Small-size enzymatic hydrogen generator from starch

Biological Systems Engineering

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Invent the Future

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Abstract

Hydrogen gas is one of the upcoming clean fuels. The goal of this design project is to produce green hydrogen for small-scale applications. The project should seek to design a 200 kg-per day hydrogen production system produced from starch. A cell-free synthetic enzymatic pathway was chosen to ensure high H_2 yield at a high volumetric productivity under mild reaction conditions (e.g. room temperature and atmospheric pressure.) The design took into account capital costs, processing costs and labor, and calculated the return on investment. The final design was not profitable economically, however scaling-up the process could ensure a positive return on investment. By adjusting certain parameters of the process (i.e. raw material cost, hydrogen selling price, etc.), our net loss can be significantly decreased and a positive outlook ensured, suggesting the great potential in improving enzymatic H_2 production technology.

Project Constraints/Criteria

Constraints

- Comply with standard environmental and safety regulations.
- The initial return on investment must be checked carefully enough to ensure scale-up of the hydrogen production design.

Criteria

- Lower processing costs to ensure minimal labor requirement.
- Safely store hydrogen product under conditions that enable it to be used for direct commercial purposes.
- Design input and output storage tanks to allow for 3 days of storage.
- Design bioreactor to allow for reasonable, assumed reaction rate.

Standards

DIN EN ISO 15156-1:2010

- Requirements for gas production equipment materials to prevent equipment failure.

ISO 16110-1:2007

- Applicable to hydrogen generators using input derived from biomass sugars for safety reasons.

References:
American National Standards Institute
International Organization for Standardization

Assumptions

- Reactors are operating continuously, at 25°C and at atmospheric pressure (1 atm).
- Factory runs 330 days for 24 hours each day, seven days a week.
- The density of the hydrogen gas is 30 kg/m^3 at 600 bars.
- Enzymes are immobilized in the bioreactor in order to simplify the process and will be in the liquid phase in the bioreactors.
- The hydrogen-carbon dioxide mixture will be in the gaseous phase.
- Enzymes in the bioreactor are replenished periodically, however this is not depicted in order to simplify the process.
- Productivity = 0.3 moles H_2/L/hr

Mass Balance

$$C_6H_{10}O_5 + 7H_2O \rightarrow 12H_2 + 6CO_2$$

Table 1. Input/output amounts and costs.

	$C_6H_{10}O_5$	H_2O	H_2	CO_2
Mass (kg)	1338	1040	200	2179
Cost ($/kg)	0.35	0.0006	2.50	0.05

Table 2. Alternative 1 (increasing selling price of H_2): Input/output amounts and costs.

	$C_6H_{10}O_5$	H_2O	H_2	CO_2
Mass (kg)	1338	1040	200	2179
Cost ($/kg)	0.35	0.0006	4	0.05

Table 3. Alternative 2 (decreasing buying price of starch): Input/output amounts and costs.

	$C_6H_{10}O_5$	H_2O	H_2	CO_2
Mass (kg)	1338	1040	200	2179
Cost ($/kg)	0.26	0.0006	2.50	0.05

Process Flow Diagram

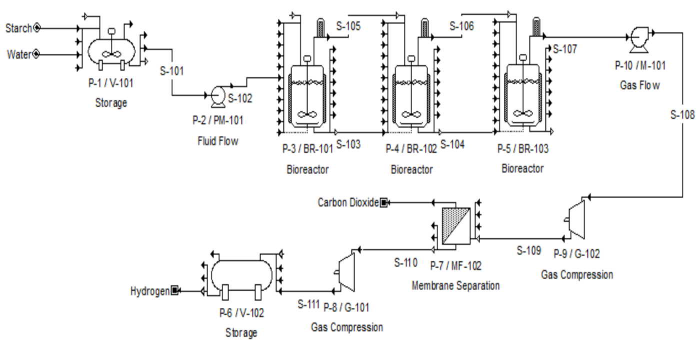

Figure 1. Process Flow Diagram for hydrogen generation process. (Intelligen, Inc. SuperPro Designer.)

Table 4. Equipment summary list for hydrogen generation process. (Alibaba.com)

Name	Type	Quantity	Parameters	Purchase Cost ($/Unit)
PM-101	Centrifugal Pump	1	-	10,000
BR-101	Bioreactor	1	5 m^3	50,000
BR-102	Bioreactor	1	5 m^3	50,000
BR-103	Bioreactor	1	5 m^3	50,000
MF-102	Membrane Filter	1	-	15,000
G-101	High Pressure Compressor	1	-	100,000
V-102	Horizontal Tank	1	20 m^3, 592 atm	60,000
G-102	Low Pressure Compressor	1	-	30,000
M-101	Centrifugal Fan	1	-	10,000
V-101	Mixer Tank	1	4 m^3	80,000

Cost Analysis

Table 5. Primary design cost analysis.

Capital Cost	$ 455,000
Annual Process and Running Cost	
• Raw Materials	$ 154,745
• Enzymes	$ 6,600
• Labor	$ 100,000
• Utilities	$ 50,000
Revenue Generated Annually	$ 165,000
Annual Profit Margin	-$ 146,345

Table 6. Alternative 1 (increasing selling price of H_2) design cost analysis.

Capital Cost	$ 455,000
Annual Process and Running Cost	
• Raw Materials	$ 154,745
• Enzymes	$ 6,600
• Labor	$ 100,000
• Utilities	$ 50,000
Revenue Generated Annually	$ 264,000
Annual Profit Margin	-$ 47,345

Table 7. Alternative 2 (decreasing buying price of starch) design cost analysis.

Capital Cost	$ 455,000
Annual Process and Running Cost	
• Raw Materials	$ 115,006
• Enzymes	$ 6,600
• Labor	$ 100,000
• Utilities	$ 50,000
Revenue Generated Annually	$ 165,000
Annual Profit Margin	-$ 106,606

Table 8. Alternative 3 (decreasing cost of labor) design cost analysis.

Capital Cost	$ 455,000
Annual Process and Running Cost	
• Raw Materials	$ 154,745
• Enzymes	$ 6,600
• Labor	$ 50,000
• Utilities	$ 50,000
Revenue Generated Annually	$ 165,000
Annual Profit Margin	-$ 96,345

Table 9. Alternative 1 (increasing selling price of H_2) + Alternative 3 (decreasing cost of labor) design cost analysis.

Capital Cost	$ 455,000
Annual Process and Running Cost	
• Raw Materials	$ 154,745
• Enzymes	$ 6,600
• Labor	$ 50,000
• Utilities	$ 50,000
Revenue Generated Annually	$ 264,000
Annual Profit Margin	$ 2,655

Future Plans

With the current size of the hydrogen generation system (200 kg H_2/day), we are unable to produce a definitive positive profit margin. Scaling-up the system is an option the design team is looking at to make the process ultimately profitable. Also, starch was selected as the input substrate for the system due to its availability and high production rate. However, there are several alternative sugars that can be considered to lower the raw material costs. Further work to decrease our processing and running costs may be to look into machine implementation in order to substantially decrease our main source of cost in labor. Additionally, the carbon dioxide produced in the process after proper purification, may possibly be sold to companies seeking pure carbon dioxide (i.e. soft drink companies). With government subsidy for green fuels or carbon credit, the potential carbon tax on fossil fuels, and the intended adjustments made to the process, the future of our project is promising.

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