Factors Affecting Moisture Distribution in 290-Kilogram Stirred-Curd Cheddar Cheese Blocks

Robert S. Reinbold
Utah State University

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FACTORS AFFECTING MOISTURE DISTRIBUTION IN 290-KILOGRAM STIRRED-CURD CHEDDAR CHEESE BLOCKS

by

Robert S. Reinbold

A dissertation submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY in

Nutrition and Food Sciences

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1991
This dissertation is dedicated to my sister
Hope Ann Posegate
ACKNOWLEDGMENTS

I thank my major professor, Dr. C. A. Ernstrom, for giving me the opportunity to earn this degree. His instruction and guidance have helped me not only in my scientific endeavors, but also in my business career.

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Robert S. Reinbold
Utah State University, 1991
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ABSTRACT

Factors Affecting Moisture Distribution
In 290-Kilogram Stirred-Curd
Cheddar Cheese Blocks

by

Robert S. Reinbold

Major Professor: Dr. C. A. Ernstrom
Department: Nutrition and Food Sciences

The purpose of this dissertation was to study factors affecting moisture distribution in 290-kilogram stirred-curd Cheddar cheese blocks cooled in stainless steel hoops. Uneven moisture distribution within blocks may create cheese with variable texture and flavor, which can be extremely costly to the producer. The effects of temperature, pH, and vacuum treatment on moisture distribution were investigated. Temperature, pH, moisture, and pressure profiles were presented. Also, comparisons were made between temperature profiles of 290-kilogram stirred-curd Cheddar cheese blocks cooled in stainless steel and in plywood hoops, as well as between temperature profiles of 66-kilogram Swiss cheese blocks cooled in cardboard and in plastic boxes.

Moisture transferred from high to low temperature in the cheese blocks. Moisture may have transferred in response to thermally induced curd moisture-holding capacity gradients in the
cheese blocks. Moisture also may have transferred in the cheese blocks by a mechanism similar to thermo-osmosis of liquids in porous solids.

The cheese in the plywood or cardboard insulating materials cooled more uniformly than the cheese in the stainless steel or plastic containers. More uniform cooling of the cheese produced more uniform moisture distribution in the cheese blocks. Recommendations were made to help the cheesemaker produce cheese with even moisture distribution.
GENERAL INTRODUCTION

Statement of Problem

Manufacturing cheese in 290-kilogram rather than 18-kilogram sizes reduces material, labor, storage, and energy costs. Therefore, this approach to cheese manufacture has found wide acceptance in industry.

Mike Harris, Quality Control Manager, and Rex Gleason, Production Manager, Cache Valley Dairy Association, observed that 290-kilogram stirred-curd Cheddar cheese blocks had uneven moisture distribution after six days of cooling. Moisture was lower in the center than in the sides of the blocks. The center of blocks was often dry and crumbly, while the sides were tightly knit and moist. The moisture content in the sides of blocks sometimes would be higher than the maximum allowable for Cheddar cheese. Great variation in moisture within blocks could not be tolerated so Cache Valley Dairy Association enlisted the help of Dr. C. A. Ernstrom. The attempt to correct the problem became the subject of this dissertation project.
Dissertation Format

This dissertation contains four studies (Chapters I through IV) concerning factors affecting moisture distribution in 290-kg blocks of stirred-curd Cheddar cheese. Chapter III contains information on cooling of 66-kg Swiss cheese blocks in a finishing cooler. Rex Gleason requested this information and it was provided to him.

The chapters are presented according to the style of the Journal of Dairy Science. Each contain Introduction, Materials and Methods, Results and Discussion, Summary and Conclusions, and References sections. Tables and figures for each chapter are presented immediately following mention in the text. The material in Chapter I was published previously in the Journal of Dairy Science, 1988. 71:1499-1506. In addition, this dissertation contains a General Summary and Recommendations section. An Appendix presents the data used to create the graphs.
CHAPTER I

Effect of Nonuniform Cooling on Moisture, Salt, and pH Distribution in 290-kilogram Stirred-curd Cheddar Cheese Blocks.

INTRODUCTION

Blattner, et al. (5) found significantly lower moisture concentrations in the center than the sides of barrel cheese. Moisture differences between the center and sides averaged 6.7 and 2.6% for cheese in steel and fiber barrels. In 290 kg stirred-curd cheese blocks (M. Harris, Cache Valley Dairy, Smithfield, UT, 1986, personal communication), moisture differences between the center and sides were 4.86 and 3.02% for cheese in stainless steel and in plywood hoops.

The centers of 290 kg blocks of stirred-curd cheese in stainless steel hoops cool much more slowly than the sides, and large temperature differences develop within 1 d (10). The thermal conductivity of cheese is approximately .30 W/m·K (11). Because 290-kg blocks are large in volume in relation to surface area, positions in the block cool non-uniformly (4).

The thermal conductivity of stainless steel is approximately 14 W/m-K (2) and that of plywood is approximately .12 W/m-K (8). Encasing cheese in insulating material such as plywood makes the block cool more slowly than when not insulated. Slower cooling produces more uniform cooling throughout the block. Moisture-holding capacity of cheese curd is affected by acidity and
temperature (12). These variables may in turn be affected by the method of cooling the pressed curd. Non-uniform cooling may produce differences in moisture holding capacity within cheese blocks.

The objective of this study was to measure the effect of non-uniform cooling on moisture, salt, and pH distribution in 290-kg blocks of stirred-curd cheese pressed in stainless steel hoops.

MATERIALS AND METHODS

Manufacturing Procedure

Cheese was manufactured at Cache Valley Dairy Association, Smithfield, UT. Curd was produced in "Double O" vats (Damrow Co., Fond du Lac, WI) from 22,727 kg milk, drained, and salted on enclosed finishing tables and then air-conveyed to stainless steel hoops (74.9 cm high x 71.0 cm long x 55.9 cm wide). Each hoop was filled with 327 kg of curd, forming a block. The cheese blocks were pressed at 7.9 kPa cheese surface pressure for 1 h, vacuum treated at 80 kPa vacuum for 1 h without mechanical pressure, and then pressed, while still under vacuum, at 12 kPa cheese surface pressure for 1 h. Finally, blocks were either cooled in a 5°C cold room or left at 22°C for 7 d. Each cheese block weighed approximately 290 kg.

Experimental Design and Sampling Procedure

Two randomly chosen vats of curd from the same day were used for the study. The first and last block from each vat were
eliminated leaving six blocks per vat for the study. Approximately 150 g of curd were collected from the beginning and middle of the fill for each hoop. Curd from the beginning of filling a hoop was equivalent to curd from the end of filling of the previous hoop. Therefore, no end-of-filling samples were taken. Samples (in plastic bags) were immediately placed in an ice bath and held until analyzed in duplicate for pH, salt, and moisture.

Clumping caused curd particle size to vary on the finishing table. Since curd was conveyed to hoops in sequence starting from the front and ending at the back of the finishing table, differences among cheese blocks during filling could possibly confound the effect of the cooling treatment. Therefore, the first, third and fifth cheese blocks in the filling sequence were cooled in a 5°C room and the second, fourth, and sixth blocks were left at 22°C so that the effect of cooling could be determined by comparing equivalent blocks. Table 1 summarizes the experimental design. Blocks were positioned in respective cooling chambers to provide uniform cooling on all surfaces.

After 7 d at 5°C or 22°C, blocks were removed from the hoops, and cheese samples were taken from each of 6 positions in each block. Four (1.94 cm in diameter and 10.28 cm long) plugs from each of five side positions in every block were obtained with a sanitized cheese trier. Figure 1 shows approximate locations where samples were taken. Plugs represented the upper corner (U), middle corner (M), lower corner (L), and middle (B) on one of the large surfaces (71.0 x 74.9 cm). Plugs also were taken from
Table 1. Experimental design for analysis of variance.

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<td></td>
<td>Vat 1</td>
<td>Vat 2</td>
</tr>
<tr>
<td>1</td>
<td>5°C</td>
<td>5°C</td>
</tr>
<tr>
<td>2</td>
<td>22°C</td>
<td>22°C</td>
</tr>
<tr>
<td>3</td>
<td>5°C</td>
<td>5°C</td>
</tr>
<tr>
<td>4</td>
<td>22°C</td>
<td>22°C</td>
</tr>
<tr>
<td>5</td>
<td>5°C</td>
<td>5°C</td>
</tr>
<tr>
<td>6</td>
<td>22°C</td>
<td>22°C</td>
</tr>
</tbody>
</table>
Figure 1. Mean and standard error (in parentheses) for 6 blocks of stirred-curd cheese cooled at 5°C for 7 d and 6 blocks cooled at 22°C for 7 d. Sampling positions were upper corner (U), middle corner (M), lower corner (L), middle of small surface (S), middle of large surface (B), and center of block (C). For every sampling position, top number is % salt in cheese, center number is pH, and bottom number is % moisture.
the middle (S) of one of the small surfaces (55.9 x 74.9 cm). Plugs from positions U, M, and L were taken at a distance 2.54 cm from the top and side, 2.54 cm from the side, and 2.54 cm from the bottom and side, respectively, on the large surface. The upper 1.37 cm (rind) of each plug was discarded, and plugs were placed in sterile sample bags. Bags were immediately placed in an ice bath.

Each 290 kg block was then cut and a 5 x 5 x 5 cm cube of cheese from the center (C) was obtained with a sanitized knife. Cubes were cut, placed in sterile plastic sample bags and immediately placed in an ice bath.

All samples were analyzed in duplicate for pH, salt, and moisture.

Temperature Profiles

In a separate experiment, temperature profiles were determined for cheese blocks cooled at 5 and 22°C.

Before the stainless steel hoops were filled, tennis string was drawn across the hoop interior and fastened to steel pegs extending across trier holes on the outer hoop surfaces. Copper-constantan thermocouples were secured in the center and 1.27 cm from the side in each hoop. Each hoop was filled, pressed, and vacuum treated in the usual way. One block was cooled at 5°C for 7 d, and the other block was cooled at 22°C for 7 d. Temperature was monitored periodically by connecting thermocouple leads to a
Leeds and Northrup Speedomax-250 automatic temperature recorder.

Analyses

Samples were prepared according to Standard Methods for the Examination of Dairy Products (1).

Duplicate pH values were determined with an Extech gel electrode and Altec pH meter.

Duplicate analyses for percent salt in cheese were made by the Quantab Chloride Titrator Method (3).

Duplicate analyses for percent moisture were made by the Atmospheric Oven Method (1).

Statistical Analysis

Data were analyzed by an analysis of variance with the model:

\[ Y_{ijkl} = V_i + S_j + (VS)_{ij} + T_k + (VT)_{ik} + (ST)_{jk} + (VST)_{ijk} + (Pl) + (TP)_{kl} + (VP)_{il} + (SP)_{jl} + (VSP)_{ijl} + (VTP)_{ikl} + (STP)_{jkl} + (VSTP)_{ijkl} + e_{ijkl} \]
Where:

\[ V_i = \text{effect of the } i\text{th vat}; \]
\[ S_j = \text{effect of the } j\text{th filling sequence}; \]
\[ T_k = \text{effect of the } k\text{th cooling treatment}; \]
\[ P_l = \text{effect of the } l\text{th position within blocks}; \]
\[ (VS)_{ij} = \text{effect of the } i\text{th vat and } j\text{th filling sequence interaction}; \]
\[ (TP)_{kl} = \text{effect of the } k\text{th cooling treatment and } l\text{th position within blocks interaction}; \]
\[ e_{ijkl} = \text{subsampling random error of duplicate samples}; \]
\[ (VT)_{ik} + (ST)_{jk} + (VST)_{ijk} = \text{error a; divisor used to calculate significance for } V_i, S_j, (VS)i, \text{ and } T_k; \]
\[ (VP)_{il} + (SP)_{jl} + (VSP)_{ijl} + (VTP)_{ikl} + (STP)_{jkl} + (VSTP)_{ijkl} = \text{error b, divisor used to calculate significance for } P_l \text{ and } (TP)_{kl}. \]

Statistical Inference from Experimental Design

No meaningful information about the effect of cooling on moisture distribution could be derived by random sampling within cheese blocks since there was a chance that only interior or exterior positions might have been selected. Also, cooling treatments had to be assigned to specified cheese blocks to eliminate the possibility of confounding variability produced on the finishing table. Therefore, calculated sums of squares are estimates of sums of squares from a completely randomized split-plot analysis of variance design (7). However, valuable information about the effects were gained by analyzing estimated
sums of squares (D. V. Sisson, Statistics Department, Utah State University, 1987, personal communication).

RESULTS AND DISCUSSION

Table 2 shows percent salt, pH, and percent moisture in curd collected at the beginning and middle of the fill for each hoop. The similarity of values indicates that salt, pH, and moisture were uniform throughout the blocks before pressing.

pH values were higher than those usually found in Cheddar curd at hooping. However, this factory salted and hooped the curd at the pH shown to avoid additional moisture loss that would have occurred if dry stirring time had been extended. Hoop 1 vat 1, and hoop 5 vat 2 were observed to contain more clumped curd than the other hoops which may have been the reason for the lower salt in these hoops (Table 2). This may, in turn, have contributed to the lower pH (5.66, 5.67) than the others (pH 5.81 to 5.88).

Figure 1 shows means and standard errors for percent salt, pH, and percent moisture in cheese at the sampling positions for cheese blocks held at 5 and 22°C for 7 d. Maximum differences between the center and sides of the blocks were .3% salt, .22 pH units, and 6.6% moisture for cheese held at 5°C, but were only 0% salt, .04 pH units, and 1.35% moisture for cheese held at 22°C. Average differences between the center and sides of the blocks were .1% salt, .12 pH units, and 5.73% moisture for cheese held at 5°C, but were only 0% salt, .03 pH units, and .96% moisture for cheese held at 22°C.
Table 2. Mean (X) and standard error (SE) data for percent salt in cheese, pH and percent moisture of curd at the beginning (B) and middle (M) of filling. Data for both vats are presented.

<table>
<thead>
<tr>
<th>Hoop</th>
<th>Vat 1</th>
<th></th>
<th></th>
<th>Vat 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>% salt</td>
<td>M</td>
<td>B</td>
<td>% salt</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>SE</td>
<td>X</td>
<td>SE</td>
<td>X</td>
<td>SE</td>
</tr>
<tr>
<td>1</td>
<td>1.3</td>
<td>.00</td>
<td>1.9</td>
<td>.05</td>
<td>5.66</td>
<td>.01</td>
</tr>
<tr>
<td>2</td>
<td>1.8</td>
<td>.05</td>
<td>1.9</td>
<td>.05</td>
<td>5.81</td>
<td>.02</td>
</tr>
<tr>
<td>3</td>
<td>1.9</td>
<td>.00</td>
<td>1.8</td>
<td>.00</td>
<td>5.85</td>
<td>.02</td>
</tr>
<tr>
<td>4</td>
<td>1.9</td>
<td>.00</td>
<td>1.9</td>
<td>.00</td>
<td>5.88</td>
<td>.01</td>
</tr>
<tr>
<td>5</td>
<td>2.1</td>
<td>.05</td>
<td>1.8</td>
<td>.00</td>
<td>5.88</td>
<td>.01</td>
</tr>
<tr>
<td>6</td>
<td>2.0</td>
<td>.05</td>
<td>1.8</td>
<td>.00</td>
<td>5.88</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>1.7</td>
<td>.05</td>
<td>1.8</td>
<td>.00</td>
<td>5.81</td>
<td>.01</td>
</tr>
<tr>
<td>2</td>
<td>2.1</td>
<td>.00</td>
<td>1.9</td>
<td>.00</td>
<td>5.84</td>
<td>.02</td>
</tr>
<tr>
<td>3</td>
<td>1.8</td>
<td>.05</td>
<td>1.9</td>
<td>.05</td>
<td>5.86</td>
<td>.01</td>
</tr>
<tr>
<td>4</td>
<td>2.1</td>
<td>.05</td>
<td>1.9</td>
<td>.05</td>
<td>5.88</td>
<td>.01</td>
</tr>
<tr>
<td>5</td>
<td>1.3</td>
<td>.05</td>
<td>1.9</td>
<td>.05</td>
<td>5.67</td>
<td>.02</td>
</tr>
<tr>
<td>6</td>
<td>1.9</td>
<td>.05</td>
<td>1.9</td>
<td>.00</td>
<td>5.86</td>
<td>.01</td>
</tr>
</tbody>
</table>
Figure 2 shows the temperature profiles for cheese stored at 5 and 22°C following pressing. After 1 d, the center and side temperatures were 35 and 8°C for blocks stored at 5 and 37°C and 24°C for blocks stored at 22°C. Temperature differences between the center and sides were 27 and 13°C, respectively.

Temperature profiles in Figure 2 and moisture data in Figure 1 and Table 2 indicate that moisture could have transferred in response to temperature differences. When the temperature difference between the center and sides of blocks was greatest, curd granules had not fused completely, and the cheese system was still porous. Collins (6) described a physical phenomenon called thermo-osmosis where moisture transfers from high temperature to low temperature areas in porous solids. Three mechanisms for moisture transfer were described. Moisture in the vapor phase transfers in response to a temperature gradient and condenses in colder regions; moisture in the liquid phase transfers in response to vapor pressure differences produced by the temperature gradient and also transfers in response to a capillary pressure gradient resulting from the temperature dependence of surface tension.

Moisture distribution in cheese also may be affected by other processes. The moisture-holding capacity of cheese curds is lower at 35°C than at 8°C (12). Therefore, moisture may transfer from high to low temperature in response to a difference in moisture holding capacity.
Figure 2. Temperature of center (C) and side (S) of 290-kg stirred-curd Cheddar cheese blocks during cooling at 5°C (5) and 22°C (22) for 7 d in stainless steel hoops.
The pH data indicate that slower, more uniform cooling produced a more uniform pH throughout the cheese block. The variability of pH and moisture in 290-kg cheese blocks cooled at 5°C suggests that acid development also may have affected moisture transfer. The moisture-holding capacity of cheese curd decreases as pH decreases in these pH ranges (12). Because the center pH was lower than side pH in blocks at 5°C, this also could have contributed to moisture transfer from the center to outer surfaces.

The salt data also may reveal important information about moisture transfer. The percent salt in the water phase was 3.5% for both the center and the average of side positions for blocks cooled at 5°C. Because the moisture in the outer positions was higher than in the center even though salt in moisture was the same, salt must have transferred with moisture in this cheese system. This in turn suggests that moisture transfers in the liquid form in cheese.

A previous study indicated that uneven moisture was established within 24 h after the start of cooling and did not change during 60 d ripening (9). It appears that, once set, uneven moisture in Cheddar cheese may take a very long time to even out if there is no difference in the percent salt in the moisture.

Table 3 shows the estimated F values for the split-plot analysis of variance. Cooling affected pH and moisture at p<.01. It was not significant for percent salt in cheese because the
Table 3. Estimated sums of squares for analysis of variance.

<table>
<thead>
<tr>
<th>Source(^1)</th>
<th>df</th>
<th>% salt in cheese</th>
<th>pH</th>
<th>% moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>1</td>
<td>.02</td>
<td>.004</td>
<td>97.35**</td>
</tr>
<tr>
<td>S</td>
<td>2</td>
<td>.01</td>
<td>.070*</td>
<td>14.51</td>
</tr>
<tr>
<td>V x S</td>
<td>2</td>
<td>.02</td>
<td>.066*</td>
<td>.8885</td>
</tr>
<tr>
<td>T</td>
<td>1</td>
<td>.00</td>
<td>1.11**</td>
<td>49.91**</td>
</tr>
<tr>
<td>Error a</td>
<td>5</td>
<td>.13</td>
<td>.028</td>
<td>9.597</td>
</tr>
<tr>
<td>P</td>
<td>5</td>
<td>.45**</td>
<td>.230**</td>
<td>251.8**</td>
</tr>
<tr>
<td>T x P</td>
<td>5</td>
<td>.23</td>
<td>2.46**</td>
<td>131.6**</td>
</tr>
<tr>
<td>Error b</td>
<td>50</td>
<td>.28</td>
<td>.169</td>
<td>38.098</td>
</tr>
<tr>
<td>Error</td>
<td>72</td>
<td>.16</td>
<td>.043</td>
<td>.5544</td>
</tr>
</tbody>
</table>

\(^1\) V = Vats; S = filling sequence; T = cooling treatments; P = position within cheese block.
*P<.05
**P<.01
Quantab method was not precise enough (3) to show variability between cooling treatments.

Position was also important in describing the significance of parameter variability because temperature at each position was dependent upon cooling treatment. The position effect was significant for percent salt in cheese because the Quantab method was precise enough to show variability between positions within cheese blocks cooled at 5°C. This further suggests that salt is associated with moisture in this type of cheese system.

The effect of filling sequence was significant at $p<.05$ for pH of finished cheese probably because some curd granules had fused into clumps (high moisture and lactose) on the finishing table, and the clumps were not uniformly distributed among the hoops. This, in addition to low salt content in cheese containing many clumps, may have allowed more rapid pH reduction than in granular cheese.

A very important effect indicated by Table 3 is variability between vats (Table 4). The mean moisture content at filling for blocks from Vat 1 and Vat 2 that were later held at 5°C for 7 d were 42.62 and 43.88%. Average differences in moisture between the center and sides after cooling were 4.90 and 6.55% for blocks from Vat 1 and Vat 2, respectively. A higher moisture content during filling resulted in cheese blocks with more uneven moisture distribution during postpress cooling.
Table 4. Mean (X) and standard error (SE) data for percent salt in cheese, pH and percent moisture at filling (F)\(^1\), and in the center (C)\(^2\), and in the sides (S)\(^3\) of cheese blocks after seven days cooling at 5°C or 22°C.

<table>
<thead>
<tr>
<th>Vat Location</th>
<th>5°C</th>
<th>22°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%salt</td>
<td>pH</td>
</tr>
<tr>
<td></td>
<td>X  SE</td>
<td>X  SE</td>
</tr>
<tr>
<td>1 F</td>
<td>1.8 .10</td>
<td>5.80 .03</td>
</tr>
<tr>
<td>1 C</td>
<td>1.4 .03</td>
<td>5.12 .03</td>
</tr>
<tr>
<td>1 S</td>
<td>1.6 .04</td>
<td>5.24 .02</td>
</tr>
<tr>
<td>2 F</td>
<td>1.7 .09</td>
<td>5.82 .03</td>
</tr>
<tr>
<td>2 C</td>
<td>1.4 .04</td>
<td>5.08 .01</td>
</tr>
<tr>
<td>2 S</td>
<td>1.5 .02</td>
<td>5.26 .02</td>
</tr>
</tbody>
</table>

\(^1\)Average of filling sample values.

\(^2\)Average of center sample values.

\(^3\)Average of side sample values.
SUMMARY AND CONCLUSIONS

A large temperature difference between the center and sides of 290-kg stirred-curd cheese blocks was probably responsible for moisture transfer from high temperature to low temperature areas. Variability in salt in the cheese and the pH within blocks also was affected by large temperature differences. Variability in pH within cheese blocks during early stages of cooling may in turn promote moisture transfer by producing differences in curd moisture-holding capacity. Finally, variability in moisture and physical characteristics of the curd during hoop filling may affect final moisture distribution.

Slow cooling reduced temperature differences within cheese blocks and helped produce cheese with more even moisture distribution. This was done by controlling the cheese block environment, but also could be accomplished by encasing the cheese in insulating material such as plywood. However, too slow cooling could result in poor quality cheese. The most desirable situation would be uniform and rapid cooling of all positions within a cheese block. Unfortunately, this is difficult to achieve in large blocks.

Removal of excess moisture before cooling helps produce cheese blocks with more even moisture distribution. This can be done by producing a drier curd in the vat or on the finishing table, using whey suction probes, and developing innovative pressing and
vacuum treatments. Low moisture curd may help make rapid cooling more acceptable.

Finally, reducing pH of curd before filling the hoop may slow down pH changes in the block during cooling. This could minimize differences in moisture holding capacity within the block and produce more even moisture distribution.

REFERENCES


CHAPTER II

Temperature, pH, and Moisture Profiles During Cooling of 290-kilogram Stirred-curd Cheddar Cheese Blocks.

INTRODUCTION

Reinbold and Ernstrom (9) observed that, after 7 d, moisture had travelled from high to low temperature in 290-kg blocks of stirred-curd Cheddar cheese cooled in stainless steel hoops at 5 or 22°C ambient temperature. Curd had not fused completely and was still porous after 24 h of cooling.

Moisture transfer from high to low temperature in porous solids has been reported. Moisture may travel in response to thermally induced differences in surface tension, vapor pressure, and hydraulic pressure (4, 6, 8, 11, 16). Syneresis rate in curd is affected by temperature and pH. Increasing temperature or reducing pH generally increases curd syneresis (12, 13, 14). However, as pH drops below a critical range, curd syneresis rate decreases (13). Syneresis of curd during early stages of cheese block cooling may affect moisture distribution.

The objective of this study was to expand on the work of Reinbold and Ernstrom (9). In the latter study, no data was presented about how moisture or pH changes occur in locations between 0 and 7 d of block cooling. Also, no data were presented about how moisture or pH changes over time in positions other than center and side locations in the cheese block.
The present study was instituted to observe moisture, pH, and temperature in many interior and corner of block locations at 0, 12, 24, 48, 144, and 240 h after the start of cooling and then to generate temperature, pH, and moisture profiles from the data. Better visualization of how temperature, pH, and moisture change during cheese cooling may provide a greater understanding of the mechanism of moisture transfer and its resulting distribution in cheese.

MATERIALS AND METHODS

Manufacturing Procedure

Stirred-curd Cheddar cheese was manufactured as described in Chapter I.

Temperature Profiles

Before filling stainless steel hoops, tennis string was drawn across the interior of two hoops and fastened to steel brackets extending across trier holes at the hoop sides. Copper-constantan thermocouples were secured in 28 different positions in each hoop. Figures 3 and 4 show approximate thermocouple position and absolute distance of thermocouple from the block center for the separate trials. Hoops were filled and the curd was pressed and vacuum treated. Thermocouple leads were then connected to a Leeds and Northrup Speedomax-250 automatic temperature recorder (30 thermocouple capacity). For Trial 1 (Figure 3), top thermocouples A, B, C, D, F, G, and H were approximately .5 cm
Figure 3. Thermocouple junction positions in 290-kg stirred-curd Cheddar cheese block for temperature profile Trial 1. Absolute distance of position from cheese block center is shown.
Figure 4. Thermocouple junction positions in 290-kg stirred-curd Cheddar cheese block for temperature profile Trial 2. Absolute distance of position from cheese block center is shown.
from the cheese block upper surface. Corner thermocouples A, E, J, and L were approximately 15.1 cm from the outer corner of the cheese block. Side thermocouples B, I, O, and R were approximately 11.9 cm from the 55.9 by 74.9 cm surface of the cheese block. Side thermocouples C, K, S, and U were approximately 9.3 cm from the 71.1 by 74.9 surface of the cheese block. For Trial 2 (Figure 4), corner thermocouples a, b, Y, x, D, B, and A were approximately .1 cm from the outer corner of the cheese block. Top thermocouples a, Z, W, and U were approximately .5 cm from the cheese block upper surface. Bottom thermocouples A, C, E, and G were approximately .5 cm from the cheese block lower surface.

Curd temperature was determined at hoop filling. Ambient room temperature during pressing and vacuum treatment was approximately 22°C. Blocks were then inverted and monitored continuously during cooling at approximately 2.2°C ambient temperature. Ambient cooling temperature varied by no more than 2°C. Invert Figures 3 and 4 to locate thermocouple positions during cooling at 2.2°C. Temperatures were monitored until all positions reached 2.2°C.

pH and Moisture Profiles

To observe pH and moisture change, comparable blocks of cheese from one vat each were chosen and assumed to have identical characteristics throughout the study. For Trial 1, individual blocks were each assigned a sampling time
corresponding to 0, 24, 48, 144, and 240 h after the start of cooling, and eliminated from the study after samples were taken. Twenty-eight sampling positions for each block were specified for the study. All samples were taken after blocks were inverted. Figure 5 shows approximate sampling positions and absolute distance of the center of the sample from the cheese block center. For Trial 2, individual blocks were each assigned a sampling time corresponding to 0, 12, 24, and 48 h after the start of cooling, and eliminated after samples were taken. Fifteen sampling positions for each block were specified for the study. All samples were taken after blocks were inverted. Figure 6 shows approximate sampling positions and absolute distance of the sample from the cheese block center. For each study, the data were combined to generate pH and moisture profiles representing one block.

Since curd did not fuse for the first few days of cooling and since samples had to be obtained by penetrating vertically from the top of the block downward, a special cheese trier was designed as depicted in Figure 7. It consisted of a stainless steel cylinder 5 cm in diameter and 1 m long with retractable claws for grabbing and holding loose curd. The trier was injected from the top to the bottom of the block. The complete plug was removed from the block and a ramrod was used to extract the curd from the trier. Samples from desired locations were obtained using a sanitized knife, bagged, and immediately placed in an ice-water bath to retard further pH change. All of the curd (rind) at the
Figure 5. Sampling positions in 290-kg stirred-curd Cheddar cheese block for pH and moisture profile Trial 1. Absolute distance of position from cheese block center is shown.
Figure 6. Sampling positions in 290-kg stirred-curd Cheddar cheese block for pH and moisture profile Trial 2. Absolute distance of position from cheese block center is shown.
Figure 7. Cheese trier used for obtaining samples from 290-kg stirred-curd Cheddar cheese blocks for pH and moisture analyses. Curd-grasping teeth (D) are connected to an inner sleeve (B) existing between the inner and outer walls of sample collection cylinder (C). Connecting handle (F) to collection cylinder support peg (A) and inner sleeve peg (E) allows curd-grasping teeth to be pulled into or pushed out of collection cylinder. Pulling handle up conceals curd-grasping teeth for injection of cylinder into cheese block. Pushing handle down withdraws curd-grasping teeth to obtain curd plug.
block surface or corner sampling positions was used for the studies.

Analyses

Samples were prepared according to Standard Methods for the Examination of Dairy Products (1).

Duplicate pH values were determined with an Extech gel electrode and Altec pH meter.

Duplicate moisture analyses were by the Atmospheric Oven Method (1).

Figure Construction

Two-dimensional graphs were created with Cricket Graph Version 1.3, Cricket Software, Malvern, PA. Three-dimensional graphs and figures were created using Wingz, Informix Software. All other figures were created with Superpaint Version 2.0, Silicon Software, San Diego, CA.

For Wingz three-dimensional graphs, positions (indicated by letters) were aligned in alphabetical order from left to right on the horizontal axis (z-axis). Positions were associated with their distances from the block center rather than their distances from block surfaces so that they could be designated by unique numerical values. Changes in temperature, pH, or moisture (y-axis) were indicated by shadings (contours). Cooling time in hours was aligned on the axis extending outward toward the observer (x-axis).
Since Wingz assigns equal distances between successive data points on both the x and z axes, three-dimensional graphs are not true depictions of surface plots. However, construction of true surface plots with this type of data produced graphs that did not depict actual trends as well as Wingz graphs. Three-dimensional graphs were employed to observe overall trends only.

**RESULTS AND DISCUSSION**

Figure 8 shows the temperature profile (Trial 1) of the cheese block during 288 h (12 d) of cooling at 2.2°C ambient temperature. Table 5 in the Appendix presents the data from which the profile was generated. Positions were aligned on the position axis according to their distance from the block center. If position cooling rate were directly proportional to distance of position from the block center (cooling rate increases as distance from center increases), the graph would have a smooth surface showing increasing cooling rate from right to left on the surface. The irregularities in the surface indicate that other factors, such as temperature of the position at the start of cooling and distance of the position from block surfaces, may have affected the cooling profile.

Figure 9 shows a comparison of temperature (Trial 1) for positions a, Y, O, S, and A in the cheese block during 12 d of cooling at 2.2°C ambient temperature. Curd temperature at hoop filling was 32°C. Ambient room temperature was 22°C. Heat of metabolism produced by starter culture bacteria (3, 7, 10) may
Figure 8. Temperature at all thermocouple positions in the 290-kg stirred-curd Cheddar cheese block in temperature profile Trial 1 during cooling at 2.2°C ambient temperature. See Figure 3 for location of thermocouple position in cheese block.
Figure 9. Temperature at thermocouple positions a, Y, O, S, and A in the 290-kg stirred-curd Cheddar cheese block in temperature profile Trial 1 during cooling at 2.2°C ambient temperature. See Figure 3 for location of thermocouple position in cheese block.
have been the reason many positions increased in temperature by up to 5°C before the start of cooling. After only 24 h there was a difference of 24°C between the center (36°C) and upper corner (12°C) of the block. Interior positions a and Y cooled most slowly between 0 and 24 h and between 72 and 96 h of cooling. These periods of time corresponded to approximately 35 to 30°C and to approximately 20 to 15°C. Latent heat of fusion of milkfat between 0 to 24 h and 72 to 96 h of cooling may have reduced cooling rate. Webb and Alford (15) reported that the specific heat of milkfat has maximum values from 30 to 35°C and 15°C. Batty and Folkman (2) reported that the specific heat maximum for milkfat is at approximately 21°C. Latent heat of fusion causes specific heat of milkfat to have maxima at these temperatures. This suggests that components of the milkfat in the cheese may have been solidifying at these temperatures. Other positions did not exhibit this phenomenon, because they were too close to the surface of the cheese block. Their rapid cooling rate could have masked the effect of latent heat. Heat generation by bacterial metabolism between 0 and 24 h of cooling also may have contributed to slow cooling. It took 12 d for the center of the block to cool to 2.2°C.

Figure 10 shows the temperature profile (Trial 2) of the cheese block during 288 h (12 d) of cooling at 2.2°C ambient temperature. Table 6 in the Appendix presents the data from which the profile was generated. In this type of profile, in contrast to the Trial 1 temperature profile, position cooling rate
Figure 10. Temperature at all thermocouple positions in the 290-kg stirred-curd Cheddar cheese block in temperature profile Trial 2 during cooling at 2.2°C ambient temperature. See Figure 4 for location of thermocouple position in cheese block.
is directly proportional to the distance of the position from the cheese block center. If no other factors besides simple cooling were involved, the graph should have appeared as a smooth surface showing uniformly increasing cooling rates extending from the midpoint of the position axis outward to the left and right on the surface. Irregularities in the surface, especially at the start of cooling and at interior positions during early cooling, indicate that other factors besides simple cooling may have affected the cooling profile.

Figure 11 helps to explain irregularities encountered in Figure 10. Figure 11 shows a comparison of temperature (Trial 2) for positions M, J, Q, a, and b in the cheese block during 288 h (12 d) of cooling at 2.2°C ambient temperature. As in Trial 1, a great temperature difference between the center and outer regions of the block developed within 24 h, and it took 12 d for the center of the block to cool to 2.2°C. Interior positions again showed slowest cooling between 35 to 30°C and between 20 to 15°C, presumably because of latent heat of fusion of milkfat. Starter bacteria heat of metabolism may have caused interior positions to increase in temperature before cooling and may have reduced cooling rate of interior positions during early cooling. Figure 11 also shows that positions a and b dropped below the 22°C ambient temperature during pressing and vacuum treatment. Position B also exhibited this phenomenon. Evaporative cooling at subatmospheric pressure during vacuum treatment may have been
Figure 11. Temperature at thermocouple positions M, J, Q, a, and b in the 290-kg stirred-curd Cheddar cheese block in temperature profile Trial 2 during cooling at 2.2°C ambient temperature. See Figure 4 for location of thermocouple position in cheese block.
the reason the temperature of those positions dropped below room temperature.

In the Trial 2 temperature profile, positions in the upper half of the block were equivalent to positions in the lower half of the block in terms of their distances from the center of the block. The data show that temperature increase was greater during pressing and vacuum treatment at every position in the lower half of the block than at their equivalent positions in the upper half of the block.

Figure 12 shows the pH profile (Trial 1) of the cheese block during 240 h (10 d) of cooling at 2.2°C ambient temperature. Table 7 in the Appendix presents the data from which the profile was generated. pH may have been lower in outer areas than in central areas of the block at the start of cooling, because the temperature in outer areas during pressing was near optimum (30°C) for lactic starter culture bacteria growth (5). The irregularities in the graph surface at the start of and during cooling show that pH may have been affected by other factors besides simple cooling.

Figure 13 shows a comparison of pH (Trial 1) for positions M, O, S, and X in the cheese block during 240 h (10 d) cooling at 2.2°C ambient temperature. At the start of cooling, position X had a lower pH (5.20) than interior positions (average of pH 5.38). After 48 h, position X was higher in pH (5.05) than interior positions (average of pH 4.95). This trend was observed within
Figure 12. pH at all sampling positions in the 290-kg stirred-curd Cheddar cheese block in pH profile Trial 1 during cooling at 2.2°C ambient temperature. See Figure 5 for location of sample position in cheese block.
Figure 13. pH at sampling positions M, O, S, and X in the 290-kg stirred-curd Cheddar cheese block in pH profile Trial 1 during cooling at 2.2°C ambient temperature. See Figure 5 for location of sample position in cheese block.
each level (diagonal extending from the center of the block to the outer corner of the block) in the cheese block.

Figure 14 shows the moisture profile (Trial 1) of the cheese block during 240 h (10 d) cooling at 2.2°C ambient temperature. Table 8 in the Appendix presents the data from which the profile was generated. At the start of cooling, moisture was higher in central areas (43.51% for position M and 45.22% for position N) than in corners (approximately 40%) of the block, because whey drained from corner locations during pressing. However, no definite moisture relationship between the upper and lower half of the block was observed at the start of cooling. Within 24 h the moisture distribution was reversed. The center moisture (35.39%) was lower than corner moisture (approximately 40%). The moisture gradient did not change after 240 h of cooling.

Figure 15 shows a comparison of percent moisture (Trial 1) for positions M, O, S, and X in the cheese block during 240 h (10 d) of cooling at 2.2°C ambient temperature. The graph shows that moisture dropped rapidly in interior positions (M, O, and S) of the block, but increased at the corner (X) of the block for the first 24 h. Interior positions M and O remained constant after 24 h, but position O stayed at a higher moisture than position M. Position S increased in moisture between 24 and 48 h and then remained constant. Position X remained constant after its increase in moisture between 0 and 24 h. These events indicate that moisture transferred from interior regions to exterior regions of the block.
Figure 14. Percent moisture at all sampling positions in the 290-kg stirred-curd Cheddar cheese block in moisture profile Trial 1 during cooling at 2.2°C ambient temperature. See Figure 5 for location of sample position in cheese block.
Figure 15. Percent moisture at sampling positions M, O, S, and X in the 290-kg stirred-curd Cheddar cheese block in moisture profile Trial 1 during cooling at 2.2°C ambient temperature. See Figure 5 for location of sample position in cheese block.
during cooling. This trend was observed within each level (diagonal) of the cheese block.

Figures 16, 17, 18, and 19 show pH and moisture profiles of cheese blocks for the 15-sample profile (Trial 2) depicted by Figure 6. Tables 9 and 10, respectively, in the Appendix present the data from which the profiles were generated. These profiles were employed to observe how pH and moisture changed over shorter increments of time after the start of cooling. The figures show that pH and moisture were not only variable in blocks at the start of cooling, but changed rapidly within 12 h after the start of cooling. pH and moisture gradients had stabilized, effectively, by 24 h after the start of cooling. All trends observed in Trial 1 were likewise observed in Trial 2.

SUMMARY AND CONCLUSIONS

It was indicated in Chapter I that moisture transfers from interior positions to outer positions in blocks in response to a temperature gradient. Moisture also travels outward in response to a pH gradient.

The present study substantiated those findings and increased our understanding of how blocks develop uneven moisture distribution. Large temperature, pH, and moisture gradients developed between 0 and 48 h after the start of cooling. Temperature in the center and corners of blocks averaged 35 and 30°C at the start of cooling, but averaged 35 and 10°C in the center and corners after only 24 h of cooling. Moisture in the
Figure 16. pH at all sampling positions in the 290-kg stirred-curd Cheddar cheese block in pH profile Trial 2 during cooling at 2.2°C ambient temperature. See Figure 6 for location of sample position in cheese block.
Figure 17. pH at sampling positions G, I, and L in the 290-kg stirred-curd Cheddar cheese block in pH profile Trial 2 during cooling at 2.2°C ambient temperature. See Figure 6 for location of sample position in cheese block.
Figure 18. Percent moisture at all sampling positions in the 290-kg stirred-curd Cheddar cheese block in moisture profile Trial 2 during cooling at 2.2°C ambient temperature. See Figure 6 for location of sample position in cheese block.
Figure 19. Percent moisture at sampling positions G, I, and L in the 290-kg stirred-curd Cheddar cheese block in moisture profile Trial 2 during cooling at 2.2°C ambient temperature. See Figure 6 for location of sample position in cheese block.
center and corners of blocks averaged 42 and 39% at the start of cooling, but averaged 35 and 40% in the center and corners after only 24 h of cooling. Moisture probably transferred from interior to exterior positions in response to the large temperature gradient between the center and corners of the blocks.

pH in outer areas of the block reached low values (average of 5.2) before cooling and changed little during 48 h of cooling, but pH in interior regions dropped greatly during the first 48 h of cooling (average of 5.5 to 5.1). Curd syneresis was probably stronger in the interior than the outer regions of blocks during early stages of cooling. This could have forced moisture from interior to exterior positions.

Before cooling, temperature was always higher at positions in the lower half of the block than at their equivalent positions in the upper half of the block. Drainage of whey with its associated lactose may have aided starter bacteria in the production of more heat of metabolism in the lower half of the block. However, no definite pH or moisture relationships were observed for equivalent positions.

This study showed that other variables besides simple cooling may have affected moisture distribution. Vacuum treatment of curd appeared to reduce the temperature at corner positions before the start of cooling. Milkfat may have affected cooling of interior positions. More research is required to assess each factor's importance. In the meantime, the cheesemaker must implement measures to ensure uniform whey drainage from
blocks, uniform pressure application and vacuum treatment within blocks and uniform cooling of all positions within blocks.

REFERENCES


CHAPTER III

Effect of Container Materials on Temperature Profiles During Cooling of Swiss and Stirred-curd Cheddar Cheese.

INTRODUCTION

When refrigeration became available to cheese manufacturers near the turn of the century, curing Cheddar cheese at low temperature quickly became accepted practice. Van Slyke and Price (18) presented an excellent review of the reasons cheesemakers employed cold-curing of cheese. Flavor, body, and texture were found to be more desirable and uniform when Cheddar cheese was cured at low (approximately 5°C and below) rather than high (approximately 10°C and above) temperature. This was attributed to reduction of bacterial and enzymic activity. These findings are still valid, and curing Cheddar cheese at low temperature is a common practice today.

One of the most important defects presently challenging the cheesemaker is the development of calcium lactate crystals on the surface of Cheddar cheese. Olson et al. (13) recommended cooling cheese rapidly to below 7.2°C after pressing to restrict growth of contaminants (lactobacilli and pediococci) incriminated in development of crystals. However, Reinbold and Ernstrom (15) found that rapid cooling of 290-kg blocks of stirred-curd Cheddar cheese produced uneven moisture distribution.

Finishing of Swiss cheese at reduced temperature is used to arrest eye development at the proper size, to firm cheese for easy
handling, to inhibit growth of bacteria other than propionibacteria, to permit continued flavor development, and to avoid onset of body and flavor defects. Reinbold (14) observed that finishing cooler temperature may range from 2.2 to 12.8°C but recommended temperatures below 4.4°C to arrest bacterial growth. However, substantial growth of some strains of propionibacteria is possible at 2.8 to 7.2°C (7). Failure to arrest growth of propionibacteria by low temperature during finishing cooler treatment may result in high incidence of the split defect (8), but cooling to very low temperatures may be harmful to body and texture of cheese (10). Also, rapidly cooled cheese blocks have more uneven temperature distribution during cooling than more slowly cooled cheese blocks (15) because cheese blocks cool by transient heat transfer (3). Nonuniform temperature in cheese blocks during cooling may cause variation in the size of eyes in Swiss cheese (10, 14).

The purpose of this study was to compare cooling rates of 290-kg stirred-curd Cheddar cheese blocks that were cooled in either stainless steel or plywood hoops and to compare cooling rates, during finishing cooler treatment, of 66-kg Swiss cheese blocks that were cooled in either plastic or cardboard-pressboard boxes. Understanding cooling profiles of cheese may help the cheesemaker implement procedures to eliminate temperature-related cheese defects.
MATERIALS AND METHODS

Manufacturing Procedures

Stirred-curd Cheddar cheese was manufactured as described in Chapter I.

Swiss cheese was manufactured at Cache Valley Dairy Association, Smithfield, Utah. Curd was produced in "Double O" vats (Damrow Co., Fond du Lac, Wisconsin) from 22,727 kg milk, pumped to Damrow Stationary Swiss Universals, and pressed at 1.7 kPa surface pressure for 6 h. Ambient room temperature was 22°C. Sixty-six kg blocks were brined in saturated brine for 12 h, packaged in plastic bags and placed in cardboard-pressboard boxes. Sixteen boxes were arranged on pallets to provide air circulation through the center of the stack of boxes. Stacks were cooled in a pre-cooler at 5.5°C for 14 d and then moved to a room for warm room treatment at 24.7°C ambient temperature. After development (14 to 21 d) of proper sized eyes, stacks were cooled in a finishing cooler at approximately 2.2°C ambient temperature until ready for cutting. Finishing cooler temperature varied by no more than 2°C.

Temperature Profiles

Stirred-curd Cheddar. Cheese temperature profiles for stirred-curd Cheddar cheese were determined as described in Chapter II. The study was conducted for one block cooled in a stainless steel hoop (material thickness of .5 cm) and one block cooled in a plywood hoop (material thickness of 1.6 cm). Figure 20
Figure 20. Thermocouple junction positions used for generation of temperature profiles of 290-kg stirred-curd Cheddar cheese blocks cooled in stainless steel and plywood hoops.
shows thermocouple junction position for generation of the temperature profiles.

Swiss Cheese. A pallet of comparably sized blocks (66 kg per block) was selected to be cooled in the finishing cooler. One block was taken out of its cardboard box and placed in a solid-plastic box. Fourteen thermocouple positions were designated for the block in the plastic box and also for a block in a cardboard box. These test blocks were arranged on the top of the pallet stack, and the pallet was stationed in the cooler to provide uniform cooling of all block and pallet surfaces. Figure 21 shows arrangement of the boxes on the pallet. Copper and constantan thermocouples with electrical leads were attached to a stainless steel skewer with tape. The skewer and thermocouple were injected from the top 40 x 76 cm surface downward to the desired location. The thermocouple lead was held firmly in place while the skewer and tape were removed from the block. Then the thermocouple lead was taped securely to the plastic bag around the cheese block. Figure 22 shows approximate thermocouple position and absolute distance of position from the center of the block. Upper thermocouple positions A, C, E, G, H, K, and M were 1.3 cm below the upper 40 x 76 cm block surface. Side thermocouple positions C and D were 1.3 cm from the 20 x 40 cm block surface. Side thermocouples H and J were 1.3 cm from the 20 x 76 cm block surface. Corner thermocouples A and B were 1.3 cm from the block corner. The thermocouple leads were connected to Speedomax 250 automatic temperature recorder (30 thermocouple
Figure 21. Diagram depicting top view of stack of Swiss cheese blocks. Thermocouple positions A, C, E, G, H, K, and M in blocks in plastic and cardboard-pressboard boxes are shown. See Figure 22 for location of other thermocouple positions.
Figure 22. Thermocouple junction positions used for generation of temperature profiles of 66-kg Swiss cheese blocks cooled in plastic and cardboard-pressboard boxes.
capacity); lids were placed on boxes, and thermocouple position was monitored continuously during finishing cooler treatment at 2.2°C ambient temperature for the block in the plastic box (material thickness of .6 cm) and the block in the cardboard box (material thickness of 1.0 cm).

Figure Construction

Figures were constructed as described in Chapter II.

RESULTS AND DISCUSSION

Figures 23 and 24 show respective temperature profiles of 290-kg blocks of stirred-curd Cheddar cheese during pressing and vacuum treatment in stainless steel and plywood hoops. Tables 11 and 12, respectively, in the Appendix present the data from which the profiles were generated. Curd temperature was 32°C and ambient room temperature was 22°C at the start of hoop filling. In this type of profile, position cooling rate would have been directly proportional to distance of position from the block center (cooling rate increases as distance from block center increases) if no other factors besides simple cooling were involved. The graphs would have appeared as smooth surfaces showing uniformly increasing cooling rates extending from the midpoint of the position axis outward to the left and right on the surfaces. Irregularities on the surfaces indicate that other factors besides simple cooling affected the cooling profiles. Both graphs show nonuniform increases in cooling rates at corner thermocouple
Figure 23. Temperature at all thermocouple positions in the 290-kg stirred-curd Cheddar cheese block in the stainless steel hoop during pressing and vacuum treatment. Curd temperature at hoop filling was 32°C. Ambient room temperature was 22°C.
Figure 24. Temperature at all thermocouple positions in the 290-kg stirred-curd Cheddar cheese block in the plywood hoop during pressing and vacuum treatment. Curd temperature at hoop filling was 32°C. Ambient room temperature was 22°C.
positions B, D, X, Y, and b. Also, both graphs show temperature increase, rather than temperature decrease, at interior thermocouple positions during pressing and vacuum treatment.

Figures 25 and 26 help to explain irregularities encountered in Figures 23 and 24. Figures 25 and 26 show respective temperature during pressing and vacuum treatment for positions M, A, and a in 290-kg blocks of stirred-curd Cheddar cheese in stainless steel and plywood hoops. Both graphs show that positions a and A experienced rapid temperature increase and then decrease at the start of mechanical pressure application. For the cheese in the stainless steel hoop, only positions C, L, M, R, U, V, and Q did not show temperature increases at the start of pressure application. Temperature increases at the start of pressing ranged from .6 to 3.3°C (position a) for positions in the cheese block in the stainless steel hoop. For the cheese block in the plywood hoop, only positions C, E, G, I, L, N, and P did not show temperature increases at the start of mechanical pressure application. Temperature increases at the start of pressing ranged from .6 to 1.6°C (position B) for positions in the cheese block in the plywood hoop. In both trials, corner positions showed the greatest temperature increase at the start of pressure application. Heat generation by frictional head loss (3, 6) through whey drainage may have been the reason temperature at those positions increased at the start of pressure application.
Figure 25. Temperature at positions M, A, and a in the 290-kg stirred-curd Cheddar cheese block in the stainless steel hoop during pressing and vacuum treatment. Curd temperature at hoop filling was 32°C. Ambient room temperature was 22°C.
Figure 26. Temperature at positions M, A, and a in the 290-kg stirred-curd Cheddar cheese block in the plywood hoop during pressing and vacuum treatment. Curd temperature at hoop filling was 32°C. Ambient room temperature was 22°C.
Gradual temperature increase throughout pressing and vacuum treatment was observed at interior positions in cheese blocks in both stainless steel and plywood hoops. For the cheese in the stainless steel hoop, only positions A, B, C, D, V, X, Y, Z, a, and b did not show gradual temperature increase throughout pressing and vacuum treatment. Temperature increases in interior positions in the cheese block in the stainless steel hoop ranged from 0.1 to 4.7°C (position L). For the cheese block in the plywood hoop, only positions A, B, D, X, Y, Z, a, and b did not show gradual temperature increase throughout pressing and vacuum treatment. Temperature increases in positions in the cheese block in the plywood hoop ranged from 0.1 to 5.2°C (positions I, J, K, L, M, N, O, and P). Heat generation by metabolism of starter bacteria (2, 12, 16) may have been the reason temperature increased at those positions. Temperature increase, except for rapid increase at the start of pressure application, was not observed at corner positions. Rapid heat dissipation from those areas probably masked the effect of heat generation by metabolism of starter bacteria.

For both stainless steel and plywood hoop temperature profiles, positions in the upper half of the block were equivalent to positions in the lower half of the block in terms of their distances from the center of the block. For both the block in the stainless steel hoop and the block in the plywood hoop, temperature was always higher at positions in the lower half of the block than at their equivalent positions in the upper half of
the block before the start of cooling at 2.2°C ambient temperature. Through drainage, more whey may have collected in the lower half of the blocks, and the associated lactose may have aided starter bacteria in the production of more heat of metabolism than in the upper half of the blocks.

Temperature decreased rapidly during vacuum treatment at corner positions A, B, D, X, Y, a, and b in cheese blocks in both stainless steel and plywood hoops. Temperature at position a in the cheese block in the stainless steel hoop dropped below room temperature during vacuum treatment. Evaporative cooling at subatmospheric pressure during vacuum treatment (17) may have been the reason temperature at those positions dropped so rapidly.

Another phenomenon was not depicted graphically. During pressing at atmospheric pressure, temperature at positions B, C and H in the cheese block in the stainless steel hoop and temperature at positions G and Q in the cheese block in the plywood hoop, dropped and then increased within a few minutes. Temperature at position B in the block in the stainless steel hoop dropped from 30.6 to 25.6°C in 2 minutes and then increased from 25.6 back to 30.6°C in the next 13 minutes. The other positions dropped by .6°C in two minutes and returned to their starting temperature in two minutes. Hillel (9) and Bowles (4) reported that subatmospheric pressure in interstitial spaces may develop in porous solids through capillary (surface tension) effects. Evaporative cooling at reduced pore pressure areas in blocks may
have been the reason temperature at some positions dropped rapidly during pressing.

A comparison of overall trends observed in the two trials showed that positions that increased in temperature presumably as a result of heat generation by starter culture bacteria metabolism, increased more rapidly and to greater values in the cheese block in the plywood hoop than in the cheese block in the stainless steel hoop. Positions that decreased in temperature during pressing and vacuum treatment, decreased more rapidly and to lower values in the block in the stainless steel hoop than in the block in the plywood hoop. Since the thermal conductivity of stainless steel is approximately 14 W/m-K (1) and that of plywood is approximately .12 W/m-K (11), heat transferred more rapidly out of the block encased in the stainless steel hoop. Conversely, heat generated during pressing and vacuum treatment was retained more in the block encased in the plywood hoop.

Figures 27 and 28 show the respective temperature profiles of 290-kg blocks of stirred-curd Cheddar cheese in stainless steel and plywood hoops during cooling at 2.2°C ambient temperature. Tables 6 and 13, respectively, in the Appendix present the data from which the profiles were generated. As in Figures 23 and 24, irregularities in the surfaces, especially at the start of cooling and at interior positions during early cooling, indicate that other factors besides simple cooling may have affected the cooling profiles. Both graphs show nonuniform starting temperatures at corner positions B, D, X, Y, and B. This may have been caused by the
Figure 27. Temperature at all thermocouple positions in the 290-kg stirred-curd Cheddar cheese block in the stainless steel hoop during cooling at 2.2°C ambient temperature.
Figure 28. Temperature at all thermocouple positions in the 290-kg stirred-curd Cheddar cheese block in the plywood hoop during cooling at 2.2°C ambient temperature.
vacuum treatment. Both graphs show prolonged high temperature in interior positions. Figure 27 shows that it took 288 h (12 d) for the center of the block in the stainless steel hoop to cool to 2.2°C. Figure 8 shows that many positions in the block in plywood hoop had not cooled to 2.2°C by 12 d. It took 354 h (14.75 d) for the center of the block in the plywood hoop to cool to 2.2°C. Temperature at many positions in both blocks was near optimum for coliforms, lactobacilli, and pediococci (5) during 24 to 48 h after the start of cooling.

Figures 29 and 30 show respective temperature during cooling at 2.2°C ambient temperature for positions M, J, Q, a, and b in 290-kg blocks of stirred-curd Cheddar cheese in stainless steel and plywood hoops. For the block in the stainless steel hoop, there was a reduction in the cooling rate of positions L, M, and N between 0 and 24 h (approximately 36°C) and between 72 and 96 h (approximately 20 to 17.5°C). For the block in the plywood hoop, there was a reduction in cooling rate for positions I, J, K, L, M, N, O, and P between 0 and 36 h (approximately 37°C) and between 72 and 108 h (approximately 23 to 19°C). Latent heat of fusion of milkfat during 0 to 24 or 36 h and 72 to 96 or 108 h of cooling may have reduced cooling rate (Chapter II). Heat generation by bacterial metabolism between 0 and 24 or 36 h of cooling also may have contributed to slow cooling (Chapter II). Periods of reduced cooling rate were longer for positions in the block cooled in the plywood hoop than the block cooled in the stainless steel.
Figure 29. Temperature at positions M, J, Q, a, and b in the 290-kg stirred-curd Cheddar cheese block in the stainless steel hoop during cooling at 2.2°C ambient temperature.
Figure 30. Temperature at positions M, J, Q, a, and b in the 290-kg stirred-curd Cheddar cheese block in the plywood hoop during cooling at 2.2°C ambient temperature.
because it took longer for heat to transfer from the plywood encased block.

Figure 30 shows that during the first 6 h of cooling, position a in the block in the stainless steel hoop cooled at a rate of 2.2°C per h. Center position temperature remained constant. Figure 30 shows that during the first 6 h of cooling, position a in the block in the plywood hoop cooled at a rate of 1.6°C per h. Center temperature remained constant. Observing other position temperature change showed that the block encased in plywood cooled more slowly and uniformly than the block encased in stainless steel. Reinbold and Ernstrom (15) found that cooling 290-kg blocks of stirred-curd Cheddar cheese in stainless steel hoops more slowly produced more even moisture distribution within blocks. M. Harris, Cache Valley Dairy (personal communication), found that 290-kg cheese blocks encased in plywood hoops during cooling had more even moisture distribution than blocks encased in stainless steel hoops. Reinbold and Ernstrom (15) concluded that moisture transferred from high temperature to low temperature in 290-kg blocks of stirred-curd Cheddar cheese. Encasing cheese blocks in insulating material such as plywood probably reduces moisture transfer within blocks because blocks cool more slowly and uniformly.

Figures 31 and 32 show the respective temperature profiles of 66-kg blocks of Swiss cheese in plastic and cardboard boxes during finishing cooler treatment at 2.2°C ambient temperature. Tables 14 and 15, respectively, in the Appendix present the data
Figure 31. Temperature at all thermocouple positions in the 66-kg Swiss cheese block in the plastic box during finishing cooler treatment at 2.2°C ambient temperature.
Figure 32. Temperature at all thermocouple positions in the 66-kg Swiss cheese block in the cardboard box during finishing cooler treatment at 2.2°C ambient temperature.
from which the profiles were generated. If position cooling rate were directly proportional to distance of position from the block center and no other factors besides simple cooling were involved, the graphs would have smooth surfaces showing uniformly increasing cooling rates extending from the far right on the position axes to the left on the surfaces. Irregularities on the surfaces indicate that other factors such as distance of position from block surfaces or convective heat transfer from block surfaces may have affected the cooling profile. For the Swiss cheese block in the plastic box, the order of position cooling rate from slowest to fastest was I, N, F, L, B, D, G, M, J, E, K, A, H, and C. For the Swiss cheese block in the cardboard box, the order of position cooling rate from slowest to fastest was N, I, L, F, D, K, G, E, M, J, C, B, H, and A. In this type of profile, position cooling rate is dependent on both distance of position from the block center and distance of position from block surfaces. If no other factors besides transient conductive heat transfer were involved, the order of position cooling rate for both cheese blocks, from slowest to fastest would have been N, I, L, F, M, G, K, E, J, D, H, C, B, and A. The relative cooling rates of the positions in the block in the cardboard box were similar to the expected relative cooling rates. Also, the temperature profile for the block in the cardboard box had a smoother graph surface. This indicates that cooling was more uniform in the Swiss cheese block cooled in the cardboard box. The thermal conductivity of cardboard is approximately .06 W/m-K (3) and that of plastic is approximately .21 W/m-K (3).
Heat transfer from the block in the cardboard box was slower than from the block in the plastic box so cooling was more uniform in the cheese in the cardboard box. Since actual relative cooling rates were not the same as expected relative cooling rates, position within cheese blocks was not the only factor that affected the cooling profile. Position D could have cooled more slowly than position J in both blocks because of its position in relation to the other blocks on the pallet.

Figures 33 and 34 show temperature for positions N, L, D, and A during finishing cooler treatment at 2.2°C ambient temperature in 66-kg blocks of Swiss cheese in plastic and cardboard-pressboard boxes. Interior positions N, I, and F had comparable cooling rates in the block cooled in the plastic box (approximately .25°C per h for the first 20 h). Interior position L cooled more rapidly (approximately .45°C per h for the first 20 h). Its cooling rate was comparable to cooling rate of exterior positions D and B. Interior positions N, I, F, and L had comparable cooling rates in the block cooled in the cardboard box (approximately .25°C per h for the first 20 h). Since position L in the cheese block in the plastic box cooled as rapidly as some exterior positions and position J cooled more rapidly than position D in blocks in both the plastic and cardboard boxes, position cooling rate in both plastic and cardboard boxes may have been affected by the arrangement of the boxes on the pallet.

It took 100 h and 140 h, respectively, for the center of the blocks in the plastic and cardboard boxes to cool to 2.2°C.
Figure 33. Temperature at positions N, L, D, and A in the 66-kg Swiss cheese block in the plastic box during finishing cooler treatment at 2.2°C ambient temperature.
Figure 34. Temperature at positions N, L, D, and A in the 66-kg Swiss cheese block in the cardboard box during finishing cooler treatment at 2.2°C.
Temperature of some positions after 60 h of cooling at 2.2°C ambient temperature was still high enough (2.8 to 7.2°C) to allow activity of some strains of propionibacteria.

**SUMMARY AND CONCLUSIONS**

This study and the studies presented in Chapters I and II showed that rapid cooling of 290-kg blocks of stirred-curd Cheddar cheese in stainless steel hoops produces nonuniform cooling within blocks. This in turn produces uneven moisture distribution within blocks. More even moisture distribution can be produced by cooling blocks more slowly. This can be accomplished by encasing blocks in materials with low thermal conductivity such as plywood. However, temperature at interior positions within slowly cooled cheese blocks may remain high enough to allow prolonged activity of starter culture bacteria and defect causing contaminants. The cheesemaker must weigh the advantage of cooling blocks slowly against the potential for reduction in cheese quality.

Rapid cooling of 66-kg blocks of Swiss cheese in the finishing cooler produces nonuniform cooling within cheese blocks. Nonuniform cooling within blocks may cause variation in the size of eyes within blocks (10, 14). Cooling blocks more slowly produces more uniform cooling (15). However, slow cooling may allow prolonged activity of propionibacteria. This in turn may help in the development of the split defect and enlargement of eyes (8, 14). However, if the cheesemaker knows
that cheese blocks are cooling slowly but uniformly during finishing cooler treatment, he can regulate warm room treatment time and temperature and choose appropriate strains of propionibacteria to achieve desired Swiss cheese quality. Regardless, rapid and uniform cooling of all positions in Swiss cheese blocks during finishing cooler treatment would be most desirable.

REFERENCES


CHAPTER IV

Pressure and Temperature during Vacuum Treatment of 290-kilogram Stirred-curd Cheddar Cheese Blocks.

INTRODUCTION

Vacuum treatment of cheese is employed to reduce the size of mechanical openings in cheese blocks and thereby produce a smooth, close-textured cheese. Czulak et al. (1) proposed that removal of air by vacuum treatment helped reduce the size of mechanical openings in Cheddar cheese. Irvine and Burnett (3) believed that whey brine pockets trapped between curd surfaces caused mechanical openness. Price et al. (4) and Irvine and Burnett (3) found that moisture was removed from cheese blocks more effectively by pressing and vacuum treating curd rather than by pressing alone. Robertson (7), Czulak et al. (1) and Irvine and Burnett (3) recommended vacuum treating curd before applying pressure to help reduce mechanical openness in Cheddar cheese. Tabchnikov (9) concluded that unconsolidated curd was necessary for effective air removal from blocks during vacuum treatment. Scott (8) proposed that too rapid pressure application on curd could produce a compressed surface layer on blocks that could lock moisture into pockets in the body of the cheese. Reinbold and Ernstrom (6) found that 290-kg blocks of stirred-curd Cheddar cheese in stainless steel hoops released 25% more whey when pressing was eliminated before vacuum treatment.
Geurts (2) concluded that unevenness of moisture distribution in Gouda cheese increased with increasing moisture content of cheese. Reinbold and Ernstrom (5) found that removal of excess moisture before cooling 290-kg blocks of stirred-curd Cheddar cheese in stainless steel hoops produced cheese with more even moisture distribution.

The purpose of this study was to quantitate vacuum treatment by observing pressure changes during vacuum treatment of 290-kg blocks of stirred-curd Cheddar cheese that had or had not been pressed before vacuum treatment. Better understanding of vacuum treatment would aid the cheesemaker in producing cheese with desired texture and moisture distribution.

**MATERIALS AND METHODS**

Cheese was manufactured at Cache Valley Dairy Association, Smithfield, Utah. Curd was produced in "Double O" vats (Damrow Co., Fond du Lac, Wisconsin) from 22,727 kg milk, drained and salted on enclosed finishing tables and then air conveyed to stainless steel hoops (74.9 cm high x 71.1 cm long x 55.9 cm wide). Before filling stainless steel hoops, tennis string was drawn across the hoop interior and fastened to steel brackets extending across trier holes at the hoop sides. A screened plastic bulb connected to rigid Tygon tubing and a copper-constantan thermocouple were secured to the tennis string in either the center or at the side of the hoop. Each hoop was filled with 327 kg of curd at 32°C. Ambient room temperature was approximately
22°C. After filling, the screened bulb was 2.5 cm from the side of the hoop. For each vat (8 hoops per vat, one test hoop per vat), curd either was pressed at 7.9 kPa surface pressure for 2 h or remained unpressed for 2 h. Then the hoops were transferred to a vacuum chamber.

Before vacuum treatment, Tygon tubing was attached to a Super TJE absolute pressure transducer (0.05 % accuracy, 0-100 kPa absolute pressure range, Sensotec, Columbus, OH) located inside the vacuum chamber. Electrical leads from the copper-constantan thermocouple in the cheese block, a thermocouple attached to the inside wall of the vacuum chamber, and the pressure transducer were connected to a Campbell Scientific 21X Datalogger (Campbell Scientific, Logan, UT) outside the vacuum chamber. Curd in hoops was vacuum treated at 80 kPa vacuum gage pressure (8.0 kPa absolute pressure) for 1 h without mechanical pressure. While still under vacuum, mechanical pressure was applied and curd was pressed at 12.4 kPa surface pressure for 1 h. Then vacuum was released. When the pressure in the vacuum chamber reached atmospheric pressure, mechanical pressure was released. Pressure and temperature in blocks and pressure and temperature in the vacuum chamber were monitored continuously throughout vacuum treatment. Vacuum chamber pressure was monitored by observing the vacuum chamber pressure gage. Figure 35 depicts the experimental setup.

Pressure and temperature at the center of the block, side of the block, and in the vacuum chamber during vacuum treatment
Figure 35. Diagram depicting apparatus setup for determining pressure change during vacuum treatment of 290-kg stirred-curd Cheddar cheese blocks.
were determined three times each for a test block from vats that had been given the 2 h prepress prior to vacuum treatment and from vats that had no prepress prior to vacuum treatment. Data from the three trials were averaged and depicted graphically in Figures 36 through 39. The pooled estimator was the average standard deviation about the means of the data from either the center of the block, the side of the block or the vacuum chamber. Figure 35 was drawn with Superpaint Version 2.0, Silicon Software, San Diego, CA. Figures 36-39 were created with Cricket Graph Version 1.3, Cricket Software, Malvern, PA.

RESULTS AND DISCUSSION

Figure 36 shows pressure, during vacuum treatment at 8.0 kPa absolute pressure, in the center and side of 290-kg blocks of stirred-curd Cheddar cheese in stainless steel hoops. Curd was pressed at 7.9 kPa surface pressure prior to the vacuum treatment (prepressed blocks). Figure 37 shows pressure, during vacuum treatment at 8.0 kPa absolute pressure, in the center and side of 290-kg blocks of stirred-curd Cheddar cheese in stainless steel hoops when curd was not pressed prior to the vacuum treatment (non-prepressed blocks). The center pressure of prepressed blocks decreased from an average of 89.5 kPa absolute pressure to 17.0 kPa absolute pressure (range of 15.3 to 20.9 kPa absolute pressure for the three trials) before mechanical pressure was applied. The center pressure of non-prepressed blocks dropped from an average of 88.6 kPa absolute pressure to 11.9 kPa absolute pressure (range
Figure 36. Three trial averages of pressure in the center and side of 290-kg stirred-curd Cheddar cheese blocks in stainless steel hoops during vacuum treatment at 8.0 kPa absolute pressure. Blocks were pressed for 2 h at 7.9 kPa surface pressure prior to vacuum treatment. Average vacuum chamber pressure also is shown. The pooled estimator is the average standard deviation about the means of the three trial averages.
Figure 37. Three trial averages of pressure in the center and side of 290-kg stirred-curd Cheddar cheese blocks in stainless steel hoops during vacuum treatment at 8.0 kPa absolute pressure. Blocks were not pressed prior to vacuum treatment. Average vacuum chamber pressure also is shown. The pooled estimator is the average standard deviation about the means of the three trial averages.
Figure 38. Three trial averages of temperature in the center and side of 290-kg stirred-curd Cheddar cheese blocks in stainless steel hoops during vacuum treatment at 8.0 kPa absolute pressure. Blocks were pressed at 7.9 kPa surface pressure prior to vacuum treatment. Average vacuum chamber temperature also is shown. The pooled estimator is the average standard deviation about the means of the three trial averages.
Figure 39. Three trial averages of temperature in the center and side of 290-kg stirred-curd Cheddar cheese blocks in stainless steel hoops during vacuum treatment at 8.0 kPa absolute pressure. Blocks were not pressed prior to vacuum treatment. Average vacuum chamber temperature also is shown. The pooled estimator is the average standard deviation about the means of the three trial averages.
of 10.0 to 13.1 kPa absolute pressure for the three trials) before mechanical pressure was applied. Atmospheric pressure ranged from 87.1 to 87.5 kPa absolute pressure during the studies. Since pressure in the center of non-prepressed blocks was lower than in the center of prepressed blocks, prepressing may have compressed and sealed the surface curd which created a barrier to rapid air and whey evacuation from the blocks. No difference in vacuum chamber pressure between the two treatments was observed.

Figure 38 shows the temperature in the center and side of prepressed 290-kg blocks of stirred-curd Cheddar cheese in stainless steel hoops during vacuum treatment. Vacuum chamber temperature also is shown. Figure 39 shows temperature in the center and side of non-prepressed 290-kg blocks of stirred-curd Cheddar cheese during vacuum treatment. Vacuum chamber temperature also is shown. For both studies, the decrease in temperature in the center and side of blocks and the decrease in temperature in the vacuum chamber at the start of vacuum treatment were probably caused by evaporative cooling. Increases in temperature were probably caused by heat of condensation as the vacuum chamber pressure returned rapidly to atmospheric pressure. Center temperature decreased by an average of 5.87°C (range of 5.8 to 5.9°C for the three trials) in non-prepressed blocks. Center temperature decreased by an average of only 3.63°C (range of 3.1 to 4.7°C for the three trials) in prepressed blocks.
This indicates that lower pressures were attained in non-prepressed blocks. This also suggested that curd was more compressed in prepressed blocks. Rapid heat transfer from compressed curd to thermocouple junctions could have opposed evaporative cooling in pre-pressed blocks. This in turn provides evidence that compressed curd at the surfaces of pre-pressed blocks could have provided a barrier to rapid air and whey evacuation from the cheese.

Another important observation was made by monitoring vacuum chamber temperature. The center and side of blocks and the vacuum chamber showed temperature increases at the time of mechanical pressure application when the chamber was filled with non-prepressed blocks. Temperature increases ranged from .2 to .6°C and from .1 to 2.0°C for the center and side of non-prepressed blocks. Temperature increases in the center and side of blocks, and in the vacuum chamber, were not observed when the chamber was filled with pre-pressed blocks. Temperature increase in the vacuum chamber may have been in response to a temperature increase in non-prepressed blocks at the time of mechanical pressure application. This indicates that non-prepressed blocks may have behaved as open systems in comparison to prepressed blocks. This in turn suggests that prepress treatment compressed curd which provided a barrier to air and whey evacuation.
SUMMARY AND CONCLUSIONS

Pressure and temperature were higher during vacuum treatment in blocks that were pressed before vacuum treatment than in blocks that were not pressed before vacuum treatment. Through this work and previous studies (1, 3, 4, 6, 7, 8, 9), we conclude that pressing before vacuum treatment compresses surface curd to produce a barrier to air and whey evacuation. Entrapped air and whey may produce mechanical openness in cheese (1, 3, 4, 7, 8, 9). Excessive free moisture trapped in cheese blocks at the start of cooling may increase uneven moisture distribution in cheese (2, 5). Novel pressing and vacuum treatment regimes must be devised by the cheesemaker to minimize mechanical openness and uneven moisture distribution in cheese.

REFERENCES


Review and Conclusions

Figures 40, 41, and 42 in this section were designed to show trends in a different way than were depicted in the previous chapters and serve as good tools for review. They depict data taken from Temperature Profile Trial 2, Chapter II, and pH and Moisture Profile Trial 2, Chapter II. In every graph in Figures 40, 41, and 42, positions C and S represent positions M and X, respectively, in Temperature Profile Trial 2, or positions G and L, respectively, in pH and Moisture Profile Trial 2. Position M represents position O in Temperature Profile Trial 2, or position I in pH and Moisture Profile Trial 2. That is, C, M, and S represent the positions on the midlevel diagonal extending from the center (position C) of the cheese block outward (through position M) to the side-corner of the block (position S). Position M is approximately equidistant between positions C and S. The relationships between temperature and pH, between temperature and moisture, and between moisture and pH at 0, 12, and 24 hours of cooling at positions C, M, and S are shown. These relationships represent generally how moisture, pH, and temperature change in 290-kg stirred-curd cheese blocks during cooling.

Figure 40 shows that at the start of cooling, position C temperature was 36°C and position S temperature was only 26°C. Position C pH was 5.45, but position S pH was 5.18. The temperature and pH of curd at hoop filling at this factory averaged...
Figure 40. Temperature and pH at center (C), midpoint (M), and side (S) positions in 290-kg stirred-curd Cheddar cheese blocks in stainless steel hoops after 0, 12, and 24 hours of cooling. For pH, positions C, M, and S are the same as positions G, I, and L, respectively, in Figure 6. For temperature, positions C, M, and S are the same as positions M, O, and X, respectively, in Figure 5.
Figure 41. Moisture and pH at center (C), midpoint (M), and side (S) positions in 290-kg stirred-curd Cheddar cheese blocks in stainless steel hoops after 0, 12, and 24 hours of cooling. For pH, positions C, M, and S are the same as positions G, I, and L, respectively, in Figure 6. For temperature, positions C, M, and S are the same as positions M, O, and X, respectively, in Figure 5.
Figure 42. Temperature and moisture at center (C), midpoint (M), and side (S) positions in 290-kg stirred-curd Cheddar cheese blocks in stainless steel hoops after 0, 12, and 24 hours of cooling. For pH, positions C, M, and S are the same as positions G, I, and L, respectively, in Figure 6. For temperature, positions C, M, and S are the same as positions M, O, and X, respectively, in Figure 5.
approximately 32°C and 5.85. The lower temperature may have contributed to the greater pH decrease at position S before the start of cooling as it was nearer to the optimum growth temperature of lactic starter bacteria (30°C). However, other factors may have contributed to the large pH difference between the center and side of the block. It was indicated in Chapter I that curd may clump in the enclosed finishing vats before salting. Clumped curd absorbs less salt per unit weight than granular curd so pH decrease is not retarded to the extent that it is in granular curd. We observed that clumped curd often rolls to the sides of the hoop during hoop filling. This could have been a major contributor to the large pH decrease at the side and corners of the block before cooling. Another possible contributor to this phenomenon, but presumably less important, was the difference between the oxidation-reduction (OR) potential of the center and outer regions of the cheese block. It was indicated in Chapter IV that the center of the block may contain more air than the sides during pressing and vacuum treatment. Higher oxygen tension in the center of the block before the start of cooling may have helped to retard pH decrease there.

After 12 hours of cooling, center temperature did not change, but side temperature decreased to 10°C. pH in the center of the block decreased by .09 unit (from 5.45 to 5.36), and pH at the side decreased by .06 unit (from 5.18 to 5.12). The temperature in the center of the block was still too high or oxygen tension in the center of the block was still too high to allow rapid
pH decrease. The temperature at the side of the block was too low to permit a large pH decrease. Also, the pH at the side was approaching values where its rate of decrease would be expected to decline regardless of temperature.

After 24 hours of cooling, center temperature had decreased by only 2°C (from 36 to 34°C). However, center pH decreased by .22 unit (from 5.36 to 5.14). Position M showed a similar response. When position M temperature decreased from 35.3 to 33.9°C, pH at that position decreased by .22 unit. Starter bacteria activity appeared to be reduced above a temperature of 34°C. The pH in the center of the block probably decreased from 5.85 at hoop filling to 5.45 at the start of cooling before the temperature in the center of the block had increased much above 34°C (during hoop filling and early stages of pressing).

Since pH at the side of the block effectively remained unchanged throughout cooling, but pH in the center changed greatly, a curd syneresis gradient may have existed during the first 24 hours of cooling. Syneresis was still strong during the pH decrease from 5.45 to 5.15 in the center of the block, but was weak at the side of the block where pH was not changing. This could have helped to force moisture from the center to the sides of the cheese block.

Figure 41 shows the relationship between moisture and pH and supports the previous conclusion. At the start of cooling, moisture was high in the center of the block (41.82%) and lower in the side (37.48%). After 12 hours of cooling, moisture was the
same in the center as in the side of the block (approximately 39%),
but in order to achieve this, it had decreased in the center and
increased in the side. Position M had not changed greatly. This
indicates that moisture transferred from interior positions
through position M to exterior positions in the cheese block. After
24 hours of cooling, moisture was lower in the center (34.52%)
than the side (39.89%) of the block. The moisture at position M
was comparable to the moisture in the center of the block. This
indicates that there was a driving force pushing moisture to the
outer regions of the block. Throughout cooling, pH was decreasing
in the center of the block, but was not changing greatly in the
sides. The pH (syneresis) gradient may have been the driving force
that was pushing moisture outward.

Figure 42 shows a comparison of temperature and moisture
and shows strikingly the relationship between temperature and
moisture transfer. Moisture transfers from high to low
temperature. Whether moisture transfers in response to a pH
gradient that is, in turn, created by a temperature gradient, or
whether moisture transfers in response to the physical phenomena
described in Chapter I (thermo-osmosis) are mechanisms that
must be explored.

Summary

The studies have shown that: 1) Moisture in 290-kg stirred-
curd Cheddar cheese blocks transfers from high to low
temperature (from the center to outer regions of the cheese block)
during early stages of cooling. More uneven moisture distribution occurs when the temperature difference is larger, that is, when cooling is non-uniform. Information in Chapter I revealed that moisture may transfer in the liquid state. Information in Chapter II indicated that moisture may transfer in response to temperature-dependent curd moisture-holding capacity. 2) Blocks with higher moisture before cooling have more uneven moisture distribution after cooling. 3) Eliminating pressing before vacuum treatment appears to permit more rapid escape of air and whey from blocks. 4) Cooling cheese blocks encased in insulating materials produces a more uniform temperature in blocks during cooling.

Recommendations

From these results we concluded that the following procedures would help to minimize uneven moisture distribution in blocks: 1) Employ whey suction probes to reduce moisture content prior to cooling. 2) Eliminate pressing prior to vacuum treatment to allow more effective release of whey. 3) Cool cheese in insulating materials to decrease the driving force (temperature gradient) for moisture transfer.

Because cheese should be cooled rapidly, cooling blocks in insulating materials is not the best method for minimizing uneven moisture distribution. Numerous methods for cooling blocks rapidly and uniformly can be envisioned, but their cost probably
would outweigh the benefit of manufacturing cheese in 290 kilogram sizes.

The best technique probably would be to increase block surface area in relation to volume to allow more rapid and uniform cooling, but this would be comparable to retreating to the old 18-kg block system. Again, the benefits of manufacturing 290-kg blocks would be eliminated.

Perhaps a viable approach to minimizing uneven moisture distribution would be to make temperature gradient adjustments. Blocks could be produced that, before cooling, have gradients of high temperature in the sides to lower temperature in the center. Their temperature gradient would oppose the gradient of higher temperature in the center to low temperature in the sides that develops during cooling. This might produce blocks with more even moisture distribution and probably would be much less costly than trying to cool individual blocks uniformly. For example, during hoop filling, cooled curd that is still able to knit properly could be diverted to the interior of the hoop. Warmer curd, but not so warm as to impart defects to the cheese, could be diverted to the sides of the hoop. Even a small reverse gradient at the start of cooling might make a big difference in final moisture distribution. This method deserves study.

Regardless of the method used to cool cheese, it is very important to remove free moisture from blocks. Our studies indicated that whey drainage may not be uniform throughout blocks and the sides of blocks may be more compacted than
interior regions. Moisture surely transfers in response to gravity, but it also might transfer from the center to outer regions of blocks in response to capillary (surface tension) effects created by surface curd compaction. Temperature may be the most important, but it is surely not the only factor that affects moisture distribution in 290-kg cheese blocks.
Table 5. Data from Chapter II, page 33, graph representing Temperature profile-1 for stirred-curd Cheddar cheese. Letters (A,B,C,...Z,b,a) represent thermocouple positions. Time (h) indicates time data point was taken. Columnar data (35.89,etc.) are temperature in °C.

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Table 6. Data from Chapter II, page 36, graph representing Temperature profile-2 for stirred-curd Cheddar cheese. Letters (A,B,C,...,Z,b,a) represent thermocouple positions. Time (h) indicates time data point was taken. Columnar data (35.89,etc.) are temperature in °C.

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Table 7. Data from Chapter II, page 40, graph representing pH profile-1 for stirred-curd Cheddar cheese. Letters (A,B,C,...Z,b,a) represent sampling positions. Time (h) indicates time sample was taken. Columnar data (5.21,etc.) are pH units.

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Table 8. Data from Chapter II, page 43, graph representing Moisture profile-1 for stirred-curd Cheddar cheese. Letters (A,B,C,...,Z,b,a) represent sampling positions. Time (h) indicates time sample was taken. Columnar data (40.33,etc.) are % moisture.

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Table 9. Data from Chapter II, page 46, graph representing pH profile-2 for stirred-curd Cheddar cheese. Letters (A,B,C,...M,N,O) represent sampling positions. Time (h) indicates time sample was taken. Columnar data (5.21,etc.) are pH units.

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Table 10. Data from Chapter II, page 48, graph representing Moisture profile-2 for stirred-curd Cheddar cheese. Letters (A,B,C,...M,N,O) represent sampling positions. Time (h) indicates time sample was taken. Columnar data (40.33,etc.) are % moisture.

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Table 11. Data from Chapter III, page 61, graph representing pressing temperature profile of stirred-curd Cheddar cheese in the stainless steel hoop. Letters (A,B,C,...,Z,b,a) represent thermocouple positions. Time (h) indicates time data point was taken. Columnar data (35.89,etc.) are temperature in °C.

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Table 12. Data from Chapter III, page 62, graph representing pressing temperature profile of stirred-curd Cheddar cheese in the plywood hoop. Letters (A,B,C,...,Z,b,a) represent thermocouple positions. Time (h) indicates time data point was taken. Columnar data (35.89, etc.) are temperature in °C.

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Table 13. Data from Chapter III, page 70, graph representing cooling temperature profile of stirred-curd Cheddar cheese in the plywood hoop. Letters (A,B,C,...,Z,b,a) represent thermocouple positions. Time (h) indicates time data point was taken. Columnar data (35.89, etc.) are temperature in °C.

| time (h) | A     | B     | C     | D     | E     | F     | G     | H     | I     | J     | K     | L     | M     | N     | O     | P     | Q     | R     | S     | T     | U     | V     | W     | X     | Y     | Z     | b     | a     |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 0.00     | 30.00 | 30.00 | 35.56 | 28.33 | 36.67 | 35.56 | 36.67 | 36.67 | 37.22 | 37.22 | 37.22 | 37.22 | 37.22 | 36.67 | 36.67 | 36.67 | 37.22 | 37.22 | 37.22 | 37.22 | 37.22 | 37.22 | 37.22 | 37.22 | 37.22 | 36.67 | 36.67 |
| 12.00    | 14.44 | 14.44 | 29.44 | 14.44 | 35.00 | 30.00 | 36.11 | 31.11 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 | 34.44 |
| 18.00    | 11.11 | 11.67 | 25.00 | 12.22 | 32.22 | 25.56 | 34.44 | 27.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 | 32.22 |
| 36.00    | 7.22  | 7.78  | 8.89  | 8.89  | 25.00 | 18.89 | 28.33 | 21.67 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 |

**Note:** All temperatures are in °C.
Table 14. Data from Chapter III, page 75, graph representing cooling temperature profile of Swiss cheese in the plastic box. Letters (A,B,C,...,L,M,N) represent thermocouple positions. Time (h) indicates time data point was taken. Columnar data (18.59,etc.) are temperature in °C.

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Table 15. Data from Chapter III, page 76, graph representing cooling temperature profile of Swiss cheese in the cardboard box. Letters (A,B,C,...,L,M,N) represent thermocouple positions. Time (h) indicates time data point was taken. Columnar data (18.59, etc.) are temperature in °C.

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VITA

Robert S. Reinbold

Candidate for the Degree of
Doctor of Philosophy

Dissertation: Factors Affecting Moisture Distribution in 290-Kilogram Stirred-curd Cheddar Cheese Blocks

Major Field: Nutrition and Food Sciences

Biographical Information:

