The Economic Significance of Batch Calculation

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ilis gmbh

Products and services for the glass and packaging industry

Founded 1998 in Clausthal-Zellerfeld, based in Erlangen, Germany since 2001

Privately owned and financed

Main activities and products:
- Measurement of glass color:
  - PRISMA Software Package & SmartSpec Spectrometers
- Batch calculation/glass property prediction:
  - BatchMaker® Software Package
- Measurement of residual stresses birefringence:
  - StrainMatic® Polarimeter Systems
- Corporation-wide operational data management:
  - GLASDATA (developed for Saint-Gobain Oberland)
Overview

- Motivation
- Basic principle of batch calculation
- Reliable prediction of glass properties
- Raw material cost optimization

Motivation

- The raw material costs have a decisive share of the production costs
- A constant glass composition is a prerequisite for steady melting and glass properties
- The objective of batch calculation is compliance with a defined chemical glass composition at minimum raw material costs
- In face of constantly rising raw material and energy prices, batch calculation is of great economic importance
Practical Example

- Reduction of Na₂O by 1 percentage point (in exchange with CaO and SiO₂).
- At assumed costs of 30 €/t sand, 200 €/t soda, 15 €/t limestone, 20 €/t feldspar and 30 €/t dolomite and an average daily production of 300 t glass, the raw material costs can be decreased by approx. **1000 € per day** or **350,000 € per year**.

<table>
<thead>
<tr>
<th>Material</th>
<th>Before change</th>
<th>After change</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>72%</td>
<td>72.5% (+0.5%)</td>
<td></td>
</tr>
<tr>
<td>Na₂O</td>
<td>14%</td>
<td>13% (-1%)</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>10%</td>
<td>10.5% (+0.5%)</td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>1.5%</td>
<td>1.5%</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>2.5%</td>
<td>2.5%</td>
<td></td>
</tr>
<tr>
<td>Thermal expansion</td>
<td>9.32 10⁻⁶K</td>
<td>9.01 10⁻⁶K</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>2.504 g/cm³</td>
<td>2.504 g/cm³</td>
<td></td>
</tr>
<tr>
<td>Rel. machine speed</td>
<td>110.2%</td>
<td>113.3%</td>
<td></td>
</tr>
<tr>
<td>Batch costs (per day)</td>
<td>21,939 €</td>
<td>20,987 € (-952 €)</td>
<td></td>
</tr>
<tr>
<td>Batch costs (per year)</td>
<td>8,007,589 €</td>
<td>7,660,116 € (-347,473 €)</td>
<td></td>
</tr>
</tbody>
</table>

Batch Calculation Workflow

- Calculation of raw material weights for a given glass composition. 
  - **Batch recipe**

- **Synthesis**: Calculation of the (theoretical) glass composition for a given batch.

  „The trouble-free operation of any glass works begins in a thorough knowledge of both the chemical and physical properties of the batch materials“

  (Taylor, 1975)
Principle of Calculation (simplified)

- Raw material analyses and desired glass synthesis:

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Glass sand</th>
<th>Feldspar</th>
<th>Dolomite</th>
<th>Limestone</th>
<th>Soda</th>
<th>Synthesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>99.5%</td>
<td>69.0%</td>
<td>72.0%</td>
<td>1.5%</td>
<td>9.0%</td>
<td>3.0%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.9%</td>
<td>18.0%</td>
<td>9.0%</td>
<td>3.0%</td>
<td>14.5%</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>2.0%</td>
<td>31.0%</td>
<td>50.0%</td>
<td>9.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>5.0%</td>
<td>21.0%</td>
<td>5.0%</td>
<td>3.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na₂O</td>
<td>5.0%</td>
<td></td>
<td>58.5%</td>
<td>14.5%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Corresponding linear equation system:

\[
\begin{align*}
\text{SiO}_2: & \quad 0.995 \times x_1 + 0.690 \times x_2 + 0.000 \times x_3 + 0.000 \times x_4 + 0.000 \times x_5 = 72.0 \\
\text{Al}_2\text{O}_3: & \quad 0.005 \times x_1 + 0.180 \times x_2 + 0.000 \times x_3 + 0.000 \times x_4 + 0.000 \times x_5 = 1.5 \\
\text{CaO}: & \quad 0.000 \times x_1 + 0.020 \times x_2 + 0.310 \times x_3 + 0.500 \times x_4 + 0.000 \times x_5 = 9.0 \\
\text{MgO}: & \quad 0.000 \times x_1 + 0.000 \times x_2 + 0.210 \times x_3 + 0.050 \times x_4 + 0.000 \times x_5 = 3.0 \\
\text{Na}_2\text{O}: & \quad 0.000 \times x_1 + 0.050 \times x_2 + 0.000 \times x_3 + 0.000 \times x_4 + 0.585 \times x_5 = 14.5 \\
\end{align*}
\]

Principle of Calculation (cont.)

- Representation as extended coefficient matrix:

\[
\begin{bmatrix}
0.995 & 0.690 & 0 & 0 & 0 & 72.0 \\
0.005 & 0.180 & 0 & 0 & 0 & 1.5 \\
0 & 0.020 & 0.310 & 0.500 & 0 & 9.0 \\
0 & 0 & 0.210 & 0.050 & 0 & 3.0 \\
0 & 0.050 & 0 & 0 & 0.585 & 14.5
\end{bmatrix}
\]

- After Gauss elimination method and normalization to 100 kg of glass sand:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Glass sand: 67.890 = 100 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>67.890</td>
<td>Feldspar: 6.458 9.51 kg</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6.458</td>
<td>Dolomite: 11.820 17.41 kg</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>11.820</td>
<td>Limestone: 10.413 15.34 kg</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>10.413</td>
<td>Soda: 24.235 35.70 kg</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>24.235</td>
<td></td>
</tr>
</tbody>
</table>
Glass Synthesis

- Calculation of the theoretical glass composition from the determined raw material weights and the corresponding raw material analyses:

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>72.0%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>11.0%</td>
</tr>
<tr>
<td>CaO</td>
<td>9.0%</td>
</tr>
<tr>
<td>MgO</td>
<td>3.0%</td>
</tr>
<tr>
<td>Na₂O</td>
<td>14.5%</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Glass sand</th>
<th>Feldspar</th>
<th>Dolomite</th>
<th>Limestone</th>
<th>Soda</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>0.995 · 100 kg = 99.5 kg</td>
<td>0.000 · 100 kg = 0.000 kg</td>
<td>0.020 · 17.41 kg = 0.310 kg</td>
<td>0.050 · 15.34 kg = 0.767 kg</td>
<td>0.585 · 35.7 kg = 21.36 kg</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.005 · 100 kg = 0.500 kg</td>
<td>0.180 · 9.51 kg = 1.612 kg</td>
<td>0.310 · 17.41 kg = 5.388 kg</td>
<td>0.000 · 15.34 kg = 0.000 kg</td>
<td>0.000 · 35.7 kg = 0.000 kg</td>
</tr>
<tr>
<td>CaO</td>
<td>0.000 · 100 kg = 0.000 kg</td>
<td>0.020 · 9.51 kg = 0.190 kg</td>
<td>0.310 · 17.41 kg = 5.388 kg</td>
<td>0.500 · 15.34 kg = 7.670 kg</td>
<td>0.000 · 35.7 kg = 0.000 kg</td>
</tr>
<tr>
<td>MgO</td>
<td>0.000 · 100 kg = 0.000 kg</td>
<td>0.210 · 9.51 kg = 1.956 kg</td>
<td>0.000 · 17.41 kg = 0.000 kg</td>
<td>0.000 · 15.34 kg = 0.000 kg</td>
<td>0.000 · 35.7 kg = 0.000 kg</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.000 · 100 kg = 0.000 kg</td>
<td>0.000 · 9.51 kg = 0.000 kg</td>
<td>0.000 · 17.41 kg = 0.000 kg</td>
<td>0.000 · 15.34 kg = 0.000 kg</td>
<td>0.585 · 35.7 kg = 21.36 kg</td>
</tr>
</tbody>
</table>

Sum = 106.06 kg

Workflow in BatchMaker®

- **Edit Configuration Data**
  - Definition of used raw materials and cullet (master data)
  - Input of chemical analyses for all ingredients

- **Create/Edit Glass Recipe**
  - Definition of the nominal chemical composition
  - Selection of carrier raw material to be used

- **Calculate Batch Recipe**
  - (Automatic) calculation of raw material weights
  - Calculation of glass synthesis and comparison with nominal analysis
  - Prediction of important melt and glass properties (redox number, thermal expansion, density, viscosity, etc.)
Raw Material Analyses & Prices

List of user-defined raw materials
Available oxides and elements
chemical composition (here of Dolomite, as selected above)

Glass Recipe

Desired glass composition (synthesis)
Available oxide and elements
Available raw materials
Main oxide carriers, e.g. Feldspar for Al₂O₃
Calculated Batch (initial weights)

Oxide analysis, here of foreign cullet

Calculated weights

Bach Recipe (glass synthesis)

Chem. composition calculated from initial weights

Nominal values as defined in the glass recipe

Differences to nominal values
Batch Recipe (glass properties)

Glass property calculator

Chemical compositions of three glasses

Switchover between wt% and mol%,
exceeded application limits

Calculated glass properties

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Example: Utilization of Limiting Values

- Permissible iron percentage in the glass: 0.15%
- Actual iron percentage: 0.10%
  - Add a second glass sand with higher iron content (lower quality, therefore less expensive) so that the actual iron percentage matches the limit.
- In BatchMaker®: Define a nominal value of 0.15% for Fe₂O₃ with the second glass sand as „carrier“ raw material
- Possible savings at 300 t glass/d and 40% cullet usage: approx. 500 € per day or 180,000 € per year.
Example: Continuous Batch Correction

- When using fixed weights even minor changes of the raw material chemistry inevitable lead to variations of the glass composition.
- This is unwanted especially for components introduced by expensive, synthetic raw materials such as soda.
- By regular recalculation of the initial weights the range of fluctuation can be minimized.
- Potential savings for reducing the Na₂O variation by 0.1% (at 300 t glass/d): **100 € per day** or **36,500 € per year**.

Example: Utilization of Filter Dust

- The exhaust gas cleaning delivers significant amounts of filter dust, resulting in high disposal costs.
- Potential savings when using 1200 kg filter dust per day and assumed disposal costs of 100 €/t: **120 € per day**
- Soda and limestone can partly replaced by filter dust. Additional saving: **80 € per day**.
- Total savings: approx. **200 € per day** or **73,000 € per year**.
Summary and Prospects

- In many cases the raw material costs can be reduced significantly
- Prerequisite for the cost optimization are reliable tools for batch calculation and prediction of glass properties
- **BatchMaker® Suite** and **BatchMaker® Express** allow the simple and fast calculation of batch recipes and glass properties
- Further developments:
  - Automatic optimization of raw material costs and glass price
  - Automatic optimization of the glass composition on basis of given melt and glass properties

*Thank you for your attention!*

*Questions?*