# Experimental modeling of a beer fermentation process

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## 1 Introduction

During beer brewing, the fermentation stage is crucial to guarantee beer quality. Beside, the complex behavior of the involved components makes beer fermentation an interesting candidate application for advanced monitoring and control, which require a mathematical model. To this end, Gee and Ramirez [1] proposed a complete fermentation model, which however would imply a complex instrumentation for control purposes. Andrés-Toro et al. [2] derived later on a simpler model validated with various temperature profiles and measurements from industrial breweries. This model however involves biomass, which is difficult to measure online in common fermentors. A more practical and control-oriented description was proposed by Trelea et al. [3], based on the carbon dioxide dynamics instead of biomass, also considering total sugar and ethanol concentrations.

In this work, the model of [3] is slightly adapted, with among other changes, the introduction of a logistic kinetic structure for the $CO_2$ production. Structural and local identifiability analyses are also achieved to avoid possible over-parametrization and provide parameter estimation accuracy assessment.

## 2 Mathematical model

The dynamic model is obtained by mass balancing based on reaction scheme (1) where sugars (S) are consumed by yeast (X) to produce, ethanol (E), carbon dioxide ($CO_2$), and among the byproducts, vicinal diketones (VDK) which are later converted into other products (P). Stoichiometry is normalized with respect to carbon dioxide, replacing the biomass as main variable to monitor the status of the fermentation process.

$$
\begin{aligned}
&K_S \mathrm{S} \xrightarrow{\mu_X \mathrm{X}} k_E \mathrm{E} + k_V \mathrm{VDK} + \mathrm{CO_2} \\
&\mathrm{VDK} \xrightarrow{r_{Ab}} \mathrm{P}
\end{aligned} \tag{1}
$$

## 3 Results

A set of experimental runs have been achieved using a 30L batch fermentor, producing a kölsch (Ale) beer, and varying the initial concentrations, and the operating temperature. The resulting data sets are used for model identification and validation. The parameter identification procedure is based on a weighted least-squares criterion. Minimization is achieved using a combination of the MATLAB® optimizers fminsearch and lsqnonlin, in order to reach the best local minimum and evaluate the parametric sensitivity Jacobian, which can be further used to compute the fisher Information Matrix and assess parameter local identifiability and confidence intervals.

Figure 1 shows the resulting model fitting with the experimental data.

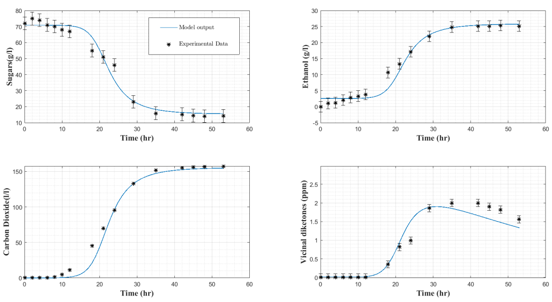


**Figure 1:** Experimental data and model prediction.

The model is in good agreements with the experimental data. Ongoing research considers the dependency of the latency phase to temperature.

### References

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[3] I.C. Trelea, M. Titica, and G. Corrieu, “Dynamic optimization of the aroma production in brewing fermentation”, Journal of process control, 14(1), 1-16, 2003.