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Process Optimisation of Beer Fermentation through Dynamic Simulation

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1. Beer Fermentation: Background
Fermentation is an essential step in beer brewing; yeast is added to sugars released from barley grain, which ferment into ethanol (EtOH) and higher alcohols. The process is:
• Time-consuming (>120 hours)
• Energy-intensive (cooling)
• Highly complex (200+ species)
Because this chemical system is sensitive to the imposed temperature profile, fermentation success and efficiency strongly depend on the selection and implementation of the most effective dynamic temperature manipulation.

2. Process Optimisation: Project Objectives
This research project has evaluated published kinetic models and then focused on optimal operating conditions, to improve plant performance:
• Literature review and evaluation of prior published kinetic models and fermentation optimisation studies.
• Computational implementation of the most reliable kinetic model for fermentation, and assessment of a range of published operating temperature profiles (MATLAB®).
• Computational identification of the optimal temperature manipulation profile via stochastic optimisation.
• Experimental validation vs. WEST industrial production plant data.

3. Dynamic Mathematical Model of Fermentation
Beer Fermentation Kinetic Model (B. de Andrés-Toro, 1998)

\[
\frac{dC_B}{dt} = f \cdot \mu_T \cdot X_{act}(t);
\]
\[
\frac{dC_S}{dt} = -\mu_S \cdot X_{act}(t);
\]
\[
\frac{dX_{act}}{dt} = -\mu_{SG} \cdot X_{act}(t) + \mu_{ST} \cdot X_{act}(t);\]
\[
\frac{dX_{tag}}{dt} = \mu_{ST} \cdot X_{act}(t) - \mu_{ST} \cdot X_{act}(t) + \mu_{ST} \cdot X_{tag}(t);\]
\[
\frac{dC_{ByP}}{dt} = \mu_T \cdot C_B(t) \cdot X_{act}(t) - \mu_{AB} \cdot C_{DP}(t) \cdot C_B(t).
\]

4. Dynamic Simulation of Industrial Operation

5. Stochastic Optimisation of Fermenter Operation
• Ensemble: 175,000 unique profiles (MATLAB® run time: 1 hr only!)
• Rapid, comprehensive evaluation of all output profiles for performance
T Profile Generation Constraints:
9 °C ≤ T ≤ 16 °C
T ≥ t_1-1 ≤ 80 hr
T ≤ t_1 ≤ 80 hr

6. Attainable Envelope of Product Compositions

7. Fermentation Process: Operational Improvements

8. Conclusions
• The de Andrés-Toro (1998) model reliably describes beer fermentation
• Performance of published operating profiles is accurately predicted
• Simulation-based optimisation determines key beer quality attributes
• Three new profiles (A, B, C) demonstrate clear process improvements
• Optimal operating temperature profile accelerates beer fermentation
• Fermentation time is minimised without any loss of product quality
• Experimental validation of the model vs. WEST plant data under way

9. Literature References