The production complexity of a complex fluid

Gil Katz¹, Uzi Merin², Gabriel Leitner³

¹ S.A.E. Afikim, Israel
² A.R.O., The Volcani Center, Israel
³ Kimron Veterinary Institute, Israel
Outline

• Introduction
• Complexity of milk and its quality for the industry
• Curd firmness and milk clotting time for cheese production
• Milk quality for monitoring health
• On-line milk separation
The Challenge of monitoring a modern Dairy farm

The basic **production unit** in the dairy is the individual cow

A modern farm comprises a large amount of heterogeneous basic **production units**

Physiological and interface changes (lactation curve, health problems, feed etc.) dictate that these basic production units by themselves are not homogeneous between sessions and between days.
Herds of all sizes comprised of individual animals.

Each one of these animals contribute to the performance of the entire herd.

The key to success in whichever herd size is taking good care of each individual animal.

Management system

Automated Data Collection and Analysis

New 24 years old Concept: Management by exceptions.

zoom-in on exceptions and treat individually to improve total performance
Dairy farmers focus on optimizing the product flowing into the bulk milk tank.

Meanwhile, on the other side of the milk tank extensive research is going on.

- “…milk constituent levels have taken on new importance in herd management.
- In addition to being indicators for cow health and nutrition, constituent levels now directly impact farm income.”

(Heinrichs et al., Penn. State Univ.)
The Market Needs

- **Milk value** - The value of the milk depends on quality and composition
- **Milk value for Cheese Manufacturing** - USA

**Optigraph: the gold standard for evaluating milk quality for the cheese industry – efficiency of process**

- **Clotting time** (seconds) - RCT
- **Curd firmness** (volts) 90 min after coagulating enzyme addition (C\(_y\), C\(_f\))

![Graph showing clotting time and curd firmness](graph.png)
The Market Needs

- **Milk value** - The payment for the milk is formulated by composition

\[
\text{Percent Yield} = \frac{[0.93F + (C-0.1)] \times 1.09}{(1-W)}
\]

- \(F\) = % fat in milk
- \(C\) = % casein (protein) in milk
- \(W\) = % moisture in the cheese/100

**Van Slyke Price formula for Cheddar cheese**

\[
y = 0.1562x - 0.2678
\]

\(R^2 = 0.9248\)
Van Slyke Price formula for Cheddar cheese applied for individual cow’s milk

VanSlyke Yield % vs. CY(90)

\[ y = 0.264x + 6.8325 \]

\[ R^2 = 0.3399 \]

un-unified basic production units

Un-unified Product?
The composition of milk (mg/L)

Water: 76-80
Fat: 30-40 emulsified in water
Caseins: 30-40 colloids
Whey proteins: 6-7 globular proteins
Enzymes ~70 different Enzymes

Minerals: 7-8 soluble and bound to protein
Milk Proteins

$\alpha_{s1}$-Casein
$\alpha_{s2}$-Casein
$\beta$-Casein
$\kappa$-Casein

Whey Proteins

$\alpha$-lactalbumin
$\beta$-lactoglobulin
Blood Serum Albumin
Immunoglobinulins
Proteose peptone

Caseins ratio:
$\alpha_{s1}$-CN:$\alpha_{s2}$-CN:$\beta$-CN:$\kappa$-CN – 3:0.8:3:1
Properties and “packing” of Milk Proteins

- Resistant to thermal treatment, including boiling and sterilization
- Unstable at 4.6 pH (isoelectric point)
- Extremely flexible structures
- No data available on crystal form of caseins - do not form crystals
- Do not have well defined three-dimensional structure
- Best evidence for secondary and tertiary structure is obtained from x-ray diffraction
β-Casein structure

Three-dimensional model for κ-casein
Enzymatic Coagulation process

$k$-casein

Chymosin

$\text{Ca}^{2+}$

para-$k$-casein
glycomacrot peptide
Enzymatic coagulation of milk proteins - casein micelle sub-unit

Hydrophobic α-casein and β-casein center

$k$-casein rich surface

$\text{Ca}_9(\text{PO}_4)_6$ complex

Casein micelle
Deterioration of milk quality

- In the udder during production and between milking
- During post milking storage
Healthy

Strep. dysgalactiae

Day 2
Cheese hardness (48 h) (*Strep. dysgalactiae*)

![Graph showing force vs. distance for healthy and infected udders]
Cheese yield (g/L)

- Healthy quarters: -7.6%
- Infected quarters: -9.1%

Can milk coagulation properties be used for diagnostics?

Staph. chromogenes

Strep. dysgalactiae
**Results: single udder level**

45 uninfected udders
51 bacteria infected udders – no clinical score

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Infected</th>
<th>NBF</th>
<th>( P[F] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCC (x 1000)</td>
<td>1241±103</td>
<td>99±19</td>
<td>0.001</td>
</tr>
<tr>
<td>Fat (g/L)</td>
<td>38.3±0.8</td>
<td>37.0±1.8</td>
<td>NS</td>
</tr>
<tr>
<td>Protein (g/L)</td>
<td>34.7±0.7</td>
<td>33.9±0.7</td>
<td>NS</td>
</tr>
<tr>
<td>Casein (g/L)</td>
<td>25.6±0.6</td>
<td>26.9±0.6</td>
<td>NS</td>
</tr>
<tr>
<td>% Casein of protein</td>
<td>75.85±0.7</td>
<td>78.72±0.7</td>
<td>0.001</td>
</tr>
<tr>
<td>Lactose (g/L)</td>
<td>42.1±1.4</td>
<td>49.8±1.2</td>
<td>0.001</td>
</tr>
<tr>
<td>Clotting time (sec)</td>
<td>2394±238</td>
<td>930±220</td>
<td>0.001</td>
</tr>
<tr>
<td>Curd firmness (Volt)</td>
<td>4.71±1.18</td>
<td>11.57±1.03</td>
<td>0.001</td>
</tr>
</tbody>
</table>
The Cy-90 distribution, mean, Standard deviation (StdDev) and t-test significance level ($P$ value) between NBF and Infected udders
Cheese making parameters in uninfected and infected udder

Curd firmness A90 (V)

Clotting time (s)

Uninfected(11)     Staph. chrom(4) Strept. dys(4) E.coli(8)

Curd firmness (V) Clotting time (s)
The idea of low curd firmness

Casein micelle

Compact structure

Loose structure

A: a submicelle; B: protruding chain; C: Calcium phosphate; D: κ-casein; E: phosphate groups
AutoLab™

Automated on-line analysis of milk constituents at every stall

- Fat
- Protein
- Lactose
- Blood
- Cy & RCT

This new feature operating on-line allows controlling the properties of milk entering the bulk milk tank by exceptions of the milk tank to optimize its value.
Bulk milk tank
Average milk of all cows
SCC, Fat, Protein and Casein
Average product
Bulk milk tank
Average milk of all cows
SCC, Fat, Protein and Casein
Average product

“Industrial milk”
Optimal product

Milk unfit for human consumption
Bulk milk tank
Average milk of all cows
Scc, Fat, Protein and Casein

Average product

Cheese
Maximal product

Drinking milk
Maximal product
On-line milk separation at the individual cow level will enable prevention of “unfit” milk from entering the milk tank as well as a product adjusted for industrial channeling.
On-line apparatus for milk separation
Field test results: real time analysis of Cy and RCT by the Afilab

CY(90) – Curd firmness

RCT – Rennet clotting time
On-line milk separation based on CY – field test results
Maximal product separation: **cow level (9 cows)**

Cheese production from 100 mL

The objective:
- optimal 30/70 yield

Channeling for
drinking/cheese making

<table>
<thead>
<tr>
<th>Production Channel</th>
<th>Milk yield (kg)</th>
<th>Cy (60)</th>
<th>R - Clotting time (min)</th>
<th>Dry matter (g)</th>
<th>Fat %</th>
<th>Protein %</th>
<th>Lactose %</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Cheese”</td>
<td>11.27</td>
<td>9.1</td>
<td>15.3</td>
<td>21.77</td>
<td>4.65</td>
<td>2.90</td>
<td>5.02</td>
</tr>
<tr>
<td>“Liquid”</td>
<td>3.73</td>
<td>6.8</td>
<td>19.2</td>
<td>15.15</td>
<td>2.14</td>
<td>2.99</td>
<td>5.10</td>
</tr>
<tr>
<td>Difference</td>
<td>75/25</td>
<td>-25%</td>
<td>+25%</td>
<td>-30%</td>
<td>-54%</td>
<td>+3%</td>
<td>+2%</td>
</tr>
</tbody>
</table>
Optimal product separation:

Cheese production from 300 mL

<table>
<thead>
<tr>
<th>Product</th>
<th>Cy(60)</th>
<th>Whey protein %</th>
<th>Fat in Whey %</th>
<th>Dry matter g</th>
<th>Fat %</th>
<th>Protein %</th>
<th>Lactose %</th>
<th>SCC x 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Optimal</td>
<td>12.4</td>
<td>0.91</td>
<td>0.2</td>
<td>25.83</td>
<td>4.53</td>
<td>3.44</td>
<td>5.05</td>
<td>28</td>
</tr>
<tr>
<td>b. “unfit milk”</td>
<td>0.6</td>
<td>na</td>
<td>na</td>
<td>0.0</td>
<td>4.18</td>
<td>3.04</td>
<td>4.16</td>
<td>7767</td>
</tr>
<tr>
<td>c. 10/90 mix</td>
<td>10.6</td>
<td>0.98</td>
<td>0.4</td>
<td>24.2</td>
<td>4.50</td>
<td>3.40</td>
<td>4.96</td>
<td>800</td>
</tr>
</tbody>
</table>
summary

Our management system concept of improving production through management by exceptions is extended and can now manage the milk in the tank and improve the value of the product as well as its volume.

For better performance shift the critical point for research of milk properties from the exit of the tank to its entrance on the individual cow level.
Thank You