A generic modelling and simulation platform for assessing novel malting and brewing technologies

Mr. Eemeli Hytönen (PhD), Ms. Lotta Sorsamäki and Ms. Marja Nappa

VTT Technical Research Centre of Finland, Ltd.

EBC Symposium, Wrocław, 18-20 September 2016
Content

- Background
- Objective
- The platform
- Examples
- Conclusions
- Acknowledgements
Background

- The work presented here has been developed together with PBL Brewing Laboratory and partially within an ongoing Eco-efficient malting and brewing processes -project
- The overall goal of the project is to create knowledge and prerequisites that, compared to the present technology, enable the development of ecologically more efficient processes for malting and brewing
  - Specifically research focus has been on purification and reuse of malting process waters and opportunities for saving energy in cooling and drying
Background

- Key indicators and significant cost factors for the industry are water and energy use, e.g.
  - 116,8MJ.hl energy was needed on average in European breweries (2010). The variation is very large, between 70,6 and 234,1MJ.hl, resulting from varying brewing landscape across Europe
  - Energy use has been reported to equal 3...8,5% of beer production costs but varies very much depending on for example the beer type or technological age of the brewery
  - The true cost of water is more than sum of the water price and sewer service costs
  - Specific water consumption on average in European breweries in 2010 was 4,2hl.hl beer, of which 2,7hl.hl beer was discharged as wastewater

- Technological solutions for more sustainable brewing industry are constantly being developed in R&D projects. These solutions target also energy and water efficiency improvements

- A systematic approach at conceptual level was seen needed to quantify the key indicators for new developments and technological solutions. Between 2012-2016 a tool/platform was developed with emphasis first on brewery and later on malting process

---

a) C. Donoghue et al., The Environmental Performance of the European Brewing Sector, Report number 3101010DR02, May 2012
c) Chastain et al., Brewers Association Water and Wastewater: Treatment/Volume Reduction Manual, Brewers Association
# Background

Examples of simulation tools used in brewery/malthouse design/analyses

<table>
<thead>
<tr>
<th>Tool</th>
<th>Tool’s provider, focus, www</th>
<th>Purpose of simulation</th>
<th>Scope (plant wide, department, components)</th>
<th>Type (code, commercial simulator, spreadsheet,...)</th>
<th>Example references of use</th>
</tr>
</thead>
</table>
Objective

- Investigate impacts of technological choices and implementation of novel technologies on malting and brewing processes
  - Impacts of interest: energy and water consumption
- Develop a holistic and flexible platform for R&D projects’ impact analysis that is based on plantwide modelling of malting, brewing and linked processes
The platform

- Superstructure-type steady state simulation model
- The key performance measures evaluated using the platform are plant wide and departmental energy and water consumption and equipment utilisation degree.
- Platform uses two interlinked software
  - Process simulation model for mass and energy balance using Balas® process simulator *
  - Microsoft Excel -based spreadsheet system for electricity consumption and unit operation utilisation degree calculations
- User interface in Excel for parameterization and result manipulations
  - Additional automation build to handle systematically data: the setting-up a model run, conversion of M&E balances (process demands) to water and energy consumptions and unit utilisation, storing results

* balas.vtt.fi
The platform
Flexibility

- Superstructure-type process model + linked configuration and management = Flexibility
- Platform level flexibility:
  - heat source: hot water or steam
  - cooling: EtOH/water, ammonia
- Case comparisons
- setting-up scenarios

- Unit operation level flexibility
  - Brewhouse
    - mash filtering: lauter tun or filter
    - mash milling: wet or dry
    - weak wort recycling optional
    - Trub recycling optional
  - Beer processing
    - pasteurization optional
  - Malting:
    - Steeping: amount of steeps, water recycling rate, optional water purification
    - Optional barley drying
The platform
Process simulation model

- Thermodynamic properties
  - VLE calculated using thermodynamic model RKS – Redlich-Kwong-Soave
  - Model component data mainly from Reid et al. *
  - Liquid phase assumed to be ideal

- Model compounds:
  - Water, Ethanol, Carbon dioxide, Oxygen, Nitrogen and Ammonia
  - Malt and adjuncts (brewhouse): Water and solid Starch
  - Malt (malting): Starch, Protein, Beta-glucan, barley-other and Water
  - Syrup: a binary mixture of Water and liquid Glucose.
  - Hops and yeast: a binary mixture of Water and solid Hops and solid Yeast (thermodynamic properties the same as for cellulose)
  - Cans: Aluminium
  - Trub: Lipofilics

- Reactions:
  - Yield –based (kinetics not considered in the reactors)
  - Reaction heat either based on literature or actual reaction heat based on the thermodynamic properties

The platform
Process simulation model – screenshot of brewhouse flowsheet
The platform
Process simulation model

- Approach for making a steady-state process model from batch processes
  - #1 – If constant conditions (T, p, moisture) average flow through a batch unit in unit of time equals the flow rate in corresponding continuous model unit
  - #2 – If conditions change (e.g. heat profile, gas venting) the batch unit is divided into representative "phases" for which #1 can be assumed to apply. In the model, consecutive phases are modelled using a series of units
  - #3 – All batch equipment have specific volume and number of vessels defined for utilisation degree evaluation

- Examples
  - Mashing
    1 batch unit → 4 phases
  - Fermentation
    1 batch unit → 2 phases

Hytönen E., et al., 20.9.2016, EBC Symposium
The platform
Linked spreadsheet model

- Electricity (Brewing)

<table>
<thead>
<tr>
<th>Share of total consumption</th>
<th>Machine drive and process cooling</th>
<th>55%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Other equipment</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>Process HVAC and lighting</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>5%</td>
</tr>
</tbody>
</table>

- Consumption in pumps (~30 pumps dimensioned) & process cooling is calculated using M&E balances

- Electricity (Malting)

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilning and Germination, Including possible cooling</td>
<td>80 %</td>
<td>69 %</td>
</tr>
<tr>
<td>Product and barley handling, steeping</td>
<td>15 %</td>
<td>24 %</td>
</tr>
<tr>
<td>Other (laboratory, office)</td>
<td>5 %</td>
<td>7 %</td>
</tr>
</tbody>
</table>

- Equipment utilisation
  - Effect of process changes on needed equipment volume per time unit
  - maximum theoretical utilisation degree used as baseline
  - Both continuous (e.g. mash filtering, wort filtering, beer filtration) and batch (mashing, boiling, fermentation) equipment assessed

Hytönen E., et al., 20.9.2016, EBC Symposium
Examples
Case study definition

- Objectives of the case study:
  - assessment of the impacts of very high gravity brewing on a brewing process balances
  - evaluation of the impacts of malt moisture on a malt house and brewery integrate balances

- Basecase and two other cases used; main parameters in the table
  - VHG – very high gravity; design capacity basis is constant wort boiling capacity
  - high moisture malt case design capacity to fulfill basecase beer production rate

<table>
<thead>
<tr>
<th>CASE</th>
<th>Basecase</th>
<th>VHG</th>
<th>High moisture malt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beer production (ML/a)</td>
<td>150</td>
<td>220</td>
<td>150</td>
</tr>
<tr>
<td>Malting capacity (kt dry/a)</td>
<td>20</td>
<td>20</td>
<td>22.2 a)</td>
</tr>
<tr>
<td>Gravity after wort boiling (Plato number)</td>
<td>15</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>Malt moisture (%)</td>
<td>4.8</td>
<td>4.8</td>
<td>12</td>
</tr>
<tr>
<td>Syrup dose (g/kg malt)</td>
<td>0.01</td>
<td>100</td>
<td>0.01</td>
</tr>
<tr>
<td>Fermentation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>10</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>Duration (h)</td>
<td>144</td>
<td>168</td>
<td>144</td>
</tr>
<tr>
<td>Cycle duration (h)</td>
<td>290</td>
<td>338</td>
<td>290</td>
</tr>
<tr>
<td>O₂ to aeration (mgO₂/kg wort)</td>
<td>10</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Milling specific energy (kWh/t malt)</td>
<td>5.6</td>
<td>5.6</td>
<td>8.1 b)</td>
</tr>
<tr>
<td>Wort boiling time (min)</td>
<td>60</td>
<td>60</td>
<td>74 b)</td>
</tr>
<tr>
<td>Brewhouse yield (%)</td>
<td>75</td>
<td>75</td>
<td>70 b)</td>
</tr>
</tbody>
</table>

a) Simulation result; b) Experimental result, note: atmospheric wort boiling
Examples

Basecase – M&E balance and example of platform validation

- Inputs to and outputs from the brewery
- All inputs and outputs back-calculated based on the setpoint of 150ML/a beer with gravity 15 after wort boiling
- Energy consumption values only for brewery
- Validation of the simulated electricity demand using literature:
  - Simulated value (7.2kWh/hl beer) a bit lower than published values (>7.5kWh/hl beer in Europe) *


Hyttinen E., et al., 20.9.2016, EBC Symposium
Examples

VHG-case compared to Basecase

- Energy consumption values only for brewery
- When gravity is increased from 15 to 22, 47% increase in beer production, 36% increase in malt or grain demand and significantly increased by-product production
Examples
VHG-case compared to Basecase

- With the case study assumptions, moving to VHG brewing can significantly decrease energy demand and somewhat water demand.

- When gravity is increased to 22 considering same wort boiling capacity, processing after fermentation requires more capacity upto 47% in high gravity beer (HGB) adjustment and pasteurization.
Examples
High moisture malt case compared to basecase

- When malt moisture is increased from 4.8% to 12%, only small impacts on overall balances is expected based on the assumptions made in this study.
- Energy consumption values include both malting and brewing.
- Due to lower yield however, more grains are needed to produce the same amount of beer as in basecase.
Examples
High moisture malt case compared to basecase

- Increasing the malt moisture seems to lower the energy needs of malting but due to assumed yield loss in mashing the total energy consumption is about the same as in basecase.
- In order to be able to accommodate higher moisture malt in brewery, for same production rate more capacity is needed mainly in fermentation.

**Table. Brewery utilisation degree**

<table>
<thead>
<tr>
<th></th>
<th>Basecase</th>
<th>High moisture malt</th>
</tr>
</thead>
<tbody>
<tr>
<td>MASHING</td>
<td>100 %</td>
<td>103 %</td>
</tr>
<tr>
<td>MASH FILTERING</td>
<td>100 %</td>
<td>102 %</td>
</tr>
<tr>
<td>WORT BOILING</td>
<td>100 %</td>
<td>101 %</td>
</tr>
<tr>
<td>WORT FILTERING</td>
<td>100 %</td>
<td>100 %</td>
</tr>
<tr>
<td>FERMENTATION</td>
<td>100 %</td>
<td>100 %</td>
</tr>
<tr>
<td>BEER FILTRATION</td>
<td>100 %</td>
<td>100 %</td>
</tr>
<tr>
<td>HGB ADJUSTMENT</td>
<td>100 %</td>
<td>100 %</td>
</tr>
<tr>
<td>PASTEURIZATION</td>
<td>100 %</td>
<td>100 %</td>
</tr>
</tbody>
</table>

**Table. Malt house key process utilisation degree**

<table>
<thead>
<tr>
<th></th>
<th>Basecase</th>
<th>High moisture malt</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEEPING</td>
<td>100 %</td>
<td>111 %</td>
</tr>
<tr>
<td>GERMINATION</td>
<td>100 %</td>
<td>111 %</td>
</tr>
<tr>
<td>GERMINATION AIR</td>
<td>100 %</td>
<td>100 %</td>
</tr>
<tr>
<td>KILNING</td>
<td>100 %</td>
<td>72 %</td>
</tr>
<tr>
<td>KILNING AIR</td>
<td>100 %</td>
<td>72 %</td>
</tr>
</tbody>
</table>
Examples
High moisture malt -case result validation (malting process)

- Malting-process heat consumption: model compared to values derived from process data in different conditions

- Energy consumption values for malting vs. literature

<table>
<thead>
<tr>
<th></th>
<th>Heat (kWh/t malt)</th>
<th>Electricity (kWh/t malt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature</td>
<td>614 – 1066 a), 713-1105 b)</td>
<td>77.4 – 156 a), 113 – 171 b)</td>
</tr>
<tr>
<td>Platfrom (basecase)</td>
<td>700</td>
<td>100</td>
</tr>
</tbody>
</table>

a) Electricity consumption matches actual demand at Danish Malting Group, Danish energy agency; b) Stewart, D., Emissions, energy, water and malt, Brewer & Distiller International, May 2010. 38-41.
Conclusions

- A generic modelling and simulation platform has been developed for investigating impacts of technological choices and implementation of novel technologies on malting and brewing processes.
- The main features of the linked modelling platform and specifically the simulation model have been presented.
- The example case studies presented were:
  - assessment of the impacts of very high gravity brewing on a brewing process
  - evaluation of the impacts of malt moisture on a malt house and brewery integrate
- Case study results show positive impacts on both energy and water demands in the VHG case.
- The platform has shown its targeted features:
  - flexible – detailed malting department model added and linked to overall simulation model with less model compounds; easy set-up and comparison of new cases
  - holistic – plant-wide somewhat non-intuitive balances quantified for high moisture malt case show even slightly higher energy demand

Hytönen E., et al., 20.9.2016, EBC Symposium
Acknowledgements

- The authors would like to acknowledge
  - PBL Brewing Laboratory, Ecomalt project and Tekes for funding the modelling and platform development work
  - All project and company experts involved for their valuable inputs to the contents and structure of the platform
Contact

Mr. Eemeli Hytönen, PhD
Principal Scientist
VTT
P.O.Box 1000
FIN 02044 VTT, Finland

Tel. +35820 722 2729
Mobile +35840 533 6759
E-mail: Eemeli.Hytonen@vtt.fi
TECHNOLOGY FOR BUSINESS