Biogas: Statistics instead of lottery

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The maximum efficiency has not yet been reached in alternative energy production. Statistical design of experiments ("DoE") here can lead to a considerable improvement of the process. With the help of adequate software even persons without a background in statistics can apply the methodology easily.

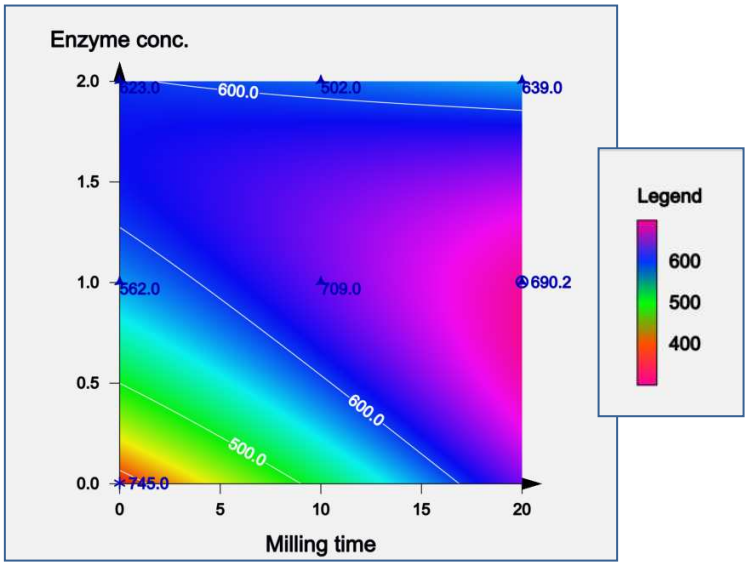
Renewable energy sources still hold a large potential of improvement. The complexity of most processes is high and not all mechanisms are identified in detail. Therefore, not only good ideas, but also informative experiments are required for successful process development and optimisation. Here, the use of statistical design of experiments (DoE) pays off. So the required experiments can be executed in a structured way instead of having to play the lottery of "Trial and Error".

Biogas production

The production of biogas from biomass is no exception. Depending on the kind of material used, the potential is still large: in some cases today's methods only reach less than a third of the theoretically possible gas yield [1]. To achieve a high degree of efficiency it is important to extract the fermentable biological macro molecules completely from the biomass. After several steps, the biogas composed of methane and CO2, is then obtained. A multitude of mechanical (different types of milling), thermochemical (organic and inorganic acids) or enzymatic (different types of enzymes) operations can be combined as pre-treatment methods.

Manifold applications

Various projects that have been executed at the University of Applied Sciences at Flensburg show how valuable the DoE approach is [2]. For optimizing the biogas yield from maize silage, the concentration of enzymes and the duration of milling



Interaction: The maximum biogas yield (pink) is reached at a large milling duration and medium enzyme concentration.

were used as quantitative parameters, as well as the adding time of the enzymes (before or after milling), besides many other influencing factors.

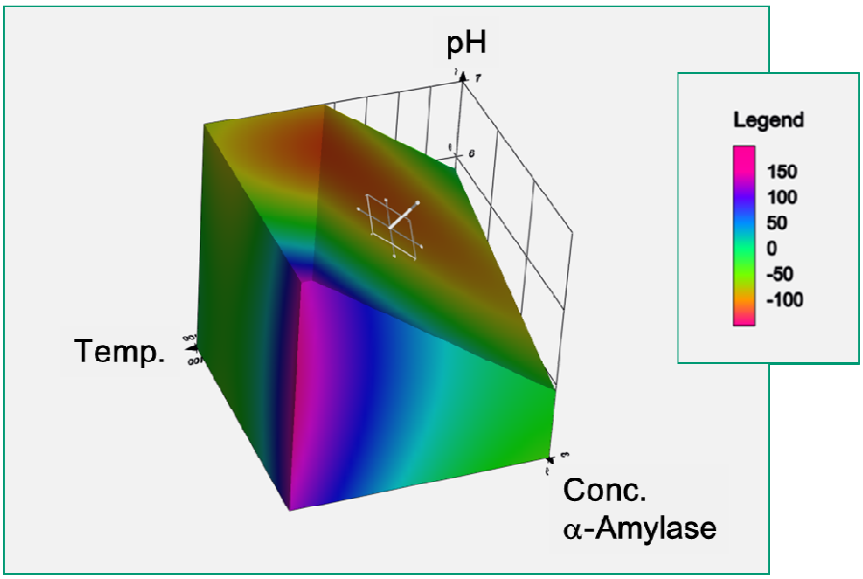
Results of the variation of parameters

In the figure above, the interaction between milling duration and enzyme concentration is clearly visible: as long as the concentration of enzymes is rather low, a longer milling duration is crucial for an acceptable gas yield. However, with a higher enzyme concentration, the milling duration barely has an effect anymore. Similarly, one receives information about the gas yield dependency on temperature, pH and enzyme concentration (amylase): high temperatures, a rather low pH value and a high enzyme concentration implies the highest yield (figure on next page). Correlations of this kind can be identified and quantified reliably with DoE. The software does not only predict what yield can be expected for which parameter setting, it also gives confidence intervals for estimating the reliability of the predictions. As yet another application, the effect of various enzymes was evaluated, by analysing the dependence of gas yield on temperature and pre-treatment duration, separately for different fermentation durations. This showed which enzymes allowed a fast gas production (after 2 days), and which ones needed a medium (4 days) or longer (11 to 30 days) fermentation duration. Several enzymes could be excluded as completely without effect.

Different raw materials - different demands

When working with sugar-beets, not only the milling duration, the temperature and the enzymes used need to be taken into account, but also the mass ratio of beets to leaves. The DoE concludes that the type of enzymes analysed as well as the mechanical pre-treatment (milling duration) have no statistically significant impact. However, a higher temperature leads to a positive effect; in contrary, a higher proportion of leaves reduces the gas yield.

The adjustments for press cakes from bio diesel production of rapeseed again differ significantly: after the execution of only eight experiments it was already obvious that the enzyme concentration can be neglected, that a higher temperature tends to have a negative effect, but that a longer mechanical pre-treatment (milling duration) will have a positive impact. The processing of algae-seaweed-alloys remains prob-



Interactive visualisation: At high temperature, large enzyme concentration and a low pH value, the biogas yield is highest.

lematic [3], because the high salt content hinders the fermentation. It will probably take some time until seaweed and algae, which have to be removed from tourist beaches, can finally be used reasonably.

A systematic approach results in efficiency

The best method when processing biomass to biogas depends heavily on the raw material used. For finding good process settings quickly, a systematic approach via statistical design of experiment is very efficient. As the methodology is independent from the problem in question, it can be used in many different situations where processes and products have to be developed and optimized.

Further information

[1] KTBL: Gasausbeute in landwirtschaftlichen Biogasanlagen; KTBL-Heft 88, überarbeitete 2. Auflage (2010) [in German]

[2] Schneider, H. and Born, J.: Standardization of Pre-treatment Methods for Hydrolysis of Varying Biomasses to Accelerate Co Fermentation Processes; Proceedings of 16th European Biomass Conference & Exhibition; Valencia (2008)

[3] Schneider, H.: „Biogas aus Algen, Tang und Seegras?“; FNR/KTBL-Kongress „Biogas in der Landwirtschaft – Stand und Perspektive“; Göttingen (2011) [in German]

[4] STAVEX 5.1: Expert system for the Statistical Design and Analysis of Experiments, AICOS Technologies (2011), www.aicos.com

Statistical design of experiments

The aim of statistical design of experiments (DoE) is to find suitable parameter settings quickly, using as few experiments as possible. With modern software tools this methodology is easily applicable. However, persons without an in-depth background in statistics should consider using a user-friendly system, such as STAVEX [4]. In this case, it is sufficient to specify the target variable (e.g. the maximum gas yield in biogas production), and the influence factors with their variation ranges. Then the program suggests a suitable design of experiments. Specialised DoE software tools also support the user in the analysis of the experimental results: giving an easily understandable interpretation of the statistical output, and providing a multitude of different graphics. Ideally, the system guides the user during the entire project, separating the important influencing factors from the unimportant ones in several consecutive steps, until the final confirmation of the optimal factor settings (sequential design of experiments).

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