples from all groups before and after drying (Figure 46). Cod was also measured after two days of drying and after compressing, both in injected and non-injected cod.

The results show that there is not much difference in water content inside the fish after 6 days drying and much less than was expected considering the weight loss.

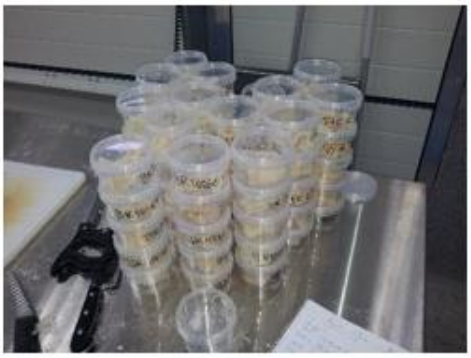
According to the weight loss, the water content after drying should have been around 44 to 50 % in all the groups compared to 56 to 58 % before drying but the results showed water content around 54 to 57 % (Figure 47). The measured values are average values from all five locations according to Equation (3.1).



a) *Sample locations of dried ling*



b) Different sample layers of the loin



c) Samples stored in plastic containers in a cooler

Figure 46 Location of different samples in ling for chemical measurements

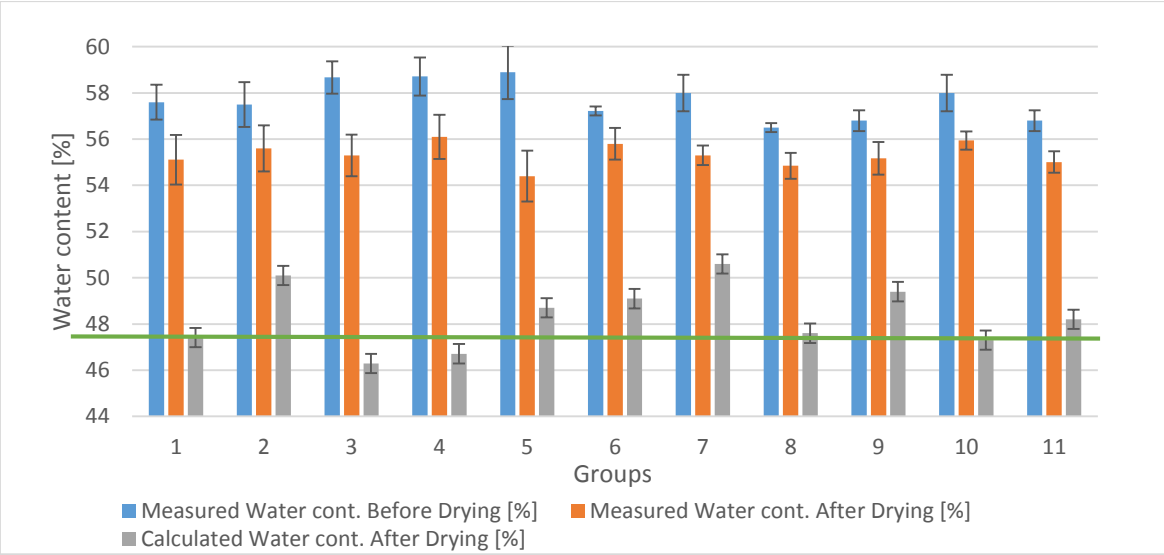


Figure 47 Measured water content before and after drying in Experiment 1 and calculated water content after drying for each group - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9), pressed cod (10-11) (further information of groups in Table 4) (ave±std) – Green line shows 47 % water content

One hypothesis was that salt crystals would crystallize inside the fish when the water is vaporized so the expected results of salt content measurements was that the proportion of salt would be higher inside the fish after drying than before. On the other hand the results show that the salt proportion stayed the same, about 19-21 %, after drying. Actually the salt content inside the fish was lower after drying than before drying (Table 9).

Table 9 Average water content, salt content and WHC for salted split fish before and after drying in Experiment 1 (n=3) (ave ± std)

	No.	Group	Before dry. [%]	After dry. [%]
Water (%)	1	Small tusk	57.6±0.8	55.1±1.1
	2	Large tusk	57.5±0.97	55.6±0.9
	3	Small ling	58.7±0.7	55.3±1.0
	4	Large ling	58.7±0.8	56.1±0.9
	5	X-large ling	58.9±1.2	54.4±0.6
	6	Small injected cod	57.2±0.1	55.8±0.7
	7	Large injected cod	58.0±0.8	55.4±0.4
	8	Small cod not injected	56.5±0.3	54.9±0.6
	9	Large cod not injected	56.8±0.5	55.6±0.7
	10	Large inj. and compressed cod	58.0±0.8	55.9±0.4
	11	Large not inj. cod compressed	56.8±0.5	55.0±0.5
	No.	Group	Before dry. [%]	After dry. [%]
Salt (%)	1	Small tusk	20.7±0.3	19.5±0.3
	2	Large tusk	20.5±0.7	19.5±0.6
	3	Small ling	21.0±0.7	19.6±0.4
	4	Large ling	21.2±0.4	19.7±0.4
	5	X-large ling	21.3±0.7	19.3±0.3
	6	Small injected cod	20.3±0.1	19.9±0.3
	7	Large injected cod	20.6±0.3	19.5±0.6
	8	Small cod not injected	20.3±0.1	19.8±0.7
	9	Large cod not injected	20.1±0.2	19.5±0.1
	10	Large inj. and compressed cod	20.6±0.3	19.6±0.1
	11	Large not inj. cod compressed	20.1±0.2	19.2±0.2
	No.	Group	Before dry. [%]	After dry. [%]
WHC (%)	**1**	Small tusk	73.7±2.0	91.1±2.4
	2	Large tusk	76.3±3.3	87.3±2.0
	3	Small ling	79.9±3.9	95.7±2.6
	4	Large ling	79.7±5.0	94.9±2.0
	5	X-large ling	79.4±3.3	98.5±0.6
	6	Small injected cod	83.4±2.2	91.4±2.5
	7	Large injected cod	84.6±2.3	93.2±0.5
	8	Small cod not injected	91.4±2.3	95.1±2.1
	9	Large cod not injected	90.4±1.7	95.2±1.8
	10	Large inj. and compressed cod	84.6±2.3	92.23±0.1
	11	Large not inj. cod compressed	90.5±1.7	95.8±1.6

Before drying

Before drying, there was significantly more water content in the small and large ling than in the non-injected cod. There was no significant difference between any other groups. The non-injected cod was the only group that was not injected with phosphate. The difference in water content was still not significant compared to the injected cod with 5 % significance level (Figure 48 and 49).

	1	2	3	4	5	6	7	8	9	10	11
1		0	0	0	0	0	0	0	0		
2	0		0	0	0	0	0	0	0		
3	0	0		0	0	0	0	+	+		
4	0	0	0		0	0	0	+	+		
5	0	0	0	0		0	0	0	0		
6	0	0	0	0	0		0	0	0		
7	0	0	0	0	0	0		+	0		
8	0	0	-	-	0	0	-		0		
9	0	0	-	-	0	0	0	0			
10											
11											

Figure 48 Results of significance test for water content between groups before drying in Experiment 1 - LSD Method with 5 % significance level - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9) (further information of groups in Table 4)

	1	2	3	4	5	6	7	8	9	10	11
1		0	0	0	0	0	0	0	0		
2	0		0	0	0	0	0	0	0		
3	0	0		0	0	0	0	+	0		
4	0	0	0		0	0	0	+	0		
5	0	0	0	0		0	0	0	0		
6	0	0	0	0	0		0	0	0		
7	0	0	0	0	0	0		0	0		
8	0	0	-	-	0	0	0		0		
9	0	0	0	0	0	0	0	0			
10											
11											

Figure 49 Results of significace test for water content between groups before drying in Experiment 1 – HSD Method with 5 % significance level - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9) (further information of groups in Table 4)

The results from the salt content measurements indicate that there was higher salt content in the ling than in the tusk and cod when the LSD method was used for comparison but the results are not so clear when the Tukey‘s method was used (Figure 50 and 51). The red fields in Figure 50 show where there is significant difference in LSD method but not in the HSD method. Where there is a plus sign in the table the row has significantly higher value than the column. On the other hand where there is a minus sign, the row has significantly lower value than the column. Where there is a “0” there is no significant difference between row and column.

	1	2	3	4	5	6	7	8	9	10	11
1		0	0	0	0	0	0	0	0		
2	0		0	0	-	0	0	0	0		
3	0	0		0	0	0	0	0	+		
4	0	0	0		0	+	0	+	0		
5	0	+	0	0		+	+	+	+		
6	0	0	0	-	-		0	0	0		
7	0	0	0	0	-	0		0	0		
8	0	0	0	-	-	0	0		0		
9	0	0	-	-	-	0	0	0			
10											
11											

Figure 50 Results of significance test for salt content between groups before drying in Experiment 1 – HSD Method with 5 % significance level - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9) (further information of groups in Table 4)

	1	2	3	4	5	6	7	8	9	10	11
1		0	0	-	-	0	0	0			
2	0		-	-	-	0	0	0	0		
3	0	+		0	0	+	0	+	+		
4	+	+	0		0	+	+	+	+		
5	+	+	0	0		+	+	+	+		
6	0	0	-	-	-		0	0	0		
7	0	0		-	-	0		0	+		
8	0	0	-	-	-	0	0		0		
9	-	0	-	-	-	0	-	0			
10											
11											

Figure 51 Results of significance test for salt content between groups before drying in Experiment 1 - LSD method with 5 % significance level - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9) (further information of groups in Table 4)

When water holding capacity was compared it showed significant difference between the cod and the small tusk, that is less WHC in the tusk and also clearly more WHC in the non-injected cod than in the ling (Figure 52 and 53). It may be noted that there was also significantly less water in the non-injected cod which might be the cause of the higher WHC.

	1	2	3	4	5	6	7	8	9	10	11
1		0	0	0	0	-	-	-	-		
2	0		0	0	0	0	0	-	-		
3	0	0		0	-	0	0	-	-		
4	0	0	0		+	0	0	-	-		
5	0	0	-	-		-	-	-	-		
6	+	0	0	0	+		0	0	0		
7	+	0	0	0	+	0		0	0		
8	+	+	+	+	+	0	0		0		
9	+	+	+	+	+	0	0	0			
10											
11											

Figure 52 Results of significance test for water holding capacity between groups before drying in Experiment 1 - LSD method with 5 % significance level - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9) (further information of groups in Table 4)

	1	2	3	4	5	6	7	8	9	10	11
1		0	0	0	0	0	0	-	-		
2	0		0	0	0	0	0	-	-		
3	0	0		0	0	0	0	0	0		
4	0	0	0		0	0	0	0	0		
5	0	0	0	0		-	-	-	-		
6	0	0	0	0	+		0	0	0		
7	0	0	0	0	+	0		0	0		
8	+	+	0	0	+	0	0		0		
9	+	+	0	0	+	0	0	0			
10											
11											

Figure 53 Results of significance test for water holding capacity between groups before drying in Experiment 1 - HSD method with 5 % significance level - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9) (further information of groups in Table 4)

The water holding capacity between groups was in the following order, even though not significant in most case. Non - inj cod > injected cod > ling > tusk.

The Z^{NaCl} value that is the salt concentration of the water in the fish, was always about 26 % which is a fully saturated brine and no significant difference was detected. The Z-value is calculated with Equation (4.1).

$$Z^{\mathrm{NaCl}} = \frac{X_{\mathrm{salt}}}{X_{\mathrm{salt}} + X_{\mathrm{water}}} = 26\ \% \tag{4.1}$$

If the chemical results were compared between locations in the fish, there was significantly more water content in b than in c and e when the LSD method was used but no difference when HSD method was used (Figure 54). Looking specifically at the cod, there was no difference in water content between locations in the injected cod but when only looked at non-injected cod there was significantly more water in a than d and e using LSD. In the ling there was higher water content in b than in c and e significantly only when using LSD

method. Comparing only locations in the tusk groups, there was significantly less water content in the tail (e) than in the other locations both for LSD and HSD method (Figure 55).

	a	b	c	d	e
a		0	0	0	0
b	0		0	0	0
c	0	0		0	0
d	0	0	0		0
e	0	0	0	0	

	a	b	c	d	e
a		0	0	0	0
b	0		+	0	+
c	0	-		0	0
d	0	0	0		0
e	0	-	0	0	

Figure 54 Results of significance tests for water content in different locations of salted split fish before drying in Experiment 1 (HSD method to the left and LSD method to the right) with 5 % significance level

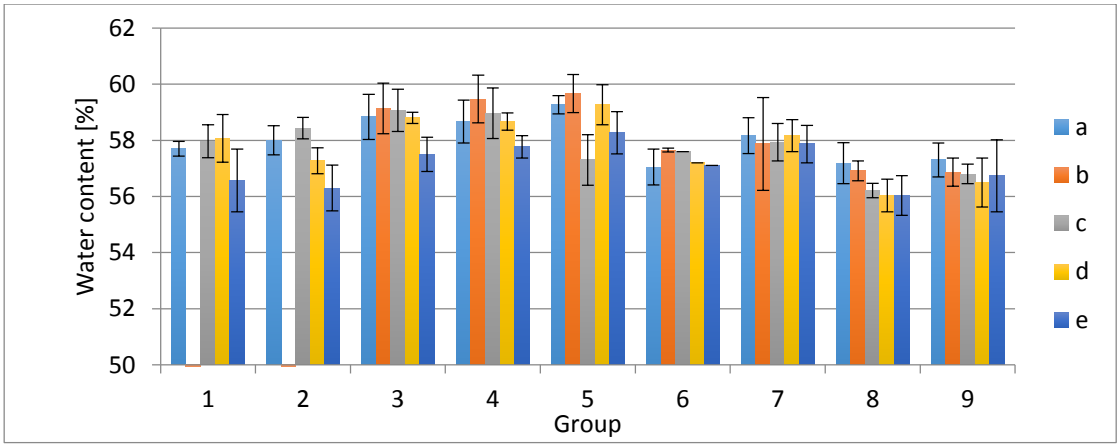


Figure 55 Water content of different groups in different locations (a, b, c, d, e) of the split fish before drying in - Experiment 1 (ave±std) - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9) (further information of groups in Table 4)

The salt content is more in a, c and e than in b (Figure 56) which matches the results that there is more water content in b than c and e. Considering the cod groups, there was no significant difference in salt content between locations for injected cod but for not injected there was more salt in e than b. When looked at only the ling groups there was only significantly more salt in a and c than in b. For the tusk there was more salt in c than in e (Figure 57).

	a	b	c	d	e
a		+	0	0	0
b	-		0	0	0
c	0	0		0	0
d	0	0	0		0
e	0	0	0	0	

	a	b	c	d	e
a		+	0	0	0
b	-		-	0	-
c	0	+		0	0
d	0	0	0		0
e	0	+	0	0	

Figure 56 Results of significance tests for salt content in different locations of salted split fish before drying in Experiment 1 (HSD method to the left and LSD method to the right) with 5 % significance level.

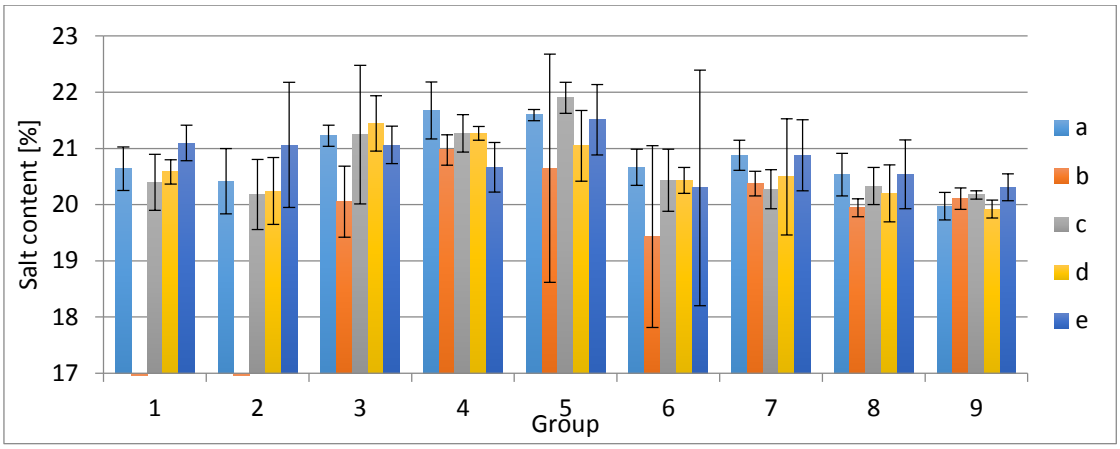


Figure 57 Salt content of different groups in different locations (a, b, c, d, e) of the split fish before drying in Experiment 1 (ave±std) - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9) (further information of groups in Table 4)

The results showed that there was no difference in water holding capacity between locations in the split fish but the variance between individual samples was quite high (Figure 58).

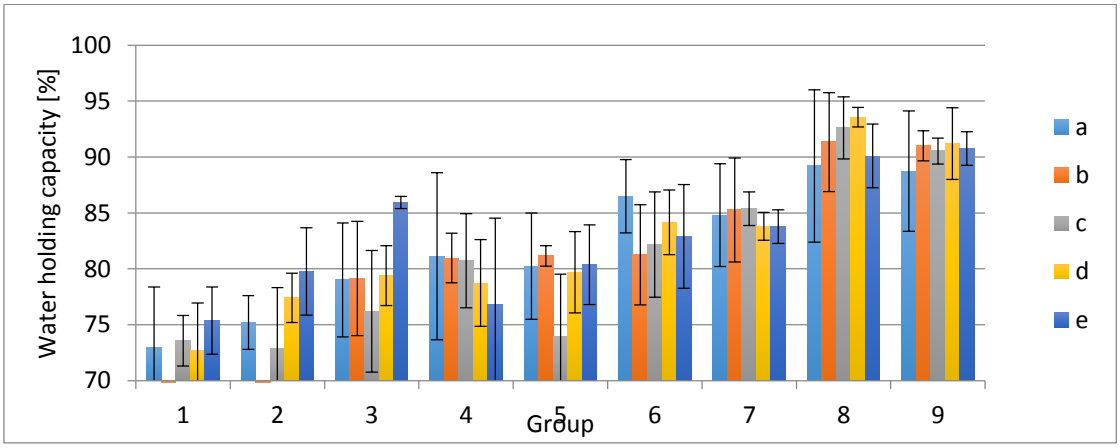


Figure 58 WHC of different groups in different locations (a, b, c, d, e) of the split fish after drying in Experiment 1 (ave±std) - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9) (further information of groups in Table 4)

Negative correlation of 0.49 was found between water content and water holding capacity of the samples. The tendency was that higher water content leads to lower WHC.

After drying

The results from the water content measurements after drying showed that the water content of extra-large ling is significantly lower than in any other group and also the small ling has less water than most of the other groups. Furthermore the results show significantly more water content in the compressed injected cod than in the not compressed cod. That is surprising because the compressed injected cod lost significantly more weight than the not compressed. When HSD method is used, much less significant difference is detected than for LSD method (Figure 59 and 60).

	1	2	3	4	5	6	7	8	9	10	11
1		0	0	-	0	-	0	0	0	-	0
2	0		0	0	+	0	0	+	0	0	0
3	0	0		-	+	0	0	0	0	0	0
4	+	0	+		+	0	+	+	+	0	+
5	-	-	-	-		-	-	0	-	-	-
6	+	0	0	0	+		0	+	+	0	+
7	0	0	0	-	+	0		0	0	-	0
8	0	-	0	-	0	-	0		0	-	0
9	0	0	0	-	+	-	0	0		-	0
10	+	0	0	0	+	0	+	+	+		+
11	0	0	0	-	+	-	0	0	0	-	

Figure 59 Results of significance test for water content between groups after drying in Experiment 1 - LSD Method with 5 % significance level - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9), pressed cod (10-11) (further information of groups in Table 4)

	1	2	3	4	5	6	7	8	9	10	11
1		0	0	0	0	0	0	0	0	0	0
2	0		0	0	+	0	0	0		0	0
3	0	0		0	0	0	0	0	0	0	0
4	0	0	0		+	0	0	+	+	0	+
5	0	-	0	-		-	0	0	0	-	0
6	0	0	0	0	+		0	+	0	0	0
7	0	0	0	0	0	0		0	0	0	0
8	0	0	0	-	0	-	0		0	-	0
9	0	0	0	-			0	0		0	0
10	0	0	0	0	+	0	0	+	0		0
11	0	0	0	-	0	0	0	0	0	0	

Figure 60 Results of significance test for water content between groups after drying in Experiment 1 - HSD Method with 5 % significance level - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9), pressed cod (10-11) (further information of groups in Table 4)

There was also significantly more water in injected cod than in non-injected cod. Water content in different locations in different groups can be seen in Figure 61.

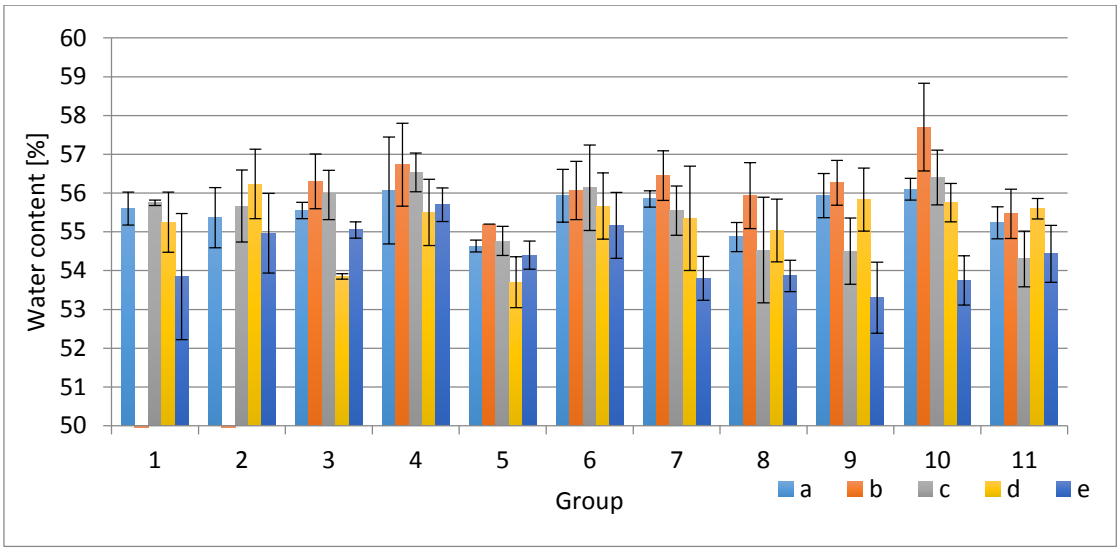


Figure 61 Water content of different groups in different locations (a, b, c, d, e) of the split fish after drying in Experiment 1 (ave±std) - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9), pressed cod (10-11) (further information of groups in Table 4)

Comparing the salt content there is more salt in the large ling than in most of the cod groups and the tusk. Other obvious pattern cannot be seen (Figure 62). If looked at the HSD method results (Figure 63) there is only a significant difference between large ling and extra-large ling and between the large ling and the large not injected compressed cod, while before drying the salt content in large and extra-large ling was measured significantly higher than in most other group.

	1	2	3	4	5	6	7	8	9	10	11
1		0	0	-	0	0	0	0	0	0	0
2	0		0	-	0	-	0	-	0	0	0
3	0	0		0	0	0	0	0	0	0	0
4	+	+	0		+	0	+	0	+	+	+
5	0	0	0	-		-	0	-	0	0	0
6	0	+	0	0	+		0	0	+	0	+
7	0	0	0	-	0	0		0	0	0	0
8	0	+	0	0	+	0	0		+	0	+
9	0	0	0	-	0	-	0	-		0	0
10	0	0	0	-	0	0	0	0	0		0
11	0	0	0	-	0	-	0	-	0	0	

Figure 62 Results of significance test for salt content between groups after drying in Experiment 1 - LSD Method with 5 % significance level - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9), pressed cod (10-11) (further information of groups in Table 4)

	1	2	3	4	5	6	7	8	9	10	11
1		0	0	0	0	0	0	0	0	0	0
2	0		0	0	0	0	0	0	0	0	0
3	0	0		0	0	0	0	0	0	0	0
4	0	0	0		+	0	0	0	0	0	+
5	0	0	0	-		0	0	0	0	0	0
6	0	0	0	0	0		0	0	0	0	0
7	0	0	0	0	0	0		0	0	0	0
8	0	0	0	0	0	0	0		0	0	0
9	0	0	0	0	0	0	0	0		0	0
10	0	0	0	0	0	0	0	0	0		0
11	0	0	0	-	0	0	0	0	0	0	

Figure 63 Results of significance test for salt content between groups after drying in Experiment 1 - HSD Method with 5 % significance level - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9), pressed cod (10-11) (further information of groups in Table 4)

The salt concentration was around 26% in every location of the split fish after drying and no significant difference was detected (Figure 64).

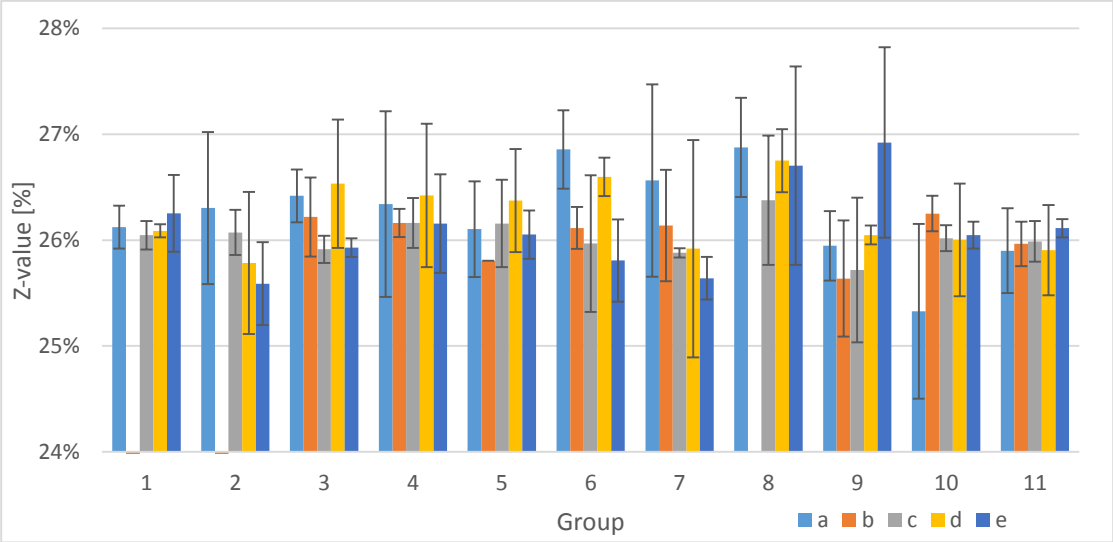


Figure 64 Salt concentration of different groups in different locations (a, b, c, d, e) of the split fish after drying in Experiment 1 (ave±std) - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9), pressed cod (10-11) (further information of groups in Table 4)

The results from the water holding capacity measurements show that the tusk had significantly less WHC than the ling and the cod. The injected cod also had less WHC than the other groups (Figure 65 and 66). It also had significantly more water content than some of the groups, which might be one of the reasons why it lost more water in the WHC test and therefore had lower water holding capacity

	1	2	3	4	5	6	7	8	9	10	11
1		+	-	-	-	0	-	-	-	-	-
2	-		-	-	-	-	-	-	-	-	-
3	+	+		0	-	+	+	0	0	+	0
4	+	+	0		-	+	0	0	0	+	0
5	+	+	+	+		+	+	+	+	+	+
6	0	+	-	-	-		-	-	-	0	-
7	+	+	-	0	-	+		-	-	0	-
8	+	+	0	0	-	+	+		0	+	0
9	+	+	0	0	-	+	+	0		+	0
10	0	+	-	-	-	0	0	-	-		-
11	+	+	0	0	-	+	+	0	0	+	

Figure 65 Results of significance test for WHC between groups after drying in Experiment 1 - LSD Method with 5 % significance level - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9), pressed cod (10-11) (further information of groups in Table 4)

	1	2	3	4	5	6	7	8	9	10	11
1		+	-	-	-	0	0	-	-	0	-
2	-		-	-	-	-	-	-	-	-	-
3	+	+		0		+		0	0	+	0
4	+	+	0		-	+	0	0	0	0	0
5	+	+	0	+		+	+	+	+	+	0
6	0	+	-	-	-		-	-	-	0	-
7	0	+	0	0	-	0		0	0	0	0
8	+	+	0	0	-	+	0		0	0	0
9	+	+	0	0	-	+	0	0		+	0
10	0	+	-	0	-	0	0	0	-		-
11	+	+	0	0	0	+	0	0	0	+	

Figure 66 Results of significance test for WHC between groups after drying in Experiment 1 – HSD Method with 5 % significance level - tusk (1-2), ling (3-5), inj. cod (6-7), not inj. cod (8-9), pressed cod (10-11) (further information of groups in Table 4)

When the results are compared between locations in the split fish, it can be seen that there is significantly more water in b than in other parts of the fish (Figure 67). That can be explained by lower drying rate in middle part of the thickest part of the fish. It also gives a reason to believe that there is some water that is lost through the skin as there is significantly less water in location c, which is nearest to the skin in the loin. Also there was more water content in b before drying too. There is no difference between a, c and d and then there is significantly less water in location e than in any other location. Location e is the thinnest part, the tail, so those results are understandable. Looking only at the tusk there is no difference between locations in water content except there is less water in e than d. For ling there is more water in b than in d and e. and for non-injected cod more in a, b and d than in e.

	a	b	c	d	e
a		-	0	0	+
b	+		+	+	+
c	0	-		0	+
d	0	-	0		+
e	-	-	-	-	

	a	b	c	d	e
a		-	0	0	+
b	+		+	+	+
c	0	-		0	+
d	0	-	0		+
e	-	-	-	-	

Figure 67 Results of significance tests for water content in different locations of salted split fish after drying in Experiment 1 (HSD method to the left and LSD method to the right) with 5 % significance level

Results from the salt measurements show that there is significantly lower salt content in e than in other parts of the fish. Also there is less salt in c than in a and b, while before drying there was significantly less salt in location b. Also after drying there is significantly less salt in e than in any other location while before drying there was no difference except there was more salt in e than b (Figure 68). The differences between locations were almost identical between cod, tusk and ling.

	a	b	c	d	e
a		0	0	0	+
b	0		0	0	+
c	0	0		0	0
d	0	0	0		+
e	-	-	0	-	

	a	b	c	d	e
a		0	+	0	+
b	0		+	0	+
c	-	-		0	+
d	0	0	0		+
e	-	-	-	-	

Figure 68 Results of significance tests for salt content in different locations of salted split fish after drying in Experiment 1 (HSD method to the left and LSD method to the right) with 5 % significance level

Before drying there was no significant difference in WHC between locations but after drying there is significantly more water holding capacity in part e than in any other location (Figure 69). Also there is less water in e, which is the same pattern as seen before

	a	b	c	d	e
a		0	0	0	-
b	0		0	0	-
c	0	0		0	-
d	0	0	0		0
e	+	+	+	0	

	a	b	c	d	e
a		0	0	0	-
b	0		0	0	-
c	0	0		0	-
d	0	0	0		-
e	+	+	+	+	

Figure 69 Results of significance tests for WHC in different locations of salted split fish after drying in Experiment 1 (HSD method to the left and LSD method to the right) with 5 % significance level

From the samples after drying there was a negative correlation of 0.93 between water content and water holding capacity. Both before and after drying there was a negative correlation around 0.3 between salt content and WHC. There was a positive correlation between water

content and salt content. Further results of correlation between chemical values can be found in Appendix E.

4.1.5 Water activity

Both the injected and non-injected salted cod had water activity around 0.75 in all three locations in the loin (a, b, c) both before and after drying. So the water activity had not decreased in the drying process. As was presented in Table 9 there was not a lot of water loss in the samples in the drying so maybe a reduction in water activity could not be expected.

4.1.6 Temperature

Temperature loggers in Tunnel B showed that there is not a big difference in temperature between the air inlet, through the tunnel and the air outlet in the drying cabinet. The temperature difference does not exceed 1 to 2 °C and in all locations the temperature loggers follow the same trend during the process. Loggers at the right side of the tunnel measure very steady temperatures between 18 and 19 °C during the whole process. The temperatures in the middle and the left side of the tunnel fluctuate a little more, from 16 to over 20 °C. Temperature in the center of Tunnel B can be seen in Figure 70. More temperature measurements can be found in Appendix A.

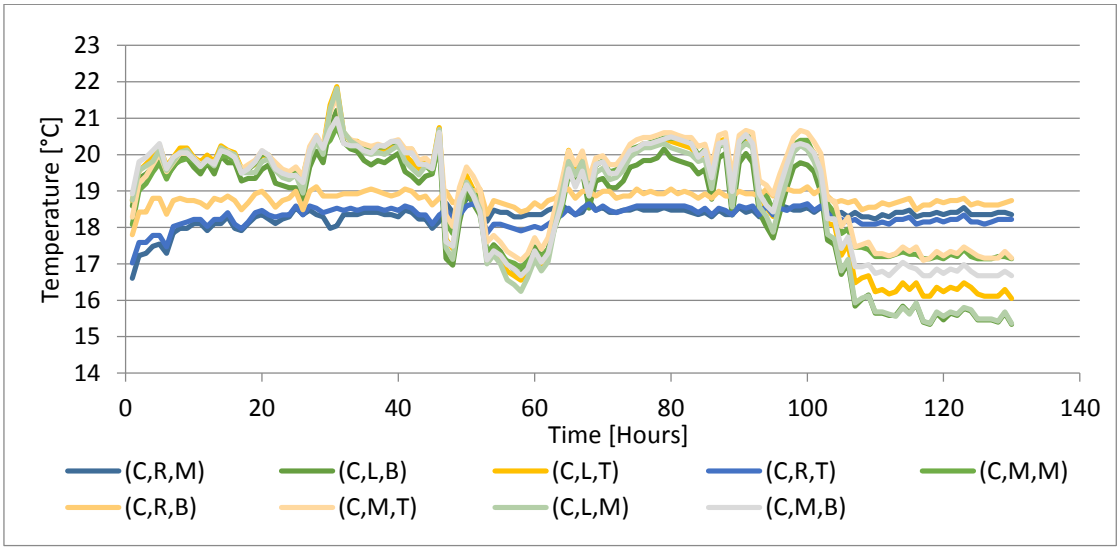


Figure 70 Temperature at different heights and width in center of Tunnel B during Experiment 1 (explanations of abbreviations in Section 3.3)

In Tunnel A there are larger spatial temperature variations or from about 15.5 to 18 °C. However the temperature is not fluctuating as much as in Tunnel B. A large top can be seen after about 95 hours, which is because the door is opened when the fish is weighed. The temperature at the center of the tunnel can be seen in Figure 71 and temperature at the door and air inlet in Appendix A. The temperature in the center of the tunnel is between 16 and 18 °C. Lower temperature could have been expected at the door than in the middle of the tunnel but it was actually very similar.

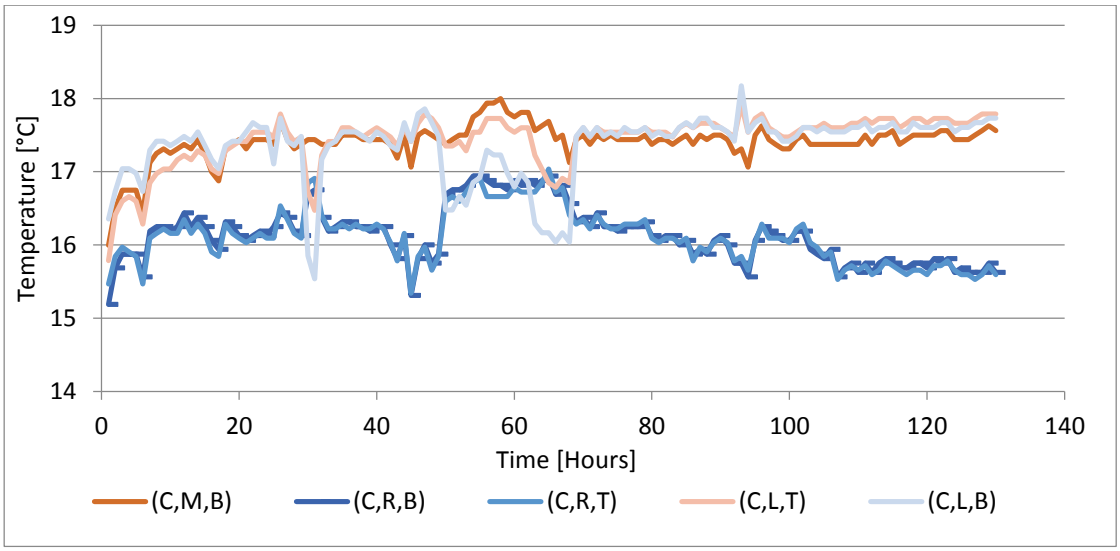


Figure 71 Temperature in different heights and width in center of Tunnel A during Experiment 1 (explanations of abbreviations in Section 3.3)

If the frequency of the fan motor is plotted it can be seen that the temperature decreases at the same time as the frequency of the motors is dropped from 40 to 35 Hz (Figure 72).

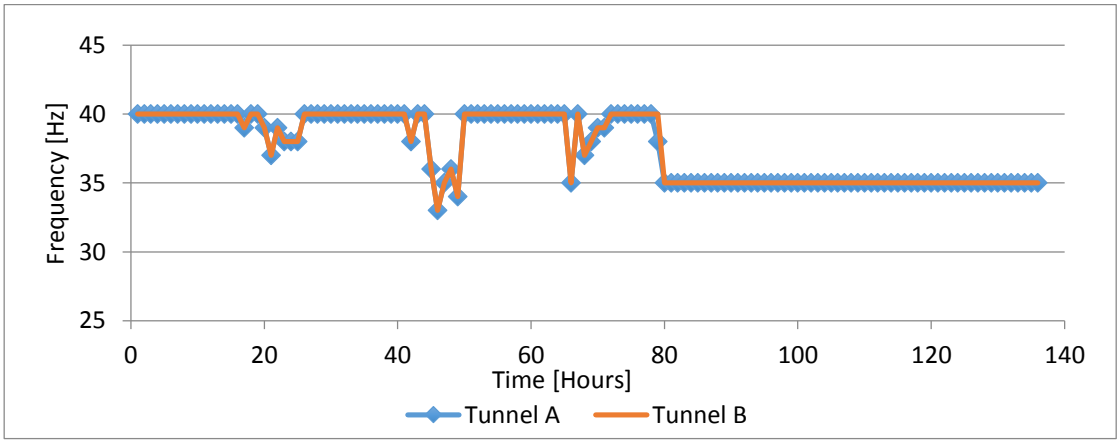


Figure 72 Frequency [Hz] of dryer fan motors in Tunnel A and B during Experiment 1

4.1.7 Humidity

Humidity loggers were only in Tunnel B in Experiment 1 and the loggers in every location showed similar results, which indicates that the humidity is homogenous in the drying tunnel. It seems like the humidity is rising when the temperature is decreasing and vice versa. When frequency of the motor of the air fans is decreased, the humidity rises. That could indicate that less air velocity might be enough to remove the water vapor from the fish and higher air velocity is a waste of energy. The humidity was between 25 to 55 % which is a considerable variation and it is undesirable that the humidity goes lower than 40 % and absolutely not under 30 % because of risk of case hardening. Most of the time during the drying the humidity was between 30 and 40 % so it might be improved (Figure 73).

The first 24 hours the humidity is between 35 and 45 %. After about 48 hours the humidity

rises to 50 to 55 % for about 12 hours and then decreases again and is between 30 and 40 % after that. It is strange to see that closest to the air inlet the humidity decreases when all the other loggers show increase in humidity after about 48 hours.The two loggers in the middle of the tunnel show very similar results and follow the same trend as the loggers closest to the air inlet.

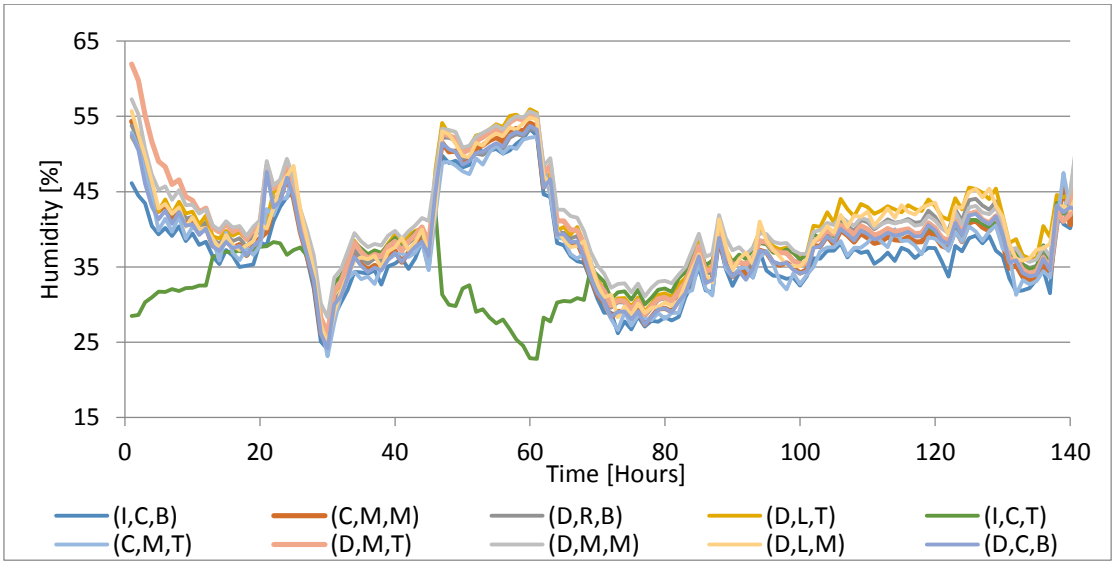


Figure 73 Humidity in different locations in drying Tunnel B during Experiment 1

If looked at the difference in humidity at air input and output of drying Tunnel B (Figure 74) it can be seen that the difference is most in the beginning but decreases fast and after 12 hours there is almost no difference between the air inlet and the air outlet. That indicates how fast the water removal is from the surface in the beginning of the process.

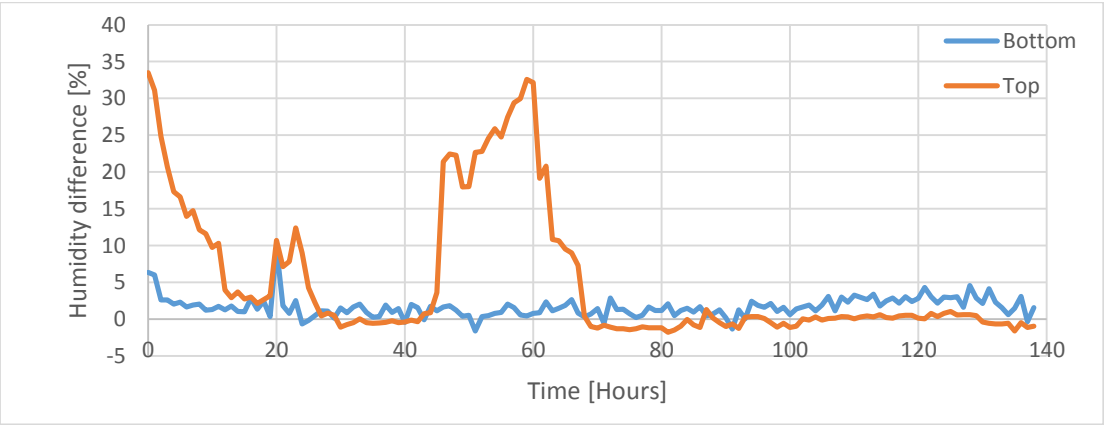


Figure 74 Humidity difference at air inlet and air outlet [out-in] in Tunnel B during Experiment 1

4.1.8 Outside conditions

To get a better view of the conditions inside the drying cabinet over time, data of the weather conditions at Keflavik airport, which is the nearest weather station to the facility, was gathered from the Icelandic Met Office. The outdoor temperature during the time

when the first experiment was in session (Figure 75) showed similar trend to the humidity data from the drying cabinet (Figure 73). The correlation between the two was calculated 58 %. No further explanation has been found for the correlation.

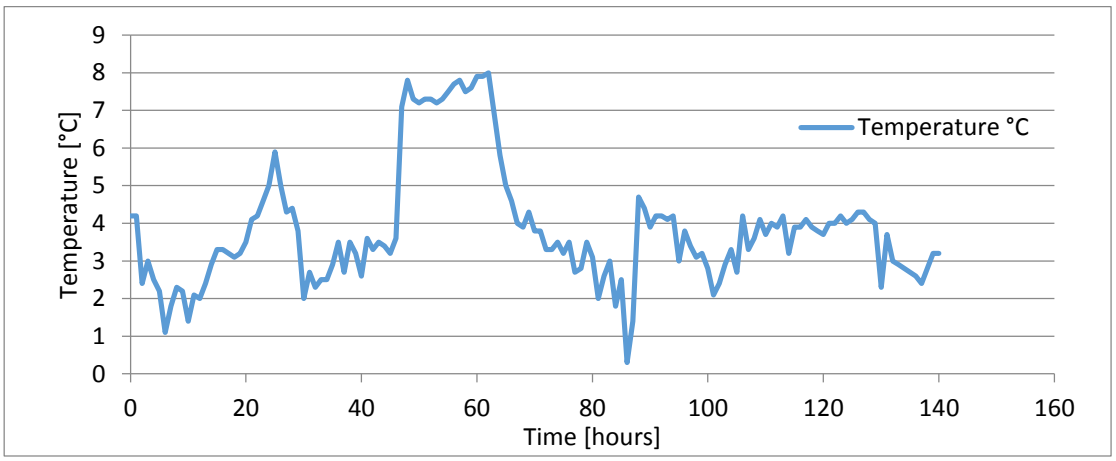


Figure 75 Outdoor temperature during Experiment 1

4.1.9 Air velocity

Air velocity was measured in Experiment 1 after about 95 hours with handheld measuring device. The air velocity was measured at nine different positions in the cross section at the end of the tunnel. In Tunnel A the velocity was measured about 1.0 - 1.4 m/s in most locations except for at the top trays where the velocity was 2.1 - 2.4 m/s, both in the middle and at the left and right wall of the tunnel. The air velocity was very similar in Tunnel B. It was measured about 1.0 - 1.3 m/s in most locations but about 1.8-2.1 m/s at the top. The measured values in each place can be seen in Appendix B. From the measured values the average velocity in Tunnel A was 1.5 ± 0.5 m/s and in Tunnel B 1.4 ± 0.4 m/s. It is difficult to make some assumption from those results as the air velocity was only measured one time over the whole drying period but from the frequency data for the fan motor the air velocity should have been quite stable the whole time.

4.1.10 Mass balance

By using the mass balance calculations introduced in Section 2.3 it can be seen that the water and salt content before and after the drying does not match the weight loss in the process.

The results from the chemical analysis show that the measured water content $X_{\text{w a.d measured}}$ is higher than the calculated water content $X_{\text{w a.d.}}$ using Equation (2.14 – 2.16)

That means that the samples taken from the fish are not giving a good perspective of the average water content of the fish. Comparison between the measured average water content and calculated water content with Equation (3.2) showed a clear difference (Table 10).

Table 10 Average water content of groups in Experiment 1. Measured water content before and after drying and calculated water content after drying (ave ± std)

No.	Group	Measured Water Content Before Drying [%]	Weight loss[%]	Calculated Water Content After Drying [%]	Measured Water Content After Drying [%]
1	Small tusk	57.6±0.9	19.3	47.4	55.1±1
2	Large tusk	57.5±1	14.9	50.1	55.6±0.9
3	Small ling	58.7±0.9	23.1	46.3	55.3±1
4	Large ling	58.7±0.8	22.5	46.7	56.1±0.9
5	Extra large ling	59.1±0.7	20.4	48.7	54.4±0.6
6	Small injectd cod	57.2±0.5	16.9	49.1	55.8±0.7
7	Large injected cod	58±0.8	14.9	50.7	55.3±0.4
8	Small cod not injected	56.5±0.3	20.0	47.6	54.9±0.6
9	Large cod not injected	56.8±0.5	15.3	49.4	55.2±0.7
10	Large injected and pressed cod	58.0±0.8	21.1	47.3	55.9±0.4
11	Large not injected cod pressed	56.8±0.5	17.3	48.3	55.0±0.5

This difference in weight loss and water loss is similar to results from previous researches where the water content of brine salted cod went from 57 % to 50.5 % and at the same time the weight loss was 28.9 % (Thorarinsdottir *et al*., 2007).

If the weight loss is used to calculate water content after drying from the water content before drying, and 47 % water content is the criterion then the small tusk (1), small and large ling (3, 4) and small non-injected cod (8) are about ready. The extra-large ling (5) would need more time in the drying and so does the injected cod (6, 7) and the large tusk (2). The injected and compressed cod (10) however is about 47 % in water content and the compressed non-injected cod (11) is considerably closer to 47 % than the not compressed, not injected large cod (9).

In the chemical measurements the samples were taken from five locations in the split fish like stated before in Section 3.7. It was noticed that the surface was very dry and covered in salt (Figure 76). There were no measurements made from the surface layer, only right below the surface. That might be the reason for the difference in water content and weight loss.

a) Salt layer removed from the surface of ling

c) Salt formation on surface of ling split fish

b) Salt accumulates in surface layer of dried ling

Figure 76 Ling after drying - The salt layer can be seen clearly on the dry surface

4.1.11 Surface measurements

Because of the small difference in water and salt content between locations in the loin of the split fish and because of the great difference in weight loss and water loss it was decided to make further measurements to analyze the chemical composition of the dried fish. One dried fish from large injected cod group, large non-injected cod and one ling were measured. Samples were taken from the surface of the fish (a) about 2mm thick from the middle part of the fish (b) about 4 mm thick and next to the skin (c) 2 mm thick (Figure 77). The samples where sent straight to chemical analysis at the laboratory at Matis ltd.

a) Considerable amount of salt on the surface

b) Sample piece taken from the loin

c) Sample taken from surface of loin (a)

d) Sample taken from middle part of loin (b)

Figure 77 Chemical measurements from surface of cod loin

A lot of salt was on the surface of the fish (Figure 77 a) and because the fish was not washed before the drying a great part of that salt is from the kench salting before storage but not salt from the inside of the fish. The salt on the surface was brushed off the samples.

The results from the chemical measurements on the surface showed that the surface was much drier than the muscle just below the surface (Figure 78). It seems like there hadn't been much water removal from the inside of the fish but only the surface. That might explain a part of the big difference between the water content measured before and the calculated water content. If these results are used to calculate the average water content in the whole fish, the injected cod has about 54.0 % water content, the non-injected cod about 52.5 % and the ling between 53 and 54 % instead of 55 to 56 % water content. If more weight would be put on the surface measures (no surface was in the middle part and tail samples either) the total water content of the fish would be even lower.

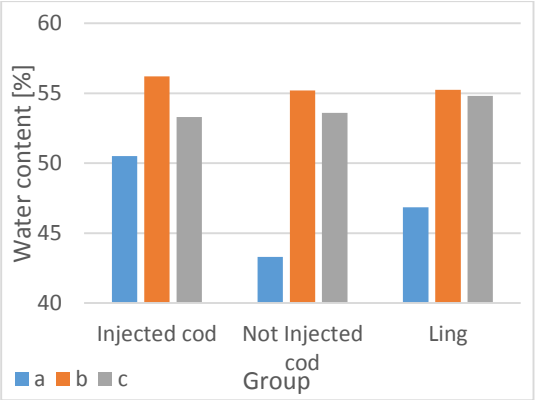


Figure 78 Surface measurements - Water content in different layers (a, b, c) of loin of split fish after drying

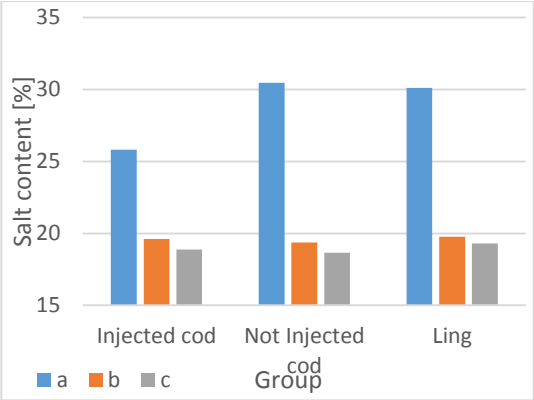


Figure 79 Surface measurements - Salt content in different layers (a, b, c) of loin of split fish after drying

The salt content measurement also showed much more salt on the surface than inside the fish (Figure 79). Some of that might be salt that was on the surface before drying but most of the salt was brushed off before the samples were sent to a chemical lab. Saturated brine is in the muscle but on the surface the brine is over saturated and the salt has crystalized when the water was removed during drying (Figure 80).

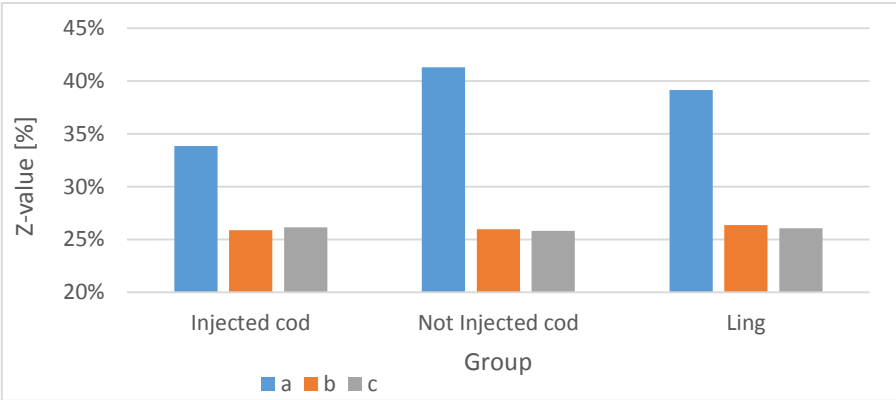


Figure 80 Surface measurements - Z^{NaCl} Salt concentration of water in different layers (a, b, c) of loin of split fish after drying

4.1.12 Weight change is storage

Seventeen split fishes from each of the eleven groups in Experiment 1 were kept in storage at Visir h.f processing facility in Grindavík for about 10 weeks after drying, from 21.01.2013 to 3.04.2013 and after that weighed (Table 11)

Table 11 Weight loss of split fish during two months in storage after drying in Experiment 1

No.	Group	Weight Change in Storage[%]	Weight Before Storage [g]
1	Small tusk	-0.5	850±100
2	Large tusk	-2.6	1700±300
3	Small ling	-0.6	2800±399
4	Large ling	-1.1	4000±400
5	X-Large ling	-1.6	5600±800
6	Small injected cod	-1.0	2800±300
7	Large injected cod	-2.2	4400±500
8	Small non-injected cod	0.4	2900±300
9	Large non-injected cod	-0.6	4000±500
10	Large inj and compressed cod	-0.7	3700±300
11	L not inj and compressed cod	-0.4	3900±600

Average humidity was 78.8 ± 0.6 % (ave±std) and the temperature was 3.6 ± 0.6 °C (ave±std) or about 2 to 4 °C the whole time, which is a good storage temperature for salted fish.

The humidity was very steady, about 78 to 80 % the whole time which is the ideal humidity for storage of wet salted fish but dryer air would be preferred for dried salted fish (Figure 81). The dried salted fish should not have lost any weight. If anything, it should have gained weight. Most likely the weight loss is due to surface salt falling of the fish or inaccuracy in the measurement.

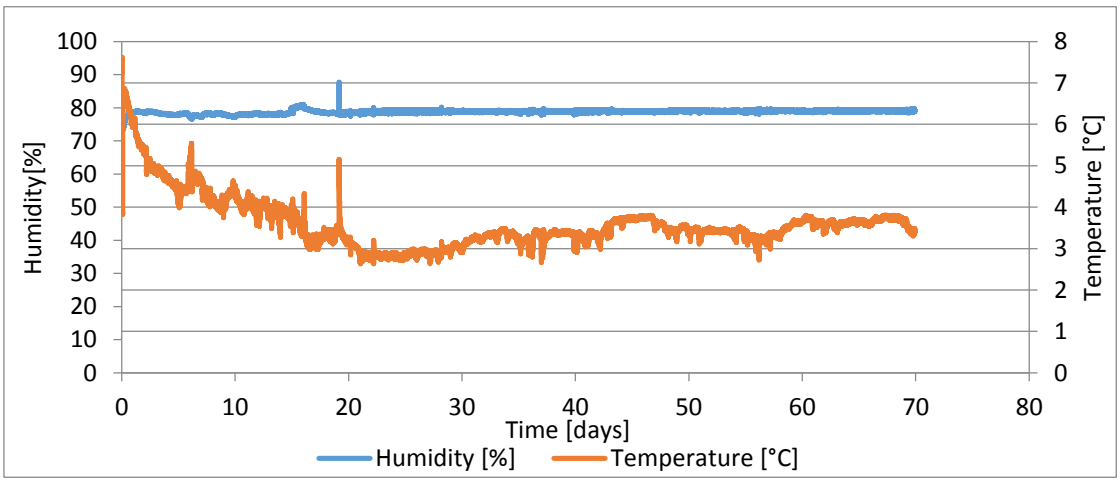


Figure 81 Ambient temperature and humidity in storage during the two months the dried salted fish was stored

4.2 Experiment 2

In Experiment 2 the main goal was to confirm the difference in drying rate between the ling and the cod and also to compare the weight loss in Tunnel A and B.

4.2.1 Yield and drying rate

The results from Experiment 2 show that significant difference is very clear between the drying of cod and ling. Using LSD method and HSD method with 5 % significance limit there was a difference between the cod and the ling but not between sizes or between the ling in different tunnels. Even though the weight loss between size grades was not significant, the small fish lost more weight than the large fish. The order from most weight loss to least was small ling > large ling > small cod > large cod.

The small ling lost about 21.9 ± 1.6 % in Tunnel B and about 22.4 ± 1.0 % in Tunnel A. The large ling lost 20.7 ± 1 % of its initial weight in Tunnel B and 20.4 ± 1.5 % in Tunnel A. The small cod lost 14.6 ± 2.2 % of its weight and the large cod 12.7 ± 1.1 % (Figure 82). The cod was in Tunnel B. That means that the ling was drying about 56 % faster than the cod.

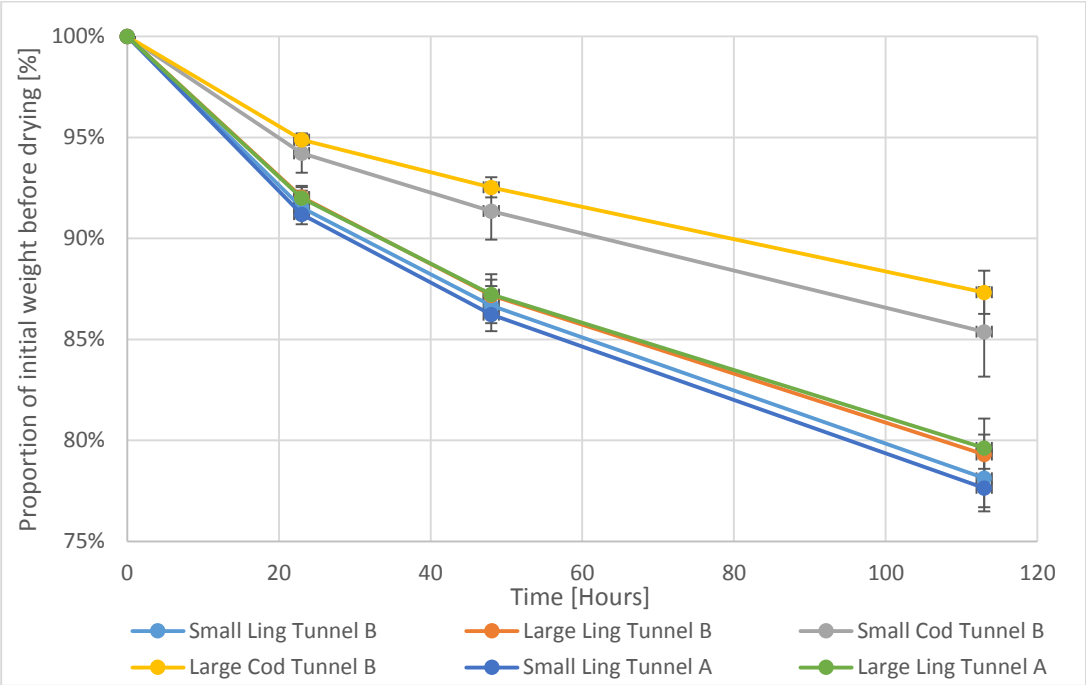


Figure 82 Weight loss of groups during Experiment 2 (ling and cod) (ave±std)

The fish lost less weight than in Experiment 1 but the drying time was also about 24 hours shorter. The drying conditions were similar in both experiments so the results indicate that the fish is losing about 1 - 2 % of its weight in the sixth day of drying.
The small cod in Experiment 2 was not significantly different in weight loss from large injected cod in Experiment 1. All the other cod was significantly different.

4.2.2 Water and salt content

Water and salt measurements were only made after the drying but not before drying as it was the same ling as in Experiment 1 and it was assumed that the results would have been similar for the cod too.

There was significantly more water in the cod than in the ling after drying and there was also more salt in the cod than in the ling (Figure 83 and 84). Assuming that there was no significant difference in water content before drying, like the results from Experiment 1 showed, it is logical that there is more water in the cod after drying as it lost less weight. It can be said that the ling dries faster.

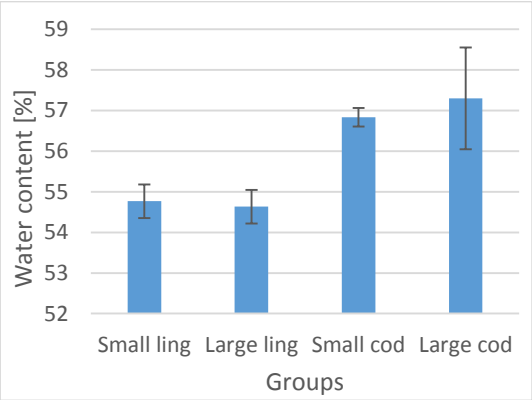


Figure 83 Measured water content of fish after drying in Experiment 2 (ave±std)

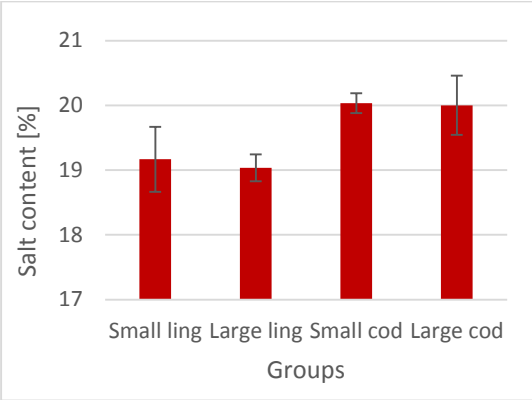


Figure 84 Measured salt content of fish after drying in Experiment 2 (ave±std)

Like in Experiment 1 the salt concentration Z^{NaCl} was not significantly different between groups or about 26 % in all cases (Figure 85). The surface was not a part of the samples used for salt content measurements and the results indicate that all extra salt crystalizing when water is removed is not staying inside the muscle.

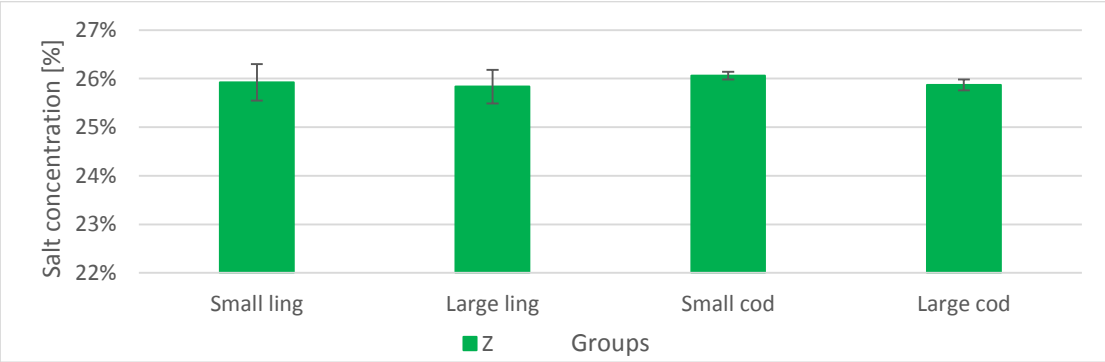


Figure 85 ZNaCl – Calculated salt concentration in water of fish after drying in Experiment 2 (ave±std)

4.2.3 Temperature

The temperature in Tunnel A was about 16 - 17 °C in most locations of the cabinet, during almost the whole drying process. The temperature was highest nearest to the air inlet. A small temperature top can be seen on all the temperature loggers after about 24 and 42 hours

of drying. The temperature in the center of the tunnel is very similar to the temperature at the door but it looks like there is little bit cooler in the right side of the tunnel (Figure 86). The temperature of the air at the air inlet is very stable, about 16 to 18 °C, depending on location. Results from other locations of the drying tunnels can be found in Appendix A.

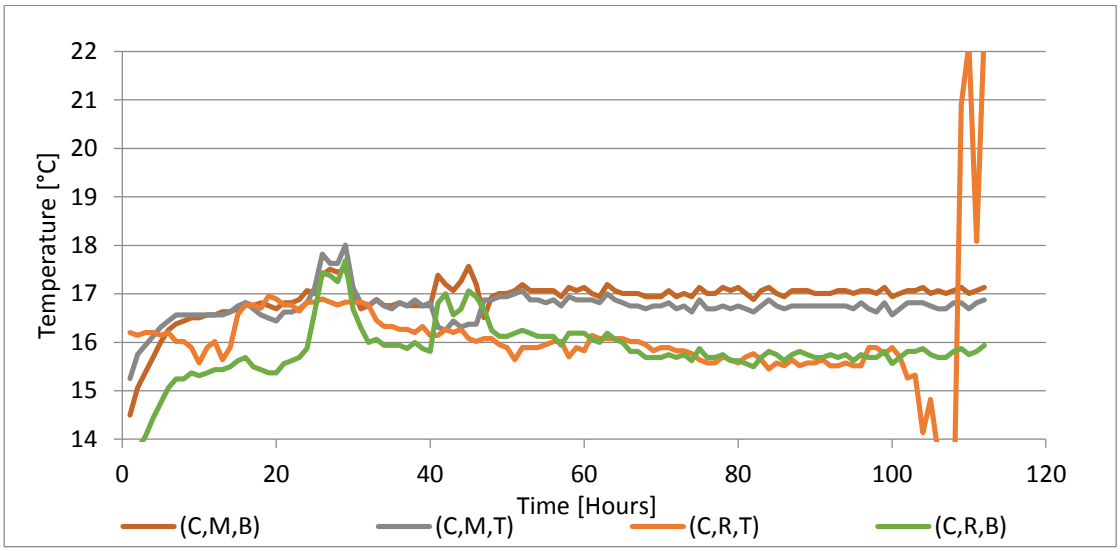


Figure 86 Temperature in different heights and width in center of Tunnel A during Experiment 2 (explanations of abbreviations in Section 3.3)

After around 28 and 42 hours the temperature rises in the drying tunnel but at the same time the frequency of the air fans motor is lowered from 35 Hz to 28 Hz for about 5 hours, which could be causing the temperature increase (Figure 87).

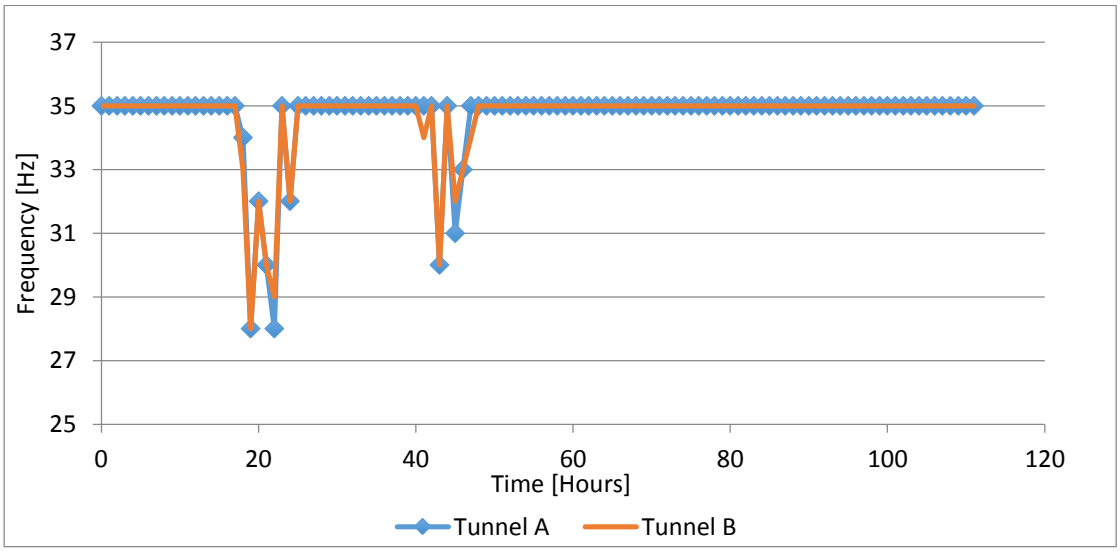


Figure 87 Frequency [Hz] of dryer fan motors in Tunnel A and B during Experiment 2

In Tunnel B, the temperature variance is larger and the temperature a little bit higher, or about 17 - 18 °C most of the time. Similar to Experiment 1, the loggers at the right side of the tunnel (seen by looking into the tunnel from the door) are more stable than in the center and left side. The temperature in the middle of the tunnel is about 16 to 18 °C most of the

time (Figure 88). The temperature at the left side is fluctuating more than in other places. *The left side in Tunnel B is the same as the right side in Tunnel A.*

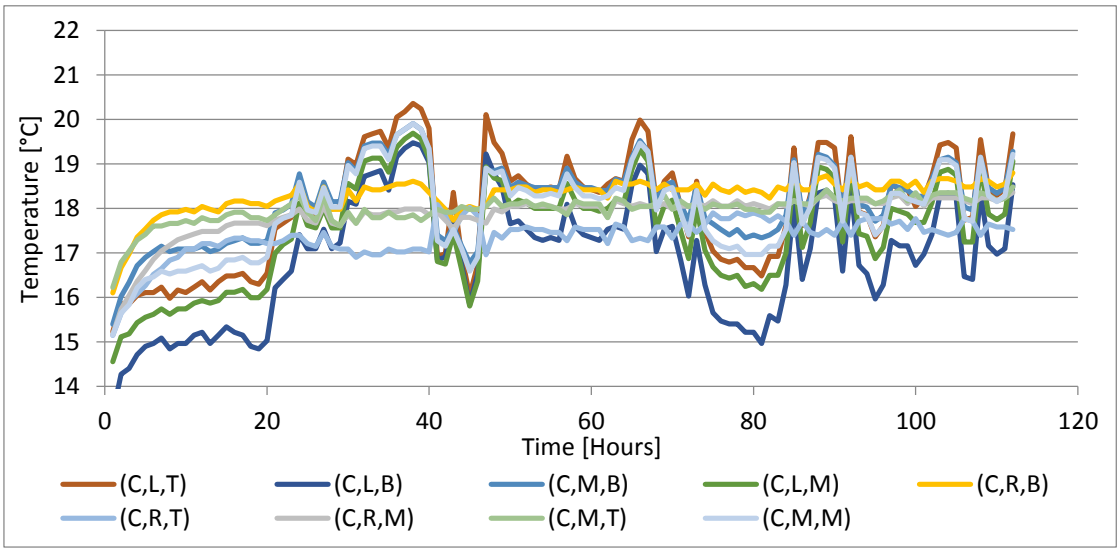


Figure 88 Temperature in different heights and width in center of Tunnel B during Experiment 2 (explanations of abbreviations in Section 3.3)

More temperature results can be found in Appendix A.

4.2.4 Humidity

The humidity is very similar in both tunnels, sSlightly higher in Tunnel A, but follows the same trend. The highest drying rate is in the first 24 hours and therefore higher humidity in that time is expected. The humidity goes up to 50 % after about 20 hours. However at the same time the power of the air fans is lowered. Except for this humidity top the humidity is about 30 to 40 % in both tunnels most of the time (Figure 89 and 90).

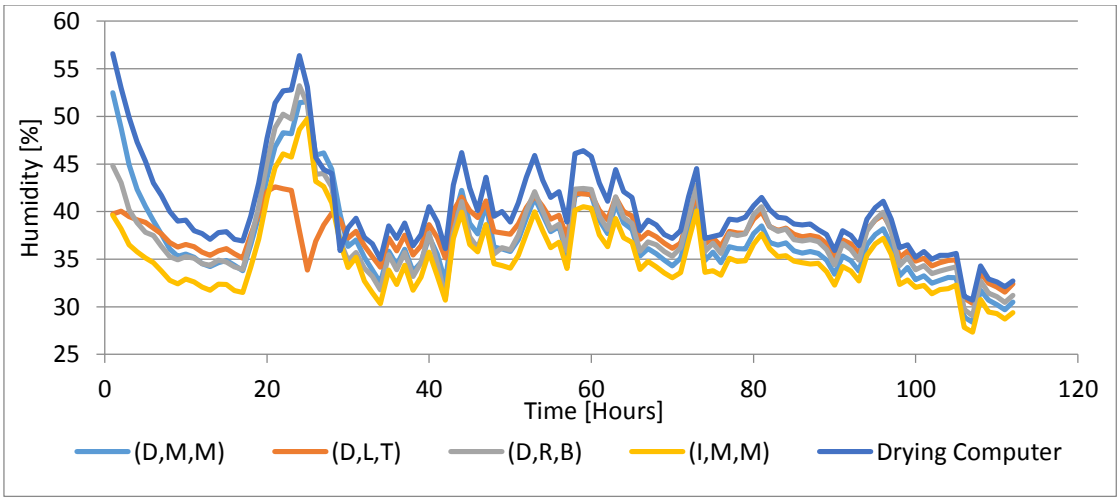


Figure 89 Humidity in different locations in drying Tunnel A during Experiment 2 (explanations of abbreviations in Section 3.3)

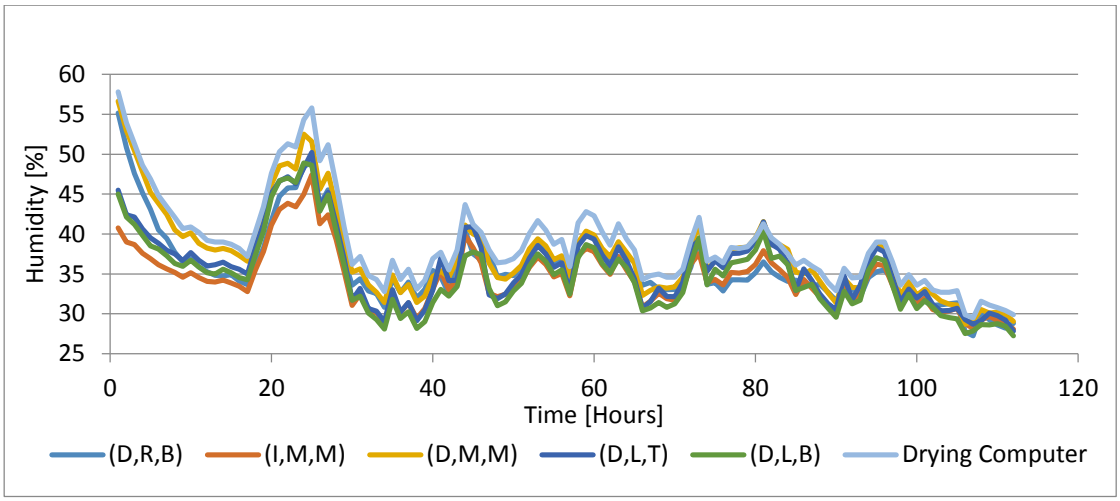


Figure 90 Humidity in different locations in drying Tunnel B during Experiment 2

If the humidity difference in the air inlet and in the air outlet is plotted it can be seen how the difference is highest in the beginning and then rapidly decreasing (Figure 91). Similar to the results in Experiment 1, which indicates that most of the water is removed in the first 10 to 20 hours.

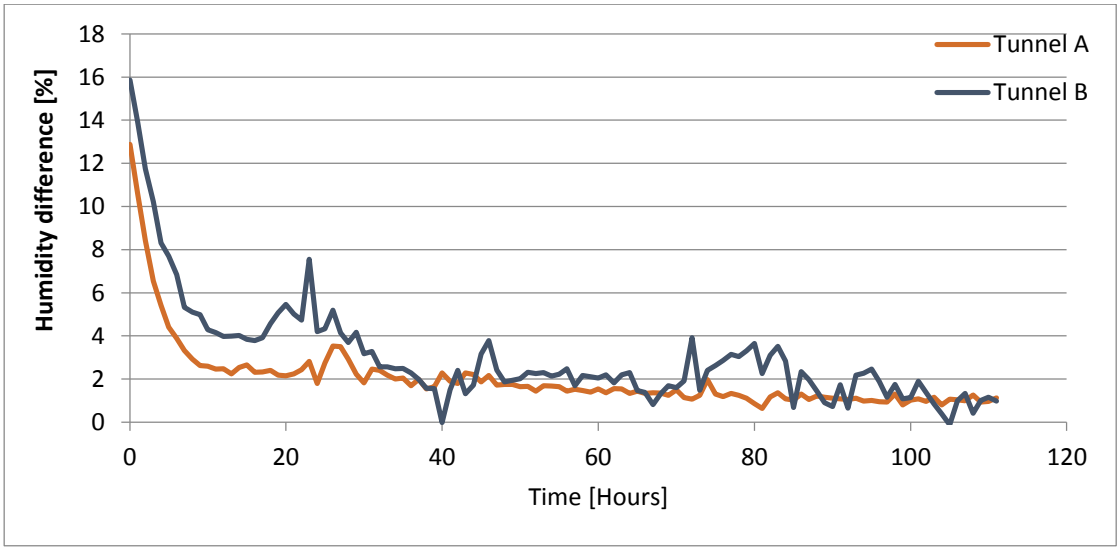


Figure 91 Humidity difference at air inlet and air outlet [out-in] in Tunnel A and B during Experiment 2

4.3 Experiment 3

In Experiment 3 the drying rate of fish between different locations of the drying tunnel was examined. Five split fishes of both large and small ling were placed in ten different locations in the drying tunnel.

4.3.1 Yield and drying rate

Drying curve of the ling in Experiment 3 was similar to the earlier experiments (Figure 92 and 93).

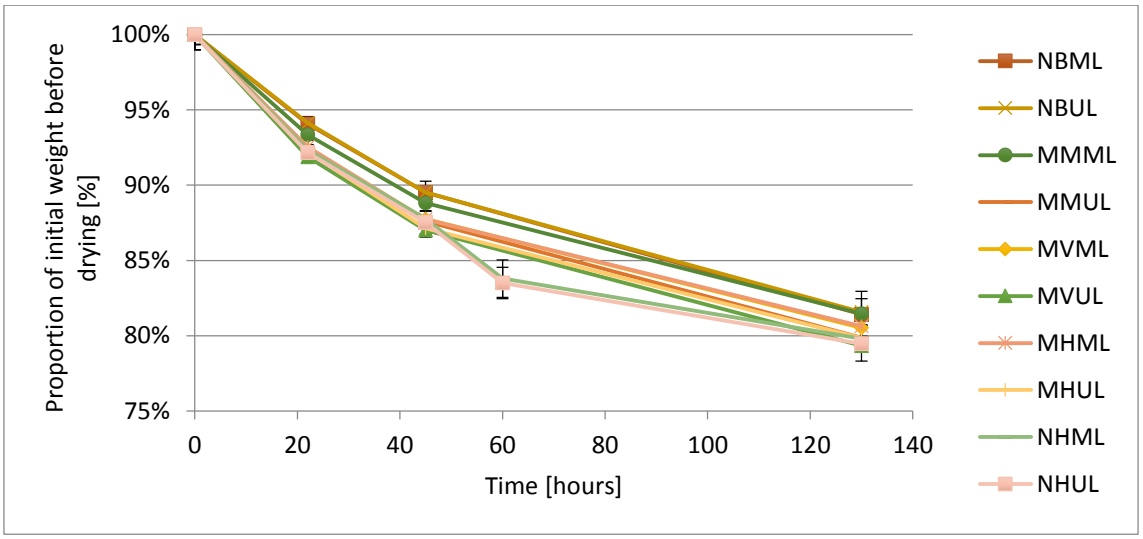


Figure 92 Weight loss of large ling in different locations of drying tunnel during Experiment 3 (ave±std) (explanations of abbreviations in the nomenclature section)

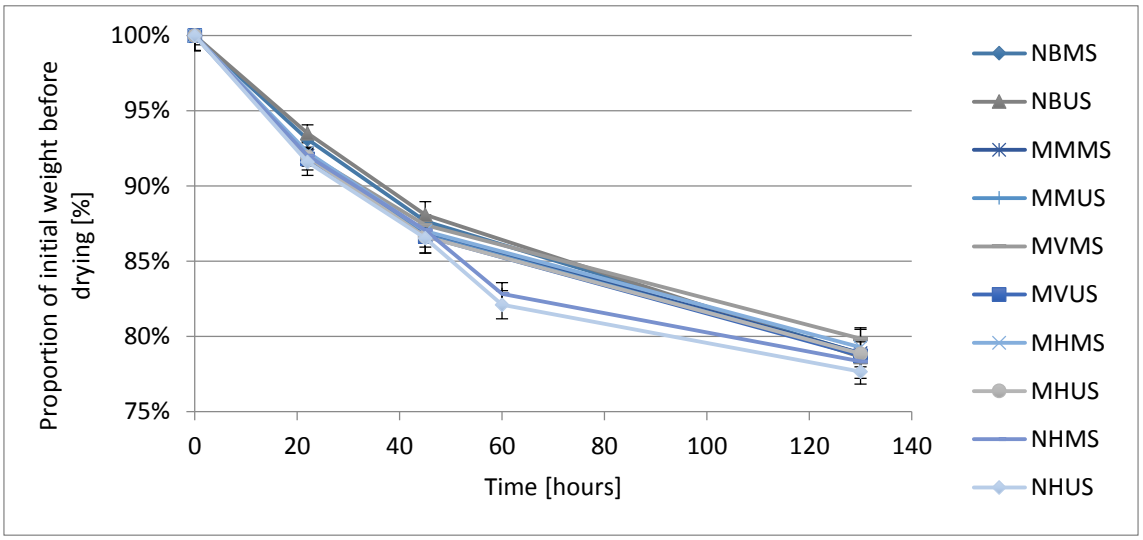


Figure 93 Weight loss of small ling in different locations of drying tunnel during Experiment 3 (ave±std) (explanations of abbreviations in the nomenclature section)

Using HSD method to analyze the difference, no significant difference between those 20 groups was found except that the small ling nearest to the door/air outlet, both in the middle part and top of the rack, lost significantly more weight than the large fish nearest to the air blower (both in the middle and top), the large fish in the center of the drying cabin in middle height and the small fish in the center of the drying cabin at top of the rack (Figure 94). When the LSD method was used there was significant difference between more groups (Figure 95).

	NBMS	NBML	NBUS	NBUL	MMMS	MMML	MMUS	MMUL	MVMS	MVML	MVUS	MVUL	MHMS	MHML	MHUS	MHUL	NHMS	NHML	NHUS	NHUL
NBMS		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
NBML	0		0	0	-	0	0	0	0	0	0	0	0	0	0	0	-	0	-	0
NBUS	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NBUL	0	0	0		-	0	0	0	0	0	0	0	0	0	0	0	-	0	-	0
MMMS	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MMML	0	0	0	0	-		0	0	0	0	0	0	0	0	0	0	-	0	-	0
MMUS	0	0	0	0	-	0		0	0	0	0	0	0	0	0	0	-	0	-	0
MMUL	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
MVMS	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0
MVML	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
MVUS	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0
MVUL	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
MHMS	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
MHML	0	0	0	0	-	0	0	0	0		0	0	0		0	0	0	0	0	0
MHUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0
MHUL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0
NHMS	0	+	0	+	0	+	+	0	0	0	0	0	0	+	0	0		0	0	0
NHML	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
NHUS	0	+	0	+	0	+	+	0	0	0	0	0	0	0	0	0	0	0		0
NHUL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 94 Results of significance test in weight loss between groups in Experiment 3 - HSD method with 5 % significance level (explanations of abbreviations in the nomenclature section)

	NBMS	NBML	NBUS	NBUL	MMMS	MMML	MMUS	MMUL	MVMS	MVML	MVUS	MVUL	MHMS	MHML	MHUS	MHUL	NHMS	NHML	NHUS	NHUL
NBMS		+	0	+	0	+	+	0	0	+	0	0	0	+	0	0	0	0	0	0
NBML	-		-	0	-	0	0	0	0	0	-	-	-	0	-	0	-	0	-	-
NBUS	0	+		+	0	+	+	0	0	+	0	0	0	+	0	0	0	0	0	0
NBUL	-	0	-		-	0	0	-	-	0	-	-	-	0	-	-	-	-	-	-
MMMS	0	+	0	+		+	+	0	0	0	0	0	0	+	0	0	0	0	0	0
MMML	-	0	-	0	-		0	0	0	0	-	-	-	0	-	0	-	-	-	-
MMUS	-	0	-	0	-	0		0	0	0	-	-	-	0	-	0	-	-	-	-
MMUL	0	0	0	+	0	0	0		0	0	0	0	0	0	0	0	0	0	-	0
MVMS	0	0	0	+	0	0	0	0		0	0	0	0	0	0	0	0	0	-	0
MVML	-	0	-	0	0	0	0	0	0		-	0	0	0	-	0	-	0	-	0
MVUS	0	+	0	+	0	+	+	0	0	+		0	0	+	0	0	0	0	0	0
MVUL	0	+	0	+	0	+	+	0	0	0	0		0	0	0	0	0	0	-	0
MHMS	0	+	0	+	0	+	+	0	0	0	0	0		0	0	0	0	0	0	0
MHML	-	0	-	0	-	0	0	0	0	0	-	0	0		-	0	-	0	-	0
MHUS	0	+	0	+	0	+	+	0	0	+	0	0	0	+		0	0	0	0	0
MHUL	0	0	0	+	0	0	0	0	0	0	0	0	0	0	0		0	0	-	0
NHMS	0	+	0	+	0	+	+	0	0	+	0	0	0	+	0	0		0	0	0
NHML	0	0	0	+	0	+	+	0	0	0	0	0	0	0	0	0	0		-	0
NHUS	0	+	0	+	0	+	+	+	+	+	0	+	0	+	0	+	0	+		+
NHUL	0	+	0	+	0	+	+	0	0	0	0	0	0	0	0	0	0	0	-	

Figure 95 Results of significance test in weight loss between groups in Experiment 3 - LSD method with 5 % significance level (explanations of abbreviations in the nomenclature section)

It seems like the large ling nearest to the air inlet (blower) in high position (NBUL) has significantly less weight loss then most of the other groups and the small fish nearest to the door in the high position (NHUS) has lost more weight than most of the other groups. The significant difference is also present with 1 % significance limit ($p < 0.01$). The fish in high position in the middle of the drying cabin and the large ling nearest to the blower is drying less than the fish nearest to the door. And no significant difference is in the weight loss compared to the fish in either side of the tunnel in the center. Beforehand it would have been expected that the fish nearest to the air inlet would dry more than the fish closer to the air outlet, as the air gets more humid as it travels through the tunnel. If anything the results were

opposite. The weight difference between groups could have something to say there. The average weight is highest for the large fish nearest to the blower (Figure 96). It is likely that the difference in weight loss is due to the difference in initial weight but not the location of the fish in the drying tunnel.

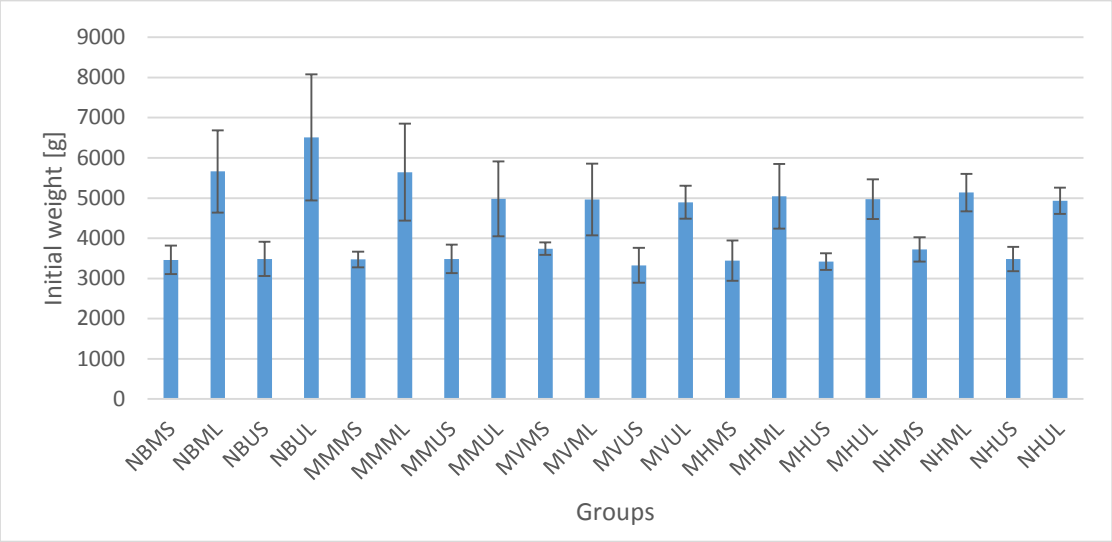


Figure 96 Initial average weight of the location groups before drying - Experiment 3 (ave±std) (explanations of abbreviations in the nomenclature section)

There were only five fishes in each group weighed but it might be safe to say that the drying is considerably homogenous between different locations of the tunnel. It would be logical to think that the fish nearest to the air inlet would dry faster as there is the humidity lowest and the temperature highest but the results don't show that.

The average weight loss of the ling is about 20.3 % in Experiment 3. The fish was weighed after 130 hours in the drying cabinet but it had been turned off for about 30 hours so the drying process was only in action for about 100 hours. If the weight loss of the ling in the three drying experiments is summarized it can be seen that it is very similar, depending on the duration of the drying process (Table 12).

Table 12 Summary of weight loss of ling in experiments 1-3

Experiment	**Exp 1**	**Exp 2**	**Exp 3**
Time	**136 hours**	**112 hours**	**130 (100) hours**
Small ling	23.1 % ± 1.3 %	22.2 % ± 1.6 %	21.2 % ± 1.4 %
Large ling	22.5 % ± 1.4 %	20.5 % ± 1.4 %	19.6 % ± 1.2 %
Extra-large ling	20.4 % ± 1.3 %	-	-

4.3.2 Water and salt content

In Experiment 3 samples were taken from fish in the opposite ends of the tunnels - three fishes from four groups. Small and large ling at the air inlet (NBS and NBL) and small and large ling at the door (NHS and NHL). The samples from the five locations (a, b, c, d, e) in each fish were pooled together and results of average water content from three fishes in each group (n = 3) obtained (Figure 97).

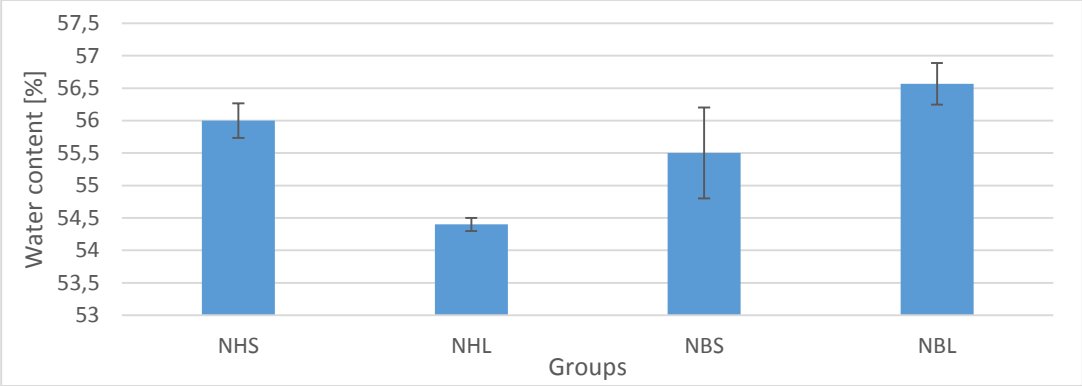


Figure 97 Measured water content of ling from different locations of drying tunnel after drying (small ling nearest to air outlet (NHS), large ling nearest to air outlet (NHL), small ling nearest to air inlet (NBS), large ling nearest to air inlet (NBL)) - Experiment 3 (ave±std)

The water content was measured lowest in the group of large ling at the door (NHL) or 54.5 ± 0.1 % and thereafter from the small fish at the air inlet (NBS), 55.5 ± 0.7 %. Most water was in the small ling next to the door (NHS), 56.0 ± 0.3 % and the large ling at the air inlet (NBL) or 56.6 ± 0.3 %. It is difficult to draw any conclusions from these results as it is assumed that the initial water content in all groups was 58.7 % which are the results both from small and large ling before drying from Experiment 1 from the same raw material. There was no significant difference in salt content after drying, using 5 % significance level. Summary of the water content, salt content, salt concentration and weight loss of the four groups that were taken to chemical measurements can be seen in Table 13.

Table 13 Measured water content and salt content of ling from different locations of drying tunnel after drying, weight loss and calculated salt concentration - Experiment 3 (ave±std)

Group		Water [%]	Salt [%]	Z-value [%]	Weight loss [%]
Small ling next to door	NHS	56±0.3	19.5±0.4	25.8	22.0±0.8
Large ling next to door	NHL	54.4±0.1	19.5±0.3	26.4	20.4±1.2
Small ling next to air inlet	NBS	55.5±0.7	19.5±0.5	26.0	21.2±0.9
Large ling next to air inlet	NBL	56.6±0.3	19.9±0.2	26.0	18.5±1.4

4.3.3 Air velocity

Air velocity was measured two times during the drying process of Experiment 3. First 24 hours into the drying process and then again 24 hours later. The first time the air velocity was measured three times (M1, M2, M3) in each of the nine locations. The average values

from the measurements in each place were calculated (Table 14), but all the measurements can be seen in Appendix B.

Table 14 Average air velocity in each location from measurements in Experiment 3 (ave±std)

	Left	**Center**	**Right**
Top	1.8±0.3	2.2±0.2	1.6±0.3
Middle	1.5±0.4	1.6±0.3	1.0±0.3
Bottom	1.3±0.4	1.5±0.4	1.1±0.3

From these results it seems like there is less velocity in the right side of the cabin than in the center and left side, which could explain the temperature fluctuation in the right side of the drying cabinet. Still it looks like it does not affect the drying rate, when it is compared to the weight loss of the ling in Experiment 3.

4.3.4 Temperature

The first 70 hours the temperature is about 16 to 19 °C and like in the previous experiments the temperature is more stable on the right side of the tunnel than in the middle and left side of Tunnel B. The temperature fluctuates, especially the last two days, but during that time the drying was stopped and then started again for a few hours before the product was removed from the cabinet (Figure 98).

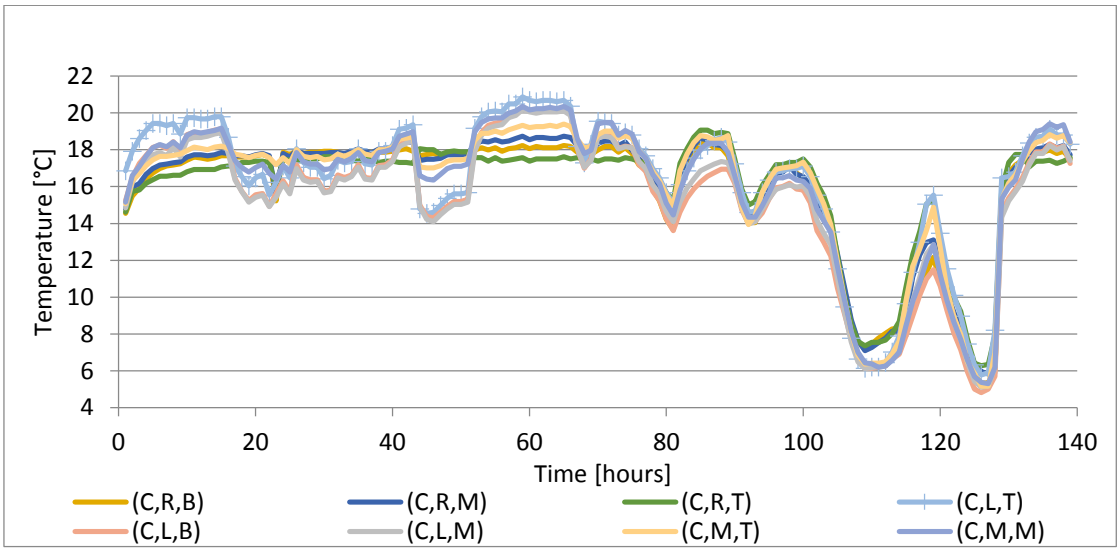


Figure 98 Temperature in different heights and width in center of drying tunnel during Experiment 3 (explanations of abbreviations in Section 3.3)

4.3.5 Humidity

The first 70 hours of the drying the humidity is about 30 to 40 % but falls below 30 % down to 22 to 23 % before it rises to 60 % the last two days when the drying is paused. It then falls again the last 12 hours of the drying. As said before, the drying was shut down over the weekend, the last days and turned on again the last hours before it was removed from the drying and the drying stopped (Figure 99).

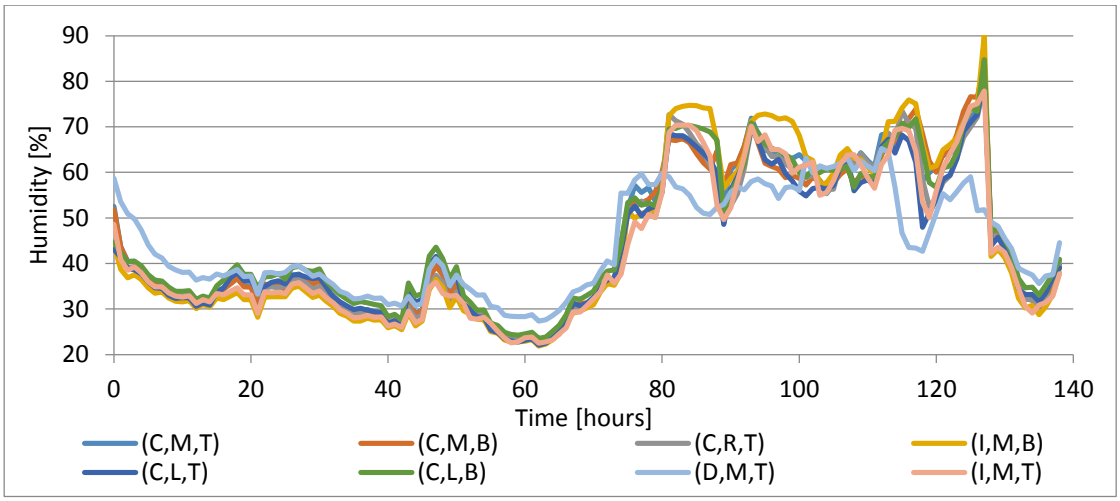


Figure 99 Humidity in different locations in drying tunnel during Experiment 3 (explanations of abbreviations in Section 3.3)

The humidity rises in the middle of the drying tunnel and next to the door in the first 24 hours. That is because the humidity rises when the water is removed from the fish. However the humidity changes less nearest to the air inlet because that is the air before it transfers over the fish. The humidity falls soon after the first 24 hours when the drying rate drops.

During the last two days when the drying was stopped the outside humidity was around 80 to 90 % and therefore it is understandable that the humidity rises inside the drying cabinet and the temperature decreases as the outside temperature reaches 0 °C (Figure 100).

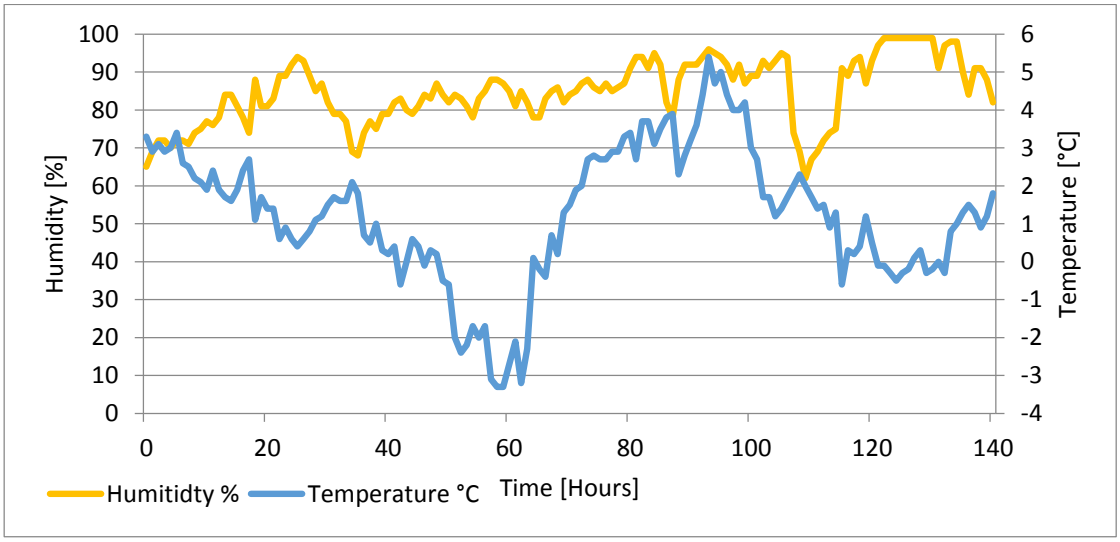


Figure 100 Outdoor temperature and humidity during Experiment 3

4.4 Experiment 4

In Experiment 4, the weight losses of five different cod groups were compared in a new drying tunnel under different drying conditions than in Experiments 1 to 3.

4.4.1 Yield and drying rate

The drying curve in Experiment 4 is similar to curves in previous experiments. The weight loss is calculated from the weight of the fish after washing. The washing process caused 1 - 3 % weight loss due to removal of the surface salt.

The injected cod that was soaked in water for ten minutes before drying, is losing most weight in the drying or about 24 % and the pickle salted cod is losing the least weight or about 16 % (Figure 101).

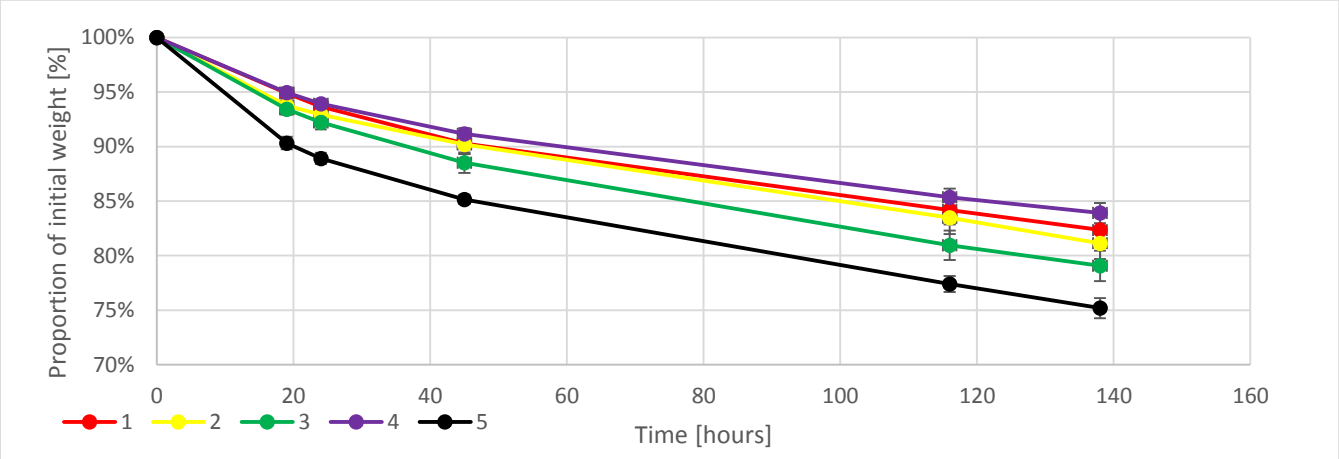


Figure 101 Weight loss of cod processed with different salting methods during Experiment 4 (ave ± std) (inj. cod not washed (1), inj. cod washed (2), brined cod (3), pickled cod (4), inj. cod washed for 10 min (5))

Using Tukey‘s HSD method to compare the weight loss between groups, there was a significant difference between all the groups except for washed and not washed injected cod. When LSD method was used there was significant difference between all the groups ($p < 0.05$). The most weight loss in group 5 (24.8 ± 0.9 %) > 3 (20. 9± 1.4 %) > 2 (18.9 ± 4.4 %) >1 (17.7 ± 1.6 %) > 4 (16.1 ± 0.3 %). The pickle salted fish was considerably larger than the other groups which might affect the weight loss (Figure 102). The results from previous experiments show that significant difference in weight loss is not very clear if there is only a small difference in weight between groups.

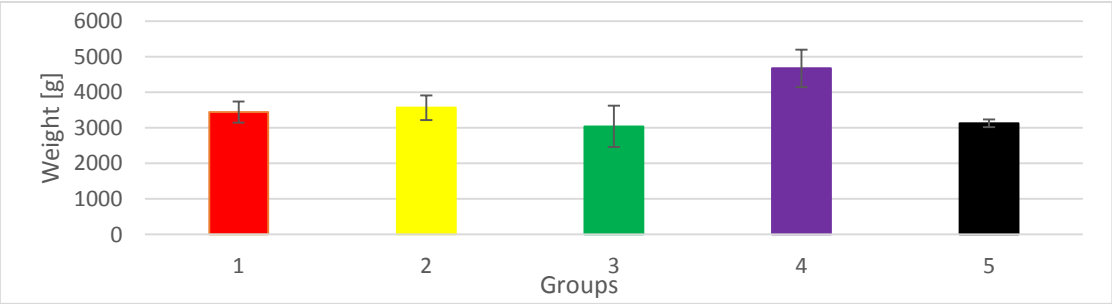


Figure 102 Average initial weight loss of groups before drying in Experiment 4 (ave±std) (inj. cod not washed (1), inj. cod washed (2), brined cod (3), pickled cod (4), inj. cod washed for 10 min (5))

The Portuguese bending test was tried on a few fishes like explained in section 1.4. The injected cod soaked in water before drying (5) did not bend much in the test and same can be said about the brined fish (3). Other fish did bend a little (Figure 103).

Figure 103 When the Portuguese method of holding the fish straight from the loin was used, the fish looked „ready“after the drying. – Left (Group 5) – Right (Group 1)

4.4.2 Chemical measurements

Before drying

Chemical measurements were made from three groups before drying. That is the injected fish (1), brine salted fish (3) and the pickle salted fish (4). The water content was highest in injected fish then in the brine salted and there was the least water in pickle salted fish (Figure 104).

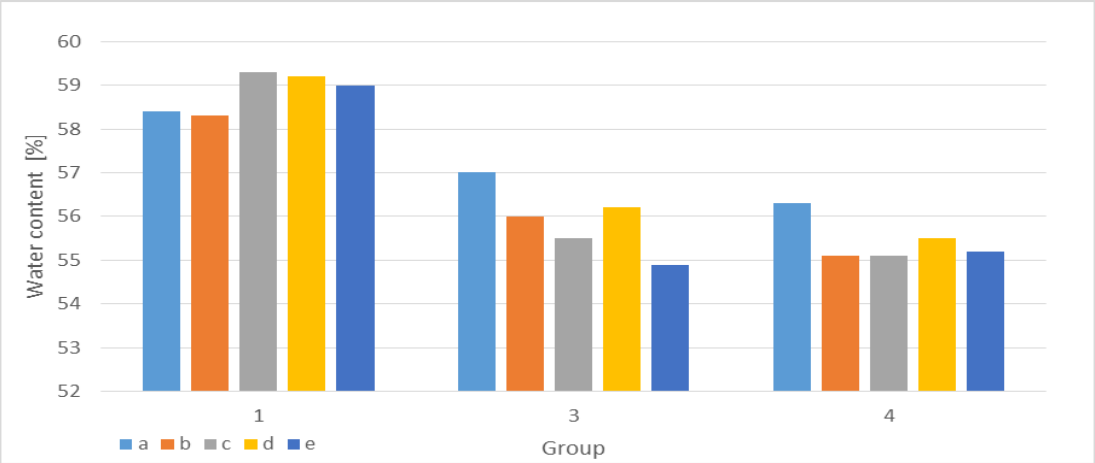


Figure 104 Water content in different locations (a, b, c, d, e) of salted fish: injected (1), brined (3) and pickled (4) before drying in Experiment 4

No significant difference was found in water content between locations before drying. Also there was no difference in salt content or salt concentration (Z^{NaCl}) between locations. The results for salt content are abnormal for group 1 in location a and no other conclusion can be drawn from that. (Figure 105 and 106).

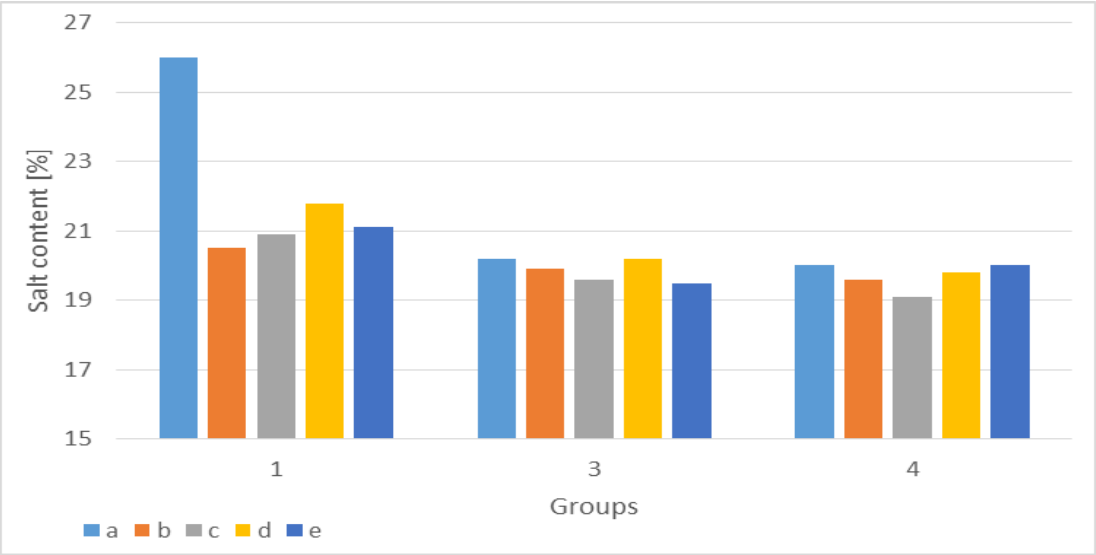


Figure 105 Salt content of groups in different locations (a, b, c, d, e) of split fish: injected (1), brined (3) and pickled (4) before drying

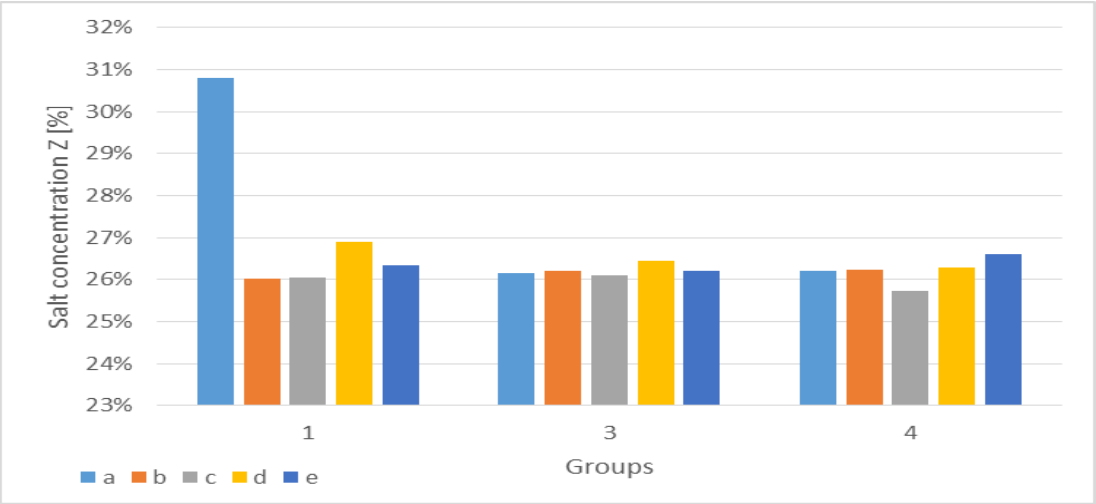


Figure 106 Salt concentration of groups in different locations (a, b, c, d, e) of split fish: injected (1), brined (3) and pickled (4) before drying

After drying

After drying, using Tukey‘s method, there was significantly less water content in a than in b and c. Using LSD method there was also significantly more water in d than in a and more water in b, c and d than in e. The difference between locations, especially between b, c, d and e was usually not more than 1 to 2 % (Figure 107). The surface (a) stands more out when it comes to water content after drying.

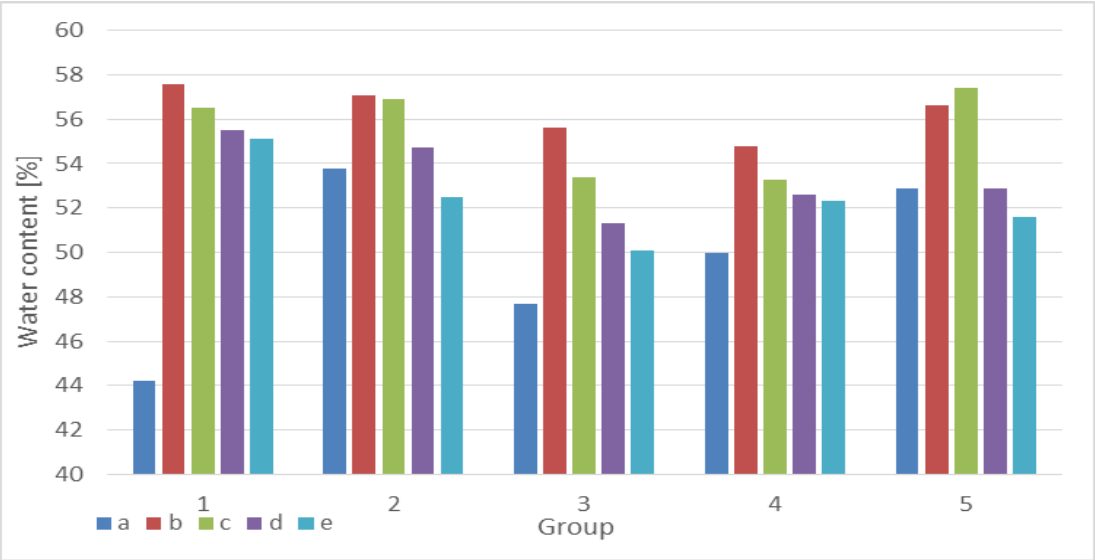


Figure 107 Water content in different locations of salted cod: inj. (1), inj. and washed (2), brined (3), pickled (4), inj. and washed for 10 min (5) after drying in different locations of split fish in Experiment 4

As seen in Figure 107 the water content on the surface of the loin in group 1 was much lower than in any other group which results in that „average water content“ is lower than it maybe is in reality.

Using Tukey‘s method for salt content there was significantly more salt in a than in b, c and d.
Using LSD method there was significantly more salt content in a than in b, c , d and e. Also there was significantly more salt content in e than in c. In Figure 108 it can be seen how the salt accumulated on the surface (location a) in sample from brined fish (Group 3).

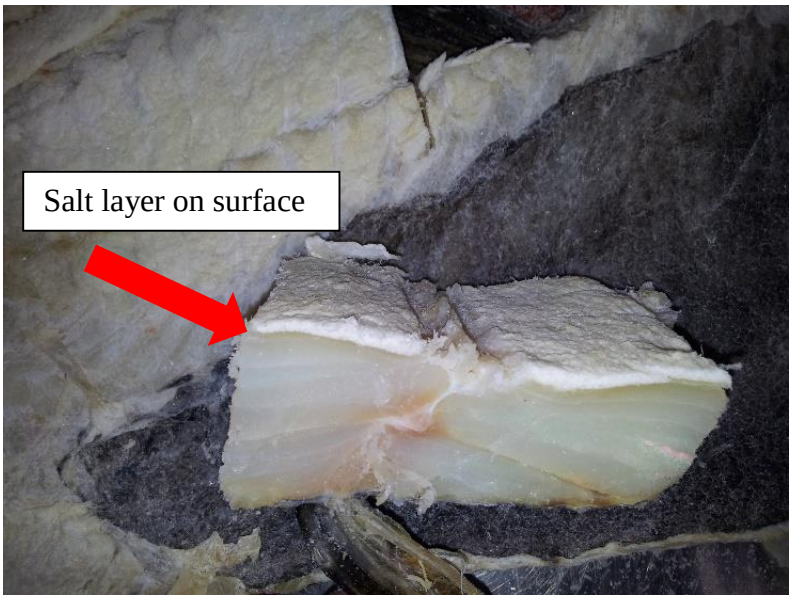


Figure 108 Visual difference can be seen between the surface and inside of the dried fish

Using Tukey‘s method on salt concentration there was higher salt concentration in a than in all other locations and higher salt concentration in e than in b and c.

Same results were obtained when using LSD method except that there was also significantly higher salt concentration in d than in c. The average brine concentration in each location in all groups together was in the following order from highest to lowest a (32 %) > e (29,2 %) > d (28,3 %) > b (26,9 %) > c (26,7 %) (Figure 109).

The salt concentration using Equation (4.2) showed more salt concentration inside the fish muscle, than in Experiments 1 to 3 but the samples were taken from the surface in locations a, d and e in Experiment 4 but only below the surface in the previous experiments.

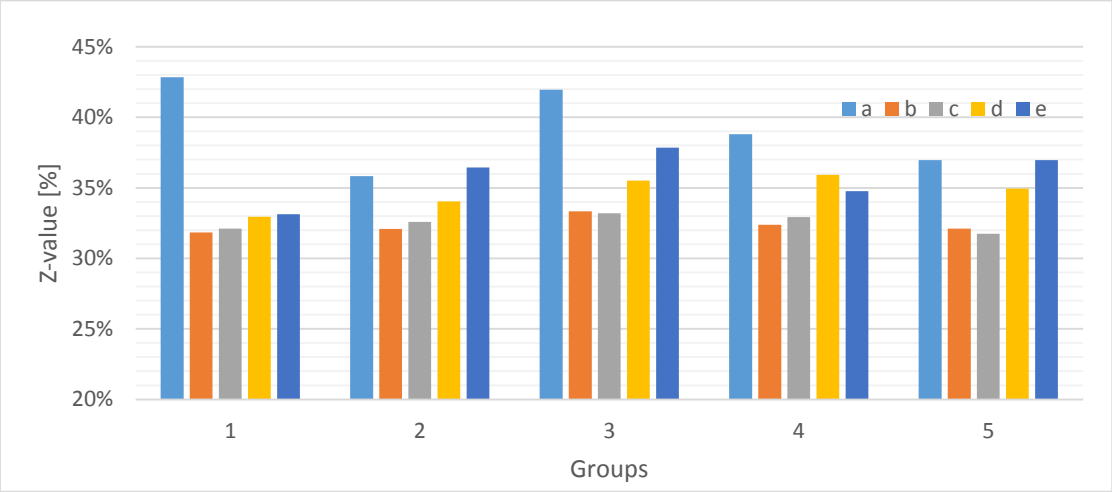


Figure 109 Salt concentration in different locations of inj. (1), inj. and washed (2), brined (3), pickled (4), inj. and washed for 10 min (5) cod after drying

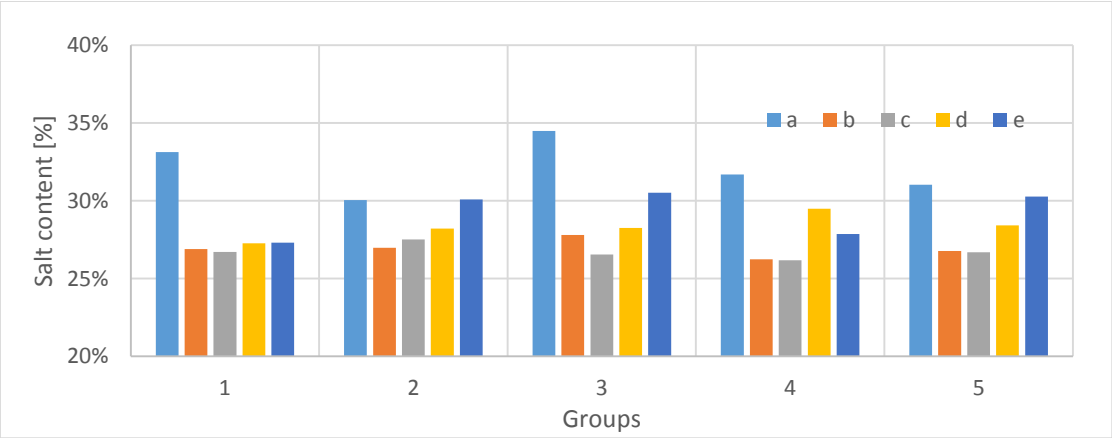


Figure 110 Salt content in different locations of inj. (1), inj. and washed (2), brined (3), pickled (4), inj. and washed for 10 min (5) cod after drying

Even though the surface had been included in samples a, d and e when water measurements were made and most of the surface salt was washed off before weighing and drying the results still, do not match the mass balance very well (Figure 111).

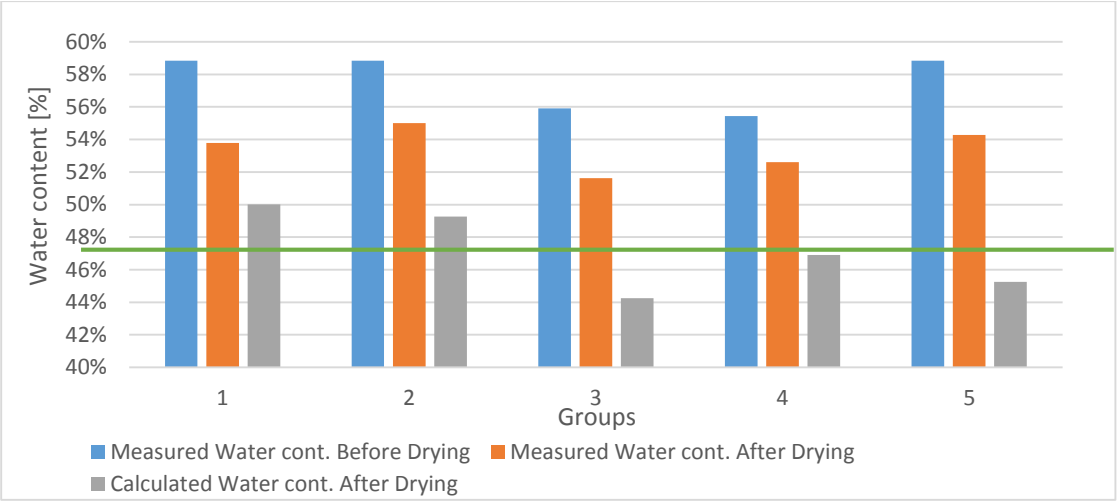


Figure 111 Measured water content before and after drying in Experiment 4 and calculated water content after drying for each group (inj. (1), inj. and washed (2), brined (3), pickled (4), inj. and washed for 10 min (5)) (ave±std) – Green line shows 47 % water content

Putting different weights on measurements in different locations might give results better fitting to the mass balance. It also has to be noted that samples were never taken from the belly flaps, which are the thinnest part of the fish and therefore water loss from that parts might be significantly higher and cause the difference between weight loss and water loss.

If weight loss is used to estimate the water content after drying from the water content results before drying, the brined fish has about 44 % water content, the pickle salted 47 % and the injected fish that was soaked in water 45.3 %. The not washed and washed injected cod still have 50 % and 49.3 % water content respectively and would need more time in the drying. Summary of water content, salt content and salt concentration before and after drying can be seen in Table 15.

Table 15 Summary of measured water content, salt content and salt concentration before and after drying - Experiment 4, weight loss and calculated water content for each group (ave±std)

Group	**1**	**2**	**3**	**4**	**5**
Description	Not washed	Washed	Washed	Washed	Water bath
Salting meth.	inj+brine	inj+brine	brine	pickle	inj+brine
Water before	58.8 %	58.8 %	55.9 %	55.4 %	58.8 %
Water after	53.8 %	55.0 %	51.6 %	52.6 %	54.3 %
Calc. Water	50.0 %	49.3 %	44.3 %	46.9 %	45.3
Salt before	22.0 %	22.0 %	19.9 %	19.7 %	22.0 %
Salt after	28.3 %	28.6 %	29.5 %	28.3 %	28.6 %
Z-value before	27.2 %	27.2 %	26.2 %	26.2 %	27.2 %
Z-value after	34.6 %	34.2 %	36.4 %	35.0 %	34.5 %
Weight loss	17.7 %	18.9 %	20.9 %	16.1 %	24.8 %

4.4.3 Temperature and humidity

Humidity and temperature loggers where attached to the two racks that the fish was on. One humidity logger was attached to tray 15 and one lower at tray 5, facing into the tunnel. The temperature loggers were in the same locations. One logger was placed on the other side of the trays (facing the door), attached to tray 10 between the two racks.

The temperature is steady during the 138 hours of drying (Figure 112). It seems to be a little lower at tray 6 than at tray 15 and lowest on the logger on the other side of the tray, facing the door. The air cools down when it removes water from the fish so it should be cooler closer to the air outlet. The humidity is about 50 to 60 % most of the time, though it goes down below 40 % for a short interval (Figure 113).

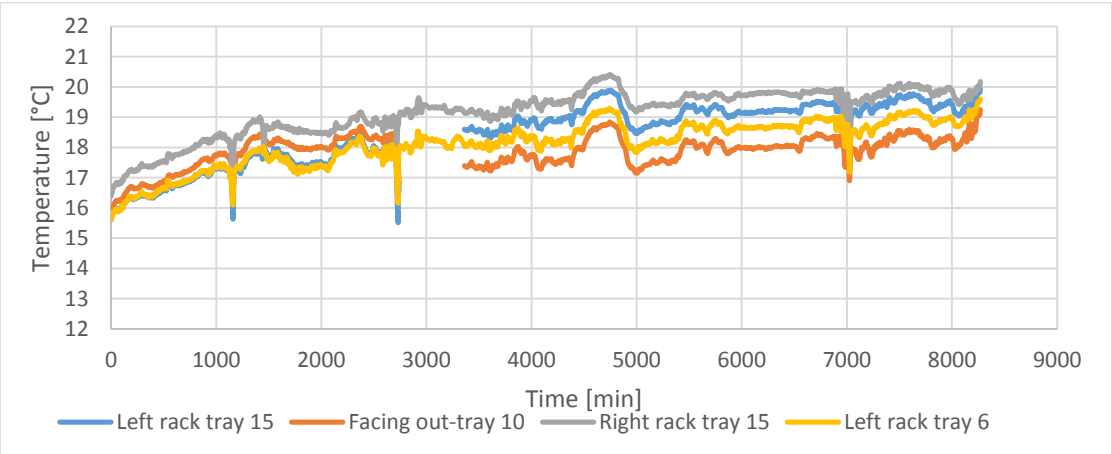


Figure 112 Temperature at the door of the drying tunnel, where the sample fish was located in Experiment 4

The temperature from the drying computer showed temperature between 18 to 20 °C the whole time and the humidity measurements were the same as the results from the humidity loggers attached to the salt fish racks.

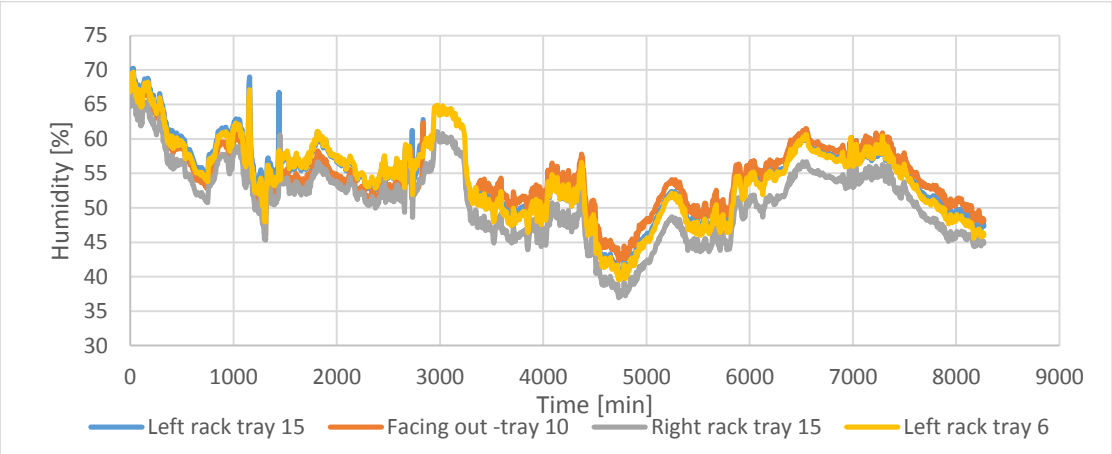


Figure 113 Humidity at the door of the drying tunnel where the sample fish was located in Experiment 4

The outdoor temperature and humidity was obtained as before and the humidity in the drying tunnel and the outdoor temperature seemed to follow similar trend. (Figure 114).

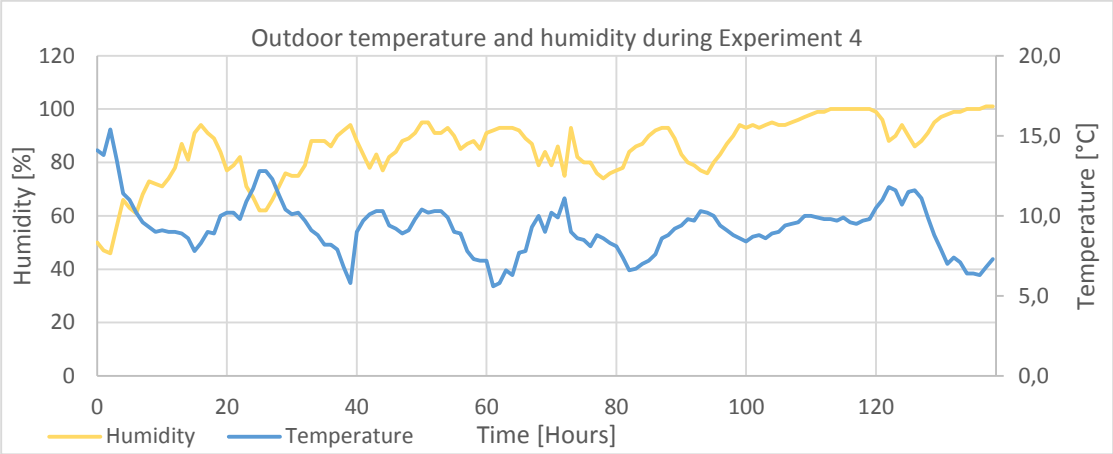


Figure 114 Outdoor temperature and humidity during Experiment 4

60 % correlation was calculated between the values which are the same results as in Experiment 1. Similar trends were not seen in Experiment 2 and Experiment 3 and therefore this was not examined further in this thesis, but interesting nonetheless.

4.4.4 Air velocity

Air velocity measurements were made on day 5. The velocity was measured in three locations in the center of the tunnel nearest to the door. The loggers were attached to tray 15, tray 10 and tray 4. In all places the air velocity was 2.1 - 2.5 m/s. It went up to 3 m/s nearest to the floor. When the air velocity was measured above the racks it was about 5.5 m/s. The frequency of the motor fans was set on 50 Hz the entire drying time which is higher than the 35 to 40 Hz used in Experiment 1 to 3, resulting in higher air velocity than before.

4.5 Rehydration

4.5.1 Preliminary Experiment

In the preliminary experiment there was no difference in weight gain between rehydration versions. There was on the other hand difference between the loin and the tail sample, where the tail gained about 25 %.weight in 72 hours but the loin only about 20 % (Figure 115).

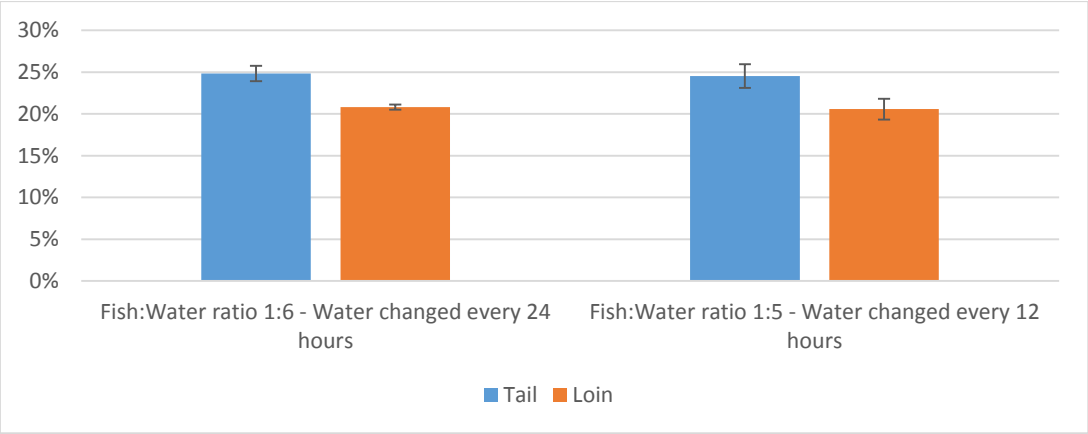


Figure 115 Weight gain in preliminary rehydration experiment. Two pieces, loin and tail and two different rehydration recipes (ave±std) No difference between recipes but tail gains more water than loin.

When tasting the fish it was too salty after the 72 hours but much better after 96 hours. One onset temperature logger was in each plastic container. The water was about 12 to 16 °C in the beginning but cooled down in the storage (Figure 116). The fish was kept in a cooler with ambient temperature around 2 °C during the process.

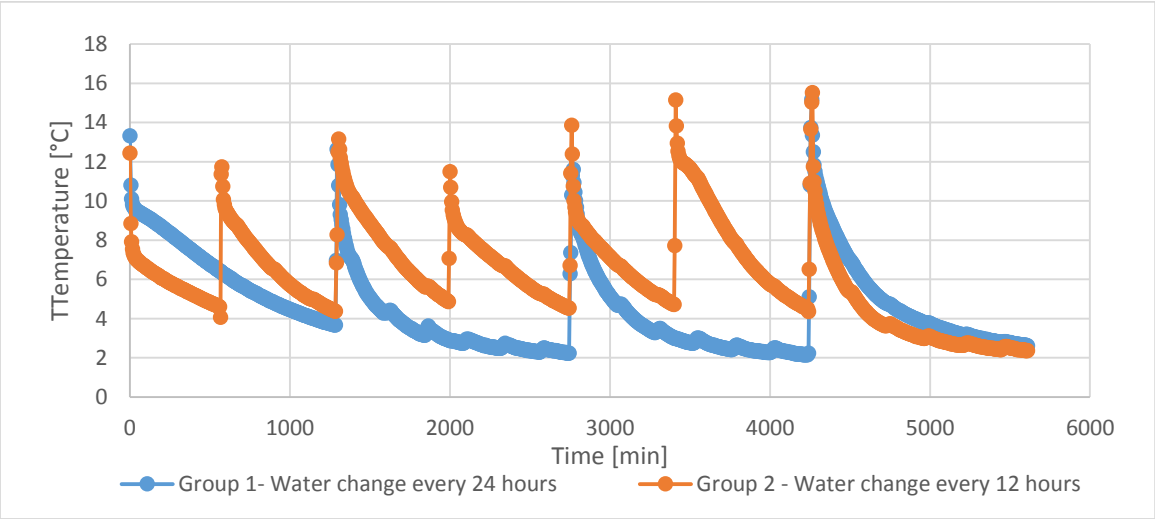


Figure 116 Water temperature during rehydration process – Water temperature is around12 to 16 °C coming from the tap but cools down during storage in a cooler

4.5.2 Primary Experiment

It was decided to have the rehydration process in the primary rehydration experiment for 96 hours but have the fish:water ratio 1:4 as the small split fish portions rehydrated should absorb water faster than the bigger portions in the preliminary experiment.. The greatest weight gain was in the first 24 hours and after 48 hours the fish did not gain much weight. The most weight gain was in the brined fish and the injected fish that was soaked in water

for 10 minutes before drying in Experiment 4 but those two groups also lost most weight in the drying. The weight gain was least in the injected fish, cod, ling and tusk (Figure 117).

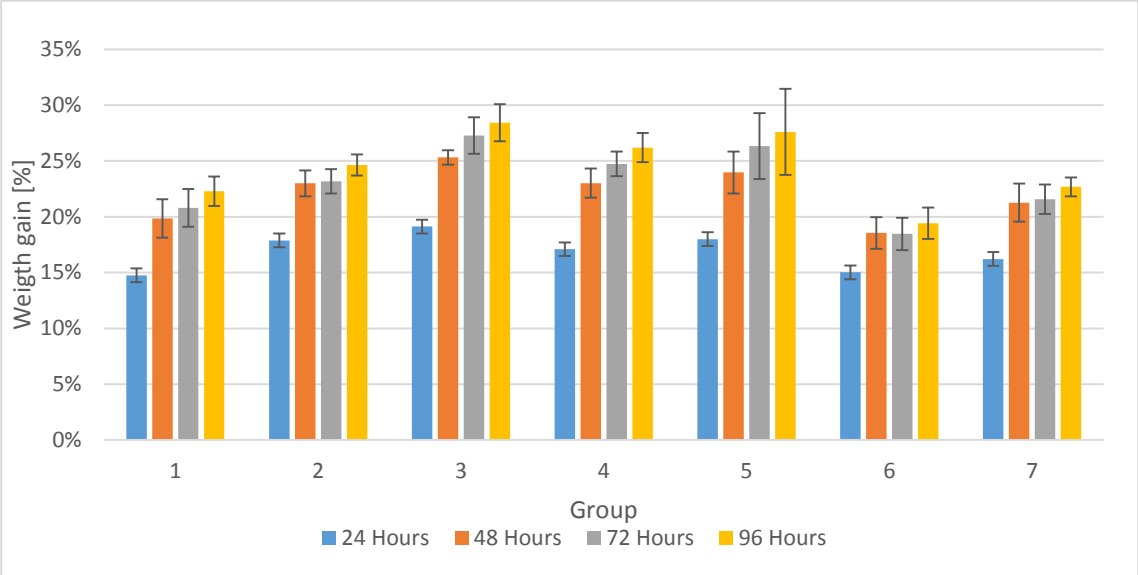


Figure 117 Weight gain each day in rehydration for each group (ave±std), inj. cod (1), not inj. cod (2), brined cod (3), pickled cod (4), inj. cod washed for 10 min (5) ling (6), tusk (7)

When significance test was made with 5 % significance limit with the HSD- method, the ling gained significantly less weight than all the groups except for the injected cod and tusk. The brined, and the injected fish washed for 10 minutes gained more weight than the injected groups. The pickle salted fish gained only significantly more weight than the ling. LSD – method showed even more groups with significant difference (Figure 118).

	1	2	3	4	5	6	7
1		0	-	0	-	0	0
2	0		0	0	0	+	0
3	+	0		0	0	+	+
4	0	0	0		0	+	0
5	+	0	0	0		+	+
6	0	-	-	-	-		0
7	0	0	-	0	-	0	

	1	2	3	4	5	6	7
1		-	-	-	-	+	0
2	+		-	0	-	+	+
3	+	+		+	0	+	+
4	+	0	-		0	+	+
5	+	+	0	0		+	+
6	-	-	-	-	-		-
7	0	-	-	-	-	+	

Figure 118 Results of significance test for weight gain of different split fish groups during primary rehydration experiment (HSD method to the left and LSD method to the right) with 5 % significance level

All the fish that was rehydrated had been weighed before drying and after drying, after storage and after rehydration and with those information the yield from salted fish to rehydrated could be calculated (Table 16).

Table 16 Weight gain in rehydration and total yield from salted fish to rehydrated fish for each group (ave±std)

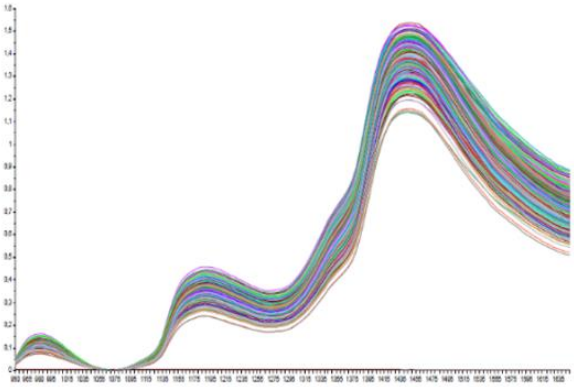
No. of group	Group	Weigth gain in rehydration [%]	Yield from salted fish [%]
1	Inj cod	22.3 %	108.2 %
2	Not inj cod	24.6 %	105.8 %
3	Brined cod	28.4 %	102.5 %
4	Pickled cod	26.2 %	106.5 %
5	Inj + washed cod	27.6 %	100.3 %
6	Inj ling	19.4 %	97.8 %
7	Inj tusk	22.7 %	105.8 %

The best yield was with cod injected with phosphate or 108.2 % then pickle salted 106.5 % and non-injected cod 105.8 %. Only one fish from each of these groups was rehydrated and as has been seen the individual difference is high so no definite conclusion is made from this. The difference in yield between phosphate and not phosphate cod is not great. Also the ling does not seem to even gain the same weight as it had before the drying in the rehydration process. Review of the sensory analysis of the rehydrated fish can be found in Appendix D.

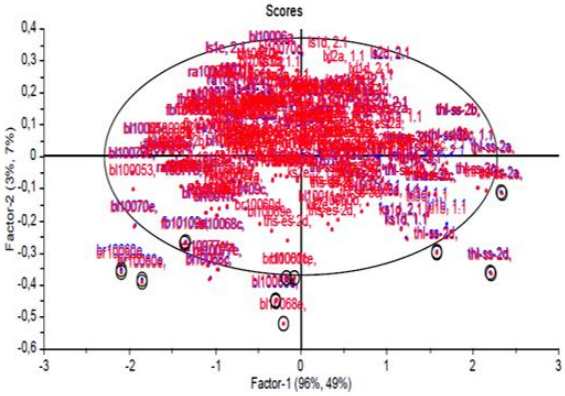
4.6 NIR Analysis

The data from the near infrared (NIR) analysis of the salted fish samples was transformed using baseline and SVN methods together with analyzing of the raw data. Using these transformation methods did not improve the data so the untreated raw data was used (Figure 119 a). A prediction model was made for the water content of the samples from half of the data samples available (about 200 values) and a prediction made for the other half.

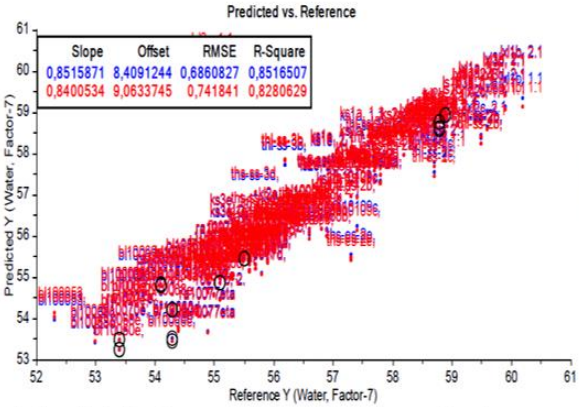
The NIR analysis gave considerably good results with the standardized water content measurements (R^2 = 0.85) (Figure 119 c and d) which is a good indicator that this method can be used to measure the water content of salted fish, as has already been proved in previous researches. The score plot shows how similar most of the samples are and do not cluster in any specific way between ling tusk and cod (Figure 119 b).



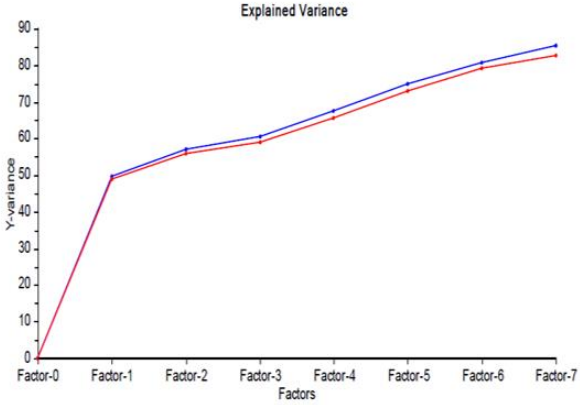
a) Line plot of spectra



b) Scores of the prediction mode – Outliers were excluded from the data



c) Predicted values vs. reference values of water content



d) Explained variance of the prediction mode

Figure 119 Main results from NIR analysis

5 Discussion

Before, drying was usually divided into 2 to 3 steps and the fish was restacked between steps depending on the desired final water content (see Section 2.2.3). In the experiments in this study the drying was done in one step, except for one group which was taken out of the drying tunnel and compressed for two days before put in again for further drying.

5.1 Drying rates and weight loss

As discussed in chapter 3, a product in drying has a constant drying rate while the surface is being dried but when all water from the surface has been removed and the water inside the fish is not able to emerge to the surface as fast as the water removal capacity is, or when bound water is removed, the drying rate falls (Figure 9). When the salt concentration of the salted fish in the experiments conducted in this thesis is calculated it can be seen that all the water in the fish has fully saturated brine in the muscle and therefore there is no free water to be removed from the fish. When free moisture in the salted fish is plotted over the drying time from results in Experiment 1, using Equation (2.10) and Equation (2.11), it can be seen that there is still a long way to go to equilibrium moisture content (Figure 120). The moisture content decreases faster in the beginning and the rate is decreasing already after the initial 24 hours. It can be seen that the rate is not as fast as for theoretical curves for drying of fresh fish but that is because all the water is bound with the salt and therefore not as easy to remove as if it was "free" water.

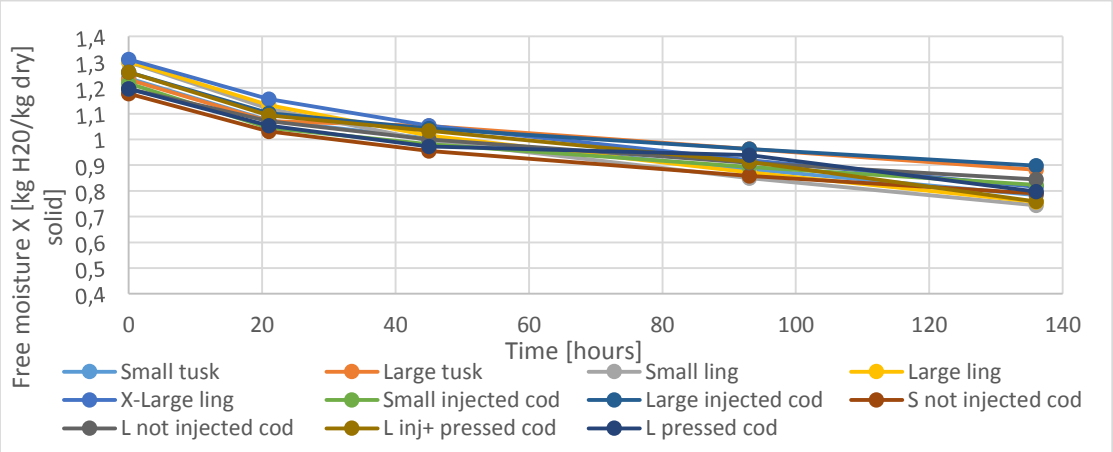


Figure 120 Calculated free moisture for each group during Experiment 1

When the drying rate is calculated at each time with Equation (2.12), it can also be seen how there is no constant rate of drying or it is at least over after the first 20 hours as the drying rate starts to fall in the beginning of the process (Figure 121). That is because there is no free water in the product. The fish has 26 % fully saturated brine in the muscle.

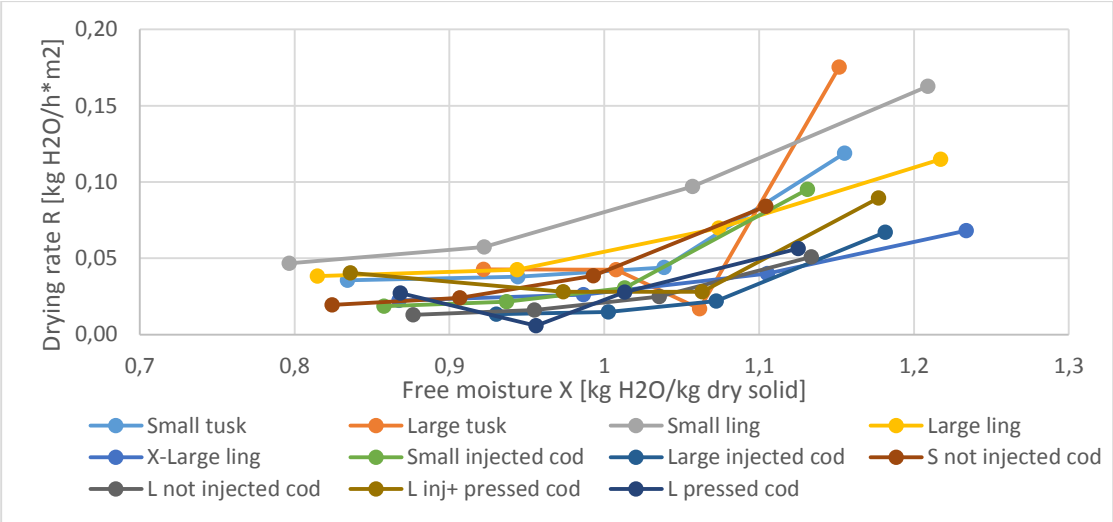


Figure 121 Calculated rate of drying as a function free moisture for each group during Experiment 1

In Experiment 4 the fish was weighed after 18 hours and again after 24 hours and no constant drying rate can be seen there either (Figure 122).

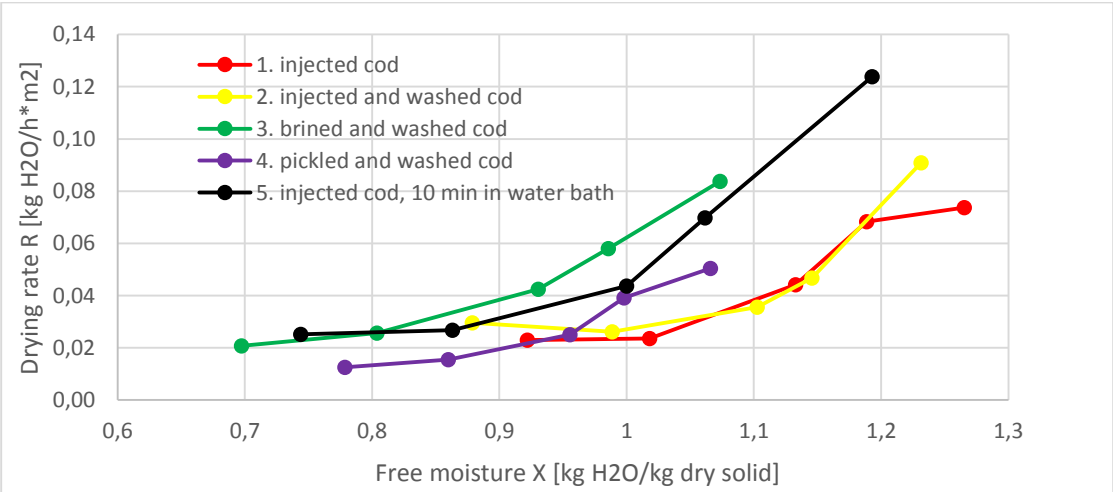


Figure 122 Calculated rate of drying as a function free moisture for each group during Experiment 4 (inj. (1), inj. and washed (2), brined (3), pickled (4), inj. and washed for 10 min (5))

The injected compressed fish did lose more weight than the cod groups that were not compressed (Figure 40) but the standard deviation was quite high and it did not result in lower water content after drying according to chemical results. If mass balance calculations are used to estimate the water content after drying, the compressing did speed up the water removal significantly ($p < 0.05$) in the injected cod. The compressed fish lost less weight during the compressing than the fish that was in the drying at the same time but when the compressed fish came back into the drying tunnel the weight loss increased clearly for short interval and in the end of the drying process it had lost more weight than the fish that was in the drying cabin the whole time. For the purpose of saving energy the compressing might be beneficial but the increased manpower needed to unload the fish and load it back in might

level out the energy savings, especially if the energy is as cheap as in the southwest corner of Iceland.

In Experiment 4, where fish injected with phosphate (group 1, 2 and 5) was compared to brine salted fish from a different producer (group 3) the brined fish lost more weight (dried faster) (Figure 101). That was also the tendency in previous researches in Iceland with split fish (Thorarinsdottir *et al*., 2007). The injected fish that was washed and soaked in water for ten minutes before drying did lose much more weight than the other groups in the drying. Even though the fish did lose about 1 % of its weight in the water bath, it probably absorbed water and released salt during that time. Therefore the weight was similar before and after the 10 minutes bath but the fish had much more water to lose in the drying. The water content measurements suggest the same, as measured water content after drying was similar to the not washed injected cod despite the great difference in weight loss (Figure 111). Still the injected cod that was washed for 10 minutes did gain much more weight than the not washed cod in the rehydration. The texture and taste of the washed fish was also more similar to pickle salted fish than the not washed fish. In Experiment 1 where comparison was made between brined fish with and without phosphate from the same producer, there was absolutely no difference in weight loss between the groups. That indicates that the phosphate itself does not affect the drying rate.

5.2 Chemical measurements

It is difficult to look in too much detail or draw too many conclusions from the chemical analysis as only three samples are taken from each group. It might be advisable to examine it closer but in researches from Norway the results have also shown high variance in water content between samples (Walde & Jonassen, 2006) which only emphasizes how great the individual difference can be and it might be difficult to get more precise results than have already been accomplished in this thesis without a greater amount of chemical measurements. All in all the difference between locations inside the fish is not very great between the tail, middle part and the loin. However, in the experiments conducted in this thesis the surface was quite different from the inner parts and dry layer of salt did appear on the surface. Those results are different from the initial hypothesis that the salt would crystalize inside the muscle when the water vaporizes but instead the fully saturated brine of the muscle seems to emerge to the surface where the water is vaporized and the salt crystals left behind. There is fully saturated brine (26 %) in the water phase of the fish muscle before and after the drying and therefore the water activity does not change in the process. Water activity was measured about 0.75 which is slightly higher than measurements in other previous researches where the water activity was about 0.73 after drying and similar before drying (0.73 – 0.74) (Thorarinsdottir *et al*., 2007). Rodrigues et. al (2003) measured the water activity of kench salted fish down to 0.70 before drying.

The water content measurements were similar to results from earlier researches conducted by Matis ltd. both before and after drying for injected cod (Thorarinsdottir *et al*, 2007). In that previous published paper the fish was dried for ten days at a temperature of about 17 °C, humidity 30 to 40 % and air speed of 1 m/s but the weight loss after 5 and 6 days was identical to the results in this thesis. The water and salt measurements were not made at five different locations in that research like in this current study but the same differences between weight loss and water content before and after drying were found.

According to mass balance theory the only weight loss of the product in drying should be water. Different parts of the fish dry at different rates. Thinner parts dry faster than thicker parts as the water does not have to travel as long way through the muscle to get to the surface. In the experiments it was shown that the water content after drying in thicker parts of the fish could not be calculated directly from the weight loss. It should be possible to make a model to calculate water content in different parts of the fish (loin, middle part, tail and belly flaps) from the weight loss but that is not done in this thesis. There were no samples taken from the belly flaps, which are the thinnest parts of the fish and therefore probably dry the fastest (and lose most water). Taking only few small samples from the fish does not always give accurate information of the water content inside the split fish. Surface salt that falls of the fish in the drying process might also affect the results. In calculations in this study it was considered insignificant.

Technology of NIR-spectra analysis might be interesting as it is nondestructive measurements so in theory the same sample could be measured before and after drying. No data was available for calibration for the NIR measurements so the 300 samples that had been analyzed in Experiment 1 were used for the calibration and prediction of the water content in the NIR measurements. Much larger dataset would have to be used for calibration and making of salt fish models to make the results sufficient but the results obtained were positive.

As the dried salted fish exported to Brazil is stored out on markets in 90 % humidity, the fish absorbs water from the environment, the salt concentration decreases and the water activity increases. It was assumed that by drying the salted fish and having crystallized salt in the muscle it would prevent increased water activity when water is absorbed as the crystallized salt dissolves and the brine is still fully saturated. However, the chemical analysis in this thesis after drying suggest that the salt is not crystalizing inside the product but it flows to the surface in the brine and crystalizes there when the water evaporates.

In Portugal the requirement for dried salted fish is maximum 47 % water content but the water content isn't homogenous in the split fish. The surface can be very dry even though almost no water has been removed from inside the fish muscle. That might be the reason why the Portuguese also use the texture and bending of the fish to decide if the drying of the fish is sufficient. In a research from Portugal, Brás and Costa (2010) state that using brine salting leads to higher water content inside the fish and less firmness than pickle salted. The drying of brine salted fish has better yield but also takes longer to dry. Also it is stated that no significant difference in color was obtained (Brás & Costa, 2010). The results in this current study show that the water content of cod injected with phosphate was about 1-2 % higher before drying than for brine salted fish without phosphate from the same producer. The water content of brined fish from another producer that went through rigor mortis in a weaker, slurry ice brine, before the actual brining was similar to the water content of pickle salted fish. The brine salted fish actually dried significantly faster than the pickle salted and the final water content after 138 hours of drying was measured similar in brined and pickle salted fish and with mass balance calculations even lower in brine salted than pickle salted.

No actual measurements were made on the color but only from looking at the fish the pickle salted looked much more yellow than the brine salted and injected fish before drying, but the difference was not so great after rehydration.

When talked about below 47 % water content as a criterion for dried salted fish in Portugal that is including some skin and spine (Brás & Costa, 2010). In the chemical analysis in this thesis attempts were made to only include muscle in the samples, which therefore might lead to higher water content results.

5.3 Drying conditions

The weight loss was quicker in Experiment 4 than in the first two experiments. The drying conditions were also a little bit different. The temperature was about 18 to 20 °C at the door where the samples were placed in Experiment 4 while about 15 to 18 °C in the first two experiments. The humidity was higher in Experiment 4 or between 50 to 60 % compared to 30 to 45 % in the first two experiments. Finally the air velocity was about 2 to 3 m/s in Experiment 4 but 1 to 2 m/s in the first two experiments. Difference in all three drying parameters might not have been ideal but the initial plan was to change only the humidity. It should also be noted that even though the fish from group 1 in Experiment 4 (not washed injected cod from Visir hf.) was the same as the injected cod in the first experiments it was not caught and processed at the same time. In the nineties a doctoral thesis was written in Iceland about drying of salted fish where small sized split fish (about 1 kg) was dried at different drying conditions. The results from that research showed that there was faster drying rate with decreased humidity, increased temperature and increased air velocity even though the difference was not often great (Arason, 2012). From that it could be concluded that the increased temperature and air velocity was causing this higher drying rate in Experiment 4 than in Experiment 1 and 2. Similar results are obtained from Norwegian researches that the drying time can be reduced by about 30 % for cod with increasing temperature from 21.9 °C to 26.5 °C and it is also stated that burning of the surface does not start until at 26.5 to 27 °C (Jonassen & Walde, 2006c). In this thesis the temperature never went much higher than 20 °C but increasing the temperature to 24 to 26 °C might be interesting. When the surface is dried and dry layer has appeared on the surface, it works as a barrier against water transport to the surface and the drying rate drops. After that the drying parameters don’t matter as much (Claussen & Magnussen, 2008). In the same research it is stated that the fish is drying from 58 % water content to 51 % in 70 hours, which is much more than in experiments conducted in this current study. Still in the Norwegian experiment only the initial water content was measured and then the water content calculated from the weight loss. If the water content is measured in the same way from the results in this thesis similar results are obtained as in the Norwegian experiments.

If looked at the humidity difference between the air inlet and the air outlet of the drying tunnel in Experiment 1 to 3, it can be seen that the difference is highest in the first five to twenty hours and after that the difference isn’t very high. From that it can be concluded that most of the water is removed from the fish in the first hours which matches results from previous researches (Magnussen & Walde, 2008).

Both temperature and humidity measurements showed fluctuation in values during the drying process. That is because of changing conditions in the outdoor temperature and humidity which affects the drying. By having panels to control, both the air coming into the system and the air that is recirculated, better control of the drying conditions can be achieved.

5.4 Yield and other discussion

The fish injected with carnal phosphate gained less weight than the non-injected fish in the rehydration. The ling that lost most weight in the drying did not recover in the rehydration, at least not in the 96 hours. After rehydration the best yield was in cod injected with phosphate, then from pickle salted and only 1 % lower was the non-injected cod from Experiment 1. Those results are made from only one fish in each group after rehydration so larger rehydration experiments would have to be conducted to get more reliable results. According to a different study there is no difference in yield after cooking between salting methods (Andrés *et al*., 2005), but no measurements were made on the cooking yield in this thesis.

In informal sensory analysis performed after the rehydration experiment, the non-injected cod from Visir hf. from Experiment 1 got the best review. Thereafter was the injected not washed cod from Visir hf. from Experiment 4. Together in third and fourth place were the pickle salted fish and the injected fish that was soaked in water for 10 minutes before drying and the brined fish from Experiment 4. None of the fish did excel in the test. The ling was also quite similar to the cod but the tusk a little more different. Washing the fish for 10 minutes before drying made it more similar to the pickle salted fish that is chewier. Better review of the sensory analysis is to be found in Appendix D.

In Experiment 4, the fish was washed before drying as the previous studies have suggested but there was no significant difference in weight loss between the washed and not washed injected cod (using HSD method) even though the washed fish did lose about 1 % more weight. The results from the water content measures still showed that there was less water content in the “not washed” fish than the washed fish. The conclusion drawn from that might be that it is not necessary to wash the surface salt of the fish before drying.

In Norwegian researches where saithe was dried along with cod, it is stated that saithe dries slower than cod (Magnussen & Walde, 2008). From the results in the current study (section 4.1.1) the ling dries faster than the cod. That might be explained by the lower water holding capacity measured in the ling before drying but the reason why the water holding capacity is lower is more difficult to explain. No references have been found of the reason for the difference in drying rate and in the Norwegian report no explanation or suggestion was given for the difference in drying rate of saithe and cod but this is something that could be interesting to research further. There was a correlation between high water content and low WHC (see Appendix E). Even though the ling had a slightly higher water content than the cod before drying, the difference in weight loss between species was much higher than could be explained by difference in water content.

6 Conclusion

In this chapter the main conclusions are summarized.

- There was a clear difference in weight loss between ling and cod. The ling lost about 30 to 60 % more weight than the cod in the drying process. The conclusion is that ling and cod should preferably not be dried together as the ling needs shorter drying time.

- Ling had the highest drying rate, followed by small tusk, non-injected cod and finally injected cod. The drying rate of the large tusk was similar to the cod groups.

- The weight loss between small cod and large cod and between small ling and large ling was not significant ($p > 0.05$) even though the small fish was losing relatively more weight than large fish. There was however significant difference between weight loss of small/large ling and the extra-large ling and between small and large tusk (the weight of the large tusk was two times more than of small ling). That indicates that very large fish, 6 - 8 kg, should need different drying process from fish weighing 1 - 3 kg.

- According to mass balance 138 hours of drying at 40 % humidity, 15 - 20 °C and 1.5 m/s air velocity is enough to dry ling less than 6 kg of size down to 47 % water content and also brined and pickle salted cod and small tusk. Compressing of the injected cod did also help. The small cod was closer to meeting the 47 % criteria than the large cod.

- No difference was in weight loss between brined cod with and without phosphate from the same producer in drying

- The brine salted cod, with and without phosphate lost weight faster than the pickle salted cod in the drying ($p < 0.05$). The water content of the pickle salted fish was much lower before drying than in the injected fish but it was similar to the water content of only brine salted fish.

- In the chemical analysis there was often considerable difference in chemical content between locations. There were small variations between groups but the trend was that more water content was in the middle of the loin than in other parts of the fish and least water in the tail. Also there was less salt in the tail than in other parts. The difference between locations before drying was much smaller than after drying. That might tell you that the salting methods, with injection, brining and finally kenching is providing the fish with quite homogenous treatment. The water holding capacity was almost the same between locations but a little more in the tail than other locations. The difference in locations was clearer when the surface was measured after drying.

- Difference in water holding capacity can be seen between species before drying even though not all significant. Cod, not injected with phosphate, was measured with the highest WHC, then injected cod and ling and finally tusk with the lowest. There was negative correlation between water content and WHC.

- The water content inside the split fish does not decrease much in the drying. It is mainly the surface that is dried. That explains the difference between measured water content and water content calculated with mass balance.

- The temperature difference in the drying tunnel was seldom more than 2 to 3 °C and humidity difference about 5 %. Most of the time a small decrease in temperature could be seen from the air inlet and the door (air outlet) but the temperature of the air decreases when it absorbs water from the fish. The rule of thumb is temperature drop about 1 °C for each rack in drying of fresh fish, and therefore 6 °C temperature drop from the air inlet to the air outlet. That great temperature drop did not occur for the salted fish. The difference in humidity between air inlet and air outlet was also 10 to 30 % in the first hours when most of the water was removed but after that almost no humidity difference was between locations in the drying tunnel. The conclusion from those results could be that the pyramid dryer is well designed for drying of salted fish.

- The drying rate of fish was not largely affected by the location of the fish in the drying tunnel.

- The experiment that was made with compressing the fish under 800 kg for two days after the initial two days of drying resulted in greater weight loss, compared to fish that was in drying the whole time. If the mass balance was used for calculations of water content compressing of the large injected cod delivered product with water content about 47 % after 138 hours of drying and the compressed not injected large cod close to that too. The results indicate that compressing the fish increases weight loss in the drying of cod, especially of cod injected with phosphate.

- The results from the NIR measurements are a good indication that the NIR technology could be used for measuring of water content, which has been showed in researches before. It should be noted that shredded samples were used in the analysis but ultimately it would be desirable to do the analysis on whole fish. That was not done in the thesis but is a possible future work.

- The salt measurements made on the fish samples before and after drying in Experiment 1 to 3 indicate that the salt does not crystalize inside the fish muscle but emerges to the surface when the water is removed.

- Washing the surface salt of the split fish before drying did not seem to benefit the drying greatly but when comparing the groups using LSD method the washed fish did lose significantly more weight ($p<0.05$) but not with Tukey's method.

- Calculations of yield from salted product, through drying and storage, to rehydrated product indicate that the best yield is for brined cod injected with phosphate.

7 Future work

Over the course of writing this master's thesis there has not been time to do everything that the author might have wished to research and other things that would have been desirable to study further.

Even though some questions regarding drying of salted fish have been answered in this thesis there are still many left unanswered and other questions that have arisen. Following are a few points.

- Having fish on a scale inside the drying tunnel to see the actual weight loss in real time. It can be helpful to gather knowledge about the drying rate of the fish instead of weighing the fish over the course of the drying process. With the information of the drying rate at each time, better knowledge can be obtained to optimize the drying process by changing conditions during the drying, depending on criterions each time.

- Use higher temperature in the drying, but results from Norwegian experiments have shown higher drying rate with temperature up to 26 °C.

- Do chemical measurements from more samples to get better statistical basis for the results and study the drying rates between different parts of the fish further. From that prediction models can be made for the falling drying rate in drying of salted fish for different species, sizes, salting methods and between parts of the split fish.

- Both compressing of fish during the process and also pausing the drying without compressing the fish would be interesting to examine further. Studies have shown that air velocity, temperature and humidity are only factors in the first hours of drying so the effects of stopping the drying after the initial 24 hours would be interesting to save energy.

- To get better knowledge of yield of different groups of dried salted fish, information is needed from fresh fish through rehydration.

- Explore the interference of factors (salting methods, sizes, species) when comparing drying rates and weight loss of different groups. In this study the different groups were only compared two-dimensional.

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Appendix A

Temperature measurements in drying tunnel.

Experiment 1

Tunnel A

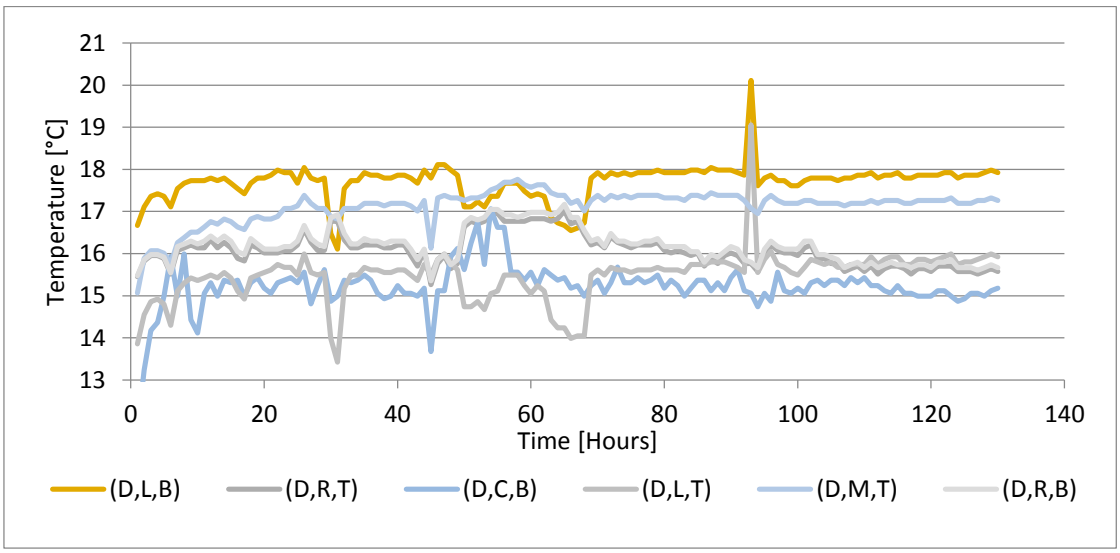

Figure 123 Temperature at the door in Tunnel A during Experiment 1 (explanations of abbreviations in Section 3.3)

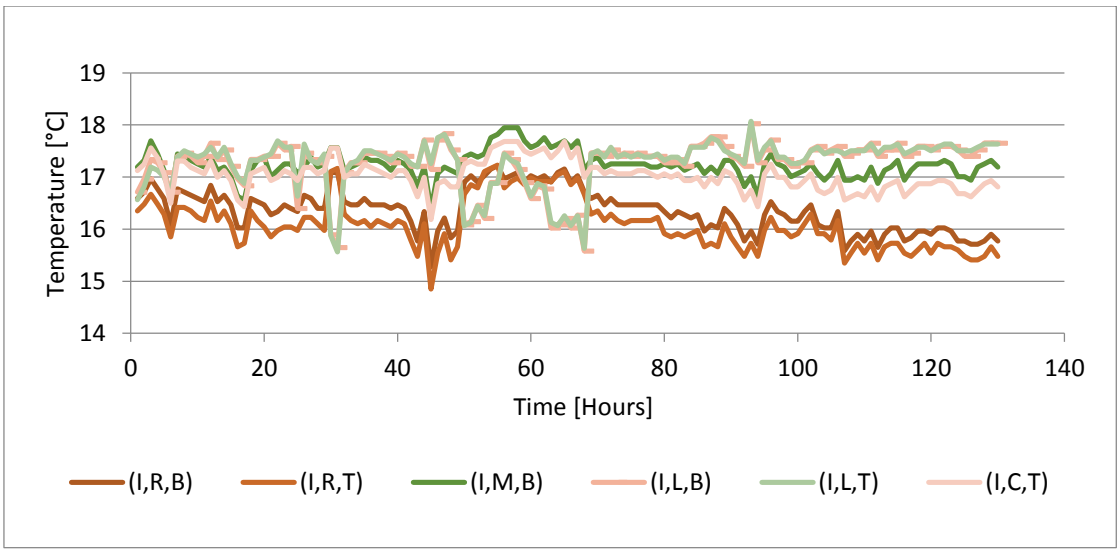

Figure 124 Temperature nearest to air inlet in Tunnel A during Experiment 1 (explanations of abbreviations in Section 3.3)

Tunnel B

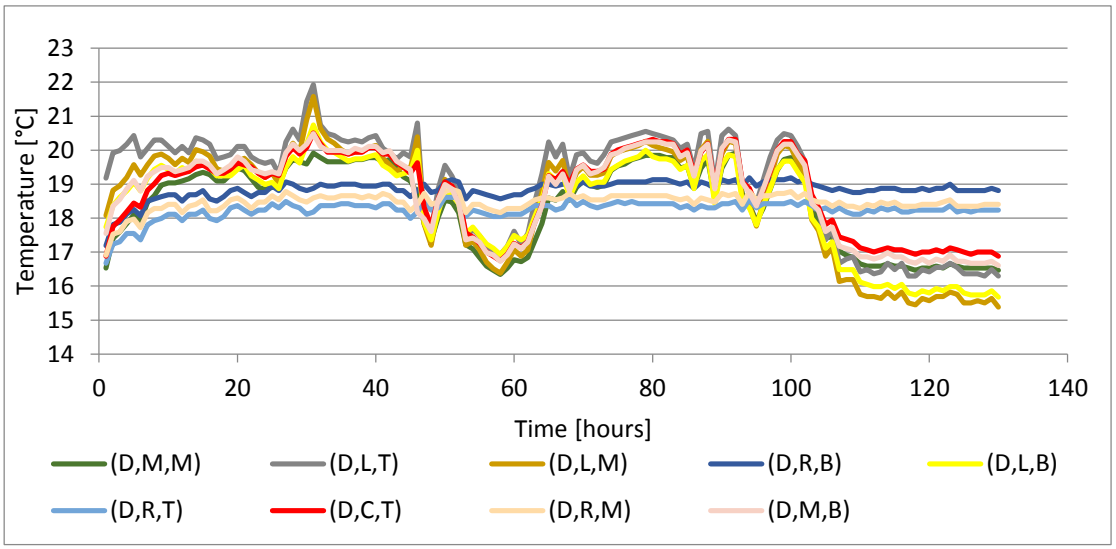

Figure 125 Temperature at the door in Tunnel B during Experiment 1 (explanations of abbreviations in Section 3.3)

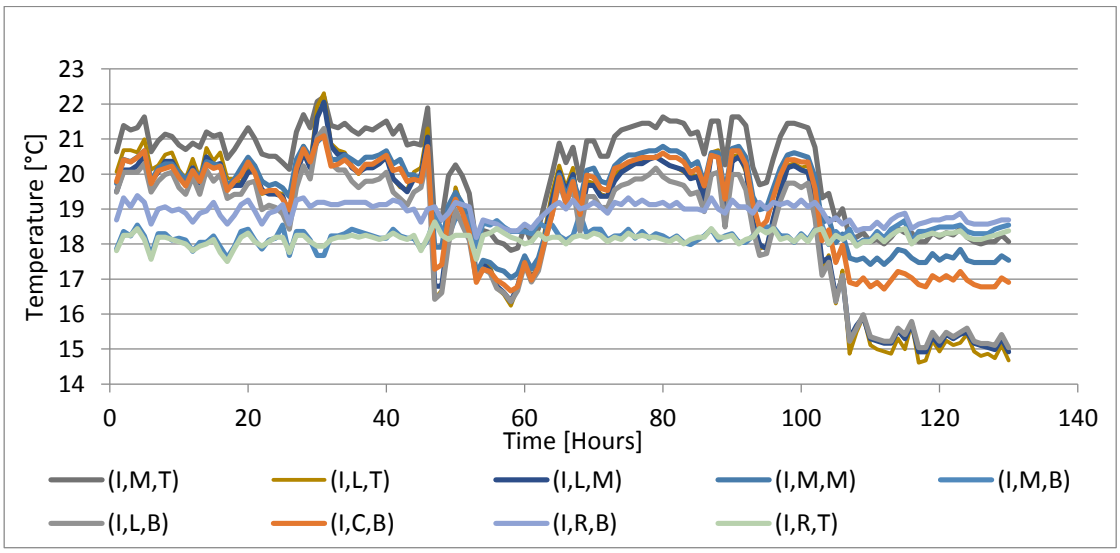

Figure 126 Temperature nearest to air inlet in Tunnel B during Experiment 1 (explanations of abbreviations in Section 3.3)

Experiment 2

Tunnel A

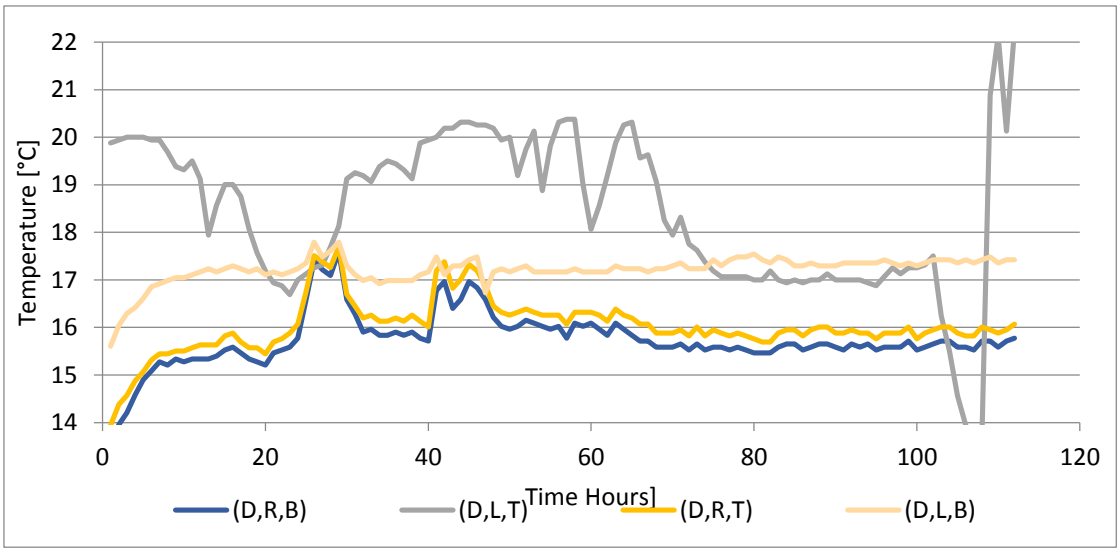

Figure 127 Temperature at the door in Tunnel A during Experiment 2 (explanations of abbreviations in Section 3.3)

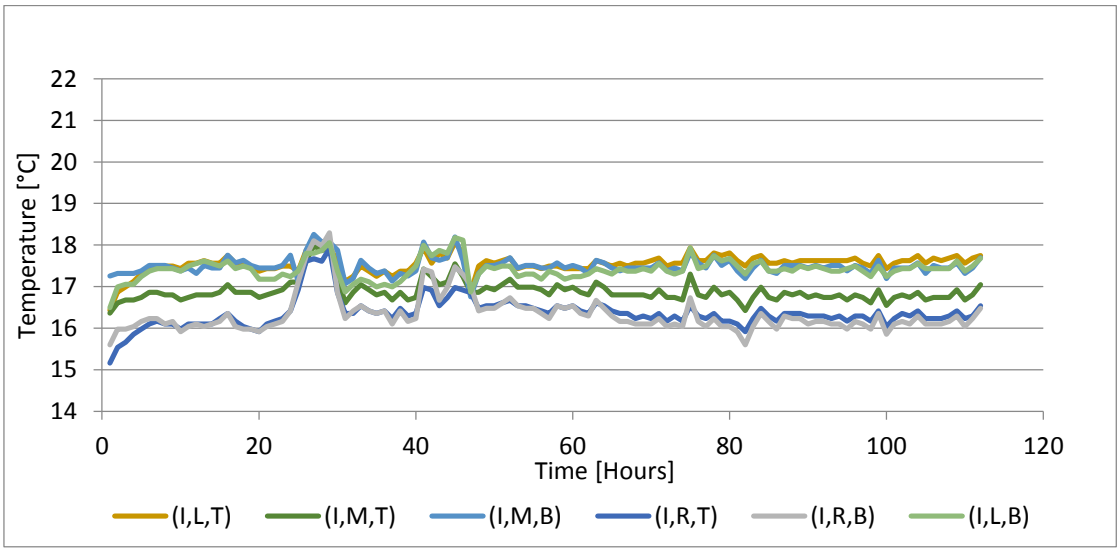

Figure 128 Temperature nearest to air inlet in Tunnel A during Experiment 2 (explanations of abbreviations in Section 3.3)

Tunnel B

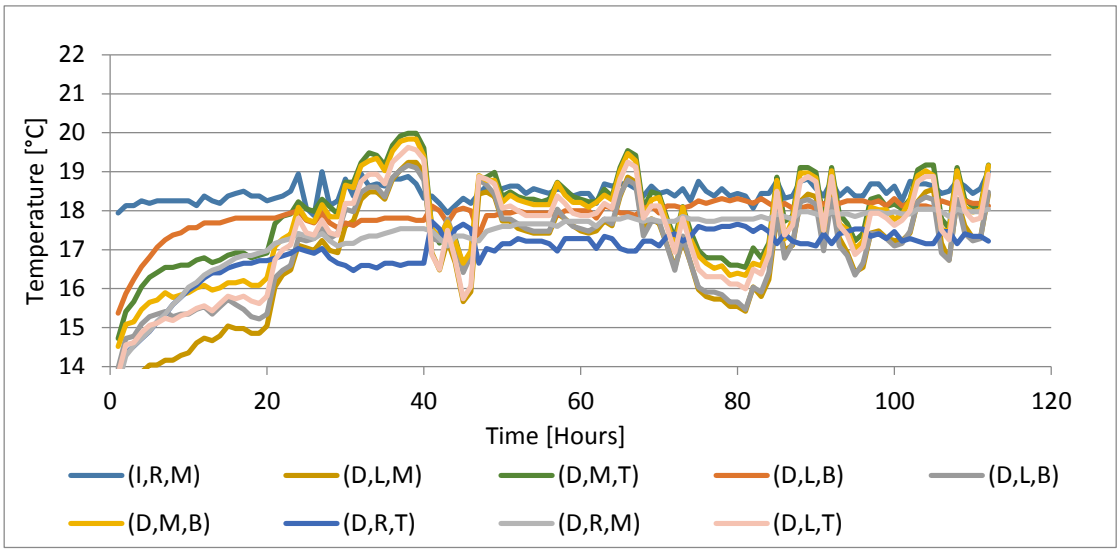

Figure 129 Temperature at the door in Tunnel B during Experiment 2 (explanations of abbreviations in Section 3.3)

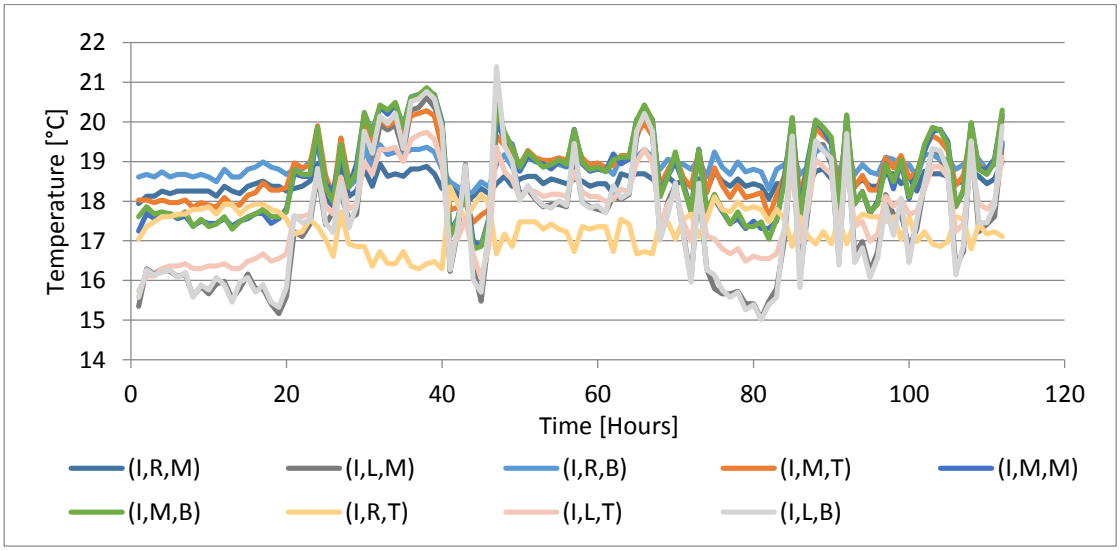

Figure 130 Temperature nearest to air inlet in Tunnel B during Experiment 2 (explanations of abbreviations in Section 3.3)

Experiment 3

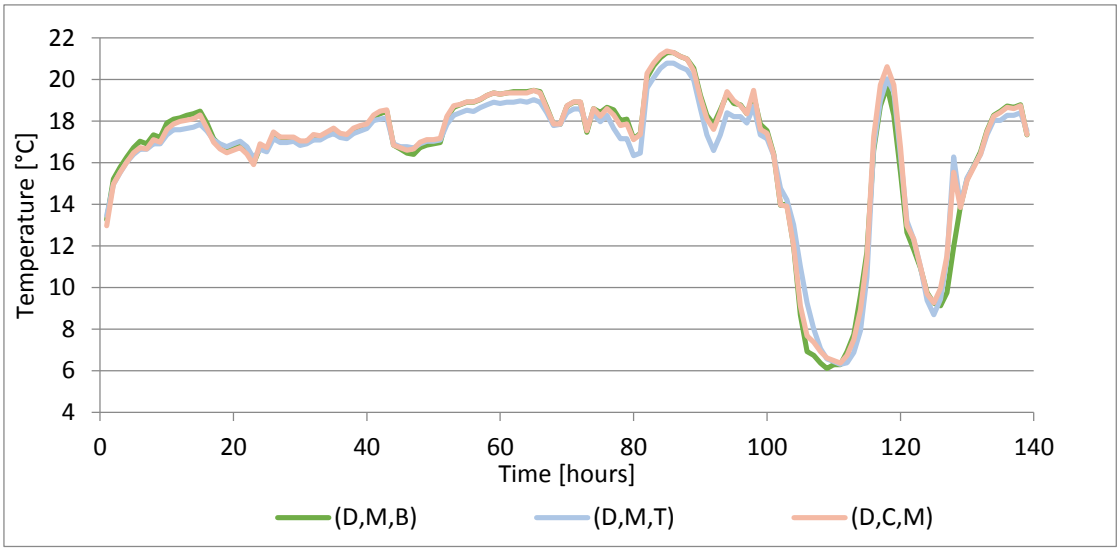

Figure 131 Temperature at the door in drying tunnel during Experiment 3 (explanations of abbreviations in Section 3.3)

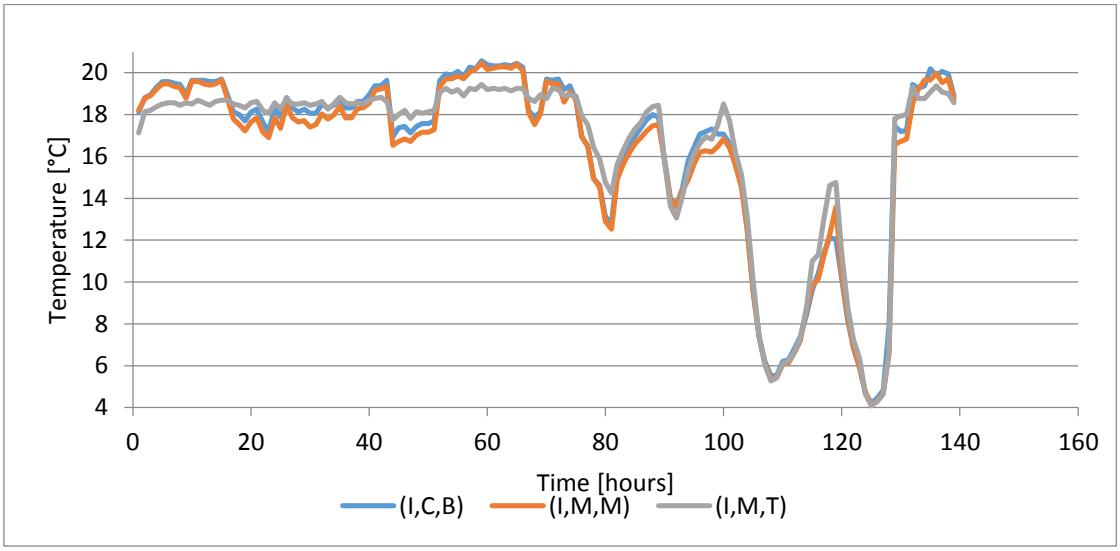

Figure 132 Temperature nearest to air inlet in drying tunnel during Experiment 3 (explanations of abbreviations in Section 3.3)

Appendix B

Air velocity measurements

Experiment 1

Tunnel A

Table 17 Air velocity measurements in Tunnel A during Experiment 1

Position Tunnel A	Left	Center	Right
Top	2.2 m/s	1.4 – 2.4 m/s	2.1 m/s
Middle	1.4 m/s	1.2 – 1.7 m/s	1.1 m/s
Bottom	1.1 m/s	1.0 – 1.1 m/s	1.0 m/s

Tunnel B

Table 18 Air velocity measurements in Tunnel B during Experiment 1

Position Tunnel B	Left	Center	Right
Top	2.0 m/s	2.1 m/s	1.8 m/s
Middle	1.3 m/s	1.1 m/s	1.1 m/s
Bottom	1.0 m/s	1.3 m/s	1.2 m/s

Experiment 3

Table 19 Air velocity in drying cabinet – 30/1 2013 [m/s]

30/1 2013	**Left**	**Center**	**Right**
Top	M1: 1.4 M2: 1.8-1.9 M3: 1.5-2.1	M1: 2.0 M2: 2.2 M3: 2.4	M1: 1.6 M2: 1.6 M3: 1.7-2.1
Middle	M1: 1.9 M2: 1.8 M3: 1.1	M1: 1.8 M2: 1.8 M3: 1.7	M1: 1.2 M2: 1.3 M3: 0.9
Bottom	M1: 1.7 M2: 1.6 M3: 1.0	M1: 1.8 M2: 1.8 M3: 1.1	M1: 1.2 M2: 1.3 M3: 1.1

Table 20 Air velocity in drying cabinet 31/1 2013 [m/s]

31/1 2013	**Left**	**Center**	**Right**
Top	2.0	2.0	1.1
Middle	1.3	1.1	0.7
Bottom	0.9	1.1	0.7

Appendix C

Outdoor conditions during drying experiments

Experiment 1

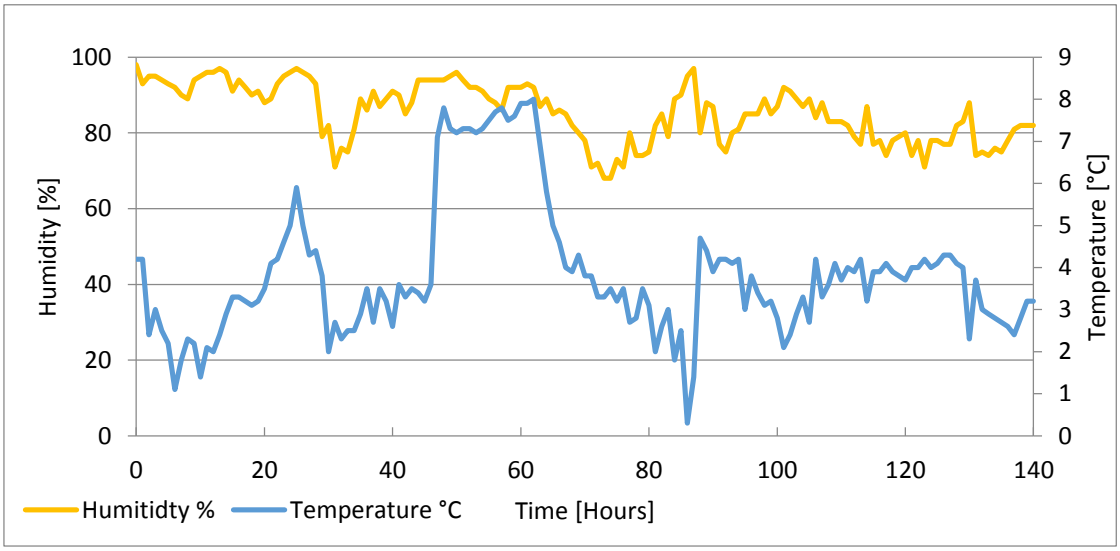

Figure 133 Outdoor conditions at Keflavik airport during Experiment 1

Experiment 2

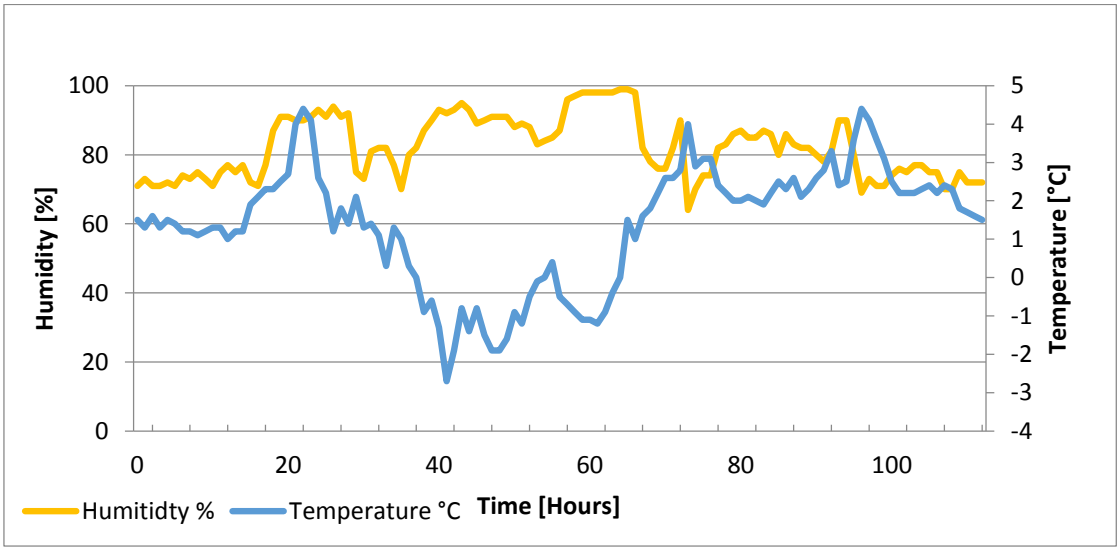

Figure 134 Outdoor conditions at Keflavik airport during Experiment 2

Experiment 3

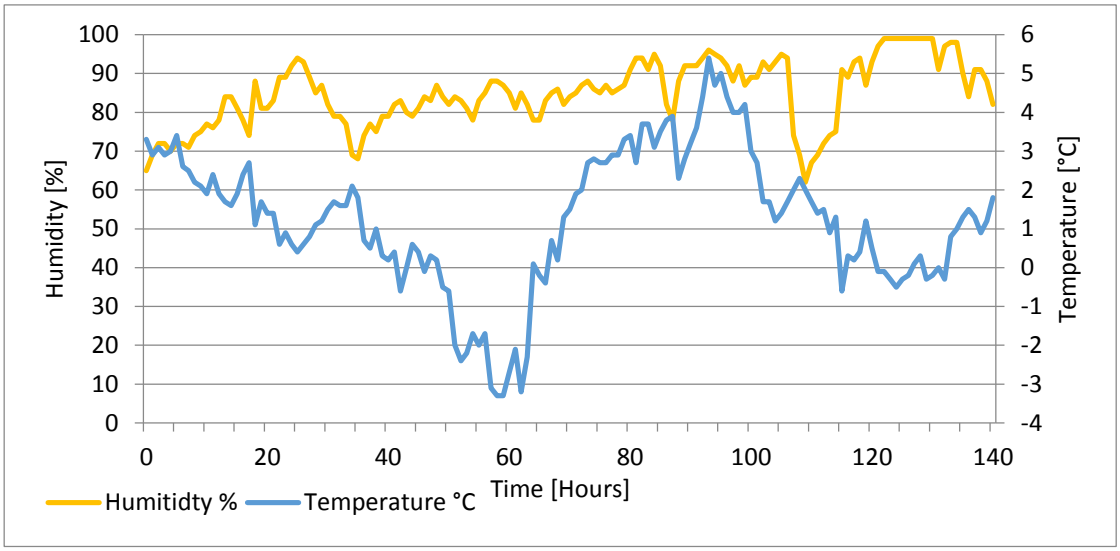

Figure 135 Outdoor conditions at Keflavik airport during Experiment 3

Experiment 4

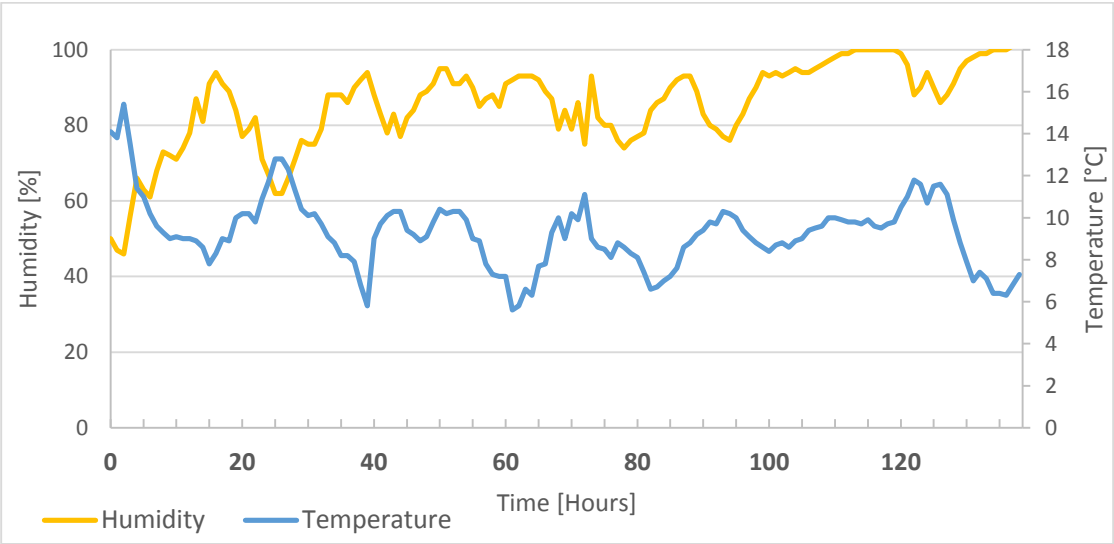

Figure 136 Outdoor conditions at Keflavik airport during Experiment 4

Appendix D

Sensory analysis

Fish samples from the rehydration experiment was cooked and tasted two days after rehydration.

The testers, apart from the author of this thesis were, Sigurjon Arason, head engineer at Matis ltd., Asbjorn Jonsson food scientist and project manager at Matis ltd., Einar Larusson, R&D manager at Thorfish hf. and Vikingur Vikingsson manager at Haustak hf.

The fish was first tasted raw to see if the rehydration was completed. The results were that the salt content of all the fish was good. Next, fish samples were prepared in the same way as costumers do it in Spain and Portugal. The fish was pan fried in olive oil together with garlic cloves for about 15 minutes. The fish was then left to cool for another 15 minutes before the sensory analysis. The different groups were then ranked by taste, texture and softness.

Figure 137 Sigurjon cuts taste samples from the raw split fish

Figure 138 Samples ready to be cooked

Figure 139 Salt fish portions with garlic

The panel of judges gave short reviews about the samples without knowing from which group each dish was.

Figure 141 The seven groups from the rehydration experiment ready for consumption

Figure 140 The panel of judges excited to taste the fish

The injected and washed cod (5) did flake well when cut and also the injected and not washed cod (1), but the not washed cod was softer. The pickle salted cod (4) did flake well and was floating between layers and quite soft.

The non-injected cod (2) from Experiment 1 was selected as the best fish. Best taste and texture.

The ling was quite similar to the cod but the tusk more different.

The injected and washed fish was not as soft as the not washed fish and had to be chewed more often, similar to the pickle salted fish. It indicates that the washing of injected fish before drying makes it chewier.

The ranking of the cod was as follows from the best to the worst:

Figure 142 The victory portion - Non-injected cod

$$\text{Not inj} > \text{Inj not washed} > \begin{matrix} Inj\ and\ washed\ for\ 10\ min \\ Pickle\ salted \end{matrix} > Brined\ (group\ 3)$$

The not injected fish from Experiment 1 was considered best (2). The runner up was the injected fish that was not washed before drying (1) and thereafter came pickle salted (4) and injected and washed cod (5) followed by the brined cod from different producer (3). <u>It has to be noted that none of the group was decisively best and there was often a difference between individual flakes of the portions.</u>

Appendix E

Correlation between chemical values before drying

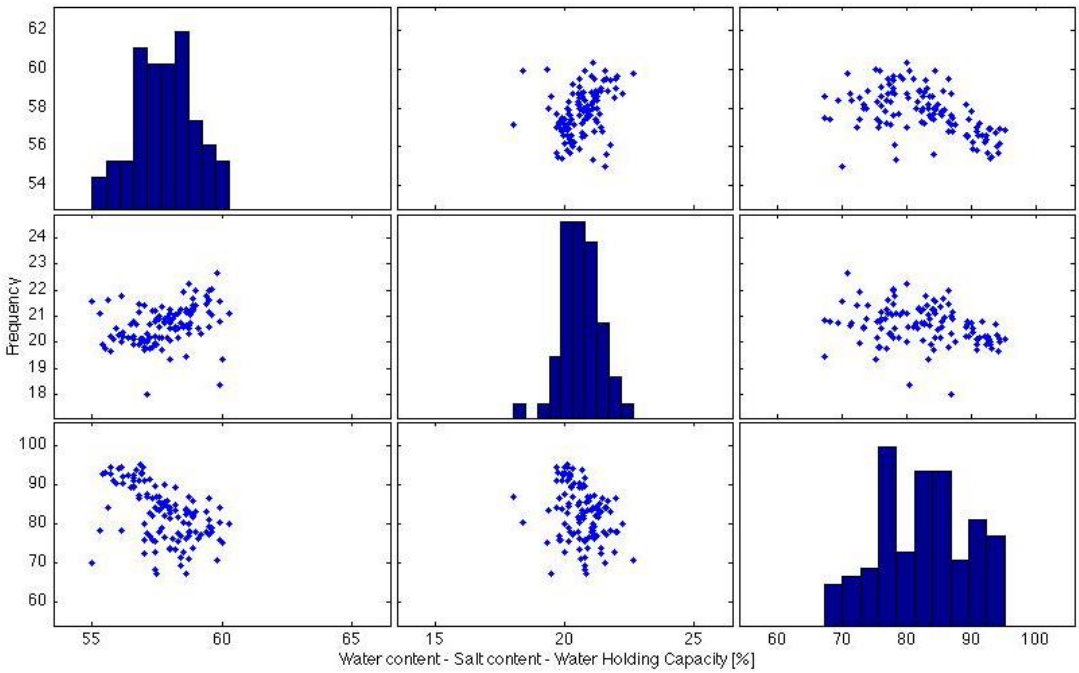

Figure 143 Histograms and correlations between water content, salt content and water holding capacity before drying Experiment 1 (n = 127)

Table 21 Correlation matrix of water content, salt content and WHC in split fish before drying Experiment 1 (n = 127)

	Water	Salt	WHC
Water	1	0.32	-0.49
Salt	0.32	1	-0.29
WHC	-0.49	-0.29	1

Correlation between chemical values after drying

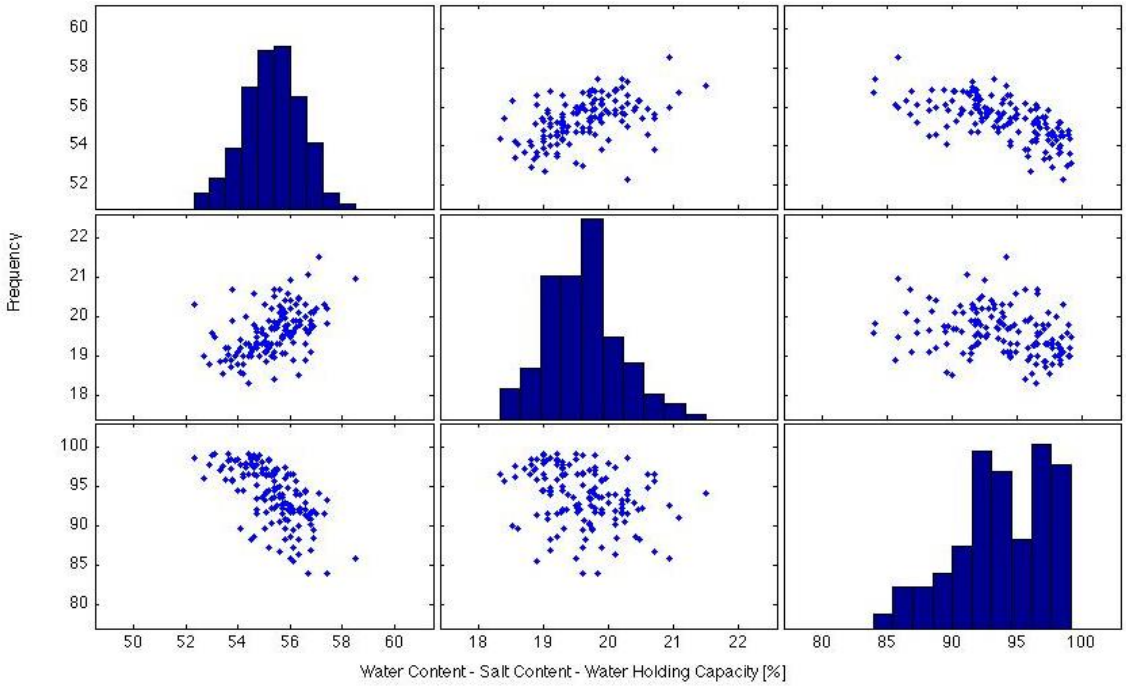

Figure 144 Histograms and correlations between water content, salt content and water holding capacity in split fish after drying in Experiment 1 (n = 147)

Table 22 Corrleation matrix of water content, salt content and WHC in split fish after drying in Experiment 1 (n = 147)

	Water	Salt	WHC
Water	1	0.50	-0.63
Salt	0.50	1	-0.30
WHC	-0.63	-0.30	1

Normplot of chemical values from salted split fish before drying

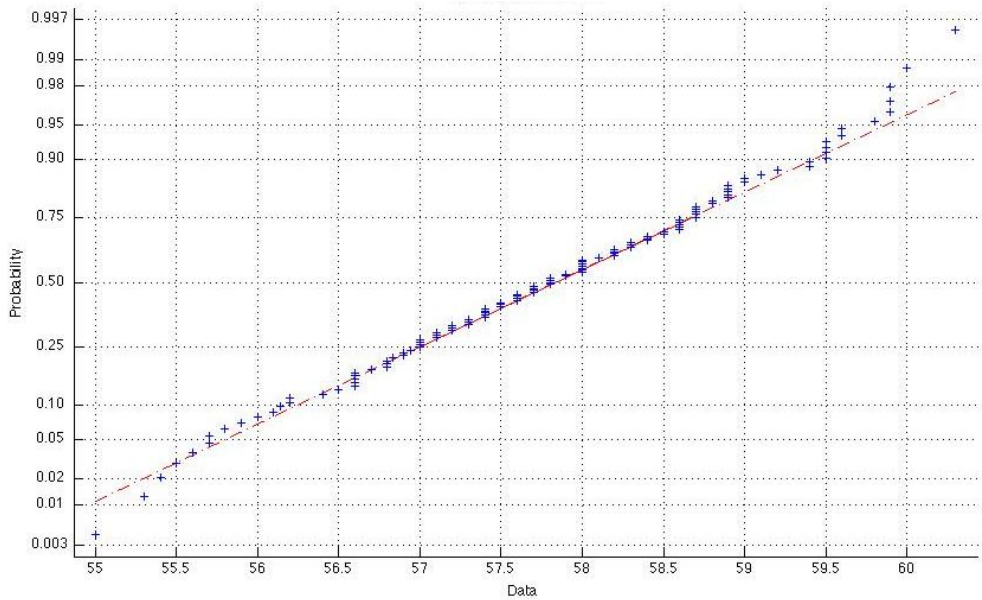

Figure 145 Normal probability plot of water content in split fish before drying in Experiment 1

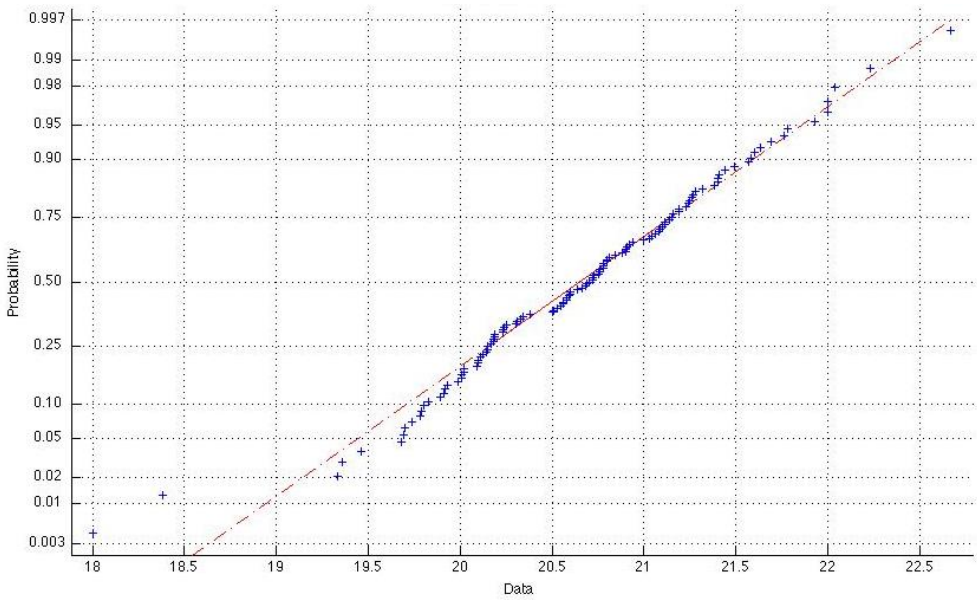

Figure 146 Normal probability plot of salt content in split fish before drying in Experiment 1

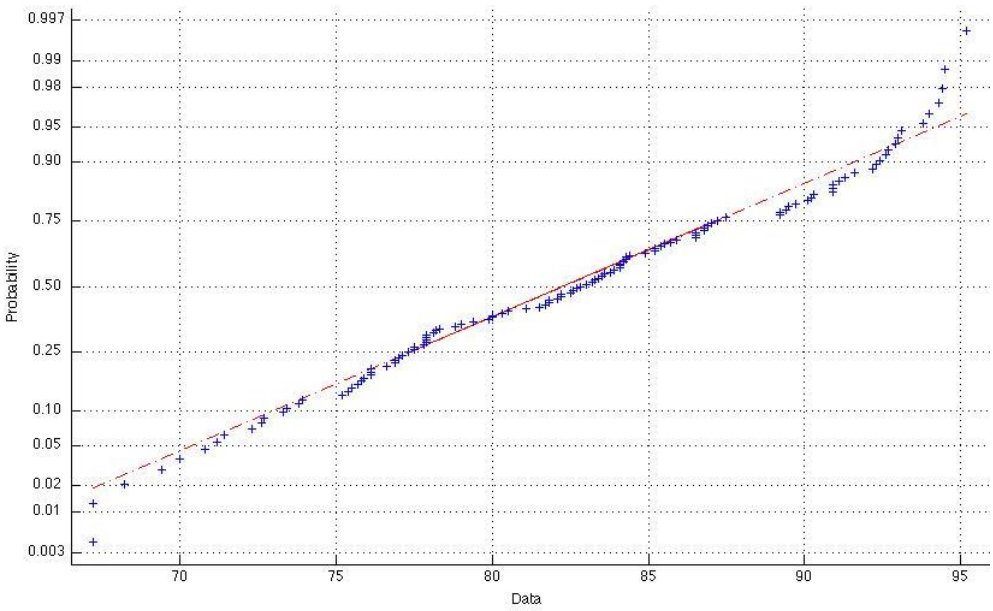

Figure 147 Normal probability plot of WHC in split fish before drying in Experiment 1

Normplot of chemical values from salted split fish after drying

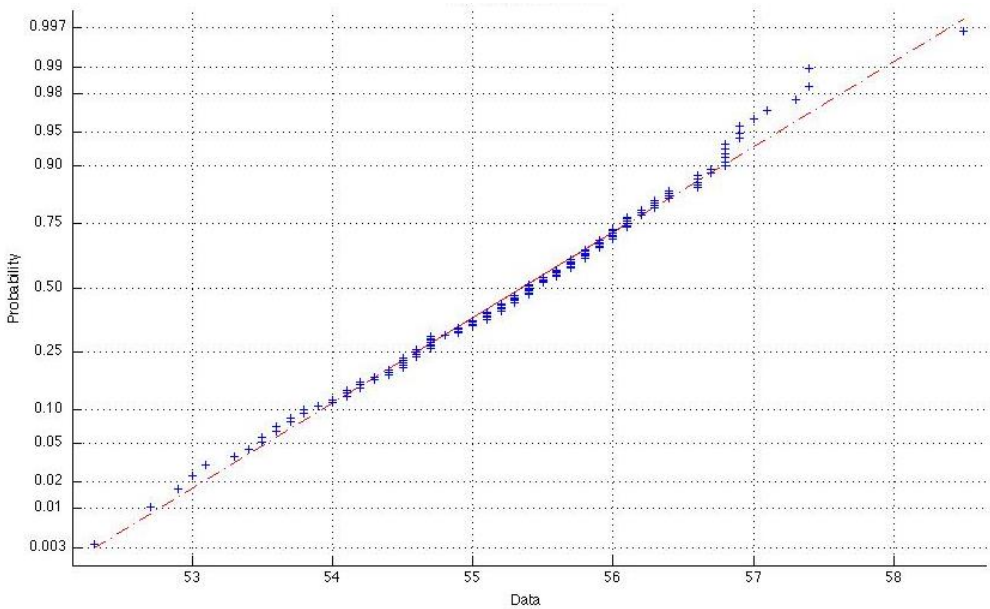

Figure 148 Normal probability plot of water content in split fish after drying in Experiment 1

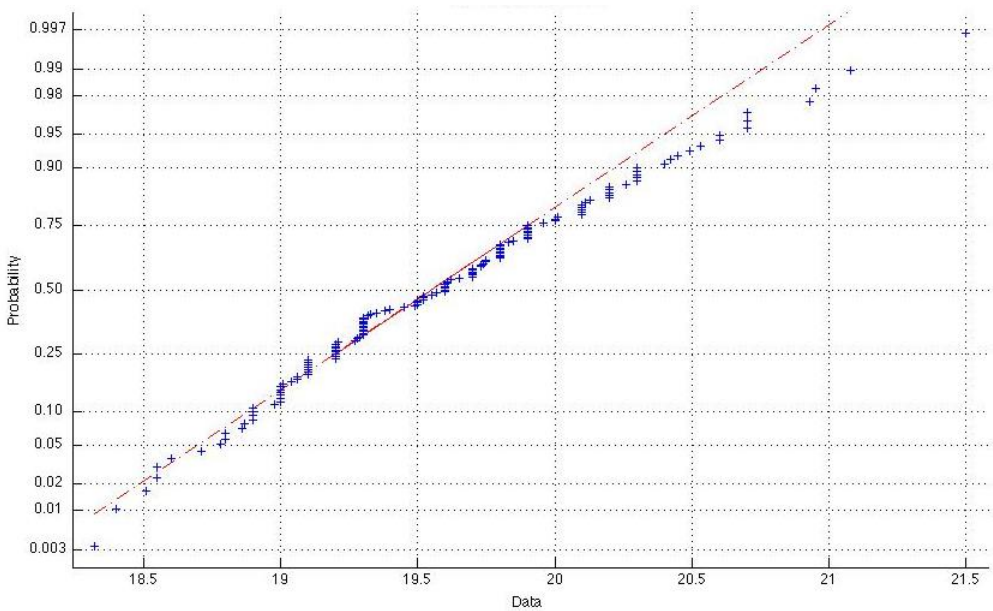

Figure 149 Normal probability plot of salt content in split fish after drying in Experiment 1

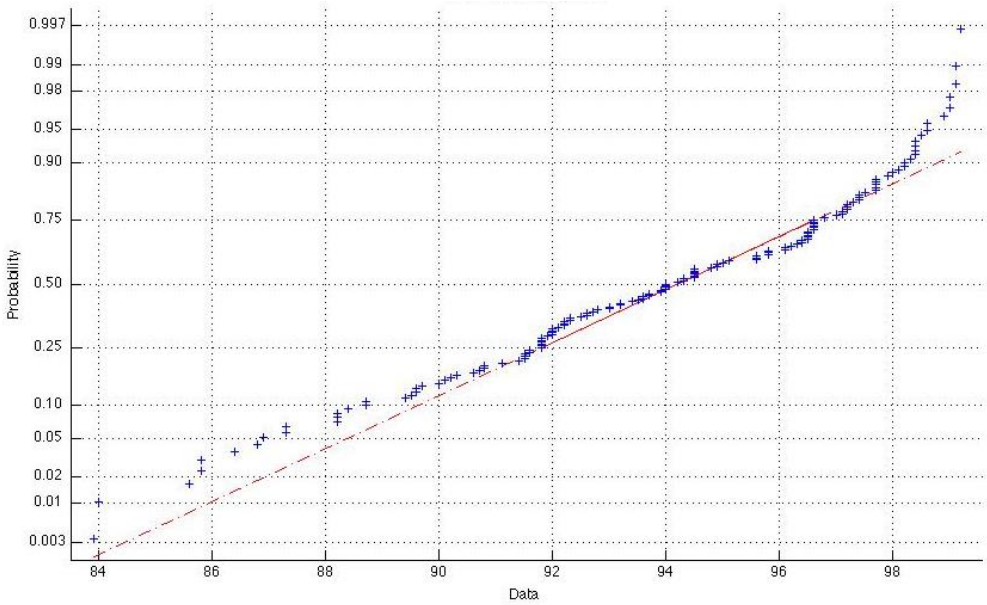

Figure 150 Normal probability plot of WHC in split fish after drying in Experiment 1