FIRST LAW ANALYSIS OF COGENERATION IN CANE INDUSTRY IN MAURITIUS: CURRENT AND FUTURE SCENARIO

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ABSTRACT
Cogeneration has been practiced in the cane industry in Mauritius since 1957. During the crop seasons, cane biomass (called bagasse) is burned in water-tube boilers of up to 82 bar and fed in condensed extraction steam turbine. Electricity, including supply for national grid, and process heat for cane-milling, distillation and sugar refinery are produced. During intercrop, coal has been used instead of biomass to provide continuous power to the grid. This paper will investigate the current and future potential of cogeneration on the basis of the first law of thermodynamics. Implementation of higher pressure boilers, varieties of biomass of higher calorific value, bagasse drying as well as Bagasse Integrated Gasification Combined-Cycles turbines are also considered as future scenario.

Key Words: Mauritius, Cane biomass, Sugar refinery, Bagasse, Gasification

INTRODUCTION
Sugarcane industry has long been a sustainable industry and more importantly, until late, the backbone of the economy of Mauritius. However, in 2006 due to the 36% decrease in price of sugar brought by the EU Sugar Regime and continually rising price oil prices on which power generation largely depends, reforms had to be undertaken through an Action Plan to ensure long term viability and sustainability of the sugarcane industry and the optimal use of bagasse. One of the main reforms was to transform the sugar industry into the cane industry, operating in flexi-factory mode, through mill centralization implying that by 2015 only 4 cane industries would be operational in Mauritius.

Cogeneration with power to national grid has been practiced in the cane industry in Mauritius since 1957. During the crop seasons, cane biomass (called bagasse) is burned in water-tube boilers of up to 82 bar and fed in condensed extraction steam turbine. Electricity, including supply for national grid and process heat for cane-milling, distillation and sugar refinery are produced. During intercrop, coal has been used instead of biomass to provide continuous power to the grid.
Sugarcane industry has always been self-sufficient, as Independent Power Producers (IPPs) either as firm power or continuous power producers, in satisfying their energy requirements through cogeneration process by producing their own electricity and steam for the manufacture of sugar by burning coal or bagasse as fuels. The first sales of electricity to the grid started as early as 1957 and in this regard the country has been a pioneer.¹

MATERIAL AND METHODS
Currently some 1500 GWh are being produced by IPPs out of which 1229 GWh are being exported to the grid² or 54 % of the island electricity demand was satisfied by IPPs.

However the IPPs are highly dependent on coal in their cogeneration system due to the insufficient availability of bagasse as shown in Fig. 1, but also due to inefficient use of the biomass potential. The gross amount of electricity produced from bagasse has remained on average at about 400GWh for the past ten years as shown in Fig. 2 while that from coal has increased from 325 GWh to some 900 GWh. This is due to the fact that the full energy potential of bagasse is not being fully tapped and there is a decrease in the amount of sugarcane produced resulting in a decrease in the amount of bagasse produced. At present, there are five power plants which generate electricity from bagasse in Mauritius. These are Belle-Vue (CTBV), Beau Champ (CEL), fuel (FSPG), Medine and Omnicane (CTSAV). The power plants of Belle-Vue (CTBV), Beau Champ (CEL), fuel (FSPG), and Omnicane (CTSAV) generate electricity throughout the year as continuous power producers: from bagasse during the harvest season, and coal during the intercrop season³ while Medine generate electricity only during crop season using bagasse and is termed as firm power producers.² From 2008 to 2009, there was a decrease in the

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¹ 2000
² 2002
³ 2004
⁴ 2006
⁵ 2008
⁶ 2010

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Fig. 1 : Amount of electricity generated from coal and bagasse from year 2000 to 2009²

Fig. 2 : Amount of electricity generated from bagasse between 2000 and 2009²
electricity generated due to a reduction from the production of bagasse as shown in Fig. 3. This curve may continue to take a decreasing trend since land area under cane is gradually decreasing annually. This will simply means more reliance on coal.

This paper will investigate the current and future potential of cogeneration on the basis of the first law of thermodynamics. Implementation of higher pressure boilers, use of land considered as difficult areas for plantation of sugarcane, varieties of biomass of higher calorific value, bagasse-drying as well as bagasse integrated gasification combined-cycles turbines are also considered as future scenario.

**Mauritius : An outlook of the cane industry**

Agriculture in Mauritius occupies about 43 % of the 186,500 hectares of the land area. About 90% of the total arable land is attributed to sugar cane cultivation. Mauritius has no natural resources apart from land. Land area is a very vital aspect to be considered for the survival of sugar cane crop.

![Fig. 3](image1.jpg)

Fig. 3 : Amount of bagasse produced during the past nine years.

If no land is available there will be no sugar cane. The European Union (EU) purchased most of the sugar produced at a guaranteed price. However, since 2006, the EU has decreased the guaranteed price by 36% and also due to the rising costs for the cultivation and production of sugar, the profit margin is drastically decreasing. For example, the area under sugar cane plantation was 64,120 hectares, which was 2.4% lower than the 65,170 hectares in 2008. More than thousand hectares of land is being lost every year. Therefore, the industry is no more attractive as far as the production of sugar is concerned. This has caused a decrease in land area for cultivation of sugar cane as shown in Fig. 4. Land is being converted to shopping mall or for urbanization or simply abandon. Moreover, if this trend continues the future of cane industry in Mauritius will be endangered as a critical mass will not be available for its operation. If it is assumed a 2% decrease in the amount of land under sugar cane each year in the next ten years, only about 50,000 hectares of sugar cane fields will be left in year 2020.

Some 12,341 ha of the arable land were identified as difficult areas in 2006. This was due to...
to the fact that abandonment of sugar cane growing these lands might have negative impact on their immediate (geographical) vicinity and the island economy resulting in soil erosion and subsequent sedimentation and eutrophication problems in rivers and lagoons and this could also adversely affect the tourism industry and artisanal fishing.

These difficult areas have been classified in three categories namely Category A representing 4642 ha, Category B representing 1365 ha and Category C representing 6334 ha. category a located on the seaward slopes of three mountain ranges of Mauritius is most vulnerable section.

**Energy analysis of cogeneration in cane industry in Mauritius**

When sugar cane arrives at the sugar mill, it is crushed. Juice and cane biomass are obtained. The water content of the juice is removed in the subsequent heating and evaporation process by steam of 2.7 bar and 175°C, leaving a thick concentrated juice which is used for the production of sugar. The cane biomass also called bagasse is burned in water-tube boilers of up to 82 bar and fed in condensed extraction steam turbine. The exit steam of the low pressure turbine is as process for the manufacture of sugar whereas the exit steam of the high pressure is fed to the condenser.

The higher the amount of bagasse, the higher will be the electricity produced. The availability of bagasse, BPb, depends essentially upon the yield and residue to crop ratio for sugarcane.

\[ BP_b = (1 - \zeta_1) (1 - \zeta_2) (A \cdot Y \cdot RC) \]  

However, the amount of bagasse can be increased by adopting new cane varieties with higher fibre content as shown in Table 1. The net electricity produced will also increased. Current varieties have a fibre content of 10 to 12%. Promising varieties are high quality cane, high fibre, energy cane. The amount of electricity generated from different cane varieties is calculated as follows:

\[ AEP_b = (1 - \zeta_1) (1 - \zeta_2) (1 - \zeta) (A \cdot Y \cdot RC) / SFC_b \]  

Moreover, cane top and leaves (CTL) and trash is another option which has the potential of optimizing the amount of renewable energy that can be obtained from sugar cane. It includes the tops, green leaves, stalk and dry leaves of sugar cane. For every 100 tonnes of canes harvested, 30 tonnes of CTL are left in sugar fields and also one tonne of CTL has the potential to produce around 100 kWh of electricity.

A large amount of trash is sent to sugar factories while loading sugarcane after harvesting. The trash is therefore crushed together with cane thus increasing the fibre content of cane and reducing the crushing capacity of plants and also leading to losses in the amount of sugar produced. The amount of trash obtained in sugarcane is calculated as follows:

\[ M = (F_{ulc} - F_{CT}) / (100 - H - F_{ulc}) \]  

Moreover, the gas turbine technology in particular has made remarkable progress in the recent past, with the incorporation of the solid (coal and biomass) fuel gasifiers. Gas turbine technologies for the biomass gasifiers are the biomass integrated gasification/gas turbines (BIG/GT), the biomass integrated gasification/steam injected gas turbines (BIG/STIG), and the biomass integrated gasification/intercooled steam injected gas turbines (BIG/ISTIG). In its use in the sugar cane milling industry, BIG/GT could be fuelled with bagasse during the milling season, palletized or briquetted for a fixed bed gasifier. It is assumed that an overall efficiency of BIG-GT Combined Cycle system with advanced process integration may lead to higher efficiencies of 60% and the net calorific value NCV of bagasse is taken as 7620 kJ/kg at moisture content of 50%, the energy potential is 3429 kJ/kg and the electrical energy is 0.9525 kWh/kg.

Another option to augment the electricity production is to dry bagasse before burning in the furnace. Sugarcane bagasse is an excellent organic material of fuel for boilers however, it contains a high level of humidity. Bagasse as used in the mills, has a moisture content of about 50% and a calorific value of 7620 kJ/kg. All constituents of bagasse with the exception of bagasse are combustible. The presence of water in the bagasse reduces its fuel value, as part of the heat value of bagasse is used for the evaporation of the moisture content of bagasse. Thus heat is wasted and the calorific value is reduced. Bagasse drying is thus a means of reducing its moisture content. This will also reduce the volume of flue gases leading to a decrease in air pollution and also the air demand.
in the furnace. The use of bagasse dryer could reduce exit gas temperature from a range of 200 to 390°C to about 140°C and increase efficiency from 54% to 69%. However, it is not recommended to dry bagasse below 25 to 30% moisture is for boiler purpose as there is the possibility of furnace temperature going up, resulting in clinker formation with bagasse ash.

RESULTS AND DISCUSSION

Mauritius has a potential to increase the production of sugar as well as electricity production by cultivating new varieties of canes on land considered as difficult areas. On such land, new vigorous canes (high quality/high fibre content) having with prolonged ratooning may represent an interesting option. It was found that abandonment of cane cultivation in category A would result in decrease of 32 490 tons of cane, 39 GWh of electricity. Moreover, electricity produced from bagasse being produced that is 1.3 Mt. This simply means there will be a shift towards coal.

The electricity could be increased by cane of higher percentage of fibre. Table 1 summarises the amount of bagasse as well as the net electricity produced using these cane. From Table 1, it is observed that increasing the fibre content increases the amount of bagasse. With energy cane having fibre content more than 30%, the amount of bagasse is more than twice

<table>
<thead>
<tr>
<th>Cane varieties</th>
<th>Fibre (%)</th>
<th>Bagasse (kt)</th>
<th>Net Electricity (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current variety</td>
<td>10 to 12</td>
<td>1146</td>
<td>535</td>
</tr>
<tr>
<td>High quality</td>
<td>12-15</td>
<td>1719</td>
<td>803</td>
</tr>
<tr>
<td>High fibre</td>
<td>20 to 30</td>
<td>2604</td>
<td>1218</td>
</tr>
<tr>
<td>Energy cane</td>
<td>&gt; 30</td>
<td>3125</td>
<td>1462</td>
</tr>
</tbody>
</table>

With the present trend of decreasing land area for sugar cane cultivation, the amount of bagasse that would available by the year 2020 is 0.9 Mt under the assumptions that the area cultivated under sugarcane in 2020 to be 50 000 hectares (2% lost for area under cane annually), the cane yield of 72 t/ha, residue to crop ratio of 0.3, ζ is 0.13 and ξ is zero. Thus, a massive decrease of 32% of bagasse available will be expected in 2020 as compared to present amount of bagasse being produced that is 1.3 Mt. This simply means there will be a shift towards coal.

The electricity could be increased by cane of higher percentage of fibre. Table 1 summarises the amount of bagasse as well as the net electricity produced using these cane. From Table 1, it is observed that increasing the fibre content increases the amount of bagasse. With energy cane having fibre content more than 30%, the amount of bagasse is more than twice

Table 1 : Amount of bagasse from different cane varieties

The current variety and the electricity generated is thrice with the assumption that 1 kg of bagasse produces 2.4 kg steam for boiler at 82 bar and 525°C for condensing extraction turbo alternator. When considering the 36% decrease in the price of sugar and while attempting to make the sugar industry a sustainable and viable industry, it is important to think in terms of optimizing bagasse for producing electricity and make the industry more profitable. The electricity produced could be augmented by using top and leaves and trashes left in the sugar cane field. The estimated amount of cane fields residues that may be available is shown in Table 2.

Assuming 50% of cane field residues left in the fields for agronomic purposes. The additional boiler fuel is therefore 340 885 tons. The electricity produced when cane trash is used as fuel in the boiler is summarised in Table 3 below under different scenarios such as operating the boiler at 45 bar or at 82 bar and also at an estimated area under cane of 50,000 by the year 2020. Moreover, electricity produced from bagasse could be increased by using gasification technologies. Table 4 shows the net electricity produced under different scenarios such as using the current varieties with either the actual area under cane or the estimated area under cane by the year 2020 and also using different cane varieties with the estimated area under cane by the year 2020. Finally, electricity production could be increased by drying bagasse before
burned in the furnace. Assuming an increased output of 20% due to improved calorific value and given that the amount of electricity produced from bagasse is expected to be increased by 20%.

Table 2: Amount of cane fields residues available

<table>
<thead>
<tr>
<th>Dry matter</th>
<th>Dry matter (t/ha)</th>
<th>Potential (t) (60 380 ha of land)</th>
<th>Dry matter left in fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane tops and green leaves</td>
<td>5.4</td>
<td>326 052</td>
<td>326 052</td>
</tr>
<tr>
<td>Trash</td>
<td>8.3</td>
<td>501 154</td>
<td>355 718.2</td>
</tr>
<tr>
<td>Total available</td>
<td></td>
<td>681 770</td>
<td>.16</td>
</tr>
</tbody>
</table>

Table 3: Extra electricity produced when cane trash is used as energy source

<table>
<thead>
<tr>
<th>CTL and trash as an energy source</th>
<th>Additional electricity produced GWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1-Boiler operating at a pressure of 45 bar</td>
<td>45.45</td>
</tr>
<tr>
<td>Case 2-Boiler operating at 82 bar</td>
<td>93.50</td>
</tr>
<tr>
<td>Case 3-by 2020-area under cane is 50000ha and boiler operating at 82 bar</td>
<td>87.11</td>
</tr>
</tbody>
</table>

Table 4: Total electricity produced when gasification technologies are used

<table>
<thead>
<tr>
<th>Bagasse Gasification</th>
<th>Net Electricity Produced(GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1: current cane varieties with fibre % of 15%</td>
<td>1388.8</td>
</tr>
<tr>
<td>Case 2: by 2020 with current varieties</td>
<td>1077.31</td>
</tr>
<tr>
<td>Case 3: different cane varieties by the year 2020</td>
<td></td>
</tr>
<tr>
<td>i) High quality cane with fibre % 15 – 18</td>
<td>1131.57</td>
</tr>
<tr>
<td>ii) High fibre cane with fibre % 20 – 30</td>
<td>1714.5</td>
</tr>
<tr>
<td>iii) Energy cane with fibre % &gt;30</td>
<td>2057.4</td>
</tr>
</tbody>
</table>

CONCLUSION

Therefore, as the amount of land harvested will be decreased in a ten year time from the above, the electricity generated could be increased from the current production of 535GWh to a maximum of 2057GWh, through new canes varieties of greater fibre content, gasification and using bagasse drying technologies. Finally, as future works, given that all sugar mills as well as most hotels are found near the sea, the efficiency could be increased further by using cogeneration also for desalination of water and trigeneration (air conditioning).

REFERENCES


