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Studies on the energy demand of two-stage fermentative hydrogen production from biomass in a factory equipped with fuel-cell based power plant

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ABSTRACT

A conceptual factory to produce hydrogen from starchy biomass is considered. The production plant comprises a pretreatment unit for starchy raw material, a bioreactor for dark fermentation, a photobioreactor for photofermentation and gas upgrading & compression units, and is supplied with the necessary heat and power from the power plant. In the power plant, a part of the stream of raw gas produced in bioreactors is burned in a steam boiler and in addition some product gas from the upgrading unit is directed to fuel cells from which waste gas flows to a catalytic oxidizer. The demand for process heat is covered by steam generation in the boiler and oxidizer, and the power demand is covered by electricity generation in the fuel cells.

The energy demand is studied as a function of selected process parameters; among them, CO_2 content in the product gas is of key importance. Conclusions are presented regarding the practicability of using own-produced hydrogen for the energy supply.

1. Introduction

Research on fermentation-based conversion of various kinds of biomass to hydrogen is expected to open the way to future commercial applications of this process. A question to be addressed is that of suitable production systems in which hydrogen can be produced in a truly sustainable manner. The present paper is concerned with a production system in which fermentative conversion of starchy raw material to hydrogen is applied.

The hydrogen production process considered here has been previously studied in the extensive research project HYVOLUTION which combined experimental work, simulation and conceptual design studies [1]. Initially, the raw material is pretreated with the aim to convert starch to glucose. In the main part of the H_2 plant, two-stage bacterial fermentation of glucose solution is employed. The fermentation process starts with the conversion of feedstock by thermophilic bacteria that produce H_2 together with carbon dioxide and acetic acid:

$$C_6H_{12}O_6 + 2H_2O \rightarrow 4H_2 + 2CH_3COOH + 2CO_2 \quad (1)$$

The co-product acetic acid is a prime substrate for H_2 and CO_2 production in the subsequent photofermentation by phototrophic bacteria:

$$CH_3COOH + 2H_2O \rightarrow 4H_2 + 2CO_2 \quad (2)$$

The gas streams from both fermentation stages are directed to a gas upgrading unit where H_2 is separated from

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the mixture of H_2 and CO_2. Finally the product gas, that is H_2 with traces of CO_2, is compressed to make it ready for market distribution.

It is worth noting that on the basis of stoichiometric relationships, the two-stage conversion of carbohydrates to hydrogen shows promise of an energy yield higher than that of ethanol fermentation. Using the lower heating values of hydrogen and ethanol, it was calculated that for a given mass of fermented sucrose, the energy value of produced hydrogen is 17% grater than that of ethanol obtained by its characteristic fermentation route; when using higher heating values, the difference is 24% [2]. Obviously, for the theoretical promise to be realized it is necessary that the substrate conversion efficiency of hydrogen fermentation reaches a level comparable with that of ethanol fermentation.

A wealth of literature on fermentative conversion of biomass to hydrogen is available. In this short paper however, citations are focused on the work of researchers who contributed to the research project mentioned above by providing experimental data for the calculations of the energy demand of process stages along with first estimates of the performance of the integrated process [1,3,4].

Production systems employing two-stage hydrogen fermentation were preliminarily studied in project HYVOLUTION and associated follow-up projects but a special feature of the factory considered here is the energy supply from an own combined heat and power (CHP) plant featuring solid oxide fuel cells (SOFC) fuelled with hydrogen from the production facility. To operate the factory, an external energy supply would be needed during production start-up only. However, of the stream of hydrogen produced by fermentation, a part would be consumed to cover process energy demand and losses associated with energy conversion in the CHP plant. The remaining part of the hydrogen stream would be available for market distribution.

In the following, the energy intensity of two-stage fermentative H_2 production in a small-capacity, stand-alone factory is estimated. The use of a raw material derived from potato, e.g. potato steam peels, is assumed.

2. Flow sheet of the hydrogen plant

2.1. *Biomass pretreatment*

The raw material is first mechanically converted into starch suspension (35 wt % starch and 65 wt % water) and then pretreated in three main process steps schematically shown in Fig. 1: enzymatic treatment, liquefaction and saccharification [3,5].

In the first step the feedstock is mixed with water and enzymes are added. The mixture is subsequently heated up to about 100 °C and kept for several hours in the liquefaction step. After inactivation of enzymes, the outlet stream of liquefied mixture is cooled down to about 60 °C and fed to the saccharification reactor where enzymes are introduced to promote the conversion of starch to glucose. Next the enzymes contained in the outlet stream from the saccharification stage are inactivated, the outlet stream is heated up and pH correction takes place. The obtained raw glucose syrup is ready for feeding to the main part of the H_2 plant.

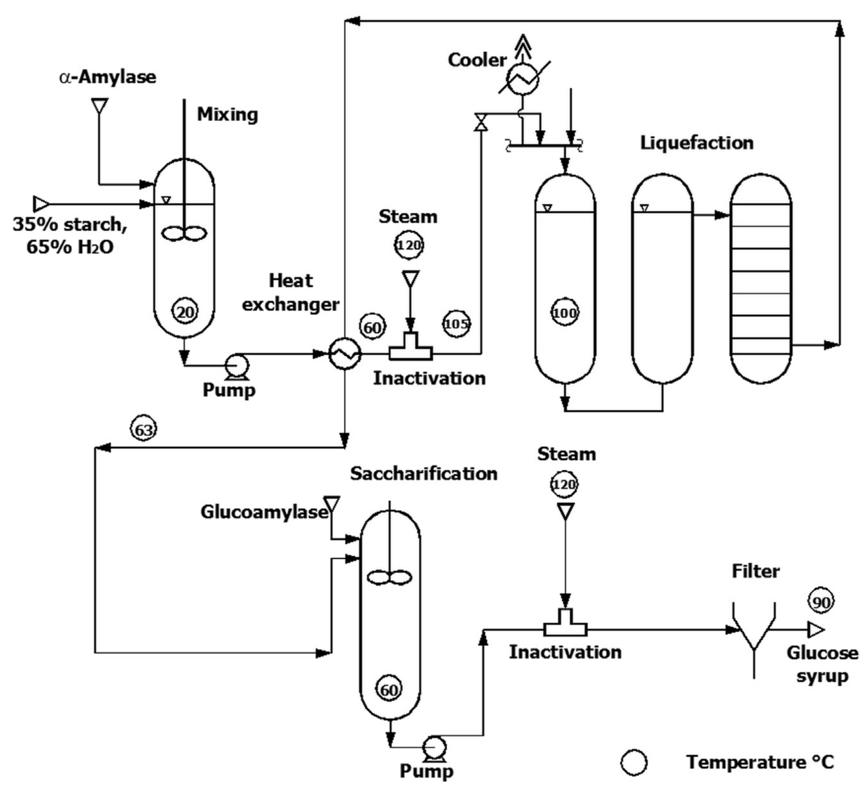

Fig. 1 – Scheme of the pretreatment of starch-containing raw material.