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Thermodynamic analysis of a high-yield biochemical process for biofuel production

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HIGHLIGHTS

- ▶ The HYBC has similar order of thermodynamic efficiency to other processes.
- ▶ Efficiency can be increased by improving the heat and power production process.
- ▶ The hydrogenation process is inherently inefficient.
- ▶ No direct correlation between yield and thermodynamic efficiency was found.

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ABSTRACT

This paper presents a thermodynamic analysis of a high-yield biochemical process for biofuel production from lignocelluosic biomass based on a previously proposed process. Unlike the standard biochemical process, which ferments sugar intermediates to ethanol, the process under consideration converts sugars to acetic acid which is esterified and hydrogenated to produce ethanol. This process has a significantly higher yield and produces no carbon dioxide. However, we find that the thermodynamic efficiency of the process is not increased in proportion to the yield gain. An additional survey of various biofuel production processes showed no direct correlation between yield and thermodynamic efficiency. This survey and the detailed thermodynamic analyses lead us to conclude that yield alone is an unreliable performance metric for biofuel technologies.

1. Introduction

A key challenge for biofuel production systems is to develop efficient conversion technologies which are able to compete economically with fossil fuels. One of the most common strategies for improving the effectiveness of biofuel production is to focus on increasing yield. In biochemical approaches to lignocellulosic biofuel production this can be achieved by increasing biofuel yield from the cellulose and hemicellulose fraction of lignocellulosic biomass (Ragauskas et al., 2006). A number of processes have been proposed that consist of a novel combination of fermentation and chemical conversion steps. These processes can significantly increase the yield of biofuel from carbohydrates compared to current biochemical routes and therefore potentially represent improved processes (Granda et al., 2009; Holtzapple et al., 1999; Lavarack et al., 2007; Verser and Eggman, 2003). On the other hand, biofuel production is fundamentally an energy conversion process and therefore energy efficiency, or more precisely thermodynamic efficiency, is also a critical factor for biofuel production. Thermodynamic analysis, based on the first and second laws of thermodynamics has been applied previously to biofuel production (Prins et al., 2005; Sohel and Jack, 2011) and has been shown to be a powerful tool in comparing different technologies and identifying inefficiencies. It is therefore important to apply thermodynamic analysis to high-yield processes to investigate the largest inefficiencies as well as to investigate any correlation between thermodynamic efficiency and yield.

In the conventional biochemical process (Huber et al., 2006), yeast fermentation is an important component step where 1 mol glucose is converted into 2 mol ethanol and 2 mol of carbon dioxide:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \quad (1)$$

This means that a maximum of 92 kg of ethanol can be produced from 180 kg of glucose, i.e., for the conventional biochemical process the theoretical yield is about 52% (w/w).

Lavarack and colleagues (Lavarack et al., 2007) have discussed a high-yield biochemical process, with the potential to utilise benefits of both biochemical and thermochemical pathways to biofuel production (Sohel and Jack, 2011). Lavarack and colleagues (2007) based their work on a previously patented work (Verser and Eggman, 2003). This process utilises bacteria to convert fermentable sugars to acetic acid. The acetic acid is then esterified

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