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Simulation and Evaluation of Autonomous and Annexed Sugarcane Distilleries

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Simulations of autonomous and annexed sugarcane distilleries were carried out with Aspen Plus®. Annexed plants with different proportions of sugarcane destined for bioethanol and sugar were considered in the technical-economic analysis. This study highlighted the relationship between plant flexibility and market oscillations. It was observed that annexed plants that diverted more sugarcane for sugar production were more profitable, considering the average prices for the last 10 y in Brazil. However, autonomous distillery presented the best economic results (internal rate of return and production costs) among the evaluated scenarios.

1. Introduction

Global concern about environmental impacts caused by the large use of fossil fuels has motivated the use of renewable energy sources. In this context, bioethanol production and demand have increased all over the world, since this fuel is renewable and less pollutant than the fossil-based ones. In view of the large Brazilian experience on bioethanol production and its position as the major exporter of bioethanol in the world (Silva, 2010), it is expected that its production increases significantly in order to attend the increasing internal and external demand.

In Brazil, bioethanol production is based in autonomous distilleries and annexed plants, which produce both sugar and bioethanol from sugarcane. The flexibility of plants to produce more ethanol or more sugar, depending upon the market needs, had a great influence on the success of bioethanol production in the country. However, the range of operation of an installed plant is somehow limited to the existing design restrictions and available facilities; thus, the plant scaling must be carefully defined taking into account process feasibility as well as economic analysis.

In this work, scenarios were simulated considering different proportions of sugarcane destined for each product (bioethanol and sugar), also including autonomous distillery, on which all sugarcane is used for bioethanol production. Another important product of the distilleries, surplus electricity, was also analyzed, since it has significant impacts on the environmental aspects and economic profitability of the sugar and bioethanol production processes. Simulations were performed using Aspen Plus® and process

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parameters were obtained from industry and in the literature. Production of bioethanol, sugar and bioelectricity was evaluated in each case. Results of the simulations were employed to evaluate the flexibility of the plant from an economic point of view.

2. Process Description

In an autonomous distillery, the processed sugarcane is used to provide sugars for bioethanol production, while in an annexed plant a fraction of the sugarcane is used to produce sugar and the remaining sugarcane and molasses (remaining concentrated impure solution obtained after sugar crystallization) are sent to bioethanol production process. Molasses have high concentration of sugars and its use in the bioethanol production may eliminate the juice concentration step, which is performed in evaporators consuming large amounts of steam. On the other hand, large amounts of steam are consumed on evaporators used in sugar production. Because the distilleries produce their own energy (steam and electricity) through combustion of sugarcane bagasse obtained as a by-product in the mills, process steam consumption directly impacts the production of surplus electricity, which is sold to the grid. The main steps required for production of bioethanol, sugar (VVHP - Very Very High Polarization) and bioelectricity from sugarcane in an annexed distillery are illustrated in Figure 1. In an autonomous distillery, operations related to sugar production (from juice treatment to drying) are not included in the process.

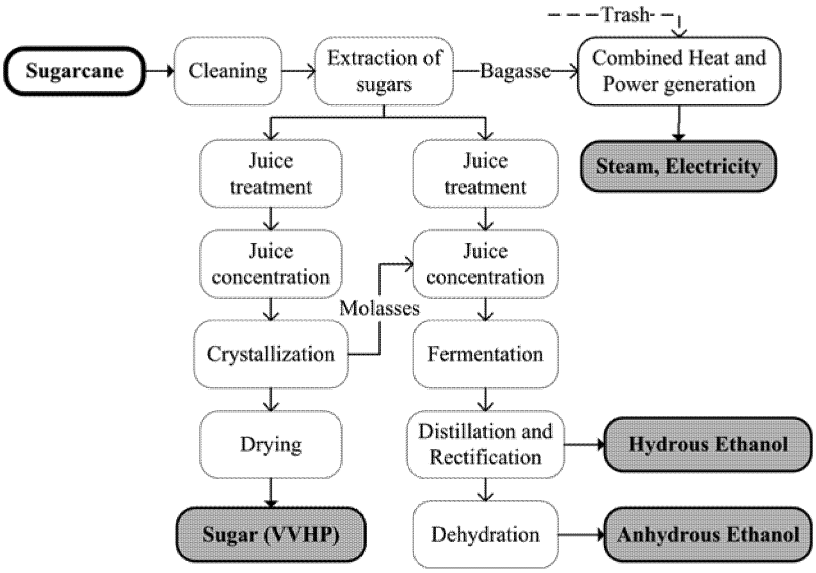


Figure 1: Block flow diagram of an annexed distillery.

3. Methodology

3.1 Process Simulation

Simulations were carried out with Aspen Plus®. Operating and process parameters of the autonomous distillery were obtained in the literature and from industries. A "standard" plant was considered, with typical unit operations found in the Brazilian bioethanol industry. Five hundred metric tons of sugarcane (TC) per hour are processed for production of hydrous ethanol (93.0 wt % ethanol), anhydrous ethanol (99.5 wt % ethanol), sugar (VVHP) and electricity. Half of the hydrous ethanol obtained in the distillation and rectification step is sent to dehydration process.

For autonomous distillery and annexed plant with sugarcane 50:50 partition for each product (ethanol:sugar), two configurations (basic, which is the configuration found in most existing plants, and optimized, introduced in new plants) were considered. For other proportions of sugarcane only optimized configurations were considered, since this study intends to offer ground to support new enterprises to benefit from the flexibility to produce more ethanol or more sugar, based on the market requirements.

Aiming at process optimization, some considerations and technology alternatives were taken into account. For instance, in ethanol dehydration, it is well-known that azeotropic distillation with cyclohexane is an energy-intensive process (Simo et al., 2008); therefore adsorption onto molecular sieves was adopted in the optimized configuration.

In the optimized configuration, a reduction of 20 % in the process steam requirement, which is feasible by means of thermal integration, was assumed. Besides, steam produced in the boilers is also used in mechanical drivers in the sugarcane preparation and juice extraction systems in the basic configuration; to improve energy efficiency, the use of electric drivers for mills and other equipments, replacing the mechanical drivers, was considered. Conventional plants are equipped with low efficiency boilers for the production of 22 bar steam, in which bagasse produced in the mills is used as fuel. Nowadays, more efficient cogeneration systems, such as those employing 90 bar boilers and back pressure and condensing steam turbines are employed for production of steam and electric energy, generating surplus electricity to be sold to the grid.

Another consideration in the optimized configuration was that 50 % of trash is used as fuel for the production of steam and electricity; the remaining fraction is left in the fields in order to provide control of weeds and diseases (Hassuani et al., 2005).

Table 1 summarizes the differences between basic and optimized configurations.

Table 1: Main parameters of basic and optimized configurations.

Parameter	Basic Configuration	Optimized Configuration
Dehydration process	Azeotropic distillation	Molecular sieves
Steam consumption	Value from simulation	20 % of reduction
Drivers	Mechanical	Electric
Boilers	22 bar	90 bar
Use of trash	Left in the field	50 % is used in the industry
Surplus bagasse	Selling	Burnt for production of electricity

3.2 Economic Evaluation

Scenarios representing autonomous distilleries (basic and optimized) and optimized annexed plants with the following percentages of sugarcane diverted to ethanol: 30, 40, 50, 60, 70 % (for 50 %, the basic configuration was simulated as well) were evaluated. Two flexible configurations, 60:60 and 70:70, meaning that sugarcane for ethanol production can vary between 40-60 and 30-70, respectively, were also analyzed.

Production of hydrous and anhydrous ethanol, sugar and surplus electricity or bagasse was determined for each scenario based on the results of the simulations. These results, along with investment costs, were employed to perform economic analysis. Moreover, prices of sugarcane and all sugarcane products were defined as shown in Table 2.

For economic analysis, project lifetime, depreciation (linear) and construction/start-up were set to 25, 10 and 2 y, respectively and there is no salvage value of equipments. Tax rate (income and social contributions) was assumed as 34 %.

Table 2: Average prices of sugarcane and derivatives.

Product	Average Price	Source
Sugarcane	US$19.44/t	Average of the last 12 m (UDOP, 2009)
Sugar	US$0.35/kg	Average of the last 10 y (CEPEA, 2010)
Hydrous ethanol	US$0.46/L	Average of the last 10 y (CEPEA, 2010)
Anhydrous Ethanol	US$0.50/L	Average of the last 10 y (CEPEA, 2010)
Electricity	US$70.61/MWh	Average prices on renewable energy auctions, values for 2009
Bagasse	US$16.58/t	Considered equal to the sugarcane price

Prices in Brazil, considering the exchange rate US$ 1.00 = R$ 2.00

4. Results and Discussion

Main results of process simulation are shown in Table 3; surplus electricity is similar for optimized scenarios, due to the fact that all the bagasse and trash available are burnt.

Table 3: Production for simulated scenarios.

Scenario	Hydrous ethanol (L/TC)	Anhydrous ethanol (L/TC)	Sugar (kg/TC)	Electricity (kWh/TC)	Bagasse (kg/TC)
E50-B	27.0	25.6	51.2	-	33.3
E100-B	43.3	41.0	-	-	39.0
E100	47.7	36.8	-	190.4	-
E70	36.9	28.4	30.7	187.8	-
E60	33.3	25.7	41.0	187.8	-
E50	29.8	23.0	51.2	187.8	-
E40	26.3	20.3	61.4	187.4	-
E30	22.7	17.6	71.7	187.9	-

Numbers in scenarios stand for sugarcane percentage diverted to ethanol (i.e., E70 represents the annexed plant on which 70% of sugarcane is used for ethanol production); B: basic configuration.

Table 4 presents the investment cost calculated for each scenario based on data provided by equipment industry (Sousa and Macedo, 2010). Economic analysis was performed based on the economic parameters described on Tables 2 and 4 and the technical results displayed on Table 3. The IRR (internal rate of return) was evaluated for all the proposed scenarios. For scenarios 70:70 and 60:60, two conditions were analyzed:

producing ethanol in the upper limit (70 and 60 %) and in the lower limit (30 and 40 %). Production costs – always excluding return on capital – were determined as those which result in IRR equal to zero, upon decreasing product prices simultaneously at the same proportion. Results are illustrated on Figure 2.

Table 4: Investment costs for autonomous and annexed distilleries.

Scenario	E50-B	E100-B	E100	E70	E60	E50	E40	E30	70:70	60:60
Investment (10^6 US$)	169	149	196	220	220	219	218	217	228	224

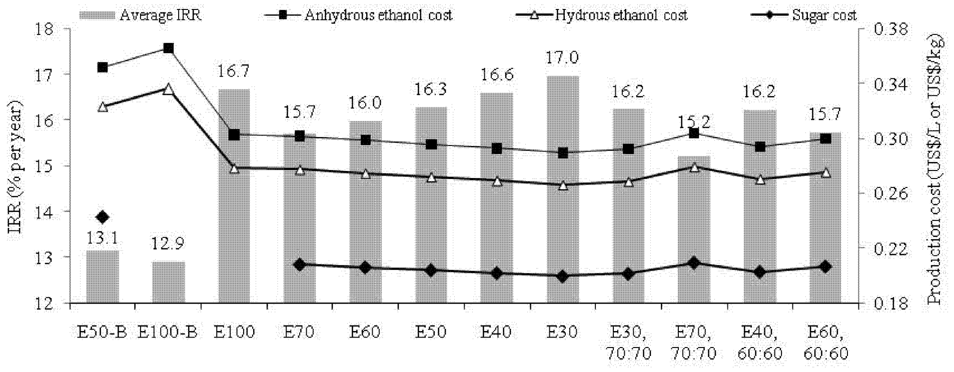
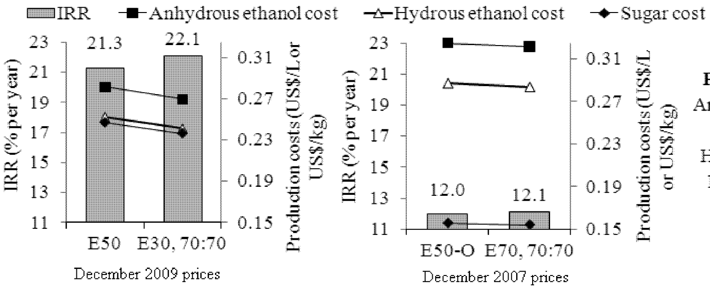


Figure 2. IRR and production costs (E30, 70:70 represents the flexible plant (70:70) on which 30% of the sugarcane is used for ethanol production).

Figure 2 shows that sugar, hydrous and anhydrous ethanol production costs are consistently lower for optimized configurations, when compared to the basic configurations (*E50-B* and *E100-B*); thus, even though optimization requires more investment, decreases on production costs are achieved. From Figure 2, it can also be inferred that the annexed plant with 30 % of sugarcane diverted to ethanol and 70 % to sugar (fixed proportion) presented the highest IRR among the evaluated scenarios, taking into consideration the average sugar and ethanol prices paid to the producers for the past 10 y in Brazil. These results indicate that, for annexed plants with fixed production (*E70* through *E30*), more sugarcane diverted for sugar production increases profitability. For flexible plants (*E30, 70:70* through *E60, 60:60*), the same behavior was observed. However, IRR of flexible plants are lower than those of fixed plants, which can be explained by the higher investment cost and the assumption that the plants always produce maximum ethanol or sugar. In fact, flexibility consists in choosing what to produce based on the market; an average price analysis as the one considered in Figure 2 may be underestimating IRR of the flexible scenarios. Thus, a different analysis was carried out assuming two situations: small and large differences between ethanol and sugar prices observed in December, 2009 and December, 2007, respectively. Parameters and results for selected scenarios are illustrated in Figure 3. Results in Figure 3 show that the flexible plant (*E30, 70:70* and *E70, 70:70*) may help improve the IRR and decrease production costs in situations where ethanol or sugar production is favored, when compared with the usual 50:50 configuration adopted in the industry. These results, however, are related to a situation on which price and production favoring one specific product is found during the entire project lifetime.



Product	Prices (US$/L or US$/kg) Dec-09	Dec-07
Anhydrous Ethanol	0.57	0.47
Hydrous Ethanol	0.51	0.42
Sugar	0.50	0.23

Figure 3. IRR and product costs for selected scenarios assuming small (Dec 2009) and large (Dec 2007 prices) differences between ethanol and sugar prices.

5. Conclusions

A technical-economic evaluation of autonomous and annexed distilleries was carried out in order to offer ground to enterprises to decide the flexibility required in their project. Investment cost revealed to be an important factor, since it increases from autonomous to annexed distilleries and from fixed to flexible plants, having significant impacts on the IRR. Other observation was that increasing sugar production, annexed plants present higher IRR for both flexible and fixed plants.

Although autonomous distillery also presented high IRR, it is important to take into account that market tendencies can considerably change and flexibility may be decisive for maintaining the profitability. Besides, further studies considering the option to produce more sugar or ethanol depending upon market oscillations during the project lifetime must be carried out. In this case, IRR of flexible plants may increase significantly over the plant lifetime, justifying the higher investment required.

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