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Energy Integration of a Large-Scale Process for Pectin Production from Cocoa Pod Husk (*Theobroma cacao L.)*

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Abstract

Pectin is an important plant cell component extracted from by-products of plant material such as citrus peels, sisal waste and peach pomace. Conventional acid extraction process includes the acidification of feedstock by a mineral or organic acid during time and using hot water. Because of the wide range of applications for pectin, alternative sources and extraction process have been studied in order to satisfy the increasing demand, improve efficiency and reduce costs. In this research, energy integration analysis was applied to pectin extraction process from cocoa pod husk (*Theobroma cacao L.*) by hydrolysis with citric acid; the results indicated that heating and cooling energy requirements savings of 93.8% and 57.7%, respectively, might be obtained, which make of this process a project with even a greater economic potential.

Keywords: Energy integration, industrial process, pectin, cocoa pod husk

1. Introduction

Biomass has gained attention due to its applicability as source of a huge variety of chemicals and materials, and for electricity and fuels production [1, 2]. Agricultural biomass wastes have been considered as an alternative approach for non-competing against food crops for land and fresh water [3]. The availability in large amounts in different areas and environments is a significant advantage of using residual biomass. In addition, it increases the economic value of waste and reduces environmental impacts of its disposal [4]. Interesting approaches have been studied for agro-forestry lignocellulosic biomass in the last years due to the needs of alternative sources for energy and materials production [5]. *Theobroma cacao L.* is an economically important crop and the cocoa beans are used primarily in chocolate manufacturing [6]. Pectin is a complex mixture of polysaccharides that exists in the primary cell wall and is widely used as a gelling, stabilizing and emulsifying agent in the food and cosmetic industries [7, 8]. Commercial pectin is obtained from citrus peel, apple pomace and sugar beet pulp, however increasing demands have generated the need to seek alternative sources. Orozco et al. conducted studies of a semi-batch plant for the production of 348 t/year of pectin from orange peel, under optimum extraction conditions (90°C, 75 min, and pH 1.5). Calculations of processing time and unit capacity were made in Microsoft Excel® and Aspen Plus v7.3®. The simulated units were acid hydrolysis of husk, filtering of hydrolyzed slurry, pectin precipitation with alcohol, pressing gel, pectin drying, and size reduction. The batch size was 3,383 kg with a period of 3.61 hours, which was determined by hydrolysis unit [9]. In this work, energy integration was performed to reduce the utilities requirements for heating and cooling in pectin extraction process from cocoa pod husk using algebraic cascade diagram method.

2. Materials and Methods

Process description

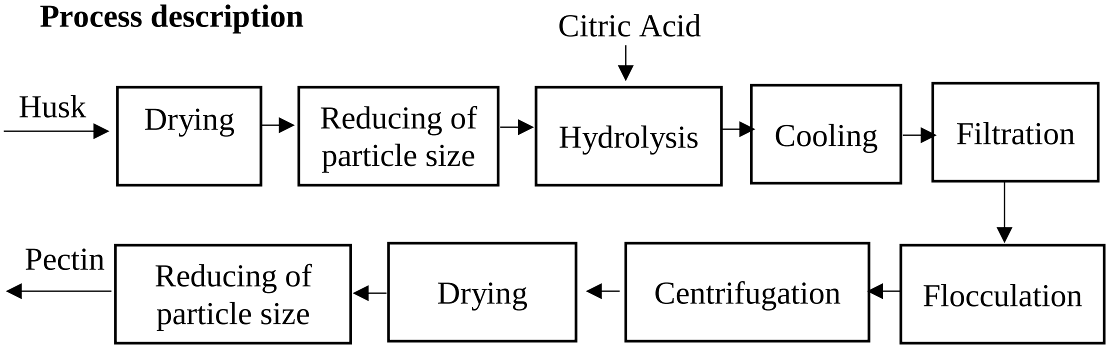

Figure 1. Block diagram of pectin extraction process

Figure 1 shows the general process for extracting pectin from cocoa husks, which includes the following stages: drying of raw material, reducing of particle size of husks, hydrolysis, cooling of hydrolyzed mixture, filtration, flocculation, centrifugation, drying of pectin and reducing of particle size of pectin.

Energy integration

Energy integration seeks to optimize the use of energy requirements of process streams, to reduce consumption of electricity, steam, fuel, cooling water and other, getting reduce operational costs, save energy and reduce emissions of polluting gases [10-12]. Thus through the design of heat exchanger networks, it look for transferring energy from hot to cold streams in order to reduce or avoid the use of additional industrial services [10].

The algebraic cascade diagram method was used to determine the minimum system requirements using energy integration, and find the percentage of energy reduction [11]. First, the temperature interval diagram was constructed. For this, the streams to be cooled (hot streams) and to be heated (cold streams), their mass flow, specific heat, and input and output temperature (target) were identified. Then, the temperature values were organized in a plot, so that the intervals were in descending order, placing hot streams to the right and the colds to the left, thus two scales of different temperature were obtained. Finally, the streams were represented in these diagrams by vertical arrows, whose tails correspond to inlet temperatures and heads to the target temperatures [11]. After completing the diagram, a table with heat loads in each temperature range was elaborated using Equation 1 and Equation 2 for hot and cold streams, respectively.

$$\mathrm{HH}_{u,z} = \mathrm{F}_u \mathrm{C}_{\mathrm{P}_u}(\mathrm{T}_{z-1} - \mathrm{T}_z) \tag{1}$$

$$\mathrm{HC}_{u,z} = \mathrm{f}_v \mathrm{c}_{\mathrm{p}_v}(\mathrm{t}_{z-1} - \mathrm{t}_z) \tag{2}$$

Where F_u (or f_v) and C_{Pu} (or c_{pv}) are the mass flow and the specific heat of the stream of the hot and cold streams, respectively, and T_{z-1} (or t_{z-1}) and T_z (or t_z) are the temperatures at the ends of each interval for the hot and cold streams, respectively. With the above data, the sum of heat in each interval of all streams was performed using Equation 3 and 4.

$$\mathrm{HH}_z{}^{\mathrm{Total}} = \sum \mathrm{HH}_{u,z} \tag{3}$$

$$\mathrm{HC}_z{}^{\mathrm{Total}} = \sum \mathrm{HC}_{u,z} \tag{4}$$

With this, it is possible to transfer heat from a z interval of hot streams to a smaller range of cold streams (Equation 5).

$$\mathrm{r}_z = \mathrm{HH}_z{}^{\mathrm{Total}} - \mathrm{HC}_z{}^{\mathrm{Total}} + \mathrm{r}_{z-1} \tag{5}$$

Heat integration methodology was used to obtain the percentage of reduction in consumption of heating and cooling services with respect to the heat required without and with energy integration [11].

3. Results and Discussion

The streams of interest for energy integration are shown in Table 1, with their respective properties, classified in hot or cold streams. Then, the different temperatures became intervals, increasing or decreasing by ΔT_{min}=10K if cold or hot stream, respectively.

Table 1. Hot and cold extraction process pectin streams

Stream	**Stream type**	**Mass flow (kg/h)**	**Cp (J/kg-K)**	**T_{in} (K)**	**T_{goal} (K)**
Air-H_2O	Hot	3057.45	1070.64	348.04	298.15
Product	Hot	304.20	4172.72	363.15	298.15
Supernatant	Hot	256.00	3730.18	305.15	298.15
Air2-H_2O	Hot	867.31	1026.38	322.75	298.15
Pect-mol	Hot	5.51	3388.77	312.52	298.15
Ambient air 1	Cold	2884.88	1019.46	298.15	348.15
Ambient air 2	Cold	860.00	1019.46	298.15	323.15

Figure 2 shows the diagram of temperature ranges, which organizes flows in vertical arrows. Tables 2 and 3 were developed with the heat of each interval for hot and cold streams.

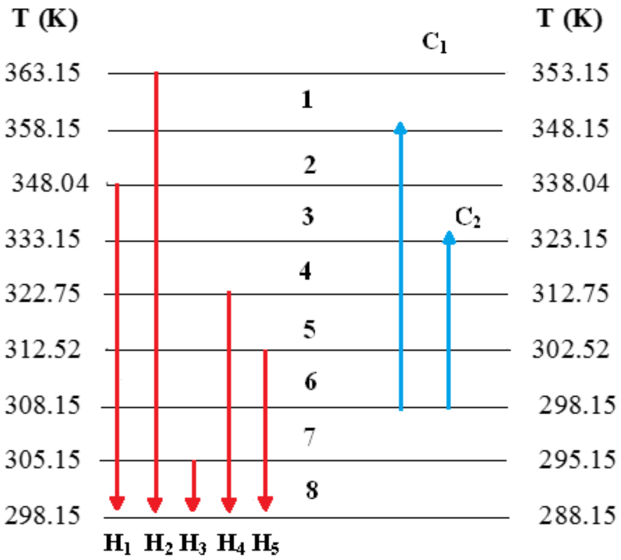

Figure 2. Diagram temperature intervals

Table 2. Heat each interval for cold streams

ΔT (K)	**Interval**	**C_1 (W)**	**C_2 (W)**	**Total (W)**
5,00	1	0.00	0.00	0.00
10,11	2	8259	0.00	8259
14,89	3	12164	0.00	12164
10,40	4	8496	2533	11029
10,23	5	8357	2491	10849
4,37	6	3570	1064	4634
3,00	7	0.00	0.00	0.00
7,00	8	0.00	0.00	0.00

Table 3. Heat each interval for hot streams

ΔT(K)	**Interval**	**H_1 (W)**	**H_2 (W)**	**H_3 (W)**	**H_4 (W)**	**H_5 (W)**	**Total (W)**
5,00	1	0.00	1763.00	0.00	0.00	0.00	1763.00
10,11	2	0.00	3564.78	0.00	0.00	0.00	3564.78
14,89	3	13539.26	5250.21	0.00	0.00	0.00	18789.47
10,40	4	9456.57	3667.03	0.00	0.00	0.00	13123.61
10,23	5	9301.99	3607.09	0.00	2529.63	0.00	15438.72
4,37	6	3973.58	1540.86	0.00	1080.60	22.66	6617.70
3,00	7	2727.86	1057.80	0.00	741.83	15.56	4543.04
7,00	8	6365.00	2468.20	1856.82	1730.93	36.30	12457.25

Then the cascade diagram is performed (Figure 3), taking the most negative value of residual heat, the temperature interval 2 (R_2 = -2931.6 W) as the new initial corrected residual heat in the diagram. With the corrected cascade diagram, the minimum requirements of heating and cooling were found. These values were compared with the energy requirements before integration (Table 4), calculating that 93.8% less energy, from external sources is required to heat cold streams and must be removed 57.7% less energy to external sources, to cool the hot streams if energetic integration is done in the extraction of pectin from cocoa. These results reduced the use of external services, thereby reducing costs.

Table 4. Minimum energy requirements with and without integration

	Without energetic integration (W)	**With energetic integration (W)**	**Percentage reduction (%)**
Q_{Hmin}	46935.94	2931.59	93.75%
Q_{Cmin}	76297.55	32293.20	57.67%

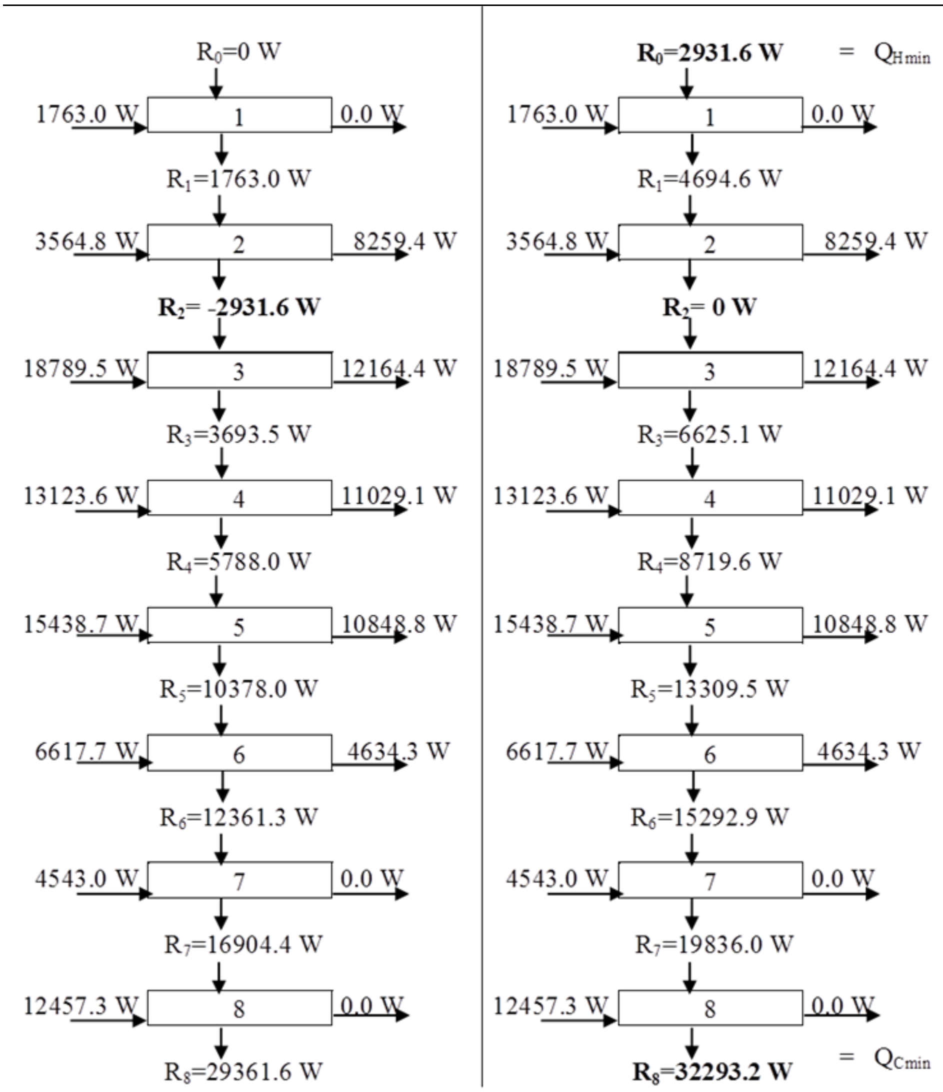

Figure 3. Diagram initial cascade and corrected for the extraction of pectin

4. Conclusions

According to the analysis performed for the production process of pectin from cocoa husk by hydrolysis with citric acid, it is determined that by implementing an energy extraction process integration, the use of external services for heating and cooling in a 93.8% and 57.7% decreases, respectively, which represents significant savings in operating costs.

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