Influence of hydrodynamics on enzymatic hydrolysis of highly concentrated lignocellulosic biomass.

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Highlights

- Increased dry matter content in enzymatic hydrolysis hinders enzyme transport in the reaction medium, limiting the rate of enzymatic hydrolysis in the initial stages.
- An increase in glucose conversion was noted when increasing stirring speed.
- A kinetic model including enzyme action and mass transfer showing the impact of stirring speed on mass transfer coefficient.

1. Introduction

Biomass composed of organic materials derived from plants represents a vast reservoir of stored energy that can be converted into valuable biofuels [1]. One possibility is the conversion of cellulose into monomeric sugars, such as glucose, which can be further converted into ethanol. The use of lignocellulosic biomass from agricultural waste is of interest as a raw material since it is not in competition with the food industry.

The enzymatic conversion of cellulose to glucose, compared with chemical conversion, is particularly interesting since it allows higher selectivity, improved yield and milder operating conditions [2]. However, to be economically feasible, this process must be operated at high solids loading [3]. Under these conditions, the produced amount of glucose increases with the amount of solids load but the overall reaction yield decreases. When at high solids load, lignocellulosic biomass slurry shows a shear-thinning behavior [4]. Considering the rheology of the media, the reduction of viscosity is caused by two different actions in the system: the breakage of cellulosic chain by enzyme action, it means that even for non-agitated system, viscosity will decrease due to the depolymerization of the chain, and the other action reducing viscosity is the shear applied during stirring.

Several authors have studied the impact of mixing on enzymatic hydrolysis, and opposite results have been found. Sometimes, an increase in mixing represented an increase in conversion, other times, it did not impact the hydrolysis rate [5]. Most of the studies did not dissociate the existence of caverns to consider the improve in conversion, with an increase in mixing only representing an increase in fluid motion and reduction of dead zones. This shows that the relation between hydrodynamics and mass transfer in the reaction has not been yet fully understood.

This work focuses on understanding how the hydrodynamics impact the glucose conversion and the mass transfer during the enzymatic hydrolysis. To do this, a series of experiments were performed during the liquefaction period of the reaction, which is the most viscous step in the conversion process. Following this, a model that couples the kinetics of hydrolysis and the mass transfer of enzymes in the reactor is being developed.

2. Methods

Several enzymatic hydrolysis reactions were conducted. The substrate used during these tests was wheat straw pre-treated using acid-catalyzed steam explosion. The enzyme cocktail was an industrial production composed of endoglucanases, cellobiohydrolases and β-glucosidase obtained from *Trichoderma reesei*. The pH (4.8 – 5), temperature (50°C), enzyme quantity (10mg proteins/g dry matter) and dry matter content (12%) were fixed at constant values. Values for stirring speed varied according to the scale of reactor used, but in a range that assured no caverns.

Two system designs were used, the first were 250mL round bottom reactors equipped with an anchor impeller (for this reactor, varying stirring speed from 80 to 450 rpm were used). The second design is a 3L stirred tank reactor, using a Paravisc ® impeller (with stirring speed varying from 50 to 150 rpm). The intention was to verify the consistency in hydrodynamics behavior with scaling up and more complex impellers.

Samples were taken each hour during the liquefaction period. Glucose concentration and rheology were analyzed at each hour using a glucometer YSI and an Anton Paar MCR302e rheometer equipped with a helical spindle, within a varying shear rate between 0,001 – 200 1/s, at 50°C.

3. Results and discussion

The wheat straw media at 12% dry matter content showed a yield stress shear thinning behavior, in accordance with literature data for other types of biomass at high solids load. Herschel-Bulkley law was obtained for each reaction hour. There was a significant reduction in the yield stress value (350 Pa to 11 Pa) and in the flow consistency index (301 to 43 $Pa.s^n$) with time, however changes in the value of the flow behavior index were the least significant (0.57 to 0.69).

Since no stagnant zones were present in the reaction media, an increase in conversion is linked to an improvement in mass transfer and not to the reduction of the size of dead zones. The results for both systems show that an increase in stirring speed resulted in an improvement in glucose conversion (see figures 2 and 3). The increase in stirring speed enhanced the diffusion and convection improving the transport of enzymes in the overall reaction volume. An increased uniformity of enzyme concentration in the media improves the contact of enzymes and the cellulose surface, promoting a better mass transfer between the liquid phase and the surface of solid substrate, decreasing external transfer limitations.

To quantify the effects of the stirring speed on the transport and conversion of glucose, a kinetics model coupling enzyme action and mass transfer is being developed.

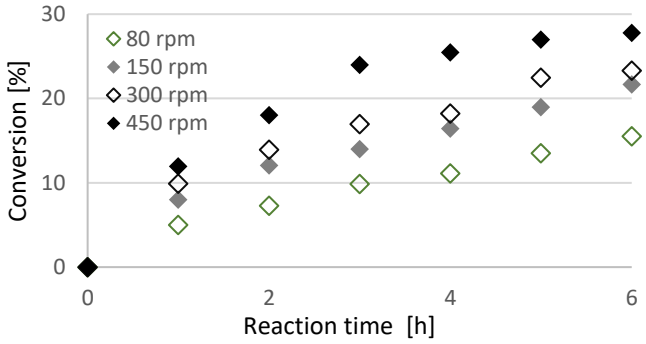

Figure 2. Glucose conversion during the liquefaction stage for varying stirring speed using an anchor and a round bottom flask.

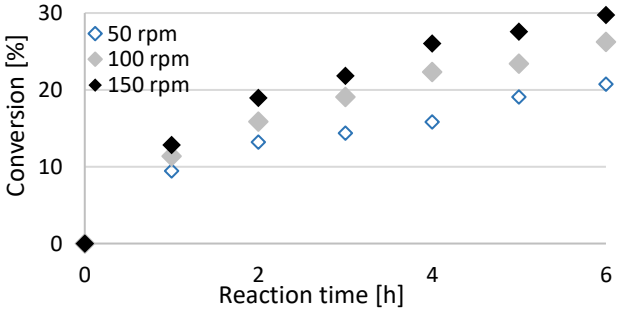

Figure 3. Glucose conversion during the liquefaction stage for varying stirring speed using a Paravisc ® and a stirred tank.

4. Conclusions

During the liquefaction stage of enzymatic hydrolysis of pretreated wheat straw biomass, increased impeller rotational speed clearly promotes the glucose conversion. Based on the experimental studies performed, a combined model including enzymatic action and mass transfer is being developed, in order to quantify the role of the enzyme mass transfer during the first steps of cellulose hydrolysis.

References

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