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Marketable Biorefinery Strategy Research: Split Sugar Refining Process from Corn Cob

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Abstract

Biorefinery is a multidisciplinary technology that can solve organic waste's recycling. But the technology is not mature. Many factors limit the development of technology, like excessive use of chemical reagents, inefficient process control, secondary environments pollution and high cost. Bring down the cost of the biorefinery process, is the core issue driving the development of this technology. In addition to technological innovation, changes in business modes can also help the development of biorefinery technology. The amoeba mode aims to make complex processes simpler to achieve their end goal by making them simpler through separate economic operations. In this study, we set up three units to build sugar refining process from corn cob: (i) Furfural production process from corn cob; (ii) Detoxification process of furfural residue; (iii) Enzymatic sugar production process from detoxified furfural residue. The production cost of fermentable sugars (50% glucose solution) was CNY ¥860 /ton (USD 119.61/ton) cheaper than the price that appeared in other report.

Keywords

Biorefinery; Furfural; Furfural residue; Fermentable sugars; Cost.

1. INTRODUCTION

Biorefining Engineering, involved in agriculture, chemical, environmental protection, integrates multiple sections like biomass conversion processes and equipment, policy orientation and economy(1). Fermentable sugars act as one of centrals which linked with biomass and fermented products. Glucose, xylose, arabinose, mannose are the main ingredient of cellulose and hemicellulose in lignocellulose(2). Although fermentable sugar doesn't exist in the form of a commodity. Fermentable sugar are the watershed. From the perspective of material type，the vast majority of organic waste can be used to produce fermentable sugar, such as microalgae residual(3), sugarcane bagasse, rice straw(4), kitchen waste(5) and so on.

Due to the lack of engineering microorganisms that can efficiently utilize C5 sugars, fermentable sugars can't be commercialized and can only be used as intermediate products. Sugar production cost produced from corn stalks up to 0.42 dollor/kg(converted to CNY ￥2.98)by sulfuric acid pretreatment(6). The minimum selling price of fermentable sugar was 0.34 dollor/kg(converted to CNY￥2.42)(7).

How to further reduce the production cost of fermentable sugar is the core link to play the advantages of biorefinery. Cheap and enzymatically digestible raw materials are the most important factor of biorefining engineering. Food waste rich in carbohydrate (65% of total solids) can produce 0.63g glucose/g total solid and 0.31g ethanol /g total solids for simultaneous saccharification and fermentation (8). In China，food waste and sludge as mature raw materials to produce biogas by anaerobic fermentation and electricity by combustion. Due

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to the high cost of technical implementation process, lignocellulose raw materials have not yet been able to achieve large-scale biorefining.

Amoebic type, a business operation mode based on independent operation calculation method. I tried to split biorefinery technical implementation process to three sustainably operating industry using the amoeba mode. As we know, corn cobs were the common raw material to make furfural and the furfural residue were cheap organic waste.

2. MATERIALS AND EXPERIMENT

2.1. Major raw material

Corn cobs purchased from Chuzhou City，Anhui Province. Furfural residue purchased from Qufu Feimao Chemical Co., Ltd.

2.2. Experiment process

Furfural production process：10t crush corn cobs mixed with 5% liquid sulphuric acid (solid-liquid ratio was 1:10) under 150-170℃ heat treatment for 1h. The steam was condensed by triple distillation to separate furfural.

Detoxification of furfural residue process: 50t furfural residue dumped in the pool, filtered with 10 times weight of water. Organic wastewater treated by coagulation-aerobic combined technique.

Fermentable sugars production process: Transport the washed furfural residue to a 10t saccharification tank (30% fill), then add 8t cellulase solution (20 U/ml), keep warm at 50 °C, and run for 24h in the stirred state.

3. RESULTS AND DISCUSSION

3.1. Furfural production process economic analysis

From table 1, corn cobs as the main raw material accounted for 73.8% of the total cost. In addition, corn cobs were a class of agricultural side-products. For the purpose of developing agriculture, the government had given tax cuts from 2021.It was also because of the tax cut that it had achieved a profit of 6.74% higher than the average profit margin of 5.45% in China's chemical industry in 2021.The cost of electricity, steam and water consumed annually accounts for 9.06%. Due to the inclusion of equipment depreciation costs in other funding items, the cost of waste treatment accounted for only 0.55%.

In this study, the yield of furfural was 9.09%. Compared with reported data, there was still a big gap in yields (9). Although China is the largest producer of furfuraldehyde, the backward conventional sulfuric acid method was still the main production process. Based on the existing production process and furfural yield, the conversion efficiency of the corn cob in this study was even lower than that of straw conversion.

3.2. Detoxification of furfural residue process economic analysis

Furfural residue (FR) contained a large amount of sulfuric acid, acetic acid, furfural and other substances which inhibited the degradation of microorganisms. Washing, one of the easiest treatment, used in the treatment of pretreated biomass widely. This practice was also known as detoxification.

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Table 1. Parameters for the techno-economics study of furfural production process

Items	Estimation assumption		
Plant capacity	100,000 MT of furfural year-1		
Feedstock	Corn cob		
Design on-stream factor	0.914(330 days year-1)		
	Annual amount (t)	Unit price(CNY ¥/unit)	Total price(CNY ¥)
Main products			
Furfural residue	121,000	280/t	33,880,000
Furfural	10,000	11,000/t	110,000,000
Raw materials			
Air-dried corn cobs	110,000	900	99,000,000
Sulfuric acid(98%)	1,900	720	1,368,000
Utilities			
Electricity	43,500kwh	0.725	31,537.50
Steam	55,010	220	12,102,200
Process water	4,180	3.0	12,540
Waste treatment			
Waste water	5,940	5.2	30,888
Watse solid	350	2,000	700,000
Waste air	34	234.9	7,987
	Other expenses		
Wages	80	100,000/person	8,000,000
Depreciation of fixed assets			2,000,000
Equipment maintenance			800,000
Administrative costs			10,000,000
Annual sales			
Furfural			110,000,000
Furfural residue			33,880,000
Total revenue			143,880,000
tax payment (National tax deduction)			127,749.02
Total expenses			134,053,152.50
Total profit			9,699,099

The washing water were typical organic wastewater. FR was a product with selling price, and the detoxified furfural residue (DFR) was not commoditization. In order to evaluate DFR's market price, I used the wash treatment in a commercial way. Design the processing price was CNY ¥ 4 per ton. The result of the operation was in Table 2. The sewage treatment adopted coagulation-aerobic combined technique to make it meet the discharge standard. The profitability rate of 14.50% was in line with the profit range of the sewage treatment industry. Of course, the government still provided tax cuts for the sewage treatment industry. 600,000 tons of organic wastewater was washed from 121,000 tons furfural residue. Therefore, it can be used to accurately determine the cost of DFR. The market price of 1t furfural residue was CNY ¥ 280, and the cost in this study was CNY ¥ 24. After detoxification, DFR lost 12.09% of weight, so we adjusted the price to CNY ¥ 345.81 per ton.

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Table 2. Parameters for the techno-economics study of furfural residue treatment process

Items	Estimation assumption		
Plant capacity	600,000 MT of furfural residue washing water year-1		
Feedstock	Organic wastewater		
Design on-stream factor	0.99(362 days year-1)		
	Annual amount (t)	Unit price(CNY ¥/unit)	Total price(CNY ¥)
Raw materials			
Organic wastewater	600,000	4	2,400,000
Calcium oxide	75	260	19,500
PAC	10	1200	12,000
PAM	8	12,000	96,000
Ferrous sulphate	83	380	66,000
Hydrogen peroxide (30%)	400	820	328,000
Utilities			
Electricity	220,000 kwh	0.725	159,500
Process water	4,800	3.0	14,400
Waste treatment			
Watse solid	355	420	149,100
Waste air	4.8	235	1,128
Other expenses			
Wages	10	70,000/person	8700,000
Depreciation of fixed assets			200,000
Equipment maintenance			150,000
Administrative costs			150,000
Total revenue			2,400,000
tax payment (National tax deduction)			6378.696
Total expenses			2,045,628
Total profit			347,993.3

3.3. Fermentable sugars production process economic analysis

From table 3, we performed enzymatic cellulolysis of detoxified furfural residue to obtain fermentable sugars. The profitability of 6.4% was due to excessively low market prices. The market positioning of fermentable sugars was similar to industrial glucose instead of edible glucose. The price ratio of feedstock and lignocellulosic sugar was about 1:5.5-6.5(6). If we took edible glucose as a reference(CNY ¥ 3600 /t), when lignocellulosic raw materials sold less than CNY ¥ 553-564/t could gain an advantage. The general price of lignocellulosic raw materials in China was CNY ¥ 150-350 / t which was far lower than this standard. Therefore, fermentable sugars should be based on industrial glucose. The market price of industrial glucose was generally CNY ¥900-1500 / t, which was often used as a carbon source supplement in the process of microbial fermentation. If the price of fermentable sugars was higher than this product, it was no longer competitive in the market. And we could see that the reported minimum market price of fermentable sugars was CNY ¥ 2420 /t. To make lignocellulose production of fermentable sugars more feasible, we designed corn cobs produce furfural section, furfural residue cleaning water treatment section, furfural residue produced fermentable sugar. In such a process, the price of 50% of glucose was CNY ¥ 860 /t, and the price of solid glucose was about CNY ¥ 1600 /t, which was much lower than the price of edible glucose, but slightly higher than industrial glucose.

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Table 3. Parameters for the techno-economics study of Fermentable sugars production process

Items	Estimation assumption		
Plant capacity	10,000 MT of fermentable sugars(50% liquid) year-1		
Feedstock	Detoxified furfural residue		
Design on-stream factor	0.914(330 days year-1)		
	Annual amount (t)	Unit price(CNY ¥/unit)	Total price(CNY ¥)
Raw materials			
Detoxified furfural residue	12,000	346	4,152,000
Cellulase	1.92	120,000	230,400
Utilities			
Electricity	34,521.88kwh	0.725	25,028.36
Steam	2,446.90	220	538,318
Process water	37,368	3.0	112,104
Waste treatment			
Waste water	745.41	0.96	715.5936
Waste air	5.42	234.9	1,274.10
	Other expenses		
Wages	28	90,000/person	2,520,000
Depreciation of fixed assets			670,000
Equipment maintenance			400,000
Administrative costs			600,000
Annual sales			
Fermentable sugars(50% liquid)	10,000	860	8,600,000
Lignin products	7,655.8	180	1,378,044
Total revenue			9,978,044
tax payment (National tax deduction)			85,199.87
Total expenses			9,249,840
Total profit			643,004.1

3.4. Marketable biorefinery strategy analysis

In order to describe the strategy more clearly, I draw the flow chart in figure 1. The three sections mentioned above were circled in light yellow boxes. Each one corresponded to a marketable industry type, chemical for furfural, sewage disposal for organic wastewater, sugar industry for fermentable sugar. All were built under a mature market mechanism. The blue dotted line indicated the technology of producing fermentable sugars from furfural residue which had reported. But their research were about using furfural residue to ferment, not marketable product of fermented polysaccharides. Of course, corncob can also be directly used for fermentation. The red solid line represented the biological refining process from corncob to fermentable sugars (10). Under the acid catalyzed degradation, the content of fermentable sugar were about 20g/L(about 16.67% solid degradation rate) in treatment condition of 4% acid,120℃,60min and 12g/L(about 10% solid degradation rate) in treatment condition of 0.4% acid, 120℃, 60min. Furfural was hard find in this acid catalyzed degradation. This method had good practicability and commercialization as the pretreatment of furfural production or the pre-/treatment of fermentable sugar. The industrial art in blue or red was a standard biological refining enterprises. This huge system based on large-scale treatment of agricultural organic waste required a lot of capital investment, and the economy was not high. Complex industry background increased the cost of enterprise construction, operation, especially the cost of government public relations in China. Amoeba independent financial mode provided new ideas in this paper.

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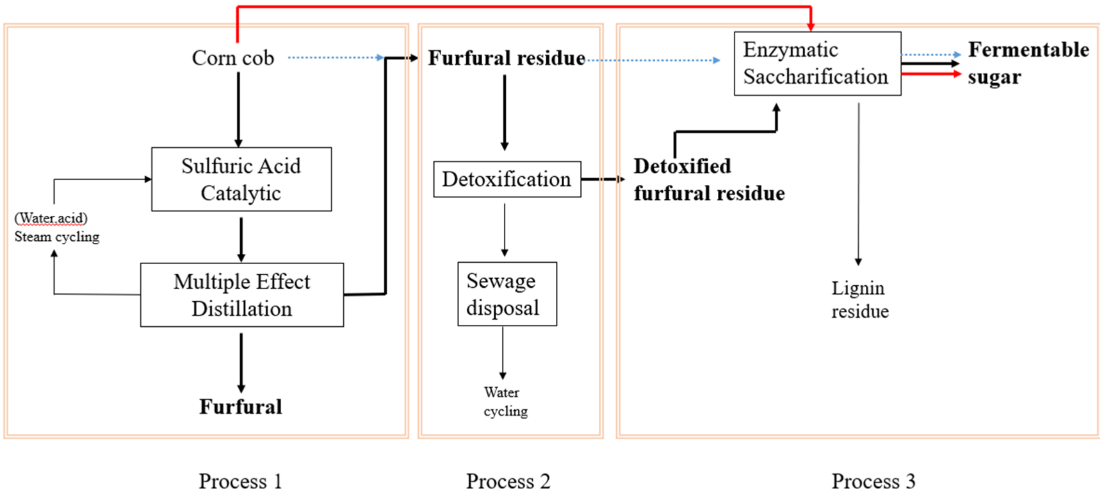

Figure 1. Flow chart of corn cob biorefinery strategy under amoeba mode

Process 1: Furfural production process;

Process 2: Detoxification of furfural residue process;

Process 3: Fermentable sugars production process.

According to popular parlance, super structure of the biorefinery mode were divided into four major part (pretreatment, hydrolysis, fermentation, separation) and other optional steps (like sugars division) (11). So I regarded furfural production as a pretreatment method in figure 2. The cost of raw materials (corn cob, not furfural residue) and hydrolysis accounted for the top 2 highest proportion with 32% and 31.25% respectively. Raw materials had always been a major part of the cost with 31.0%-38.5% (7) and 55.4% (12). Enzymatic hydrolysis was the second major contribute for acid pretreatment, which accounted for 21.5 % of total sugar production cost. These were highly similar to the cost structure in this study. I transferred detoxification to pretreatment with 7.52% higher than existing reports (1%). In this paper, furfural production process was based on single acid treatment, not a part of integrated biological refinery. This undoubtedly increased processing costs. Transportation costs were an integral part of this study in amoeba mode. The proportion of 9.62% indicated that the transportation cost cannot be ignored. Of course, industrial agglomeration as general considerations might reduce transportation costs. Productionisation was called by a joint name. That can sub-divide to separation, distillation, lyophilization and so on.

4. CONCLUSIONS

In this study, we split the ethanol production process from corn cob into three separate parts to account for the cost in the amoeba mode. Corn cob produces furfural using a proven process. Through furfural (a high-value product), the price of furfural residue is reduced (only 31.1% of the price of corn cobs, below straw price). The use of water elution to detoxify has a great impact on the increase in the price of furfural residue, with an increase of 23.58%. However, the detoxified furfural residue has better enzymatic hydrolysis performance, and the price is only 38.78% of the corn cob. After further enzymatic hydrolysis of this raw material, 50% fermentable sugars can be obtained, and its price is only CNY 860/ ton. This price is a very good advantage for biorefinery.

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