Opinion

Promising fermentation kinetics and fermenters design

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Production of bioethanol can be achieved by fermentation of sugars in different kinds of batch or continuous fermenters. The continuous fermenters may have the necessary suitable micro-organism free in solution or immobilized on a carrier such as calcium alginate. The immobilization adds certain advantages and also disadvantages. The advantages are mainly the possibility of using high flow rates without washing out of the micro-organism and the main disadvantage is the additional mass transfer resistance inhibiting the rate of reaction of the substrate. The immobilized continuous fermenter can be in the shape of Continuous Stirred Tank Reactor (CSTR) or Packed Bed Immobilized Fermenter (PBIF). Ethanol production is most useful and profitable from the sugars resulting from the hydrolysis of cellulose and hemicellulose which never produces glucose alone but produces with it xylose (~30%) and some arabinose (~5%) sugars. Rigorous design and optimization of any kind of fermenters requires reliable fermentation kinetics which may be monotonic or non-monotonic functions of the sugar concentration(s) depending on the range of sugar(s) concentrations while the product alcohol concentration has an inhibitory effect on the kinetics. Fermentation kinetics of ethanol production from glucose, xylose, and their mixtures using a recombinant Saccharomyces 1400(pLNH33) are reported in this short study. This short study gives quantitative results for both the fermentation of a single substrate and that for double substrates. Single-substrate kinetics indicate that the specific growth rate of the yeast and the specific ethanol productivity on glucose as the substrate was greater than on xylose as a substrate. Ethanol yields from glucose and xylose fermentation were typically 95 and 80% of the theoretical yield, respectively. The effect of ethanol inhibition is more pronounced for xylose fermentation than for glucose fermentation. Studies on glucose-xylose mixtures indicate that the recombinant yeast co-ferments glucose and xylose. Fermentation of a 52.8g/L glucose and 56.3g/L xylose mixture gave an ethanol concentration of 47.9g/L after 36h. Based on a theoretical yield of 0.51g ethanol/g sugars, the ethanol yield from this experiment (for data up to 24h) was calculated to be 0.46g ethanol/g sugar or 90% of the theoretical yield. The specific growth rate of the yeast on glucose-xylose mixtures was found to lie between the specific growth rate on glucose and the specific growth rate on xylose. Detailed studies over a wide range of concentrations were used to obtain reliable non-monotonic kinetic models for both single and the double substrates and also include the inhibitory effect of product ethanol.

The obtained kinetic models were used to develop reliable models for the different kinds of fermenters. For the batch fermenters the resulting model is formed of Ordinary Differential Equations (ODEs) for a closed system continuing the reactions till the rate of reactions reaches its Thermo-Dynamic Equilibrium (TDE) of zero rate of reaction. For the CSTR fermenter with the micro-organism not immobilized the flow rate is limited by the size of the microorganism to avoid wash out. If the size of the micro-organism is small enough to ignore mass transfer resistances the system is to be treated as an open homogeneous system described by ODEs for the fermenter which changes with time to reach Stationary Non-Equilibrium State (SNES) usually called Steady State and not TDE of zero rate of reaction as for the batch case. The steady state of the system is described by Non-Linear Algebraic Equations (NLAEs). If the micro-organism size is not small enough to ignore mass transfer resistance between it and the bulk of the fluid, but if the dynamics of the micro-organisms is much faster than that of the bulk fluid, then the bulk fluid is described by ODEs while that of the micro-organisms is described by (NLAEs) including the non-liner non-monotonic kinetics and the two phases are connected by the rate of mass transfer between them. The steady state is describe by two sets of Algebraic equations one Non-Linear for the micro-organisms and the other linear for the bulk fluid. The same applies to the case of immobilized micro- organisms but the mass transfer rate is that between the bulk fluid and the calcium alginate carrier of the micro-organism. For tubular fermenters the situation is a bit more complicated, for the homogeneous case the system is described by Partial Differential Equations (PDEs) and the steady state is described by ODEs. For the heterogeneous case the bulk fluid is described by PDEs without the reaction kinetics while the reaction kinetics is included in the micro-organisms phase whether free in solution but the particles is not small enough to ignore mass transfer resistance, or if it is immobilized then the calcium alginate carrier is included in this phase which is described in both cases by NLAEs which are discrete and its axial change is related to the change in the bulk fluid.

For all cases the kinetic experiments are carried out in batch fermenter over a wide range of concentrations to ensure the reliability of the kinetic models used in the fermenters models which are checked against the different configurations with the mass transfer parameters obtained from empirical correlations. The models with these parameters are checked against the experimental results of the corresponding fermenter. For the fermentation model incorporating the substrate inhibition and effects of substra inhibition, product inhibition, and inoculum size, good agreements were obtained between model predictions and experimental data for different types of fermenters described above for both steady state and dynamic behaviour for fermentation of glucose, xylose, and their mixtures.

These verified models are therefore suitable for design, optimization and control for single fermenters and multiple fermenters. The models have been tested for these purposes and proved to be quite reliable. However it is needed to extend these model equations for design, optimization and control of membrane fermenters which are very useful for eliminating the inhibitory effect of product ethanol and there for achieve high conversion and ethanol productivity. Membrane fermenters efficiency will also depend upon the type of the membrane that gives high flux per unit area and also the configuration of the fermenter that gives high membrane area per unit volume of the fermenter.

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Conflicts of interest

Author declares that there is no conflict of interest.