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Computer-Aided Economic Evaluation of Pectin Extraction from Cocoa Pod Husk (*Theobroma cacao L.)*

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Abstract

Pectin is a complex mixture of polysaccharides widely applied in food, cosmetic and pharmaceutical industry. The increasing demand of pectin has caused the search of raw materials for extracting process such as cocoa husks, sisal waste, peach pomace, banana peel and *Citrullus lanatus* fruit rinds. In this research, economic feasibility was applied for industrial implementation of pectin extraction process from cocoa pod husk (*Theobroma cacao L.*) by hydrolysis with citric acid using commercial software Aspen Plus v8.0. Aspen Process Economic Evaluator was used to perform economic evaluation, obtaining as results an Internal Rate of Return (IRR) of 33% and Payback Period (PP) of 4 years, which indicates that the proposed process is profitable.

Keywords: Economic viability, industrial process, pectin, cocoa pod husk

1. Introduction

Biomass utilization has been considered as an ever-trending process for renewable energy production, in which second-generation biofuels are suitable alternatives [1,2].

Lignocellulosic biomass is a potential source for producing ethanol [3, 4]. Therefore, residues from many traditional crops are considered as feedstock in order to obtain a variety of chemical products [5]. One of the developing crops in tropical countries is the cocoa, widely consumed all over the world [6]. However, cocoa crops brings new challenges related to the waste disposal, mainly of the cocoa pod husk, which is and abundant material that generates a negative environmental impact [7]. An alternative solution for the proper disposal of husks is the pectin extraction, which is used as gelling, thickening, texturizing, emulsifying, and stabilizing agents in food industry [8]. In addition, it is used in the pharmaceutical industry due to its low laxative tendency, protective, and regulatory role for gastrointestinal system, and its antiemetic antidiarrheal action [9]. In 2011, Cerón and Cardona conducted a comprehensive evaluation of essential oil and pectin process extraction from orange peel. Aspen Plus version 11.1 was used to simulate the process based on experimental data. Then, experimental tests were performed with 1 kg of orange peel at the same conditions of the simulation in order to compare it with its results obtaining similar yields. They concluded that the process is advantageous and is possible its implementation at industrial scale [10]. So far, economic viability of the pectin process has not been studied at industrial scale from cocoa pod husk by hydrolysis with citric acid in tropical countries as Colombia. Thus, this research aims to simulate the process from data of pectin previously obtained under optimized conditions, using the Aspen Plus v8.0® software, Aspen Process Economic Evaluator®.

2. Materials and Methods

Description of the economic analysis

Aspen Plus v8.0 and Aspen Process Economic Analyzer were used to analyze the production of pectin from cocoa shell at steady conditions. Mass flows, compositions, and physicochemical properties information for different streams allowed simulating industrial equipment. To perform economic evaluation, the cost of most relevant input and output streams was required to calculate economic parameters such as net present value (NPV) and payback period (PP). The equipment was chosen taking as selection criteria the most widely used in industry for a similar scale [11].

Simulation Considerations

Thermodynamic model was selected based on the algorithm proposed by Carlson [12], considering the nature of compounds of interest and operating conditions. The components used were those presented in higher proportion in the cocoa husk (water, cellulose, hemicellulose, lignin and protopectin), ethanol, citric acid, pectin, methanol and air. For the properties of cellulose, hemicellulose and lignin, was used the database of National Renewable Energy Laboratory (NREL) to enter them into simulation [13]. For protopectin and pectin, the molecular structure of monomer

was drawn for both compounds in Aspen Plus program, and its properties were estimated. To determine heat capacity, the Kopp rule was used [14].
For the hydrolysis reaction, it was considered that insoluble protopectin produces soluble pectin, losing the methoxyl group.

3. Results and Discussion

Process description

The sizing of the plant was carried out considering the production of cocoa in tropical regions, approximately 2,400 t/year [15] and husk represents 75% of the fruit. Therefore, the amount of processed husk was approximately 200 kg/h. The extraction conditions and composition of the husk were assumed considering experimental studies reported by Marsiglia *et al.* [5]. Thus, fractions of moisture, cellulose, hemicellulose, lignin and protopectin are shown in Table 1.

Table 1. Husk composition used for process simulation

Component	Mass fraction
Water	0.88
Cellulose	0.03
Hemicellulose	0.02
Lignin	0.02
Protopectin	0.05
Total	1.00

The thermodynamic model chosen was UNIFAC-DORTMUND, since the system works with some polar compounds, does not contain strong electrolytes, pressure under 10 atm, and does not have available parameters of interaction between components, conditions to which it fits well this model [12]. Cerón and Cardona also used UNIFAC-DORTMUND to simulate the extraction of essential oil and pectin process from orange peel [10]. Extraction of pectin from cocoa husks was simulated using the following stages: drying of raw material, decreasing of husks particle size, hydrolysis, cooling of the hydrolyzed mixture, filtration, flocculation, centrifugation, drying of pectin and particle size reduction of pectin, as shown in Figure 1. A convective dryer was fed by 200 kg / h cocoa shell with mass fractions shown in Table 1. A moisture of 16% for output stream was set according to experimental results. The input and output streams of air were calculated depending on needs of the system.

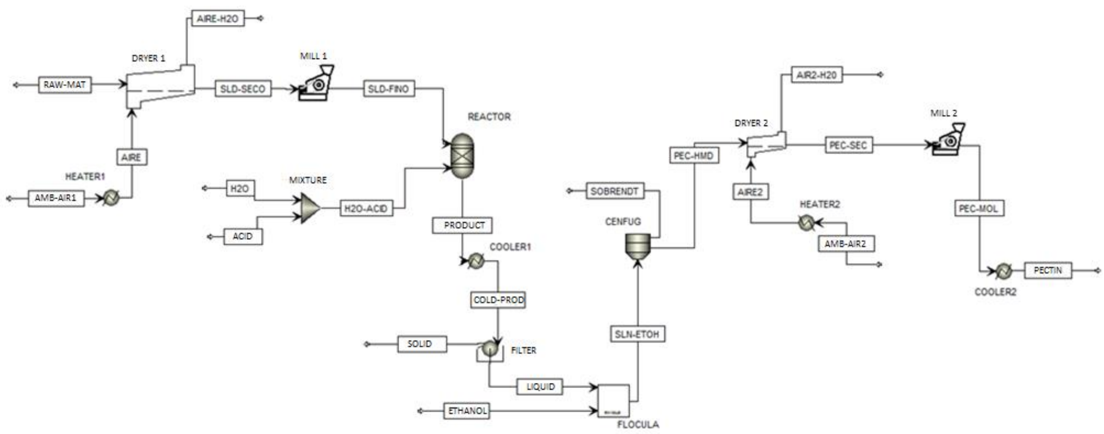

Figure 1. Flowchart of process of extracting pectin from peel cacao held in Aspen Plus.

Critical and equilibrium moisture of husk and data for drying curve were obtained experimentally by recording the values of mass loss over time when husk was dried in a tray dryer. To decrease the particle size of husk and pectin, two mills were used, whose values for mesh fractions by weight were supplied from tests performed at laboratory, based on what reported by Vriesmann [16] for husk and Torres [17] for pectin. For hydrolysis stage, dried and ground husk and a stream of acidulated water (1:10) feed the reactor [18]. Water with citric acid were mixed in a ratio of 0.0254 g of acid per mL of water, amount determined by the authors to maintain pH = 2 in the solution [5].
In cooling stage, the mixture was brought up to 30°C to stop the hydrolysis reaction. A filter module (rotary vacuum filter) was used to separate hydrolyzed pectin solution from solids. Dimensions of equipment were taken into account based on commercial information [19].

For flocculation stage, soluble pectin stream was added into ethanol at 96% v/v, in proportion of 2:1 of mixture to ethanol [16]. In order to separate pectin from ethanol-water mixture, a decanter centrifuge was used, where the residual moisture of the solid phase was specified as 0.6, according to data collected in experimental trials. Table 2 and 3 show the main parameters of inlet and outlet streams of the process. According to these, simulated plant produces 5.59 kg/h of pectin from 200 kg/h of husk. The yield on dry basis obtained was 22.58%, which was higher than that achieved experimentally at the same conditions (15.97%), although the values are not far apart, the performance increase could be related to the ideality of some equipment. The yield obtained by Cerón and Cardona [10] was slightly more than twice compared to results of this research (49.95%). However, it is necessary to consider that orange peel used by them have lower moisture content (80%) than cocoa husk (84%), in addition, pectin is less pure (61.72%) than the obtained in this simulation (92%). From this process simulation, it is observed that the extraction procedure requires large amounts of air (3744.88 kg/h), water (269.84 kg/h) and ethanol (136.78 kg/h); and that other outlet streams different to pectin, correspond to large amounts of moist air (3924.67 kg/h) and acidified water-ethanol solution (397.39 kg/h).

Table 2. Main inlet streams for the process

Components	**Mass flow of streams (kg/h)**					
	Raw material	**Ambient air 1**	**Acid**	**H_2O**	**Ethanol**	**Ambient air 2**
Water	176.74	52.62	0.00	269.84	6.49E-02	15.69
Ethanol	0.00	0.00	0.00	0.00	136.72	0.00
Air	0.00	2832.26	0.00	0.00	0.00	844.31
Citric acid	0.00	0.00	6.85	0.00	0.00	0.00
Cellulose	6.20	0.00	0.00	0.00	0.00	0.00
Hemicellulose	3.38	0.00	0.00	0.00	0.00	0.00
Lignin	4.06	0.00	0.00	0.00	0.00	0.00
Protopectin	9.62	0.00	0.00	0.00	0.00	0.00
Total	200.00	2884.88	6.85	269.84	136.78	860.00

Table 3. Main outlet streams for the process

Components	**Mass flow of streams (kg/h)**				
	Air-H_2O	**Solids**	**Supernatant**	**Air2- H_2O**	**Pectin**
Water	225.19	12.67	256.03	20.30	0.34
Ethanol	0.00	0.00	134.12	2.60	0.00
Air	0.00	4.15E-02	0.84	1.62E-02	0.00
Citric acid	2832.26	0.00	0.00	844.31	0.00
Cellulose	0.00	0.32	6.41	0.00	1.24E-01
Hemicellulose	0.00	6.20	0.00	0.00	2.96E-04
Lignin	0.00	3.38	0.00	0.00	1.61E-04
Protopectin	0.00	4.06	0.00	0.00	1.94E-04
Water	0.00	3.85	0.00	0.00	0.00
Ethanol	0.00	0.25	0.00	0.00	5.13
Total	3057.45	30.77	397.39	867.23	5.59

Economic evaluation

Economic analysis using Aspen Process Economic Evaluator allowed to estimate the investment and return of the simulated process in Aspen Plus with the possibility to obtain a considerable profitability. The assembly of the process was evaluated for a period of 20 years and production capacity of 108,127.4 lb./year of pectin, with annual interest rate of 20%, a salvage value (fraction of initial investment) of 20%, depreciation method straight line and an income tax of 40%.

Table 4. Economic results for pectin production process

Duration of startup (year)	**Capital costs (USD)**	**Operational costs (USD)**	**IRR**	**Payback period (year)**
17	$5,509,000.00	$2,135,300.00	33.00%	4

Table 4 shows that Internal Rate of Return (IRR) is 33%, higher value than standardized rate (20%), hence it justified the implementation of production process of pectin from cocoa pod husk as an investment project, since the process has better long-term benefits than those generated by investing in a bank with the prescribed fee. This IRR is close to the obtained by Castro and Sepulveda (26.49%) [20]. The costs associated with process equipment are detailed in Table 5, which shows the strong influence of Dryer1 (drying of raw material) and Reactor (hydrolysis step) in the total cost, this is due to the large requirements these have, regarding to the capacity and design, to reach the operating conditions of the process. The results indicate that the process at the current costs of cocoa husks as raw material, neglected by being agroindustry wastes, becomes a resource suitable for transformation into pectin, but it is important to remark that once profits are generated from this material, it is likely that its acquisition demands an additional cost. The extraction of pectin from cocoa pod husks according to considerations raised for its production process can be economically profitable, by having higher long-term benefits demonstrated by short period of return on capital.

Table 5. Costs of main process equipment

Equipment	**Direct Cost (USD)**	**Installation Cost (USD)**
Cooler1	60,100.00	$10,900.00
Heater1	60,600.00	$8,400.00
Reactor	159,000.00	$31,600.00
Heater2	$46,100.00	$7,600.00
Cenfug	$171,900.00	$129,700.00
Dryer1	$390,400.00	$250,900.00
Flocula	$159,000.00	$31,600.00
Dryer2	$17,300.00	$10,700.00

4. Conclusions

According to the economic analysis conducted for the production process of pectin from cocoa husk by hydrolysis with citric acid, it is found to be economically viable since the investment is recovered in 4 years and the internal rate of return is promising (33%). From the above, it is feasible to extract pectin from cocoa pod husk from the tropical regions by hydrolysis with citric acid to pH 2 for using in the food industry.

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