NTNU

Norwegian University of
Science and Technology

Dynamic modeling and optimalization of the cheese making procedure

Tomas Tungen Kjellstrøm

Chemical Engineering and Biotechnology
Submission date: July 2017
Supervisor: Sigurd Skogestad, IKP
Co-supervisor: Morten Steen, TINE SA
Turid Rustad, IBT

Norwegian University of Science and Technology
Department of Chemical Engineering

July 5, 2017

Acknowledgements

This Master thesis was conducted at the Department of Chemical Engineering at the Norwegian University of Science and Technology (NTNU).

I would like to extend my sincerest gratitude to my three supervisors:

Main supervisor Professor Sigurd Skogestad for helping me with the overall progress and computational guidance.

Morten Steen, Consultant in TINE (Prepare for Operation)

For helping me with the general approach and for his everlasting enthusiasm for this thesis and progress.

Professor Turid Rustad

For helping to better understand how to interpenetrate the computational response of the biological processes of cheese production and for general advice's and questions.

I would also like to thank Ivar Magnus Jevne in TINE Forbedring and the TINE dairy at Jæren for helping me on gathering empirical information of the cheese production at Jæren. I would also like to mention my good friend and fellow student Brage Skånøy with keeping up the good team spirit, who has also written his master thesis in corporation with TINE this spring.

Preface

The work presented in this report has been carried out at the Department of Chemical Engineering at the Norwegian University of Science and Technology (NTNU), in the spring semester of 2017 .

The thesis is done as a part of the TINE‘s LEAN project DRIV, which focus on implementing new technology and improving operator efficiency for the fourth industrial revolution.

This thesis contain the general basics of cheese production and has tried to establish how the production phases are influenced by the most important parameters of each phase.

This is the first thesis done at the Department of Chemical engineering at NTNU in collaboration with TINE and combines the results of several publications and book on creating the first known to science dynamic model of cheese production, from raw milk to matured cheese.

The thesis is built-up chronological to follow the cheese production from start to end. Chapter 1 is the introduction, chapter 2 is the utilized theory of the thesis and is divided into the seven main production phases. Chapter 3 is the method chapter and emphasizes on the understanding of the interface between the theory and the computational construction. Chapter 4 is the results and contain the matlab based programs.

Sammendrag

Denne master oppgaven har med suksess gjort det mulig å beskrive ysteprosessen av semi-harde oster som en dynamisk parameter styrt prosess, basert på analytiske løsninger i Matlab. Utgangspunktet har vært råmelk fra Norsk rødt fe (NRF). Hoved fokuset på oppgaven har vært å bygge opp et generelt rammeverktøy for hele produksjonen, som gjengir en styrende og kjent respons i de ulike produksjonsfasene. Verktøyet kan benyttes til å estimere en hel produksjon, såvell som enkelt elementer. Med tanke på verktøyets nøyaktigheten er verktøyet av størst nytteverdi i FoU-arbeid, men kan brukes lokalt på et meieri til å forlare enkeltenheter sin avhengighet.

Et betydelig problem i storskala osteproduksjon er å dannelse av B-vare ost, som totalt sett gir et lavere overskudd. Ved å benytte en teoretisk modell basert på enhetens styrende faktor, øker det operatørenes grad av kontroll, slik at dannelsen av B-vare synker. For å kunne øke utnyttelsen av oppgaven, slik at graden av automasjon og selvstendig produksjon øker er det behov for å utføre en rekke laboratoriums forsøk for å bestemme biologiske initial mengder, ensym hastigheter, nøyaktig drennerings og diffusjons koeffisienter. Det gjenstår også å forklare den interne salt og vann diffusjonen under modning.

Contents

Nomenclature

Symbols	Meaning	Unit
$[HA]$	molar consentration of acid	mol/l
$[H^+]$	molar consentration of solved (aqua) hydrogen	mol/l
$[A^-]$	molar consentration of conjugate base	mol/l
pK_a	dissosiasion constant of acid at 25 $^\circ$ C	-log(k_a)
R	universal gas constant	J/mol k
P	pressure	kPa
D	diffusion coefficient	m^2/s
J	mass flux	kg/m^2 s
K	permeability coefficient	kg/m^2
R	retentate mass flow	kg/h
t	time	s or h
T	temperature	$^\circ$ C or K
γ_{PS}	product yield from substrate	g/g
γ_{XS}	biomass yield from substate	g/g
γ_{PX}	product over biomass yield	g/g

1 Introduction

Cheese making started thousands of years ago in the Middle East and was brought to Europe during the Roman empire. Cheese is defined as the matured product obtained from coagulation and whey release by milk, cream and skimmed milk. For cheese production in Norway, milk of cows and goats have been the main milk type, whereas in other parts of the world buffalo-, sheep- and camel- milk are used as well.

The cheese making procedure has in the later years been in a change, where the production has shifted from a labor demanding production method into a automated production procedure. The cheese making procedure is in general separated into a pre-treatment stage and the six production phases: acidification, coagulation, dehydration, molding and shaping, salting and ripening. Where the molding and shaping phase is possible to merge into the end of the dehydration phase. In the figure below a scheme of the production line, byproducts, additives and equipment types are given:

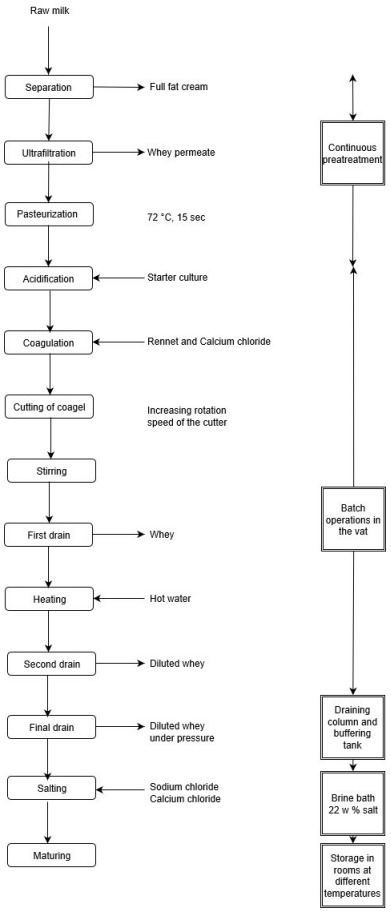


Figure 1: Overall production line of the a modern cheese production with the used equipment, additives and by-products of the phases

1.1 Aim of the thesis

The Norwegian dairy producer TINE SA are in this days implementing their efficiency strategy DRIV. DRIV is a production strategy that has the aim of increasing the overall efficiency of the plant. DRIV incorporate the taught of changing the production method by increasing the level of automation to become a part of ongoing fourth industrial revolution.
The fourth industrial revolution is the implementation of more independent cybernetics, big data and cloud computing.
The cheese productions are increasing in size and complexity, creating a narrower line of tolerated disturbance. The semi-hard cheeses Norvegia and Jarlsberg are the large scale cheese productions of TINE and are of that reason the main emphasis of this thesis.

In other industries like petrochemical- and chemical- industry the use of mathematical models for design has become an essential part of plant outfit, optimization and control. With the knowledge of how the important process parameters influence the production, a dynamic model can be made.

As far as known to academia, there have been done very few or scarce published work, describing the cheese production as an dynamic parameter based model and how variations of parameters affect the total product quantity and quality from raw milk to a commercial cheese. Earlier publications have in most cases described one step or phase of the production line. The main emphasis of the thesis has been to describe the production in the way it is done today and the accuracy is highest, in the beginning and under normal and conservative values, where the arithmetic's are not adequate fitted to extreme values. Some of the missing parameters and inadequate fits may be identified in the close future in the Sintef project Optimat, where large scale cheese production is one of the problems.

1.2 Milk

Raw milk consist mainly of water (86-88 w%), fat (3-6 w%), protein (3-4 w%), lactose (5 w%) and minerals (0.7 %), yielding an average solid content of 11-14 w% [10]. Skimmed milk, milk low in fat has a high buffer capacity with a average pka of 5.5 and at pH of 6.7 at 20 $^{\circ}$ C. The buffer capacity is due to the phosphates, citric acid and

caseins in the milk and has an average buffer intencity for strong acids and bases of 0.02 $\frac{\Delta\,[HA]}{\Delta\,pH}$ [25]. In Norway the dominant breed for milk production is Norwegian red. Norwegian red is a mixed breed of the different Norwegian breeds, with Holstein as the dominant breed. The Norwegian red was at first mixed with Finnish Ayrshire and Swedish- white and -red. In the the 70‘s Canadian and American Holstein was mixed in. Due to the introduction of Holstein approximately 20 % of Norwegian red are completely black or black and white [23]. Milk is usually divided into the three components: water (W), fat (F) and solids non-fat (SNF) based on their density contribution where fat is less dense than water and SNF is more dense than water. The density of milk can be approximated with the empirical expression [4]:

$$\rho_{milk} = \frac{100}{SNF/0.93 + F/1.608 + W}\ [=]\ kg/l \tag{1}$$

2 Cheese production

To prepare the raw milk, a number of preparation steps are conducted, all these steps are possible to conduct both batch wise and continuous. The cheese production is mainly divided into the six phases: acidification, coagulation, dehydration, molding shaping, salting and ripening.

2.1 Pretreatment

Prior to the cheese production the raw milk is processed trough three stages to remove pathogens and obtain a standardized composition.

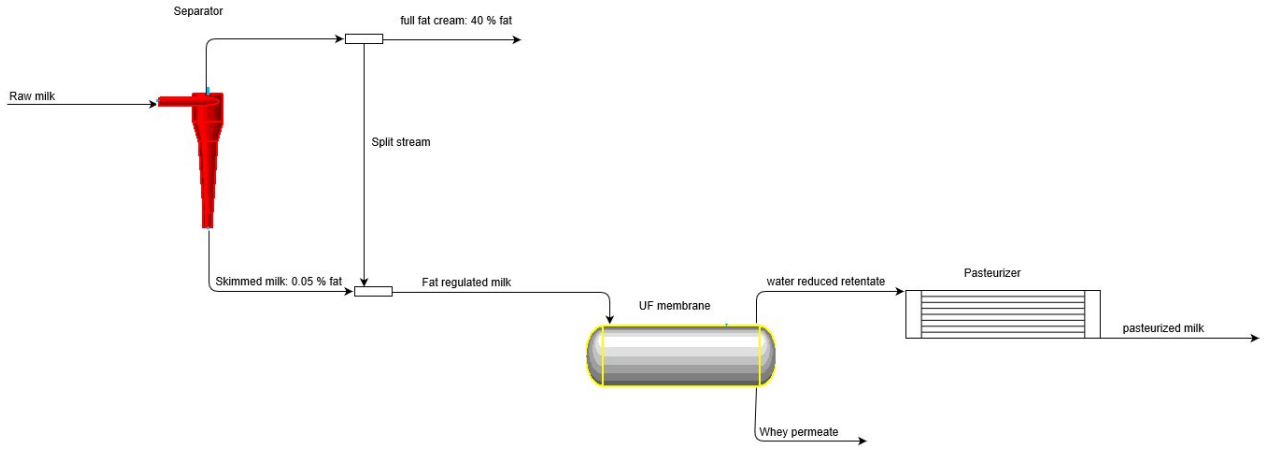


Figure 2: Process Flow diagram of the the pretreatment stages

Figure 2 illustrates how the raw milk enters the separator and fat is removed, to make skimmed milk as the main product and full fat cream as a by-product. The fat regulated milk then enters the UF-membrane, where water and lactose are removed from the milk to reduce the energy demands for further processing. The permeate, rich in water and lactose is further downstream processed to make lactose powder, as an additive to sweeteners and other fermentation processes. The retentate is then heated for a short period, before it is rapidly cooled to 7 ° C.

Separator:

The separator is an disc bowl centrifuge where the fat is an emulsion in the water, and where water is the denser component. Due to the difference in density the water will to a greater degree leave the separator out of the discs, whereas the fat emulsion will leave to a large degree at the toside of the separator as shown in figure 3.

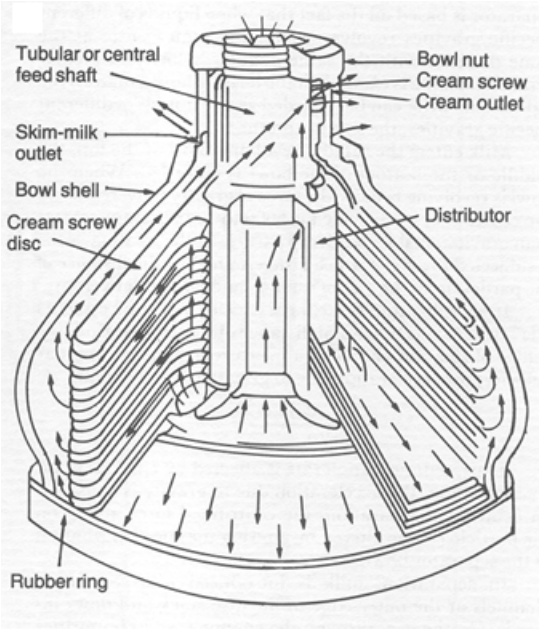


Figure 3: Illustration of the centrifugal separator, accordingly to De Laval's transport mechanism of density discrimination

The Separator for raw milk pre treatment produce a top side outlet stream with approximately 40 w% fat and bottom side skimmed stream with 0.05 w% fat. To yield the desired fat content of the regulated milk a PLS system with feed-forward control is used to meet the fat regulated milk stream with 0.5-0.7 w/w % fat [4]. The separator inlet component mass balance therefore becomes:.

$$C_r \cdot m_r = C_{sk} \cdot m_{sk} + C_c \cdot m_c \tag{2}$$

Where:

$C_r,\ C_{sk}$ and C_c are the mass fraction of fat in the raw milk, skimmed milk and the high fat cream stream.

$m_r,\ m_{sk},\ m_c$ are the mass flow of the raw milk, skimmed milk and the high fat cream stream.

And the fat regulation component mass balance becomes:

$$C_{sk} * m_{sk} + C_c * m_c = C_c * m_{surplus} + C_{fs} * m_{fs} \tag{3}$$

Solving for the concentration of fat regulated stream (C_{fs}):

$$C_{fs} = \frac{C_{sk} * m_{sk} + C_c * (m_c - m_{surplus})}{m_{fs}} \tag{4}$$

Rewriting the difference between the high fat stream (m_c) and the surplus stream ($m_{surplus}$) into a split factor A:

$$C_{fs} = \frac{C_{sk} * m_{sk} + C_c * m_c * A}{m_{fs}} \tag{5}$$

Ultra-filtration

After regulating the fat content, the skimmed milk is passed trough a ultra-filtration membrane for up-concentration of the protein content, by regulating the lactose and water content. A possible process control unit of the membrane would be a feedback controller of the viscosity of the retentate. A ultra-filtration membrane is a porous membrane which discriminate compounds based on a pressure gradient to a varying degree, based on the compounds density, molecular size, volumetric size as illustrated in figure 4.

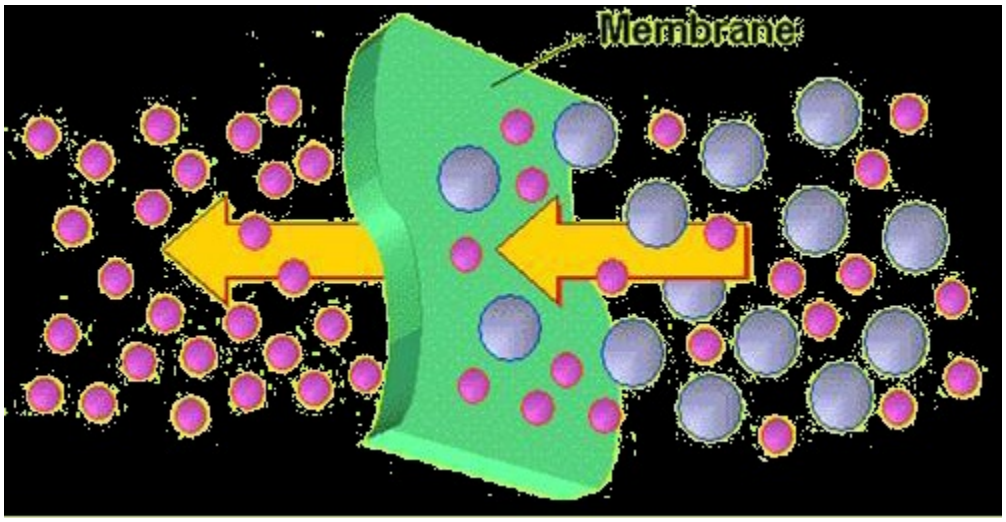


Figure 4: Principle of a semipermeable barrier in a membrane

In the case of milk it is the volumetric unit size and molecular size that becomes the important discriminating factor, where the molecular weight of water is 18 g/mole and 342 g/mole for lactose, whereas the fat-globules are in the range $10^{12} - 10^{14}$ g/mole, the casein-micelles in the range: 10^7-10^9 g/mole and the whey proteins in the range: 10^4-10^5 g/mole. The salts will also leave in the permeate stream as a result of small molecular size and water affinity. A membrane consist of the inlet flow and the outlet flows permeate and retentate. The permeate stream is the flow that is on the opposite side of the membrane of the feed stream, whereas the retentate stream is the residual stream that did not penetrate the membrane layer.

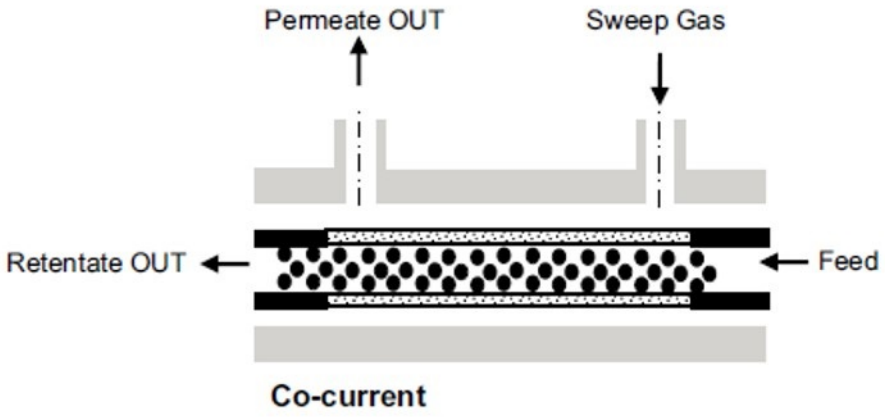


Figure 5: Schematic presentation of a co-current membrane module

All liquid membranes, like ultra-filtration membranes have a co-current flow pattern, as illustrated in figure 5 from Geankoplis [12]. In gas separation membranes one also may use a sweep fluid to lower the potential on permeate side of the desired component. Since the trans membrane transport of liquid is governed by the pressure gradient and not a component potential gradient the sweep losses its purpose and is only used in gas separation. Transport over the ultra filtration membranes is commonly described by Darcy's law. Darcy's law describes the ability of one fluid to penetrate a solid material based on a trans membrane pressure gradient (TMP), as presented in equation 6. The flux (J), trans-membrane pressure difference and the membrane area are the normal parameters used to adjust to obtain the required separation. The TMP is the sum of the hydro-static pressure difference between the feed and the permeate, subtracted by the osmotic pressure difference of the feed and the permeate ($\Delta\pi$).

$$J_i = A_i \cdot (\Delta P - \Delta\pi) = A_i \cdot (\frac{P_f + P_0}{2} - P_p) = \frac{\kappa_i \cdot (P_{TMP})}{\mu \cdot L} \tag{6}$$

Where:

J_i is the flux of component i over the membrane.

P_f is the feed pressure.

P_0 is the retentate pressure.

P_p is the permeate pressure.

P_{TMP} is the trans membrane pressure gradient.

A is the permeability constant of i.

κ is the intrinsic permeability constant of i, m^2.

μ is the dynamic viscosity of the solution, Pa s.

L is the membrane thickness, m.

Since water, lactose and ions are considerably smaller than the other milk constituents, this makes them the most abundant compounds of the permeate. For modern UF membranes the water single component flux at 50 kPa trans membrane pressure is 500 l/m^2 h [6].

The milk viscosity is approximately 1.04 cp which is slightly higher than the water viscosity. The milk viscosity is dependent on the non-fat solid content and the fat content of the milk. The permeability constant is mainly dependent on the molecular diameter of the component, as the trans membrane transport is a physical phenomenon. the diameter of ultra filtration membranes are in the range 1-50 nm.

$$\kappa = \frac{\nu \cdot L}{\mu \cdot P_{TMP}} \tag{7}$$

The liquid rentention is an other parameter, used to monitor the membrane performance. The liquid retention is a fractional measure of how much of the feed stream that is collected in the permeate stream.

$$R = \frac{C_F - C_P}{C_F} \tag{8}$$

Where C_F is the feed composition of solid matter and C_P is the solid matter composition of solid matter in the permeate stream.

From the equations above the regulating effect is the membrane area and the pressure difference, where a larger membrane area increases the total mass transfer and an increased pressure difference induces the flux. Over time the flux of the membrane is decreased as a result of fouling, which can be counteracted by increasing the pressure gradient.

To describe the ultra filtration membrane performance, the needed parameters are: the feed stream composition and amount, the ideal composition of the permeate and retentate stream, the area of the membrane, the permeability constant of one component.

The stream that leaves the retentate stream is the water and lactose reduced skimmed milk. The maximum level of water removal is based on viscosity, where the milk becomes too viscous to be easily handled and a lower water content decreases the yield of the pasteurization, which is the last step in the pre-treatment.

Pasteurization

Pasteurization it is done to remove potential microbial contaminants in the raw milk. There are three types of pasteurization: flash, batch and ultrahigh temperature (UHT). The flash method is heating the milk to 71.6 ° C for 15 seconds, and is the most used method for large scale cheese production. The batch method is heating the liquid

to a temperature of 63-66 ° C for 30 minutes. Since the operating temperature of the flash method is the highest is the most effective method against more resistant pathogens. Due to the short exposure of high temperature the flash method also yields the highest processed milk quality. Both methods inactivate most viruses and destroy the vegetative stages of 97 % and 99 % of fungi and bacteria that does not produce endospores or are thermoduric. The ultrahigh temperature pasteurization the most extreme pasteurization and heats the liquid to 134 °C for 2 to 5 seconds. The main difference is that the UHT method also removes all types of microbes and gives a sterile milk, but give a lower production yield[22].

The side effect of pasteurization are the degradation processes of the Mailllard reactions. The Maillard reactions converts sugar and amine groups to the Amadori compounds and is induced by decreased water content. The Amadori compounds in the milk can be recognized as a brown and dark substance [5].

2.2 Acidification

The acidification phase is initiated by heating the pretreated milk to 15-50 ° C and inoculating a starter culture. For Norwegian semi-hard cheeses the optimum temperature for the entire production is 30 ° C and the acidification require approximately 30 min for completion [17]. The purpose of the acidification is to create a substantial biomass of the different microbes and bring the pH down to the optimum clothing pH for the rennet action. The main bacterias in the starter culture are of the type Lactic Acid Bacteria (LAB) which are homofermentative lactic acid producers, which produces biomass as their main product and lactic acid as the secondary product, in the following mass balance.

Anaerobic glycolysis of lactose

$$C_{12}H_{22}O_{11} + b_1 \cdot H_g N_i \rightarrow c_1 \cdot CH_\alpha O_\beta N_\delta + d_1 \cdot CO_2 + e_1 \cdot H_2O + f_1 \cdot C_3H_6O_3 \tag{9}$$

The equation assumes aerobic fermentation of lactose as carbon source [9]. b_1 is the molecular ratio between lactose and the nitrogen source. The most significant nitrogen compounds in milk is the protein and the most accessible nitrogen source is non-protein-nitrogen (NPN). c_1 is the ratio produced biomass and the fermented lactose. In Norwegian cheeses the starter culture primarily consist of the four homofermentative lactic acid bacteriums: *Lactococcus lactis*, *Lactococcus cremoris*, *Lactococcus diacetylactis* and *Leuconostoc cremoris*, as well as different types of mold and yeast. A homofermentative LAB bacteria produce lactic acid as its primary by-product, whereas a heterofermentative LAB produces CO_2 and ethanol/acetic acid as well as lactic acid. The two first mentioned

bacterias are lactic acid producing and the two last bacteria strains are aromatic compounds producers. The starter culture of different cheeses contain varying ratios of the strains and is added to the pretreated milk in the ratio 1-2 % of the amount milk. At addition the starter culture is at a cellular concentration greater than 10^8 cells/ml [17].

After the inoculation of the starter culture the pH rises due to the growth phase of the LAB, shown as region A $\rightarrow$ B in figure 6. As the pH decreases the production of lactic acid will be more and more inhibited until the pH-boundary is reached and the bacterias stop fermenting lactose into lactic acid. The growth of the LAB will be subjected to a non-competitive inhibition and eventually enter the stationary phase as a result of the low pH. The LAB typically enters the stationary phase at pH values of 4.8-4.2. In the starter culture there are types of molds and yeast that ferment on lactic acid and protein. The response of of the lactic acid fermentation and the protein breakdown products causes the pH to decrease, illustrated as the region B$\rightarrow$ C in figure 6. The lactic acid fermentation is anaerobic and is described as the following relation.

$$C_3H_6O_3 + b_2 \cdot H_gO_hN_i \rightarrow c_2 \cdot CH_{\alpha 2}O_{\beta 2}N_{\delta 2} + d_2 \cdot CO_2 + e_2H_2O + f_2 \cdot protein\ breakdown\ products \quad (10)$$

This gives a synergy effect between the LAC and the molds and yeasts in the starter culture. This creates an fluctuation of the pH at the LAC upper pH bond. The milk enters the final phase of the acidification, when all lactose have been fermented. Now the molds and yeast are accompanied by proteolytic bacterias to increase the pH to the matured pH value, as an result of fermenting the lactic acid and neutralizing effect of the protein breakdown products. The final phase is shown i figure 6 as region C$\rightarrow$ D. The acidification phase is completed at different pH, dependent on the pretreatment of the milk. If the milk is preheated and cooled prior to acidification the phase is finished at a pH of 6.6 [10] if the milk is not preheated the same equilibrium pH approximately decreases to 5.6 [15]. The preheating creates an denaturation of the micelle hairs, resulting in a lowered pI to start the coagulation phase. The addition of the rennet may be added after the pH reaches pI to inhance both the effect of the rennet enzyme efficiency and casein clotting yield.

$$b_1 = \frac{n_{H_gN_i}}{n_{C_{12}H_{12}O_{11}}} \quad (11)$$

$$c_1 = \frac{n_{1\ CH_\alpha O_\beta N_\delta}}{n_{C_{12}H_{12}O_{11}}} \quad (12)$$

$$d_1 = \frac{n_{1\ CO_2}}{n_{C_{12}H_{12}O_{11}}} \quad (13)$$

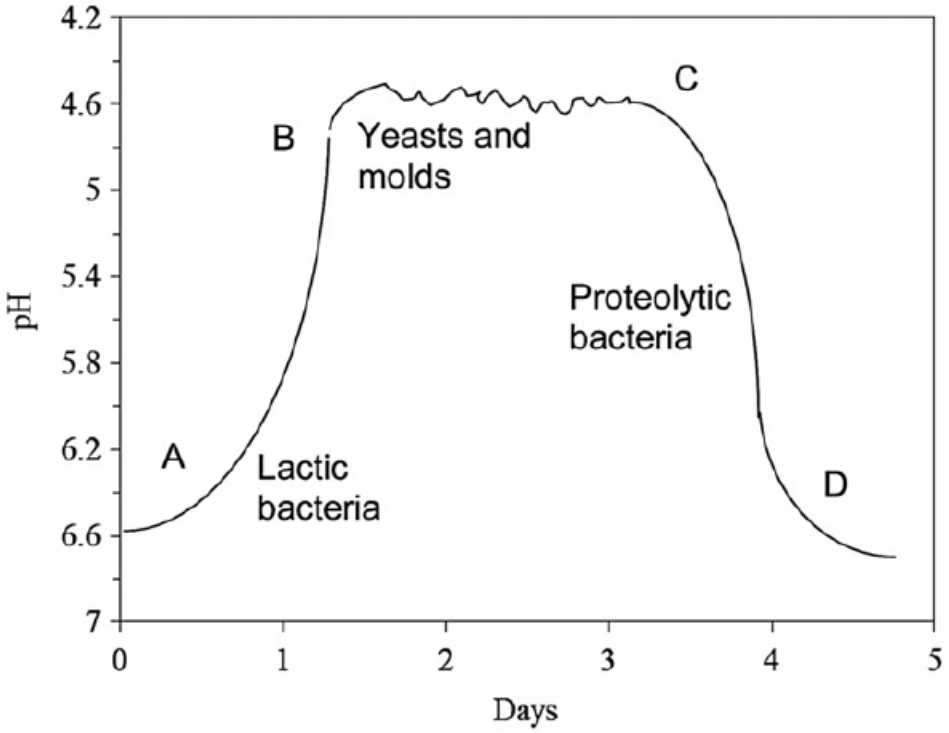


Figure 6: Natural fermentation cycle of raw milk

$$e_1 = \frac{n_{1\ H_2O}}{n_{C_{12}H_{12}O_{11}}} \tag{14}$$

$$f_1 = \frac{n_{1\ C_3H_6O_3}}{n_{C_{12}H_{12}O_{11}}} \tag{15}$$

In literature the acidification is finished when a certain pH of the broth is reached. pH therefore becomes of high interest in controlling the broth. The acidification is the most important phase for the texture and taste of the cheese [15].

Using the Henderson Equation to determine the lactic acid productions influence on the pH.

$$pH = pka_{buffer} + log_{10}\frac{[A^-]}{[HA]} = pka_{buffer} + log_{10}\frac{[buffer] - [HA]}{[HA]} \tag{16}$$

Where [A^-] and [HA] are the conjugate base and acid concentration of the total buffer concentration ([buffer]), which is related to the amount of citric acid and casein present in the milk [25]. If the use of micro or ultra filtration is increased, this will results in an increase in the buffer intensity yielding a longer fermentation time to

reach the desired coagulation pH and a higher biomass and lactic acid concentration. If the produced lactic acid [P] is assumed to be a strong acid in the first stage the change in pH becomes:

$$pH([P]) = pka_{buffer} + log_{10}\frac{[A^-] - [P]}{[HA] + [P]} \tag{17}$$

Initially the lactic acid concentration is negligible and can be defined as zero.

The evolution of lactose, biomass and lactic acid can be described with by the Monod Equation:

$$\frac{d[B]}{dt} = \mu[B] \tag{18}$$

Where d[B] is the change in biomass concentration (g/l) over a change in time dt. μ is the reaction rate (h$^-$1). By differentiating, integrating and solving the Monod with respect to the new biomass concentration of the expression becomes:

$$[B] = [B]_0 \cdot e^{\mu \cdot t} \tag{19}$$

For the LAB *Lactobacillus Helveticus* in acidic whey (pH 5.5) with lactose as limiting substrate (3.48 g/l) the biomass to substrate yield ($Y_{B/S}$ is 0.17 g/g and the lactic acid to substrate yield ($Y_{P/S}$) of lactose equal 0.83 g/g. The maximum biomass rate (μ_{max}) is 0.94 h$^-$1 [26].

After the fermentation time t the biomass has increased by d[B], which yield the new substrate- ([S]) and lactic acid ([P]) concentration to full fill the mass balance in following way.

$$Y_{P/B} = \frac{Y_{P/S}}{Y_{B/S}} \tag{20}$$

Where $Y_{P/B}$ is the lactic acid to biomass yield, g lactic acid formed/ g biomass formed.

$$[S] = [S]_0 - \frac{d[B]}{Y_{B/S}} \tag{21}$$

$$[P] = [P]_0 + d[B] \cdot Y_{P/B} \tag{22}$$

The formation speed (μ) in equation 19 is the local formation speed and is dependent on the lactose concentration and the pH of the solution.

$$\mu = \mu_{max} \cdot \frac{[S]}{[S] + K_m} \cdot \frac{K_p}{[H^+] + K_p} \tag{23}$$

Where K_m is the half saturation constant of biomass and is assumed identical the half saturation constant of lactic acid (K_s), which is 0.22 g/l [26]. The K_p is the non competitive inhibition constant. The maximum speed of reaction in Øyaas's experiment was dependent on the lactose availability and the milk used in cheese production is much more rich in lactose, meaning that the speed of reaction considrable higher than in the lactose dilute of the whey solution. In order to extrapolate a speed of reaction for the condensed milk it is assumed that the maximum growth speed is:

$$\mu_{max,\, milk} = \mu_{max,\, whey} \cdot (\frac{[S]_{0,\, milk}}{[S]_{0,\, whey}})^n \tag{24}$$

Where n is an value between 0 and 1. At n= 0 the μ_{max} is independent of the lactose concentration and n=1, the μ_{max} is linearly dependent on the lactose initial concentration. For further information on the computational part look in the material and methods or in the results.

2.3 Coagulation

The coagulation consists of the three phases: destabilization, enzymatic hydrolysis end clotting. The coagulation phase is initiated by addition of rennet to the cheese vat in stirring configuration. After the rennet has been evenly distributed, the stirring is stopped to allow the casein-micelles to start coagulating. The addition of rennet initiates the hydrolysis of the κ-casein, which is primarily found at the surface of the casein micelles. The hydrolysis of the κ-casein exposes the calcium-sensitive and hydrophobic casein fractions (α_{s1}, α_{s2} and β) [15], of that reason calcium chloride is added to the vat to counteract the calcium related destabilization. The exposure of the other casein fractions reduces the negative charge on the micelles, causing a destabilization, which ends phase one. $CaCl_2$ is added in the amounts of 5-20 g/100 kg of milk and single-strength rennet is added in the amount of 100-200 ml/ 1000 kg milk. The addition of calcium chloride gives a constant coagulation time and increases the firmness of the coagel and reduces the amount of rennet needed [4]. By increasing the solid content of the milk, the availability of rennet increases, causing a further decrease in rennet use, which can be achieved by the ultra filtration membrane process.

The second coagulation phase starts when the rennet action of facilitating the proteolysis of the casein, is the main process. The hydrolysis follows typical Michaelis-Menten kinetics and has an optimum temperature and the pH

of the solution of 30 °C and 6-6.4 [20]. The rennet action is highly dependent on pH and especially temperature and is therefor crucial for achieving adequate yields. The rennet mainly targets the κ-casein, but to a lower degree hydrolyses α_{s1}- and to an even lower degree the hydrolysis of β- casein [15]. The third phase is when the casein micelles start to aggregate and forming a coagel of the milk. In figure 7 the coagulation reaction mechanism is illustrated. The formation of enzyme-casein-water complex is the first phase, the formation of the enzyme-product complex and the final phase is the formation of free enzyme (E) and coagulated casein (P).

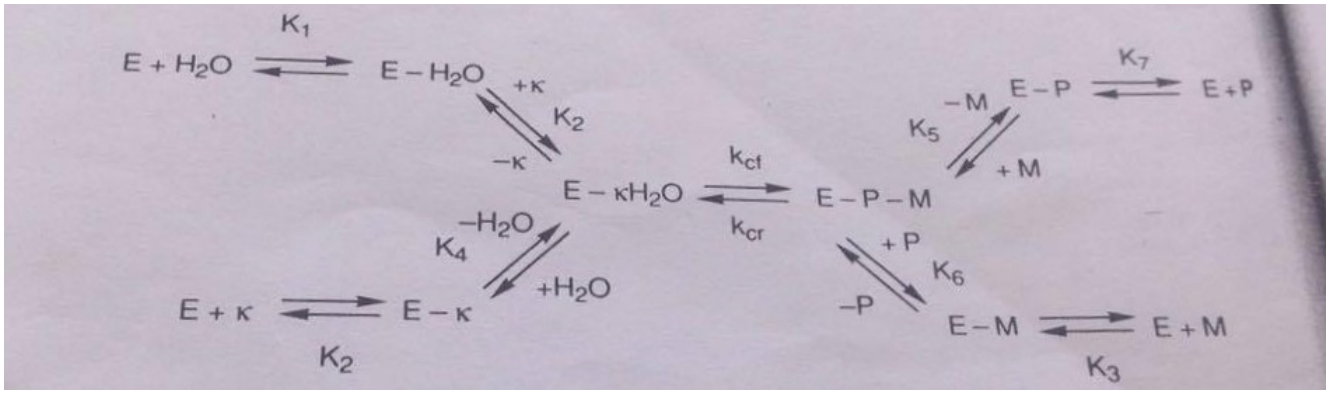


Figure 7: Scheme of the complete enzyme coagulation mechanism of milk

When the coagulation is completed, the curd has reached a desired firmness (CF). The coagel is then ready to be cut into small rims, to start liberating whey. The coagel rims of Norvegia are cut into 1 cm^3. Smaller rims liberate more whey, yielding a drier cheese. To cut the coagel, the stirring unit rotates in the opposite direction as of the stirring mode.

For the semi-hard cheese the needed coagulation time is approximately 30 minutes and the sensorial degree of coagulation can be related to the curd firmness in the 4 parameter asymptotic model of Bittante et al. (2013) [2].

$$CF(t) = CF_P \, (1 - e^{-k_{CF}(t-RCT)}) \cdot e^{-k_{SR} \, (t-RCT)} \tag{25}$$

Reformulating the equation:

$$CF(t) = CF_P \, (1 - e^{\, k_{CF} \, (RCT-t)}) \cdot e^{\, k_{SR} \, (RCT-t)} \tag{26}$$

Where:

CF(t) is the curd firmness at time t, mm.

CF_P is the asymptotic potential curd firmness, mm.

k_{CF} is the curd-firming instant rate constant, %/min.

k_{SR} is the curd-syneresis instant rate constant, %/min.

RCT is the rennet coagulation time, min.

t is the time, min.

The model describes how the curd firmness is related to time, where the initial response after addition of rennet is to start hydrolysing casein, causing a flat area. When the time reaches RCT, the effect of the curd-firming instant constant causes an increasingly degree of firmness up to a maximum value (CF_{max}) as a result of the coagulation and aggregation. After reaching maximum firmness, the firmness start to decline. The decline in firmness is the effect of the curd-syneresis, and the expulsion of whey, causes the firmness to prevail. The curd-firming instant rate constant is illustrated in figure 8. Due to the curd-syneresis instant rate constant the maximum firmness is always lower than the potential curd firmness [2].

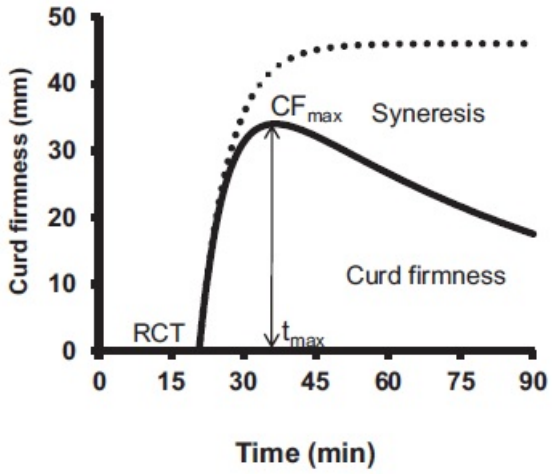


Figure 8: Modelling of curd firmness (CF) at time t, with the RCT and CF_{max} marked out and the asymptotic evolution without the presence of syneresis.

The relative curd firmness is directly dependent on the level of coagulation yield, but the curd fimness may vary between the types of cheeses and the used rennet and rennet concentration.

During the coagulation the fermentation continues in the same manner as for the acidification.

2.4 Dehydration

After the cutting is completed the vat is left for some time to settle. This is due to the low degree of firmness in the coagel and the cutting should therefor start calm and increase the intensity over time.

First drain

After the cut coagel has rested the first drainage of whey starts, with stirring the vat until the rapid whey release subsides [13]. The discharge of whey makes space for adding of water, to regulate the lactose content of the curd. The first drainage is also a step conducted to save energy for the upcoming heating. Typically 30 % of the bacth volume is removed in the first drainage [4]. Davidau (2000) [7] did experiments describes the draining as function of time and yielded a four parameter exponential decay function (equation 27).

$$W(t) = W_1 \cdot (1 - e^{-\frac{t}{\tau_1}}) + W_2 \cdot (1 - e^{-\frac{t}{\tau_2}}) \tag{27}$$

Where:

t is time, min.

W(t) is the fraction of whey removed from the vat at time t, g whey/ kg total.

W_1 and W_2 are the weight fraction constants of two known time states (τ_1 and τ_2).

The final expression of draining becomes:

$$m_{whey}(t) = m^0_{whey} - \frac{W(t) \cdot m^0_{tot}}{10^3} \tag{28}$$

Where:

m^0_{whey} and m^0_{tot} are the initial amount of whey and total mass in vat, kg.

Equation 28 is general and is possible to use for all atmospheric whey drainage.

The experimental kinetics is based on an initial milk amount of 2 kg raw milk, and are presented in table 2.

Table 2: Drainage kinetics for various states

CN	-1		+1	
IS	-1	+1	-1	+1
Mesophilic				
W_1 (g)	893	868	934	816
$3\tau_1$ (s)	53	518	93	182
W_2 (g)	827	810	757	857
3τ (10^3 s)	10.25	13.58	10.11	9.40
W_1+W_2	1720	1678	1691	1643
g_{water}/g_{casein}	2.67	3.02	2.35	2.96
Thermophilic				
W_1 (g)	1403	1305	1443	1304
$3\tau_1$ (s)	16	56	31	36
W_2 (g)	381	482	333	453
3τ (10^3 s)	5.58	6.90	6.32	8.41
W_1+W_2	1784	1787	1776	1757
g_{water}/g_{casein}	1.55	1.88	1.47	1.70

The 3τ values are the times required to drain 95 % of the given drain amount (W). CN is the casein concentration (casein-nitrogen) (g/kg) of the raw milk in the two scenarios 27 g/kg (-1) and 36 g/kg (+1) and IS is the ionic strength with the two scenarios are 1 M (+1) and 0.6 M (-1) of the milk curd prior to drainage [7].

Stirring:

To obtain the correct level of evolution of microbial activity and acidity there is possible to utilize a stirring after the first drain. The built model does not have this function, as this stirring is meant as an adjustment tool if needed. This adjustment is omitted because the level of accuracy will not be precise enough and the model is to be considered as a shortcut model rather than a definite model.

Heating

After draining of the main whey and obtaining the correct microbial activity and acidity the heating of the curd starts. During the heating the temperature increases, which eventually kill the lactic acid bacterias initiating the lysis of LAB and exposure of intracellular enzymes for the maturing. The temperature of the vat has after the addition of the starter cultures been the ideal growth temperature of 30 ° C. To heat the curd, hot water and/or steam is added to the vat. The addition of water regulates the acidity and the higher the heating temperature becomes, the lower the water binding affinity of the curd becomes, which decreases the water content of the final cheese. The heating is normally conducted with a heating slope of 0.2-0.5 °C/min until the correct temperature is reached. Mesophilic bacterias are retarded at 37-38 °, devastated at temperatures above 44 ° and killed at 52 ° if

held there for 10-20 minutes [4]. The heating slope of the model simplified by assuming that the addition of hot water to the system is an isentropic process, meaning that the system is assumed adiabatic, where external heating compensates for the heat-loss to the surroundings.

$$Q_H = Q_C \tag{29}$$

where Q_H is the hot water, heating the system and Q_C is the curd, consisting of the whey solution and the coagel.

$$m_{water,\,hot} \cdot CP_{water} \cdot \Delta T_H = \sum_{n=1}^{i=2} m_i \cdot CP_i \cdot \Delta T_C \tag{30}$$

where:

Q_H consist of the mass of water, the heat capacity of water and the temperature difference (ΔT_H) between the equilibrium temperature and the temperature of the hot water.

The right side consist of the sum of the corresponding masses, heat capacities and temperature difference of the coagel and the whey solution. Where the ΔT_C is the temperature difference between the cold system and the equilibrium temperature.

The unknown quantity of equation 30 is the mass of hot water and the equation is therefore solved with regard to the mass of the hot water.

$$m_{water,\,hot} = \frac{\sum_{n=1}^{i=2} m_i \cdot CP_i \cdot \Delta T_C}{CP_{water}\ \Delta T_H} = \frac{m_{whey} \cdot CP_{whey} + m_{coagel} \cdot CP_{coagel}}{CP_{water}} \cdot \frac{T_{scalding} - T_c}{T_h - T_{scalding}} \tag{31}$$

Equation 31 is the total sum of the entire heating and the equilibrium temperature is therfore equal the scalding temperature.

Cooling

After the heating is conducted some cheeses are cooled down by adding cold water which increases the water binding affinity yielding a more soft cheese with higher water content. The after cooling is not done for Gouda and Swiss type cheeses and is therefore excluded from the model.

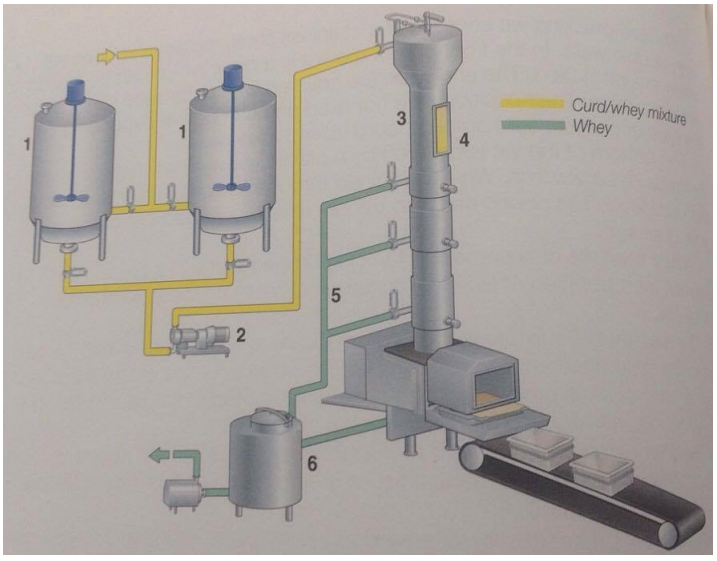
Second drainage

When the curd has reach its desired texture a second drainage of whey is done, to liberate more whey from the curd. The second drainage is the last operation in the vat and is done to downsize the scale of the drainage columns used to give the curd a cheese looking appearance. The second drainage usually ends when the curd to whey ratio

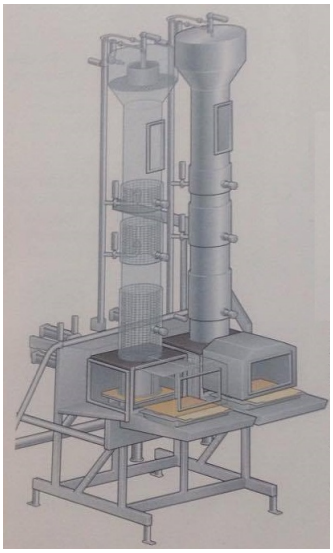
is 3.5-5 [4]. By monitoring the inlet amount and the drained amount, the ratio can be calculated from the mass- and component- balance identical to the First drain, using the four parameter model of Daviau et al (2000) [7].

2.5 Molding and shaping

After removing the redundant whey in the second drainage, the curd is pumped into a drainage column. In the column the dry-mass concentration increases as the whey is continuously removed from the curd, based on decanting with plates, illustrated in figure 9a and 9b [4]. In the drainage column the curd begins to look like a cheese. When the correct dry-mass concentration is reached, typically 35-50 w% dry-mass, the column cuts the cheese into desired sizes into a plastic mold[7].



(a) Whey drainage system



(b) whey drainage column illustration of the perforated sections

Figure 9: Illustration of a whey drainage system, where a gives the entire system and b gives the column it self

Before the curd/ whey mixture is drained it is feed to a buffer tank that maintain mixture a homogeneous dispersion of curd. Figure 9a the buffer tank is numbered 1, 2 is the positive feed pump, 3 is the drainage column, 4 is a sight glass, 5 are the whey drainage streams and 6 is the whey collection tank. The two figures also display that the shape of a cheese is based on which mold the curd is filled into, making it round, rectangular or cylindrical.

2.6 Salting

Salting is done for multiple reasons: to prevent unwanted contaminants in the cheese, drain out residual lactose and whey, to nourish the inoculated microbes in the ripening phase, but mainly to increase the salt concentration and induce flavor and texture of the cheese. Norvegia need a brining time of approximately 1 day, and is therefore the second most time consuming production phase after the maturing.

The salt transport is possible to describe using Fick‘s law of unidirectional mass transfer, from the interpretation of Fick‘s equation of unsteady mass transfer [11]:

$$\frac{\delta C}{\delta t} = \nabla(D \cdot \nabla(C(x,t)) \tag{32}$$

Where C is the ionic concentration of Na and Cl in the cheese (mol/kg), t is the time (h) and D is the effective diffusion coefficient of NaCl in the cheese (m^2/s).

For semi-hard cheeses the diffusion coefficient are found in the range: 2.8-4.2 10^{-10} m^2/s [11, 19]. By considering the diffusivity to be constant and the unidirectional mass transfer along the x-axis equation 32 becomes:

$$\frac{\delta C(x,t)}{\delta t} = D \cdot \nabla^2(C(x,t)) \tag{33}$$

The initial conditions then becomes:

t = 0 C(x,t) = C_0

where C_0 is the initial concentration of Na or Cl in the cheese at a distance x from the surface. Further it is assumed that the salinity of the saltwater remain constant during the mass transfer period, as the volume of brine is sufficiently larger than the volume of cheese and the concentration at the cheese surface is equal to that of the brine, yielding the boundary conditions:

t>0 C(0,t) = C_s and C(∞,t) = C_0

The response expression of the mass transfer then becomes [11]:

$$\frac{C(x,t) - C_s}{C_0 - C_s} = erf(\frac{x}{2\sqrt{D \cdot t}}) \tag{34}$$

Where C(x,t) is the concentration in the cheese at a distance from the surface and a given time, C_s is the salt-bath concentration and C_0 is the initial concentration. The output can be described either 2 dimentional in a concentration over distance plot of several time as Floury et al. (2009) [11] did or by creating a 3 dimentional plot of the concentration relative to the position and time plot as shown in figure 10.

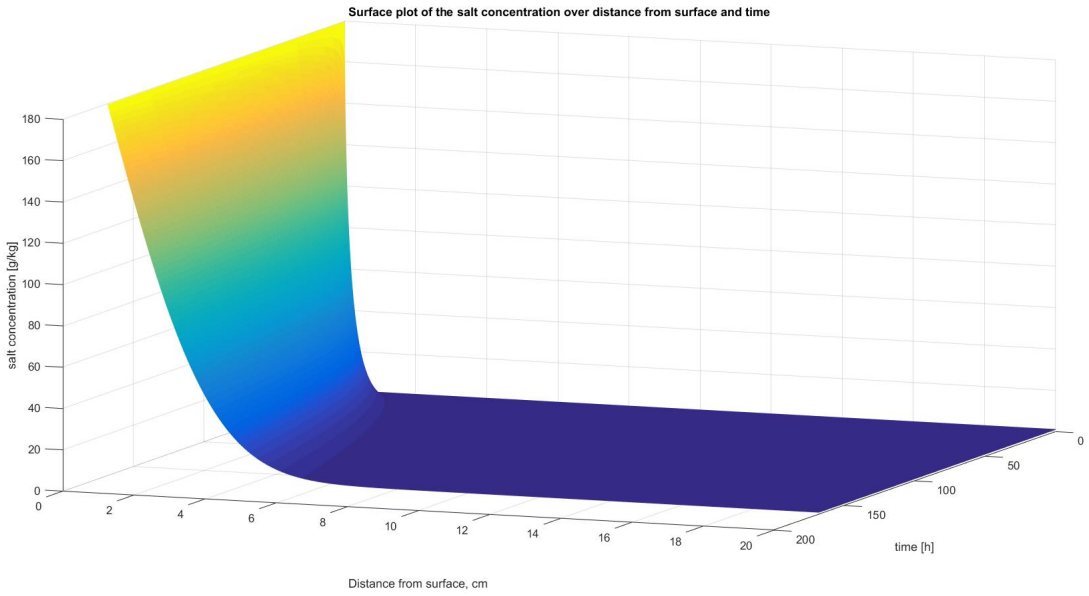


Figure 10: Salt diffusion of an unsalted cheese with an radius of 20 cm over a brining time of 200 hours.

The concentration profile is found by solving the error function response with respect to the salt concentration over time:

$$C(x,t) \;=\; C_s \;-(C_s - C_0)\cdot erf(\frac{x}{2\sqrt{D\cdot t}}) \tag{35}$$

In semi-hard cheese the typical salt concentration is 1.3-1.5 and an solid content of 55-60 % [13], which can be related to determine the required brine bath-time.

2.6.1 Diffusion coefficient and cheese size and shape

The diffusion coefficient D is mainly dependent upon the intensive variables: cheese pH, initial salt concentration, temperature, water-, fat- and solid non fat concentration [11]. The diffusion coefficient increase for the increased temperature as a result of the increased specific enthalpy. Since the diffusion of the salt is conducted by the water in the cheese, the diffusion coefficient is parallel dependent on the water concentration. The initial salt concentration influence the texture and structural properties of the cheese, where the geometry of the casein network is changed by reducing the initial salt concentration. A low initial salt concentration will increase the hardness and cohesiveness of the casein network and lower the adhesiveness of the cheese, yielding a more encapsulated cheese and a reduced potential for diffusion [11]. The pH dependency is more under debate, where Floury et all (2009) [11] reports the dependency as that a more alkaline cheese has a higher diffusion coefficient than an acidic cheese as result of the degree of swelling, where an alkaline cheese is more swelled and therefore has a more open structure

that reduces the facilitation resistance. Whereas [4, 13] describe the opposite dependency, where a more acidic cheese has a higher diffusion rate than an alkaline cheese.

The diffusion rate is dependent on the diffusion coefficient and the extensive variables of the cheese: volume, mass and geometry. Where a small and slab shaped cheese, like Norvegia need less brining time than a large spherical cheese, due to the surface to volume ratio.

2.7 Ripening

Ripening is the final stage of production and remain manly a logistics problem, since the phase take up a lot of space. As the ripening is storage of the cheese to make the microbes multiply and produce a secondary compounds to create the distinguished taste of the cheese. Cheese ripening is in general divided into maturing mechanisms based on the macro nutrients.

Metabolism of residual lactose and catabolism of lactate and citrate

The metabolism of the residual lactose and citrate is important for the final acidity of the cheese, especially in soft cheeses like Camembert.

Lipolysis and Catabolism of Fatty acids

Lipolysis is the process of catabolising the cheese fat into free fatty acids. The lipolysis is a process governed by esterases. The esterases are produces as a metabolic by-product by LAB and propioni bacterias. The main difference between the LAB and propioni bacterias are that the LAB bacterias only produce esterases intracellular and need to die and lyse in order to release esterases, whereas the propioni bacterias produce esterases both intracellular and extracellular. Dherbe´Court et al. (2010) [8] proved that the formation of free fatty acids is a delayed response to the growth curve of propioni bacterias in the ripening phase, shown i figure 11.

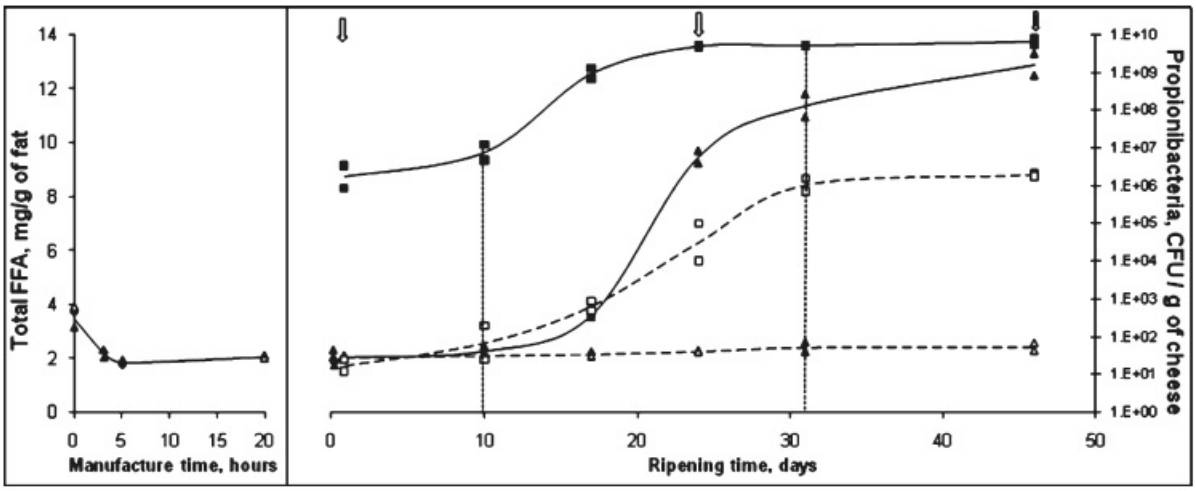


Figure 11: Free fatty acid and propioni bacteria formation during the ripening of Swiss cheese

In figure 11 day 0-10 was cold room ripening (12 ° C), 10-30 days warm room ripening (24 ° C and 30-45 was cold room ripening (4 ° C). Figure 11 clearly states the importance of temperature in the formation of free fatty acid in propioni bacteria containing cheeses, like Jarlsberg.

Proteolysis and Amino Acid Catabolism

Proteolysis is the process of cutting the casein molecules into amino acids and smaller protein units. Zorrilla and Rubiolo (1997) did an analyis on the kinetics of proteolysis of the casein [24]. They found the proteolysis kinetics of the semi-hard Fynbo cheese to be mainly influence by the remaining rennet and therefor follows first order kinetics:

$$C(l, r, t) = C_0 \cdot e^{-k_{lr} \cdot t} \tag{36}$$

Where:

C(l,r,t) is the concentration at the slice region l (height from core), r is where on the slice l the measurement is conducted (distance from core) and t is the time after ripening has started.

C_0 is the initial concentration of the ripening and k_{lr} is the decay constant in region l, r.

Since the rennet has a much stronger affinity to alfa s1 it detected that only alfa s1 casein was subjected to a measurable catabolic activity. The Fynbo cheese is a small and cylindrical semi-hard cheese with large grit size and a short ripening time.

In order to reduce the ripening time multiple strategies have been purposed:

Elavated Storage Temperature

Increasing the ripening temperature has been tested on Cheddar with two approaches. The first approach is to increase the ripening temperature permanent, by less than 10 ° C. This method yielded a decreased ripening time with approximately 60 % without altering the wanted body and texture at an elevation of 12 ° C [10]. The second method is to mature the cheese at reducing level of elevated temperature. Starting with a cycle of 20 ° C for 1 week, 12 ° C for 6 weeks, followed up by the normal temperature 8 ° C for 8 months, reducing the ripening time by 2 months. This ripening time reducing method is only possible on pasteurized milk and for cheeses with an simple LAB micro-flora, like hard and semi-hard cheeses like Cheddar, Edam and Gouda.

High-Pressure Processing

Several publications have shown indications of conducting the ripening of young cheeses at ultra-high pressure (10-100 MPa) can induce the maturation speed. To perform this method the cheese can only be held at ultra high pressures over a short time-frame. The elevated pressure increases the cell break-up speed. The cell lysis releases intracellular enzymes at an earlier time than to wait for the cells to die by other reasons. The release of intracellular enzymes increases the proteolytic and flavor activity [10].

3 Materials and methods

Raw milk

To create a realistic initial point, the composition of milk from Norwegian red is used. Norwegian red is the dominant breed in Norway for milk production and is a hybrid between traditional Norwegian cattle with high milk quality and Swedish Holstein, where Holstein is the dominant breed in Norwegian red (NRF). In the file Raw__milk.m the values of the milk composition is from Kirsti Hagenes book ”Production of dairy products” [13] and the composition of the protein is found in ”Biochemisty of Foods” [10].

Separator

The separator is only constructed as a mass balance, under the assumption that the raw milk is a fat in solids enriched water emulsion, meaning that the ratios between the other components are identical in the raw milk, skimmed milk and the high fat cream. It is further assumed that the composition of the raw milk, skimmed milk and high fat cream remain constant and that the PLS system is working correctly in order to yield a fat mass fraction equal to the mass fraction of casein in the fat regulated milk [4]. The separation process consist of the two

functions separator.m and sep__mass__balance.m. separator.m contain composition of the high fat top side stream and the skimmed milk stream extracted in the bottom of the separator. sep__mass__balance.m calculates stream flows and compositions to full-fill the mass balance.

Ultra filtration

The ultra filtration unit is not an crucial unit for the cheese quality, but rather a mater of reducing the energy consumption and equipment sizing. To define the membrane permeability accordingly to Darcy‘s law a known water flux at a given trans membrane pressure (TMP) was used as a basis [6]. Further the other permeability constants where constructed relative to numerics of an ultra filtration mass composition of Norwegian milk [13]. The program is defined to construct the needed membrane area to yield a desired casein mass fraction of the retentate stream with an initial raw milk stream, inlet membrane pressure, retentate pressure and permeate pressure at a given mass flow of raw milk. The system start with defining the permeability constants, thereafter an iteration to obtain the required casein mass fraction and membrane area start at a fixed liquid retention (theta) of 50 %.

Pasteurization

The pasteurization unit conducts a flash pasteurization of the milk, assuming that the pasteurization yield is 100 %. It is also assumed that the heat requirement to maintain the flash temperature is negligible compared to the heat requirement to reach the flash temperature of 71.6 $^{\circ}$ C. The pasteurization is found in the file: pasteurizer.m.

Acidification

The acidification is the main fermentation phase and is simulated a consisting of an addition of a mono-starter-culture of *Lactobacillus Helveticus*-strain and it‘s fermentation kinetics [øyaas]. To simulate the fermentation a modified version of the Monod-equation is used. The modified Monod equation assumes a non-competitive inhibition of and decreasing pH [3]. The needed fermentation time is calculated as the sum of all time iterations, as the system iterate the change in composition over a short period of time and updates the mass balance to check if the coagulation pH is reached. When the coagulation pH is reached the for loop is terminated and the acidification is completed. To calculate the pH of the broth the Henderson-Hasselbach equation is used with a theoretical milk buffer capacity with a pka of 5.5 and a buffer based on the casein and citric acid is used to replicate the fermentation evolution [25].

Coagulation

The coagulation is the precipitation phase, where the casein micelles are precipitated out of the milk. The model is constructed around the four parameter value of Bittante et al. (2013) [2]. The program simulates how the curd firmness changes over time after addition of rennet, where the level of firmness is related to the level of

precipitation. The for loop is initiated by an guessed needed time. The for loop then calculates the firmness at the given time. If the firmness is correct the for loop is terminated with the calculated coagulation time. If the firmness is lower or high than the requirement, the for loop defines a new coagulation time related to the tested coagulation time and the difference between the calculated firmness and the required firmness. The steps of the for loop is therefor decreasing as for loop is approaching the needed coagulation time.

The coagulation time is thereafter used to define the fermentation occurred during the coagulation, calculated similar to the acidification, where the fermentation time is the sum of multiple small time steps. The fermentation in the coagulation is terminated when the sum of all steps is equal the coagulation time.

First drain

The draining kinetics of Daviau (2000) [7] is used derive the needed draining time. The for loop tests how much volume of in the vat that is removed at a certain time and based on weither it is adequate, to much or to low the time is change in the next iteration. The iteration step size is reduced as the step size is dependent on how unlike the previous value is to the desired value. The fermentation is constructed similar to that of the coagulation, whereas in the draining part, the mass balance is also updated.

Heating

The heating is assumed to have a linear temperature increase caused by the addition of hot water, which dilutes the whey and immobilize the LAB from the start of the heating. **Second drain**

The second drain is more or less identical to the first drain, where the draining is assumed to follow the kinetics Daviau (2000). The termination loop of the second drain is based on the whey to solid matter ratio.

Draining column

The final draining is assumed to follow Daviau (2000) drainage kinetics in linear combination with the applied pressure. The termination loop is based on reaching an desired water concentration.

Salting

The salting is assumed to follow Fick's law of diffusion and an analytic solution purposed by several authors, among them Floury et al. (2009). The salting updates the mass balance continuous as the diffusion occurs and a average salt concentration expression is made. The average salt concentration is combined with the solid content in the cheese to generate a salt fraction over solid fraction relation, as the salt and solid is assumed to not change after the brining. The termination loop is based on a known salt to solid fraction ratio in Norvegia. **Ripening**

The ripening is not an process that has an termination loop as the ripening is by comparison to the other phases, not time dependent to the same degree and the ripening time is therefore defined in the matlab-file: ripening.m. The ripening is divided into protolysis and lipolysis, which both follow fist order kinetics.

4 Results

4.1 Pretreatment

raw milk

The results from rawmilk.m can be found in the attached files.

separator

The results from separator.m and sepmassbalance.m can be found by running them in the attached files.

UF-membrane

The results from UFfilter.m can be found by running it in the attached files.

4.2 Acidification

The results from fermenter.m can be found by running it in the attached files. The fermenter produce a plot of the pH, the buffer capacity and the lactic acid concentration during the acidification.

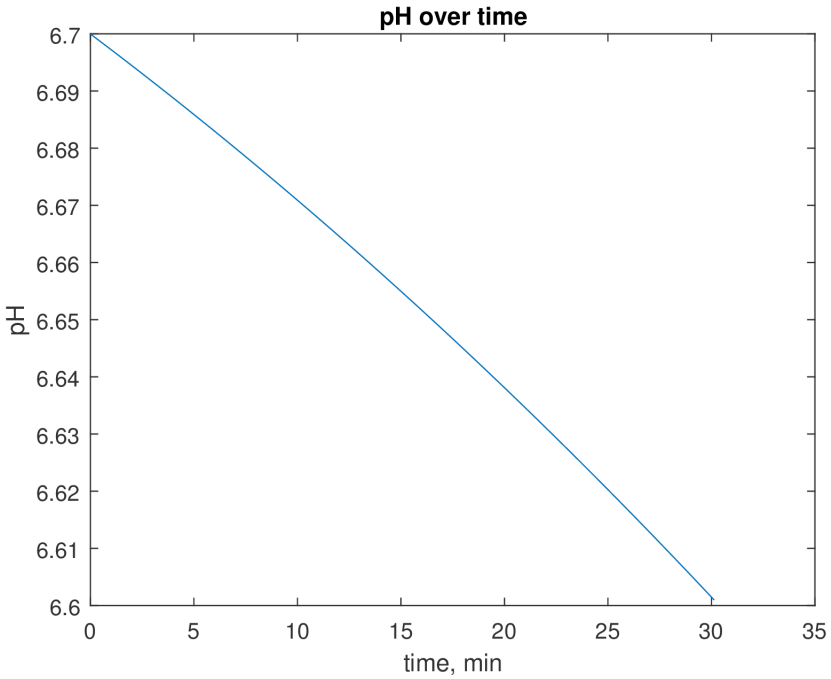


Figure 12: pH during the fermentation

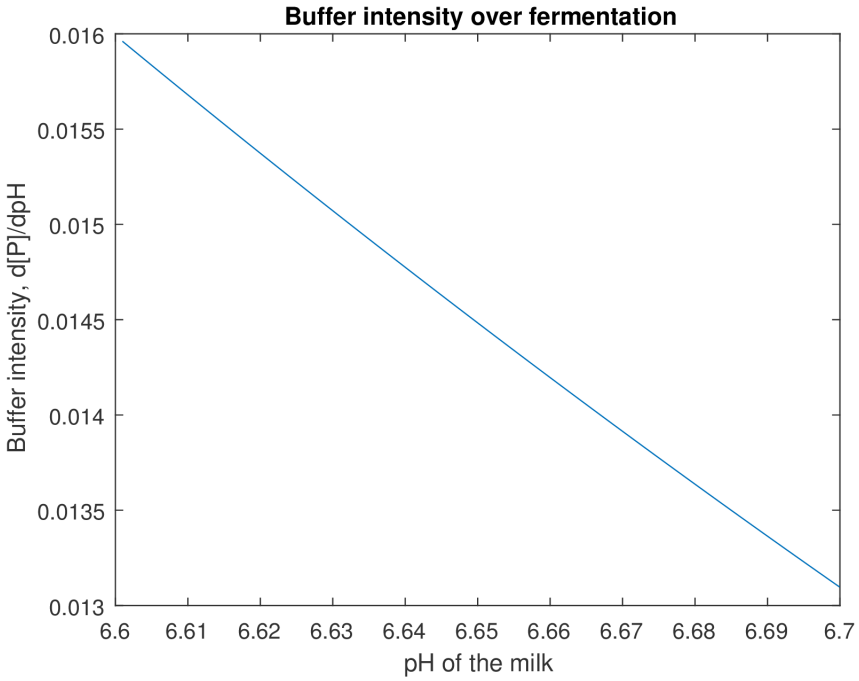


Figure 13: Buffer intensity during the fermentation

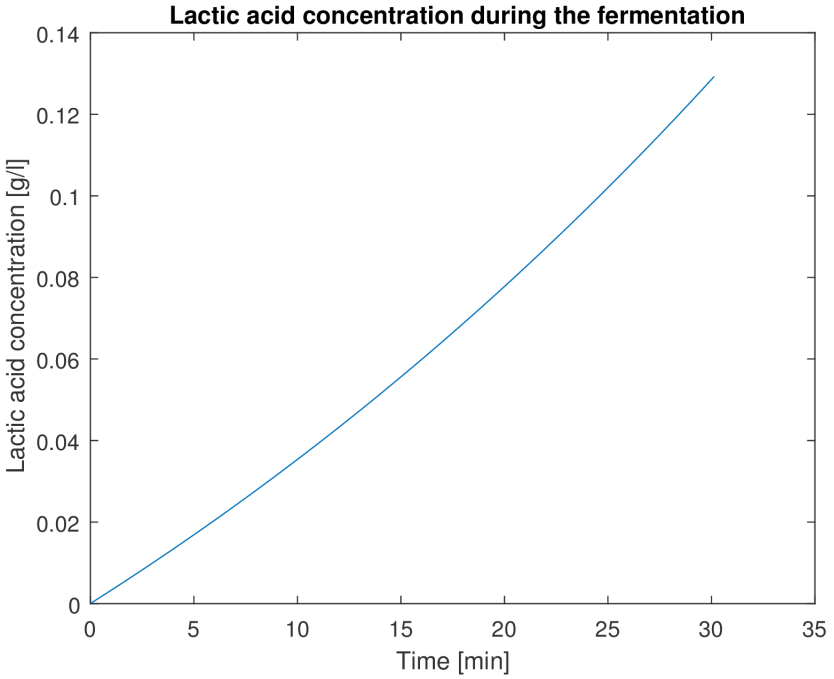


Figure 14: Lactic acid concentration during the fermentation

4.3 Coagulation

The function coagulation.m produces an time plot of the curd firmness after addition of rennet.

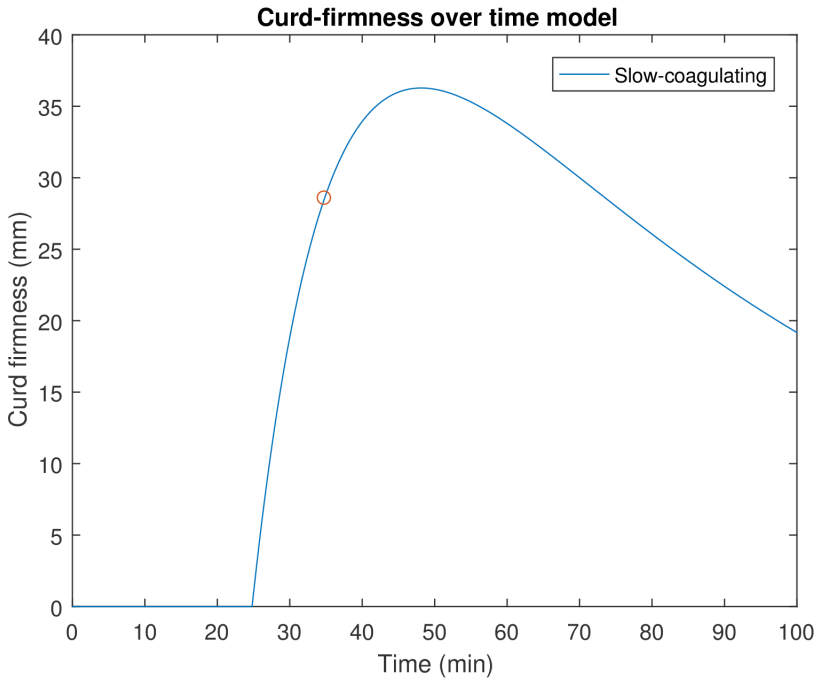


Figure 15: Curd firmness during the coagulation, with the stop marked out with a ring

4.4 Dehydration

First drain

The firstdrain.m produced an plot of the volume in the vat and the volume that has left the vat over the first drain.

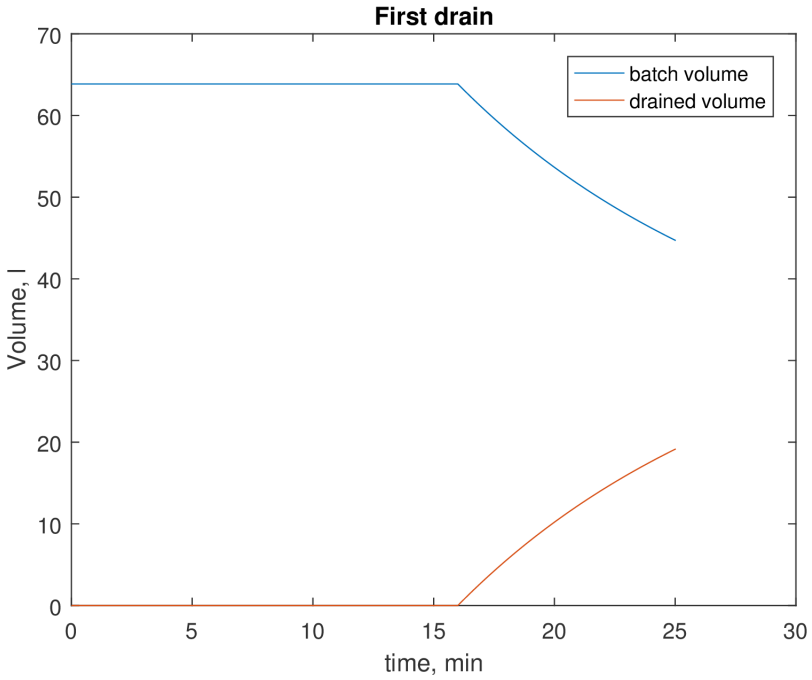


Figure 16: Vat volume and whey volume expelled during the first drain

Heating

The heating.m produces an plot of the whey component matrix during the heating.

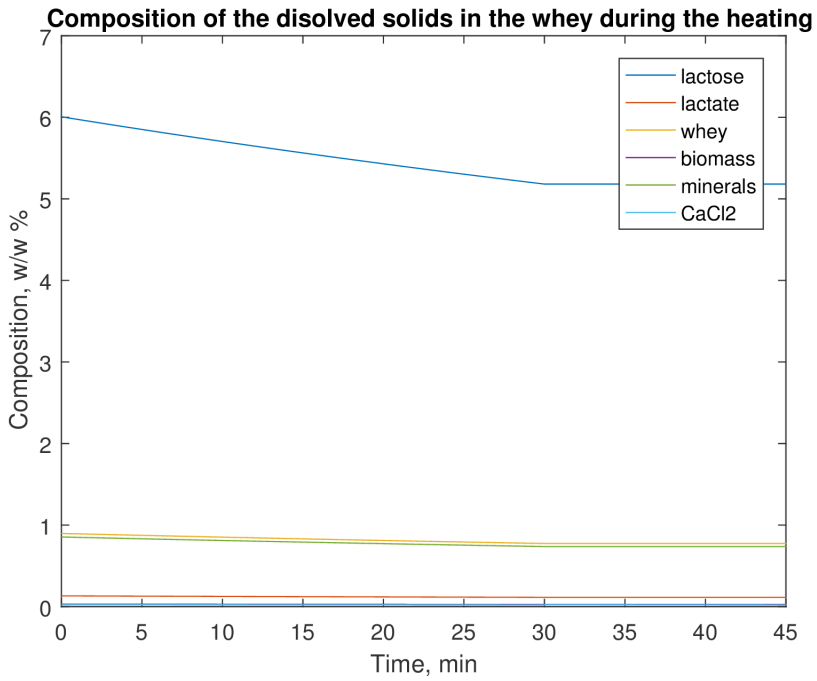


Figure 17: component composition in the whey during the heating

Second drain

The second draining is assumed to have the identical composition in the whey as at the end of the heating and can be found in the seconddrain.m file.

4.5 Molding and shaping

The final draining is assumed to have the identical composition in the whey as at the end of the heating and can be found in the drainingcontinuous.m file.

4.6 Salting

The salting.m file produces the four plots: error-function plot, salt over location and time plot, average salt concentration over time plot and salt over solid content plot.

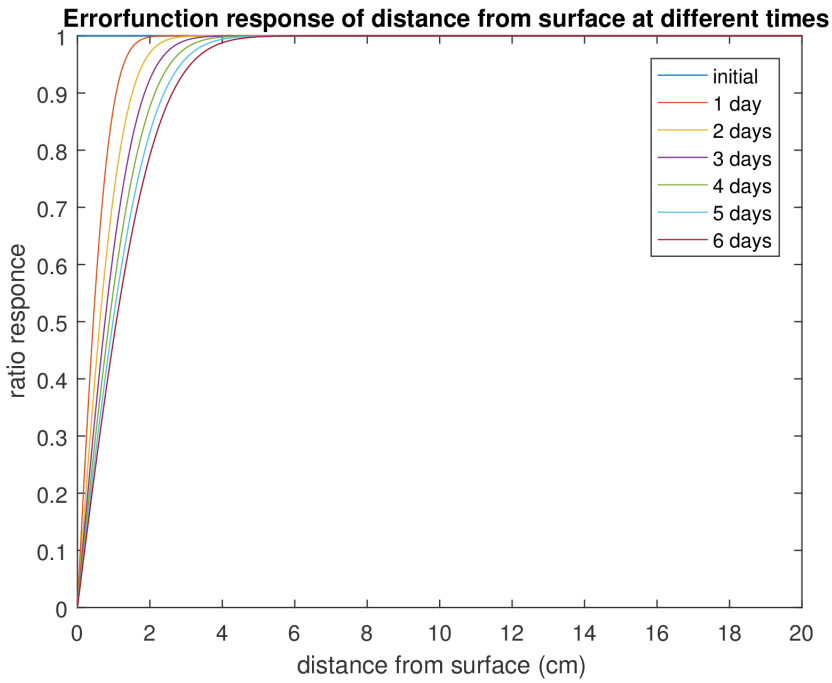


Figure 18: error-function plot over time

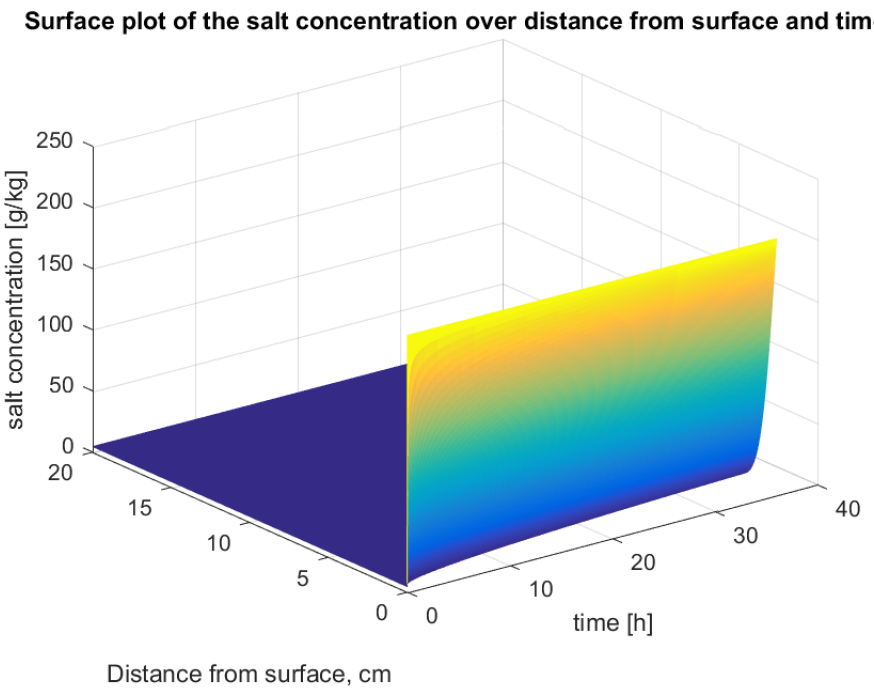


Figure 19: Salt concentration over time and location plot

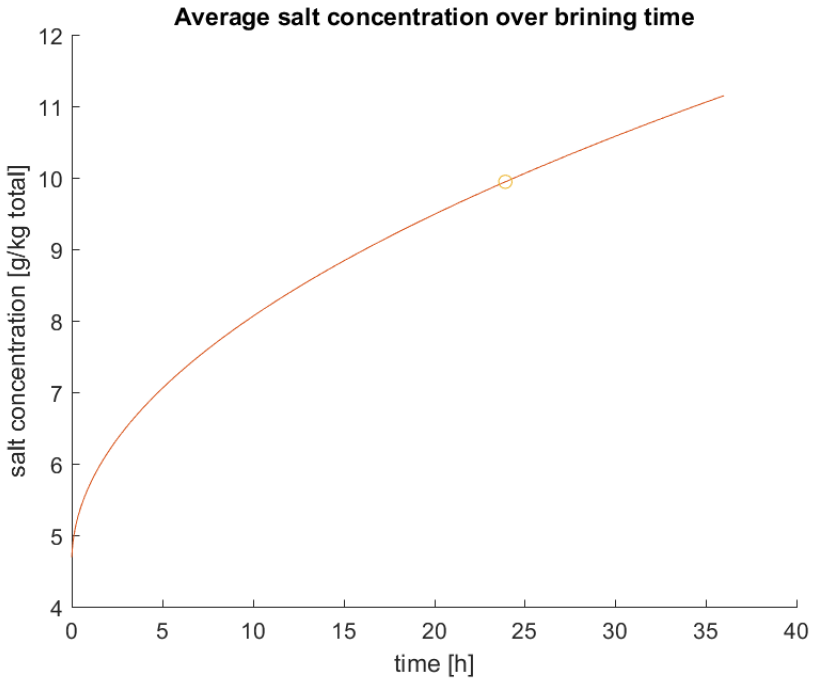


Figure 20: Average salt concentration over time plot

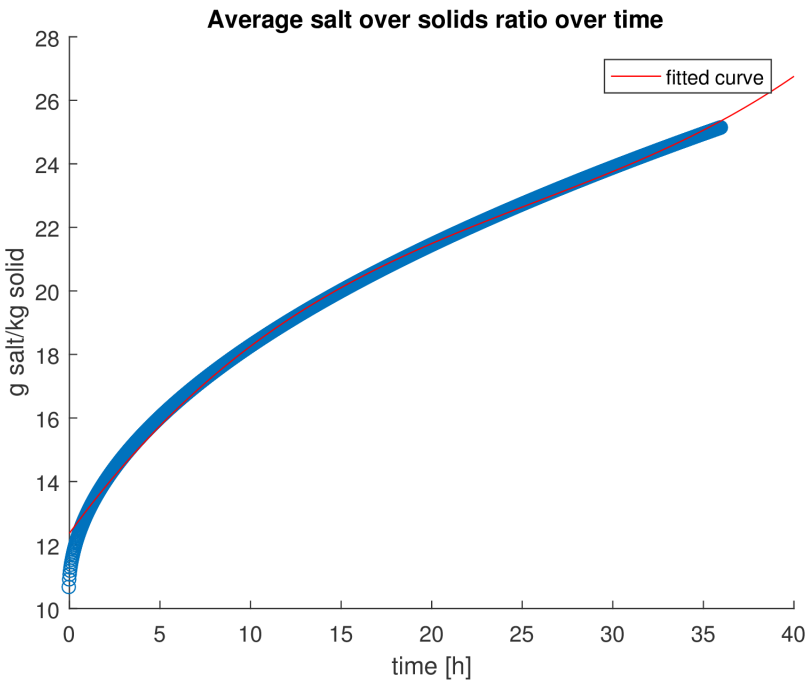


Figure 21: Average salt over solid content ratio over time plot

4.7 Ripening

The ripening.m file produces a time plot of the protolysis and lipolysis during a theoretical maturing time.

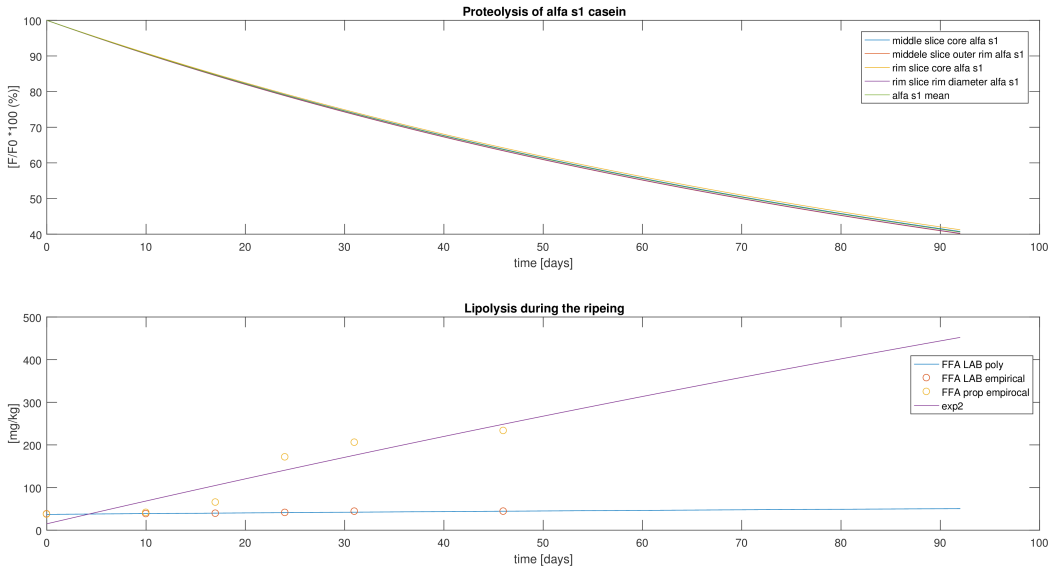


Figure 22: Protolysis and lipolysis during the maturing

5 Discussion

The model is constructed under the assumption that the potential users are new to Matlab. The model is therefor designed with a low level of user interface, where all programs have a dummy input version consisting of normal or conservative values. If an program is not able to converge it will end or add an comment in the command window, addressing the problem of conversion.

The construction of dynamic and static models in the dairy industry is a rather new and unknown approach, where most publications are based on analytic solutions and models. This has resulted in the model to be constructed around these analytic solutions. To increase the range of the model, the for-loops are set to make small steps before updating the initial conditions and conducting the new step, similar to what an numerical solver would conduct.

The buffer capacity of milk is quite high and is closely related to the casein micelles of the milk, with a pka of 5.5. During the coagulation and the draining the pH remains higher than what literature suggest, This gives a indication that the assumption of a one phase system of the buffer capacity during the entire production does not hold. For future improvements an equilibrium two phase system of a viscus and solid phase may become a more adequate model description when the precipitation start.

Scaling is an Central question of efficiency, especially for biological industry, but is not included to the model since the model is simplified and does not attempt to establish the needed size of the plant.

5.1 Separation

The separator is the unit that has the highest level of process control of all the units and is of that reason simplified to only a mass balance unit constructed around obtaining desired fat concentration in the fat regulated milk. The mass balance was not constructed to be solve, based on density, as the PLS does, this is done to be able to construct the exact desired milk quality. By comparing the fat regulated milk from the simulation with the fat regulated milk for the dairy at Jæren it becomes quite obvious that the assumption of a two phase system of fat emulsion in whey is correct. Where the milk from the dairy has the composition: F: 2.8 w/w %, SNF:8.8-9.1 w/w % and water:88.1-88.4 w/w % and the milk from the simulation has the composition: F: 2.6 w/w %, SNF: 9.05 w/w % and water 90.49 w/w %. The deviations in the composition is likely due to a higher quality of the milk at Jæren, than the milk used in the simulation. Where the milk used at Jæren has a sligtly higher casein content. The milk used at Jæren is called Elite milk, meaning it holds the highest quality for milk and the milk used in the simulation is an average measure for Norwegian milk used for cheese, yougurt, drinking milk and more. For most chases the protein or

casein content is the major contributor for determining the milk quality, where a milk with high protein content (especially casein) is a good factor and is well suited for cheese production. In Canada there was a discussion on whether the farmers was to be paid for per liter milk or per kilo protein produced, in order to influence the breeding in the direction of quality over quantity [10].

5.2 Ultra filtration membrane

The Ultra filtration membrane is as mentioned earlier an unit which is not an unit that has to be built, but will decrease the energy consumption and and overall equipment sizing. The hypothesis of utilizing a known water flux [6] and thereafter construct the residual component fluxes, based on an known UF membrane compositions [13] has shown to generate an inherent error. Where the permeability constant (κ) is both dependent on the component size and component feed flow. Since the permeability constant is dependent on the component size and component feed flow the system will not be able to predict accurate if the feed composition deviates to a large degree from the design basis as the permeate composition is fixed. However that the permeate composition is fixed will fist become a problem of significance if the mass balance is not possible to converge, meaning that the system runs dry of one or more components. The main components of the permeate in chronological order is water (95.53 %), lactose (3.77 %), minerals (0.52 %) and non-protein nitrogen (0.16 %). Simulations at high casein concentrations reveal that the mass balance remain conserved. At the end of UF __filter there is a test which measure if the ratio between the sum of inlet component flow of minerals (mineral__test) and lactose (lactose__test) is equal to the sum of the outlet component flows. at 30 % casein in the retentate the ratios where 1.00.

5.3 Pasteurization

The pasteurization process is one of the processes that for the thesis is of less importance and is therefore simplified and more or less not applicable.

5.4 Acidification

The acidification is the main fermentation phase of the cheese production and is one of the most important phases in creating the cheese taste and texture. The simulation of the acidification has meet some challenges, especially in determining of the kinetics and initial biomass concentration. It seems as if there has been done very scarce

attempts to qualitatively describe the fermentation of industrial LAB in milk for cheese production. The first challenge was to create the buffer capacity, represented by the casein content in the fermentation milk, as most of the buffering agents are found inside or nearby the casein micelles. Too obtain the required buffer concentration, to meet the buffer intensity, the molar concentration of casein and citric acid was multiplied. The Buffer intensity was on purpose constructed higher than the buffer intensity presented by Whittier [25], as a result of lactic acid being an one of the stronger weak acids ($pka_1 = 3.13$), whereas Whittier used hydrochloric acid as a titrant. In the Norwegian book: Norsk ost by Anders Oterholm (2008) it is presented that the starter culture has a cell concentration multiple times greater than hundred million cells per milliliter and that the added amount of starter culture is equal 1-2 % of the vat milk [17]. This thesis has assumed that one cell has a weight of 1 pg. When simulating an addition of starter culture to be 2 % of the vat milk and a cell concentration of $17 \cdot 10^{11}$ cells/l this yield total fermentation time, to reach pH 6.6 is 30 minutes, which is in the normal range of the acidification of 30-35 minutes. At this configuration the initial and end generation times are 30 and 37 minutes, which is fast for LAB bacterias, but not imopossible. For future work there will be needed to obtain more accurate initial conditions in order to construct a model based on knowledge rather than adjusting the conditions to fit the time model.

The model also revealed that by increasing the solid content of the acidification milk by the ultra filtration unit only had minor effect on the fermentation time, but increased the lactose concentration and therfore increased the generation time and but significantly decreased the total biomass production.
Since most LAB bacterias are in their optimum pH range in the acidification (6.5 ± 1) the inhibition constant K_p was set high enough to make only create a small change in the rate of formation [18]. The approach of dividing the fermentation into a sum of small time steps seam to be working quite well and allow to more accurately predict the evolution of the compositions and kinetics parameters as the previous step end condition becomes the new initial condition of the upcoming step. By setting the step size small enough it is possible to assume an linearly dependence over the time frame. The drawback of decreasing the step size is the simulation time needed to converge. The step size and allowed tolerance can easily be adjusted to meet the level of accuracy needed.

5.5 Coagulation

The coagulation time calculated by the program, using the four parameter asymptotic model with the slow coagulation parameters have proven to fit quite well to mesophilic semi-hard cheese, where the coagulation time is approximately 30 minutes and the operator manually approves if the cheeses has reached the desired firmness to start cutting the coagel into rims. In order to verify whether this dependence is a random coincidence, simple

sensoric tests might be needed, to reveal the coagulation kinetics of the specific cheeses, all four parameters are highly dependent on pH and might be dependent on the type of milk, rennet type, level of fermentation and several other variables. The coagulation kinetics computed by Britannte et al. [2] was conducted on raw milk of Swiss Holstein, whereas the coagulation in this thesis is fermented, skimmed and slightly condensed milk of Norwegian red (where Holstein is the main breed). The main difference between the two milk is the water content, and a the rennet concentration. A future goal to aspire for might be to add rennet and water concentration dependency of the coagulation and coagulation time. The model computed in this process is not able to predict an decency between the water concentration and will remain as one of the unanswered problems of the coagulation. One of the mentioned benefits of reducing the water concentration in the milk is that the availability of rennet for the casein, yielding an reduced requirement of rennet to the milk [ëskin]. The cutting of the coagel in the model is simplified to take 11 minutes and can be found as the initial part of the first draining. At Jæren the cutting starts with an intensity of 1-2 rpm and increases to 6-7 rpm, the entire cutting takes 10-12 minutes. The fermentation during the coagulation, cutting and resting is calculated with a similar goal, but where the fermentation time is defined and the iteration stops when the sum of iterations is equal the coagulation, cutting and resting time. The pH after the coagulation is in the same area as Eskin [10] define it to become. Eskin define pH of Gouda type cheeses to have a pH of 6.45 after the coagulation, whereas the simulation yields pH 6.5976. This deviation might be caused as a result of the pka of the milk to be 5.5, meaning that the combination of an high buffer capacity and a pH close to the pka value will to a great extent oppose an change in the pH. Since most of the buffer capacity of the milk is in the casein it is possible that the coagel to a less degree is a buffer capacity of the whey now that the casein is no longer a part of the liquid phase.

5.6 Draining

First drain

The main purpose of the first drain is to drain of whey, to reduce the heating demand of the upcoming heating phase and downstream processing of the whey. The literature suggest a volumetric removal of in the range of 30 %, is the norm. At Jæren the first drain require 7-12 minutes to remove the desired amount. The simulations, using the four parameter decay model of Daviau et al (2000) [7] with states: mesophilic, CN:-1, IS:-1 seams to fit as an adequate description of the first drain, calculating an draining time of 9 minutes with 4 % casein in the broth. The CN:-1, IS:-1 is draining configuration yielding the fastest response of the four mesophilic states and was chosen due to

low inoic strength as a result of high pH and a low casein concentration (CN). This implies that by increasing the casein content the configuration might change to CN:+1, IS:-1, yielding the second fastest response. In order to obtain this configuration the milk has already been condensed by the micro-filtration unit, reducing the draining amount.

The first drain is the last stage where there is lactic acid production, due to the heating stage, in which kills or immobilize all LAB. The fermentation in the draining part of the first drain, there is a high degree of uncertainty. In which the updating mechanism of for loop causes some error, creating the calculated concentrations to become identical to each other. The output concentrations is however decreasing as expected, but not to the same extent as the hand calculations.

Heating

The heating process is the only step where the LAB are killed. The lactic acid production is stopped and initiation of the LAB bacteria lysis with the release of intra cellular enzymes for the maturing is conducted. The regulation perspective of adjusting the pH up, as a result of the addition of hot water is not conducted, based on the lack of information on which state is the desired acidity. The heating therefor follow the standard heating curve of 0.3 $^\circ$ C/min and a scalding temperature of 39 $^\circ$ C and 15 minutes of scalding, to match Norvegia. The pH in the vat is quite high, at 6.3, giving further conformation that the buffer capacity of the whey and the coagel must be evaluated as two phases in equilibrium, where the coagel is pH neutral and the whey is acidic.

Second drain

The second drain is not an essential part of the production, where Jæren only uses the second drain as a regulation unit prior to the final drain. The second drain mechanism is identical to the draining mechanism of the first drain, where the four parameter model of Daviau et al (2000) is used [7]. The difference is in the termination sequence of the two drainings. The first drain terminates when a chosen fraction of the vat volume is removed, whereas the second drain terminates when a chosen curd to mass ratio is obtained.

Final drain

The final drain is defined with the same kinetics as the first and second drain and is of that reason correct in the matter of composition. Since the draining process is removal of the whey solution. The draining time however has a high degree of uncertainty. As the draining rate of the final drain is related to the applied column pressure and

not only atmospheric- and hydro-static pressure as of the first and second drain are. In this thesis an simplification of the pressure relation is utilized, by assuming an linear dependency. In order to verify this assumption further information on the column must be given. The pressure relation is only meant to point out that the draining column is pressurized.

5.7 Salting

The brining of cheese is in literature is described by Fick's second law of diffusion, with the analytic solution: $C(x,t) = C_S + (C_i - C_S) \cdot erf(\frac{x}{2\sqrt{D \cdot t}})$. figure(8) (in salting.m) reveal that most of the salt in the cheese is found close to the surface, as expected [13]. The simulation yield the expected response, that a smaller cheese need less brining time as a result of reduction in the extensive properties. The fist assumption of the salting is that the salt concentration in the brine is constant during the salting, as a result of the high volume ratio between the cheese and the brine. Since other publications use this assumption it is assumed the constant brine concentration assumption holds. The second assumption is that there is only salt diffusion present in the brine. This is incorrect, but is done as a combination of simplifying the simulation and as a result of vague information on the whey diffusion. This assumption is indicated as not adequate by and remaining lactose of 3 %, whereas matured Norvegia is 0.01 % lactose (lactose free) This assumption is possible to remove in the future if compositions of and weight of the unsalted and salted cheese is added to yield the diffusion coefficients.

Most literature on the subject describe the effective diffusion coefficient in cheese to be in the range: 2.8-4.2 $\cdot 10^{-10}$ m^2/s [11, 19], where the results of the simulation becomes: 1.9-2.93 $\cdot 10^{-10}$ m^2/s. This low diffusion coefficient is mainly caused by a initial salt concentration lower than that of experiments of Floury et al (2009) [11], who tested 0.5 and 1.5 %, where the simulations achieved an initial salt concentration of 0.37-0.53 %. The main difference in the tests of Floury et al (2009) and this thesis is the direction of the diffusion, where Floury et al tested salt reduction and this thesis simulates brining. The diffusion coefficient in the simulations is therefore subjected for an fifth extensive variable, namely the brine salt concentration. General considerations of Stokes-Einsteins equation would suggest that the mobility of the brine would be reduced by increasing the salt concentration, due to the high increase in viscosity from 1 cp at 0 % salt and 1.99 cp at 26 % salt [14]. The reduced mobility will reduce the self diffusion and increase the boundary layer, causing a reduction in the effective diffusion coefficient.

5.8 Maturing

The maturing is the simulation stage that has the highest degree of uncertainty, both as a result of the maturing kinetics to be unique for the type of cheese and that of it being the last stage of simulation and therefore inherit all error from the previous stages. In order to make the maturing more realistic, empirical work to determine the inherent kinetics for protolysis, lipolysis and fermentation of residual lactose and citrate must be conducted. As mentioned, the brining simulation does assume whey diffusion, leaving an residual lactose concentration much greater than what is expected.

In subplot 1 (protolysis) from figure 11 (in ripening.m) it becomes quite evident that the protolysis is not dependent on the location in the cheese and that the exponential coefficients are small enough to yield and linear response.

Subplot 2 (lipolysis) in figure 11 reveal the obvious difference between an cheese without propioni bacteria and with propioni bacteria. The difference is that the lab does not produce extra cellular esterases, but only contain intra cellular esterases, which is released at cellular lysis. The propyonic bacterias produce extra cellular esterases and contain intra cellular esterases. The concentration of esterases in propyonic bacteria free cheese therefore is declining with time, but is constant or slightly increasing for propyonic bacteria containing cheese like Jarlsberg. The reason for the rapid increase in FFA of the propioni bacteria cheese plot between 17 and 24 days, is the shift from the pre ripening (10 $^\circ$ C) to the main ripening phase (24 $^\circ$ C) and the flattening in the end is due to the third ripening phase of 4 $^\circ$ C. The internal salt diffusion and internal diffusion and external water evaporation is not conducted, both because there was not time left to implement it, but for most of the relevant cheese the salt has become evenly distributed before 2 months (Norvegia) have past and for Jarlsberg the internal salt distribution is not relevant as it is ripened from 8 months or more. Norvegia is ripened in plastic wrapping and is therefore prevented from evaporation. In Jarlsberg the crust is essential for ripening and the internal water concentration gradient may be assumed constant with time, but where the cheese becomes more and more dry over time.

6 Conclusion

The thesis has successively described how the cheese production is a parameter driven process, in a simplified manner, combined with a low level of needed user interface. Results from several publications and books regarding the parameter evolution has been combined to derive a matlab based dynamic model of the different production stages. The model has the highest level of accuracy in the physical phases and a lower level of accuracy in the biological stages compared to information given of the cheese production at the TINE dairy at Jæren, Norway.

The model has some errors and inaccuracies, as a result of simplifications and assumptions made. In order to correct these errors, empirical research is needed to establish the specific parameters and initial and end states of the stages.

7 Future work

This thesis has not produced empirical values and empirical work on the initial states of acidification remains, kinetic parameters of the both the physical and biological driven processes remain to verify.

References

[1] Aylward, G., Findlay, T. (2008). *SI Chemical Data*. Sixth edition. Milton, Australia: John Wiley Sons Australia Ltd

[2] Bittante et al. (2013). Prolonged observation and modelling of milk coagulation, curd firming, and syneresis. Vol. 29(2). International Dairy Journal.

[3] Bouguettoucha, A., Balannec, B., Amrane, A.(2011). Unstructured Models for Lactic Acid Fermentation - A Review. Volume 49(1). Food Technology and Biotechnology

[4] Bylund, G. (2003). *Dairy processing handbook*. Second edition. Malmö, Sweden: Tetra Pak Processing Systems AB

[5] Coultate, T. (2009),*FOOD The Chemistry of its Components*. Fifth edition. Cambridge: The Royal Society of Chemistry

[6] Datta, N., Tomasula, P. M. (2015). Emerging dairy processing technologies. Retrieved from http://ebookcentral.proquest.com

[7] Daviau, C. (2000). Rennet coagulation of skim milk and curd drainage: Effect of pH, casein concentration, ionic strength and heat treatment Vol 80. Pages 397-415. Le Lait

[8] Dherbe´Court et al. (2010). Time Course and Specificity of Lipolysis in Swiss Cheese. Vol 58(22). pages 11732-11739. Journal of agricultural and food chemistry

[9] Doran, Pauline M. (2012). *Bioprocess Engineering Principles*. Second edition. Academic Press

[10] Eskin, M., Shahindi, F. (2013).*Biochemistry of Foods*. Third edition. San Diego: Academic Press

[11] Floury, J et al. (2009). Reducing salt level in food: Part 2. Modelling salt diffusion in model cheese systems with regards to their composition. Volume 4. Pages 1621-1628 . Food Science and Technology

[12] Geankoplis, J. C. (2014), *Transport Processes Separation Processes Principles (Including Unit Operations)*, 4 edition, Essex: Pearson Education Limited

[13] Hagenes, K. (2010). *Produksjon av meieriprodukter*. Second edition. Oslo: Baneforl

[14] Haynes (2016). *CRC handbook of chemistry and physics*. 97th edition. Boca Raton: CRC press/ Taylor Francis group

[15] Handout by Turid: 10.2 Dairy Products

[16] Mulder, M. (1996), *Basic Principles of Membrane Technology*, second edition, Kluwer Academic Publishers

[17] Oterholm, A.(2008). *Norsk ost: fra ystekar til ostebord*. Grønland, Norway: Tun Publishing

[18] Salaün, F. Mietton, B. Gaucheron, F.(2005) review: Buffering capacity of dairy products

[19] Simal et al. (2001). Water and salt difusion during cheese ripening: efect of the external and internal resistances to mass transfer. vol 48. pages 269-275. Journal of Food Engineering

[20] Simpson, B. Nollet, L. Toldrá, F. (2012), *Food Biochemistry and Food Processing*. Second Edition. Wiley

[21] FJERNE???? Sinnott, R., Towler, G. (2014), *Chemical Engineering Design*. Fifth Edition. Oxford: Butterworth-Heinemann

[22] Talaro, K. Chess, B.(2012). *Foundations in MICROBIOOGY*. Eighth edition. New York: McGraw-Hill

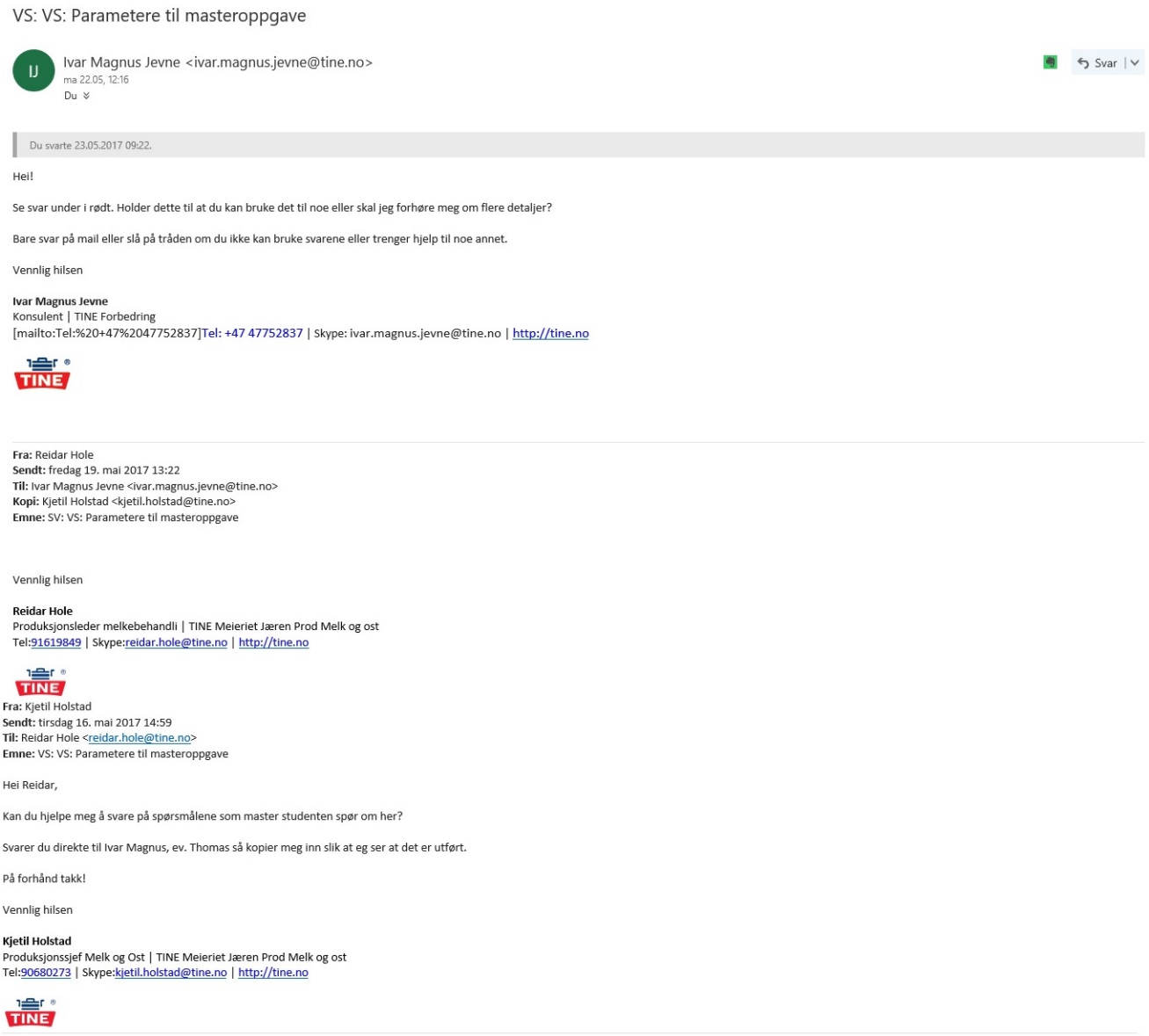
[23] Vangen, O.(2016), Norsk rødt fe (Norwegian red). available from:`https://snl.no/norsk_r%C3%B8dt_fe` (31.01.2017)

[24] Zorrilla, S. Rubiolo, A. (1997). Kinetics of Casein Degradation during Ripening of Fynbo Cheese Salted with NaCl/KCl Brine. Volume 62. Pages:386-389. Journal of Food Science

[25] Whittier, E.O. (1929). Buffercapacity of milk and milk constituents. vol 83. p:79-88. Journal of Biological Chemistry

[26] Øyaas, J (1995). P. hD STUDY OF DIFFUSION PROCESSES AND LACTIC ACID PRODUCTION BY LACTOBACILLUS HELVETICUS IMMOBILIZED IN Ca-ALGINATE GEL. PhD thesis. University of Trondheim

Appendix



VS: VS: Parametere til masteroppgave

IJ Ivar Magnus Jevne <ivar.magnus.jevne@tine.no>
ma 22.05, 12:16
Du

Svar

Du svarte 23.05.2017 09:22.

Hei!

Se svar under i rødt. Holder dette til at du kan bruke det til noe eller skal jeg forhøre meg om flere detaljer?

Bare svar på mail eller slå på tråden om du ikke kan bruke svarene eller trenger hjelp til noe annet.

Vennlig hilsen

Ivar Magnus Jevne
Konsulent | TINE Forbedring
[mailto:Tel:%20+47%2047752837]Tel: +47 47752837 | Skype: ivar.magnus.jevne@tine.no | http://tine.no

TINE

Fra: Reidar Hole
Sendt: fredag 19. mai 2017 13:22
Til: Ivar Magnus Jevne <ivar.magnus.jevne@tine.no>
Kopi: Kjetil Holstad <kjetil.holstad@tine.no>
Emne: SV: VS: Parametere til masteroppgave

Vennlig hilsen

Reidar Hole
Produksjonsleder melkebehandli | TINE Meieriet Jæren Prod Melk og ost
Tel:91619849 | Skype:reidar.hole@tine.no | http://tine.no

TINE

Fra: Kjetil Holstad
Sendt: tirsdag 16. mai 2017 14:59
Til: Reidar Hole <reidar.hole@tine.no>
Emne: VS: VS: Parametere til masteroppgave

Hei Reidar,

Kan du hjelpe meg å svare på spørsmålene som master studenten spør om her?

Svarer du direkte til Ivar Magnus, ev. Thomas så kopier meg inn slik at eg ser at det er utført.

På forhånd takk!

Vennlig hilsen

Kjetil Holstad
Produksjonssjef Melk og Ost | TINE Meieriet Jæren Prod Melk og ost
Tel:90680273 | Skype:kjetil.holstad@tine.no | http://tine.no

TINE

Figure 23: Empirical parameter settings, desired compositions and draining times of the TINE dairy at Jæren, page 1

Fra: Ivar Magnus Jevne
Sendt: onsdag 19. april 2017 12:47
Til: Kjetil Holstad <kjetil.holstad@tine.no>
Emne: VS: Parametere til masteroppgave

Hei, Kjetil!

Hvordan går det med standardisering av oppgaver og innføring av elektronisk ysteskjema på Jæren?

Du, jeg videresender mailen under til deg ettersom vi gjerne kunne tenkt meg å bruke parametere fra Jæren.

Jeg lurte på om du har tid og mulighet til å sjekke noe av dette for meg?

Jeg vil tro at du ikke finner svar på alle disse spm., fordi det kan være parameter vi ikke kjenner til, men det bør være mulig å finne svar på flere av parmaterene som går på standardisering, kutting og drenering. Regner også med Reidar har kontroll på mye av dette.

Noen korte forklaringer:

- Standardisering: SNF = Solid non fat (tørrstoff uten fett) Ja dette er vanlig å regne med
- Koagulering: CF star for Curd Firmness (er dette er kjent uttrykk i TINE/ meieriverden?) Regner med du mener Start Curd Firmness som er sentralt ved måling av koaguleringstid med optisk eller mekanisk utstyr.

Er det ev. andre i TINE som har kompetanse angående noe av dette som jeg kunne kontaktet om dere ikke kan hjelpe meg.

Bare slå på tråden om du ev. har spørsmål.

Vennlig hilsen

Ivar Magnus Jevne
Konsulent | TINE Forbedring
[mailto:Tel:%20+47%2047752837]Tel: +47 47752837 | Skype: ivar.magnus.jevne@tine.no | http://tine.no

Fra: Tomas Kjellstrøm [mailto:tomaskjellstrom@hotmail.com]
Sendt: tirsdag 18. april 2017 09:07
Til: Ivar Magnus Jevne <ivar.magnus.jevne@tine.no>
Emne: Parametere til masteropgave

Hei, en stund siden sist.
Fikk tips av Morten om å høre med deg om det er mulig å skaffe relevante parametere til modellen, ettersom oppgaven min er koblet opp mot kritiske prosesser og at du har samme utdanning som meg og forstår hvordan en parameter er av avhengig av en annen parameter.
Jeg har til nå fullført den forenklede modellen og har oppnådd et godt overblikk på ysting og har derfor funnet ut hvilke parametere jeg finner fra publikasjoner og lærebøker.
De parameterne jeg ønsker er:

Standardisering:
- Hvilken sammensetning er ønskelig ut av separatoren (fett prosent, SNF, vann prosent)? Ca 2,8, 8.8-9,1 88
Har nå en modell som regulerer kasein-innholdet relativt til fettinnholdet, slik at kasein/fett-ratio er lik 1.

- Hva er viskositetsgrensen for den mikrofiltrerte melken og hvordan kan viskositeten av melk relateres til tørrstoff-innehold? Har aldri arbeidet med dette
Det er flere lærebøker som nevner at det er ønskelig å ha så høy tørrstoff-innhold som mulig (inn mot for eksempel koaguleringen), men at det begrenses av viskositeten. Sikkert det viktigste er att dett er så likt som mulig fra dag til dag, så vi kan standardisere ysteprosessen

Jeg har til nå generert en permabilitet til mikrofilteret, basert på inn og ut komposisjoner. For å kunne gi en faktisk representasjon av mikrofilteret trenger jeg: melk mengde og komposisjon inn, permeat og retentate mengde og komposisjon, membran areal, trykket ved innløp, retentat og permeatet. ca. 36.000 liter, skummetmelk med ca8,9% ts, 34.200 og 1800, usikker på arealet da dette er ceramiske filter , 7,0 bar, 2,5 bar og 5,0-2,7 bar avhengig i hvilket utløp du måler.
Ca.
Fermentering:
Ca biomasse til laktat konsentrasjon etter fermentering (biomasse til produkt omsetningsgrad, Ypx)? Dette finnes vel i literaturen eller spør ROLF Heskestad

Koagulering:
Spesifikk løypeakktivitet, fasthetsgrader av koagellen (maksimal fasthet (CFmax), teoretisk maksimum fasthet (CFp) og ønsket fasthet ved koaguleringens slutt)? Koagelet blir bedømt visuelt, finnes utstyr som kan måle dette ed trykkfasthet (spør i gamle FoU)

Kutting:
Hvor lang tid tar kuttingen, hvor hurtig roterer kutteren og hvordan måles det at "riktig" størrelse er oppnådd? 10-12 minutter, med økende hastighet fra 1-2 til 6-7 runder pr minutt. Vurderes manuelt

Drenering:
hvor lang tid tar første og andre myseavtapp? 7-12 minutter, 0-7 minutter
Hvor lenge varmes ostemassen i varmingen (heating) og til hvilken temperatur for Norvegia og Jarlsberg (antar til mesofil skolding temperatur på 44 grader celsius og en oppvarmingskurve på 0.35 grader

Figure 24: Empirical parameter settings, desired compositions and draining times of the TINE dairy at Jæren, page 2

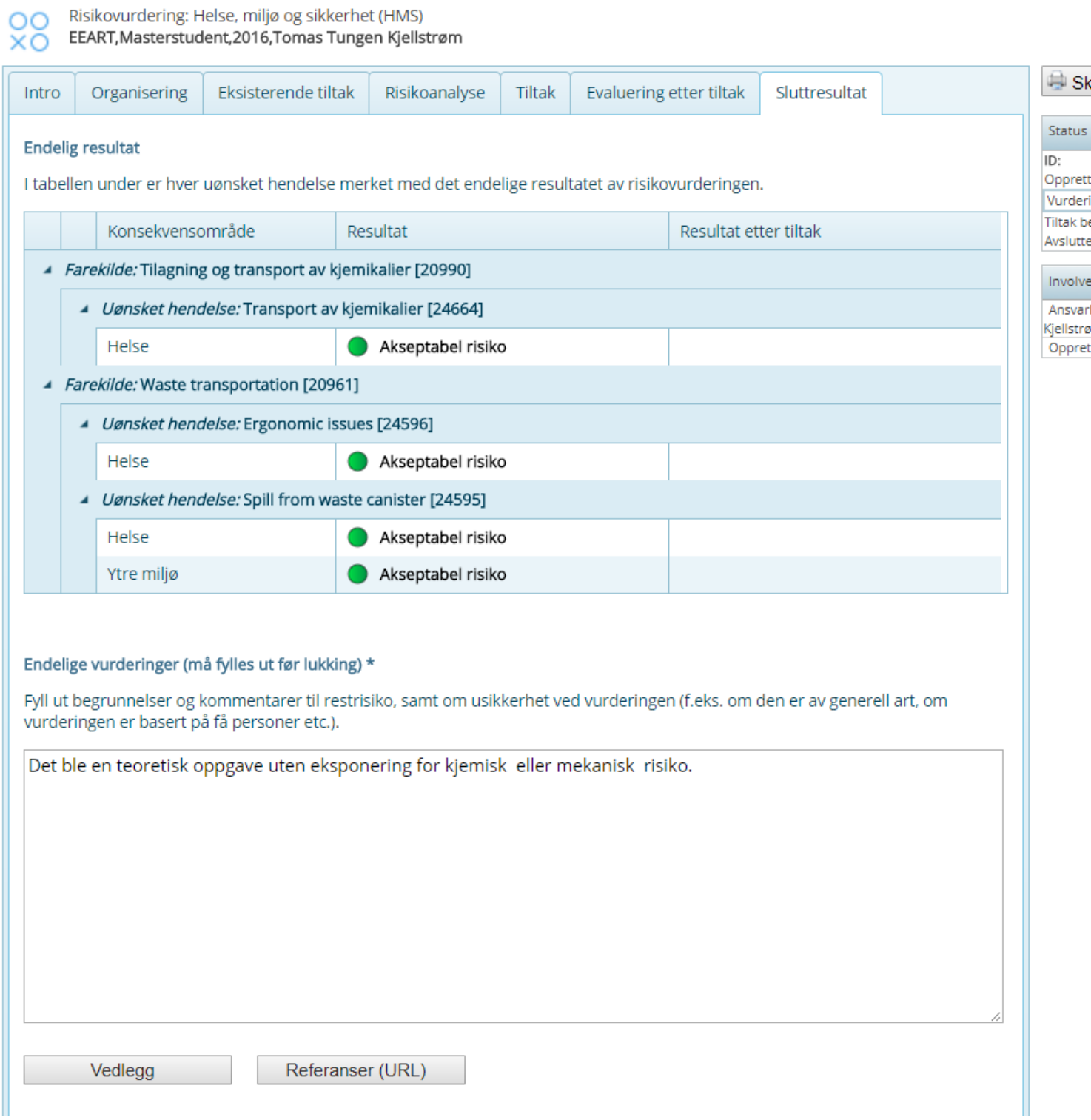


Figure 25: Risk assessment for the thesis