TECHNOECONOMIC ASSESSMENT FOR PRODUCTION OF BIOETHANOL USING CASSAVA AS THE FEEDSTOCK

Hsi-Jen Chen, Chen-Yu Chien, Shih-Chieh Chien and Shih-Yun Huang
Department of Chemical and Materials Engineering
Tamkang University, Tamsui Dist., New Taipei City 25137, TAIWAN

SUMMARY: In this work, we have presented a chemical process synthesis and design for the production of bioethanol from cassava. The study aims to simulate a plant capacity of 30,000 metric tons per year of 99.5 wt% (or >99.3 vol%) purity of ethanol fuel. Starting with cassava as the raw material, we use the liquefaction, saccharification, and fermentation process to accomplish the making of crude ethanol; then, we employ purification processes to achieve the dehydrated ethanol production with a 99.5 wt% purity and the yield we desired. There are two kinds of purification process we use to separate ethanol and water. The first is the traditional azeotropic distillation process with benzene as the entrainer; the second is pervaporation process with the hydrophilic membrane. Additionally, we have conducted heat integration for the overall cassava-to-ethanol with pervaporation process. Ultimately, as seen from the economic analysis, we found that the yearly cost of manufacture, cost of bioethanol per liter, and fossil energy ratio (FER) are US\$27.0x10^6, US\$0.68, and 0.74, respectively, in the overall cassava-to-ethanol with azeotropic distillation process; and US\$23.6x10^6, US\$0.59, and 1.5 in the overall cassava-to-ethanol with pervaporation process after heat integration. Three kinds of software are utilized in the research—Aspen Plus, Aspen Custom Modeler (ACM), and SuperTarget. The first and second are applied to implement the process synthesis and design; the third is applied to perform the pinch analysis and the synthesis of heat exchanger network.

Keywords: bioethanol, technoeconomic evaluation, process synthesis and design, hybrid pervaporation distillation, azeotropic distillation, cassava

INTRODUCTION

Cassava (Figure 1) is the third largest source of food carbohydrates in the tropics, after rice and maize. Cassava is a major staple food in the developing world, providing a basic diet for over half a billion people. It is one of the most drought tolerant crops, capable of growing on marginal soils. Nigeria is the world's largest producer of cassava, while Thailand is the largest exporting country of dried cassava. Cassava root is a good source of carbohydrates, but a poor source of protein. A diet consisting predominantly of cassava root can cause protein-energy malnutrition. Cassava is classified as sweet or bitter. Like other roots and tubers, cassava contains anti-nutritional factors and toxins. It must be properly prepared before consumption. Improper preparation of cassava can leave enough residual cyanide to cause acute cyanide intoxication and goiters, and may even cause ataxia or partial paralysis [1].

An overall cassava-to-ethanol process is designed to produce 99.5 wt% bioethanol in this study. Three kinds of process software are used in the research—Aspen Plus [2], Aspen Custom Modeler (ACM) [2], and SuperTarget [3]. The first and second are applied to implement the process synthesis and design; the third is applied to carry out the pinch technology.

RESEARCH METHOD

Cassava is used as the feedstock in the study, which consists mainly of 68 wt% starch, 13 wt% water, 8 wt% cellulose, 3 wt% protein and other components 8 wt%. The thermodynamic property model we choose is NRTL (Non-Random Two Liquid). In the saccharification, we used Aspen Plus "RStoic" module with conversion of 99%. The reaction is as follows:

$$(C_6H_{10}O_5)_n + (H_2O)_n \rightarrow nC_6H_{12}O_6$$

In the fermentation, we also used "RStoic" module with 100% of conversion. The reaction is as follows:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

As to the design of the pervaporation membrane, we consulted with the parameters outlined in Professor Luyben's paper [4]. The distillate is heated and fed to the first of four pervaporation modules in series. Each module has three cells. Note that the retentate decreases in temperature as it flows through the first module due to the phase change. The temperature of the permeate from each cell is assume to be equal to the temperature of the retentate in that cell. Note also that the distillate should be pumped to ensure the retentate remains liquid. After four serious pervaporation modules, we are able to obtain dehydrated ethanol with 99.5 wt% (99.6 vol%) purity.

PINCH TECHNOLOGY

The pinch technology consists of the following steps [5]:

- data extraction;
- pinch analysis;
- heat exchanger network synthesis;
- network configuration.

The first step, data extraction, involves translation of flowsheet information into relevant thermal and cost information required for the application of pinch analysis. This step usually calls for a process simulation. The second step, pinch analysis, is to explore various options for process improvement quickly and easily using targeting, without getting into the detail of specific flowsheet changes. This allows quick screening of various options for process improvement such as energy recovery, process modifications, utility system integration, and so forth. Note that given a minimum approach temperature (ΔT_{min}) of a heat exchanger, the exact amount for minimum utility consumption can be predicted in this step. The key improvement options identified in the pinch analysis stage need to be implemented in design. In this step the focus is on the design aspect of pinch technology. This translates the ideas into the specific synthesis of the heat exchanger network. The third step, heat exchanger network synthesis, is based on pinch analysis principles and is called the pinch design method. There are basically three rules behind the pinch design method: (1) Heat must not be transferred across the pinch, (2) There must be no external cooling above the pinch, and (3) There must be no external heating below the pinch. The method systematically leads the engineer to good network designs that achieve the energy targets within practical limits. The network design procedure uses a special representation for heat exchanger networks called the grid diagram. Note should be made that the fewest number of exchangers is often equal to the number of process and utility streams minus one. The network design procedures are capable for doing both grassroots design and retrofit design. Answer to the step three leads to step four, the final network configuration.

ECONOMIC EVALUATION

To determine the yearly cost of manufacture (COM) and cost of bioethanol from cassava per liter, the following equation is used [6].

$COM = 0.28FCI + 2.73C_{OL} + 1.23(C_{UT}+C_{RM}+ C_{WT})$

where FCI = Fixed capital investment, C_{OL} = cost of operating labors, C_{UT} = Cost of utilities, C_{RM}= cost of raw materials, and C_{WT} = cost of waste treatment.

RESULTS AND DISCUSSION

This paper has studied a chemical process synthesis and design for the production of bioethanol from cassava with a plant capacity of 30,000 metric tons per year of 99.5 wt% (or >99.3 vol%) purity of ethanol fuel. In sum, we found:

1. On the basis of 8,000 hr/yr of operating time, we will need 80,000 tonnes of cassava per annum.
2. There is tremendous amount of energy savings by using pinch technology in the design.
3. The yearly cost of manufacture, cost of bioethanol per liter are US$$23.6\times10^6$, and US$0.59, respectively, in the overall cassava-to-ethanol with pervaporation process after heat integration. If the membrane price drops in the future, the costs will reduce even more.

References

[1] http://en.wikipedia.org/wiki/Cassava
[2] Aspen Plus, *ASPEN PLUS User's Guide, Version 7.3*, Aspen Tech., Boston, Ma, U.S.A. (2011).
[3] SuperTarget, *SUPERTARGET User's Guide*, Linnhoff March Ltd., Cheshire, U.K. (2013).
[4] W.L. Luyben, "Control of a Column/Pervaporation Process for Separating the Ethanol/Water Azeotrope," *Ind. Eng. Chem. Res.*, **48**, 2009, pp.3484-3495.
[5] H.J. Chen et al., "A paraffin-fueled SOFC system design and integration", *J. Chin. Inst. Chem. Engrs.*, 2007, **3**, pp.185-190.
[6] R. Turton et al., "*Analysis, Synthesis, and Design of Chemical Processes*," 2012, 4th ed., Prentice Hall, New Jersey, U.S.A.

Illustrations and graphics

Figure 1. A picture of cassava roots

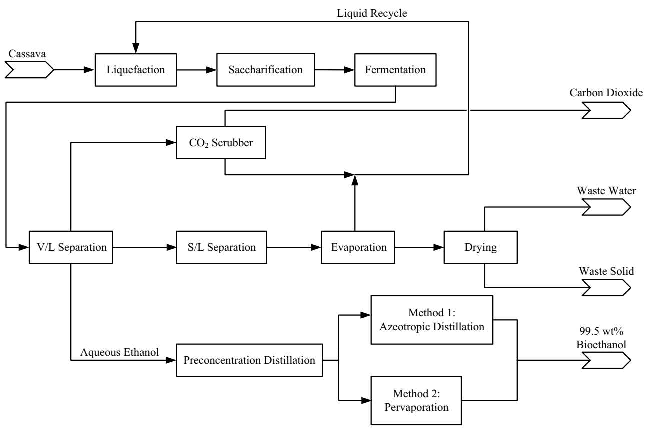

Figure 2. Overall block flow diagram for the production of bioethanol from cassava

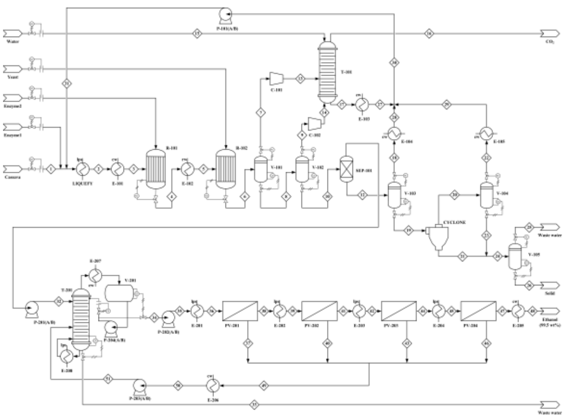

Figure 3. Process flow diagram for the production of bioethanol from cassava using hydrid preconcentration/pervaporation process

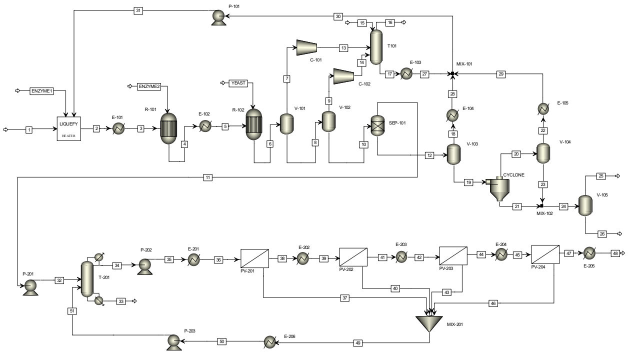

Figure 4. Flowsheet structure used by Aspen Plus in the simulation of the production of bioethanol from cassava using hybrid preconcentration/ pervaporation process

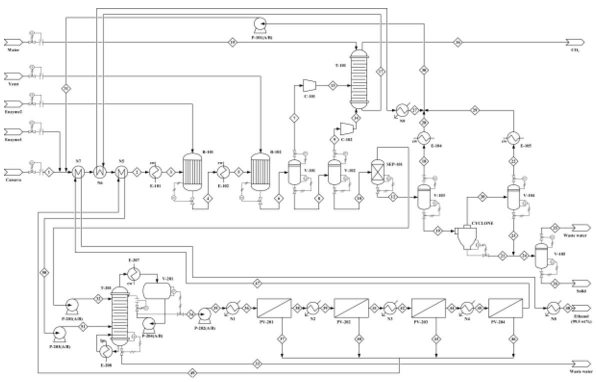

Figure 5. Final Process flow configuration for the production of bioethanol from cassava with heat integration

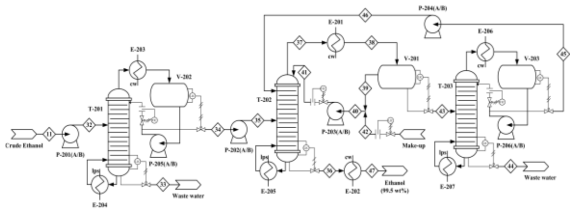

Figure 6. Process flow diagram for the production of bioethanol from cassava using azeotropic distillation

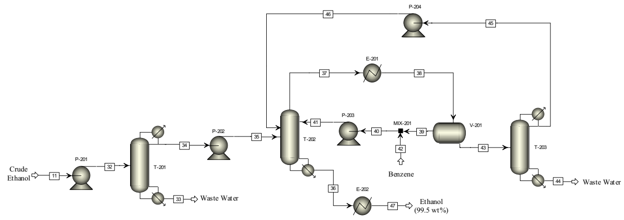

Figure 7. Flowsheet structure used by Aspen Plus in the simulation of the production of bioethanol from cassava using azeotropic distillation

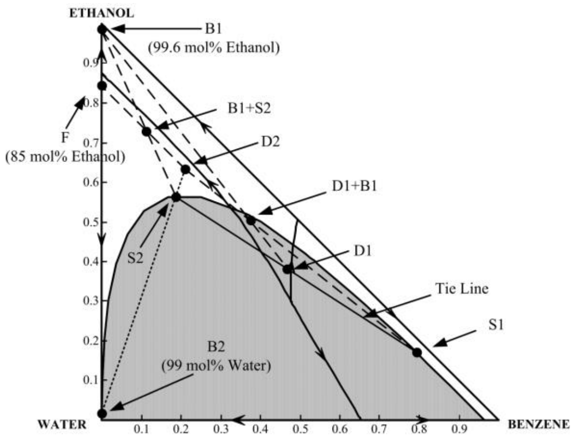

Figure 8. Material balance lines showing azeotropic distillation of the purification process of bioethanol from cassava