A multivariate statistic approach to detect process imbalance in lab scale continuously stirred tank anaerobic reactors submitted to inadequate organic loading rate

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INTRODUCTION

During recent decades, anaerobic digestion (AD) of organic substrates has become one of the most mature technologies to produce renewable energy from waste biomass. Biogas production using AD process implies to manage a complex microbial flora that is highly sensitive to variations of the ecological conditions existing in the reactors. The main biological dysfunctions are nowadays better understood and are for the most part related to inappropriate feeding of the digesters. So far various methods have been evaluated to monitor the process but none seems to be ideal. These methods usually consist in measuring a set of variables judged to be characteristic of the process status (i.e. pH of the liquid phase, CH₄/CO₂ ratio of the biogas...) and interpreting the collected data for each parameter individually. However, since these variables reflect the conditions of the reactor anaerobic microbial community, it appears very probable that they present a certain degree of correlation. An efficient tool for AD process monitoring should therefore benefit from the integration of information about the way the measured parameters interact when the process is in control. A way to satisfy this condition is to monitor the reactors using multivariate statistic methods as an alternative to usual univariate approaches. Control charts built with Hotelling’s T² statistic are well adapted to this kind of application. Those charts are becoming more and more popular to monitor continuous processes were the quality of the final product is related to several dependant variables (Adam et al., 2012).

AIMS of the STUDY

Assessing the potential of Hotelling’s multivariate control charts and decomposition methods for the early detection of anaerobic AD process indicators to detect dysfunction of anaerobic reactors submitted to inadequate feeding conditions.

• The most applied chart in multivariate process control.
• Phase I: Data set built with measurements performed during a period where the process is supposed to be “in control”. It authorizes to compute 2 parameters that characterize this in-control situation: the covariance matrix (S) and the mean vector (Xm).
• Phase II: Each collected data sample is used to compute a unique statistical parameter (T²) that compare the current sample data structure with Phase I Xm and S. T² value are compared to an upper control limit (UCL) to identify out-of-control situations:

RESULTS AND DISCUSSION

1) Selection and optimization of the phase I data set (model building)

Phase I (T² after outliers cleaning)
Phase II (CSTR1)

Fig. 1. All the measured parameters are used for model building except pH. Phase I is performed with a dataset issued from the cautiously fed control reactor (CSTR2). In phase II, an excessive number of samples are interpreted as out-of-control situations even though the digestion process is not perturbed.

Fig. 2. All the measured parameters are used for model building except pH. Phase I is performed with a dataset combining mixed data from the 4 reactors. In phase II, the detected unusual events can be related to real process dysfunction or real failures of the measurement system (cf. 2).

2) Process control for 1 overfed reactor (CSTR1)

• Event 1 & 6: A stirrer malfunction occurred causing an important hydrogen production. Decomposition showed that hydrogen concentration in the biogas was the parameter responsible for the detected out-of-control situation (Fig. 4).
• Event 2: An important foam formation caused a failure of the gas sensors and required the disconnection of the biogas analysis for maintenance.
• Event 3: Shift of CH₄ and CO₂ sensors.
• Event 4: H₂ sensor was used to analyse a gas sample extremely concentrated. The sensor stayed perturbed during some hours after the measurement.
• Event 5: Unexplained hydrogen production peaks.
• Event 7: The reactor reaches an abiotic situation. The first out-of-control samples are related to an unusual relationship between CH₄ and CO₂ concentrations. Highest T² values are related to increasing hydrogen concentration.

CONCLUSIONS

• Hotelling’s T² control charts appear as an interesting tool for AD process monitoring. The study showed that it was possible to quickly detect out-of-control situations (related to both biological dysfunctions and measurement system failures).
• T² is a unique parameter — the charts are easy to read and the T² value can be easily used to trigger various events to inform the manager of the reactors (i.e. alarm signal).
• Using the data of a reactor that was cautiously and steadily fed to define the in-control situation of the process did NOT appear as the best option. It was shown as more efficient to add to the training data set the measurements from overfed reactors. After cleaning of the outliers, the data set included more information on how the variables interact each others for a wider range of OLR values. Subsequent event detection was then more realistic.
• In this study, liquid phase measurements did not seem to provide important added-value to the process control tool, probably because of their low frequency of measurement compared to biogas parameters.

REFERENCES


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